Precision electroweak measurements with ATLAS

N. Andari (CEA Saclay)

On behalf of the ATLAS Collaboration

EW precision measurements

3 precision observables define the EW sector of the SM for example: α_{EM}, G_F, m_Z

—> define the other EW observables at tree-level:

$$m_W^2\left(1-\frac{m_W^2}{m_Z^2}\right)=\frac{\pi\alpha}{\sqrt{2}G_F}$$

$\sin^2\theta_W = 1 - M^2_W/M^2_Z$

EW precision measurements

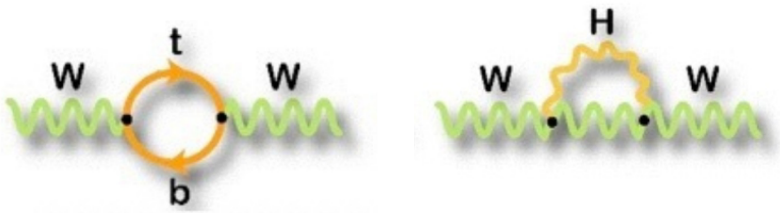
3 precision observables define the EW sector of the SM for example: α_{EM}, G_F, m_Z

—> define the other EW observables at ~~tree-level~~ loop-level:

$$m_W^2\left(1-\frac{m_W^2}{m_Z^2}\right)=\frac{\pi\alpha}{\sqrt{2}G_F}(1+\Delta r)$$

$\sin^2\theta_W = 1 - M^2_W/M^2_Z$ → $\sin^2\theta^l_{eff} = \kappa^l \sin^2\theta_W$

κ^l and Δr reflects loop corrections and depends on m_t^2 and $\ln(m_H)$



<u>EW precision measurements:</u>

- Test the self consistency of the SM
- Complementary approach for New Physics discovery
- Probe very high energy scale via radiative corrections

EW precision measurements

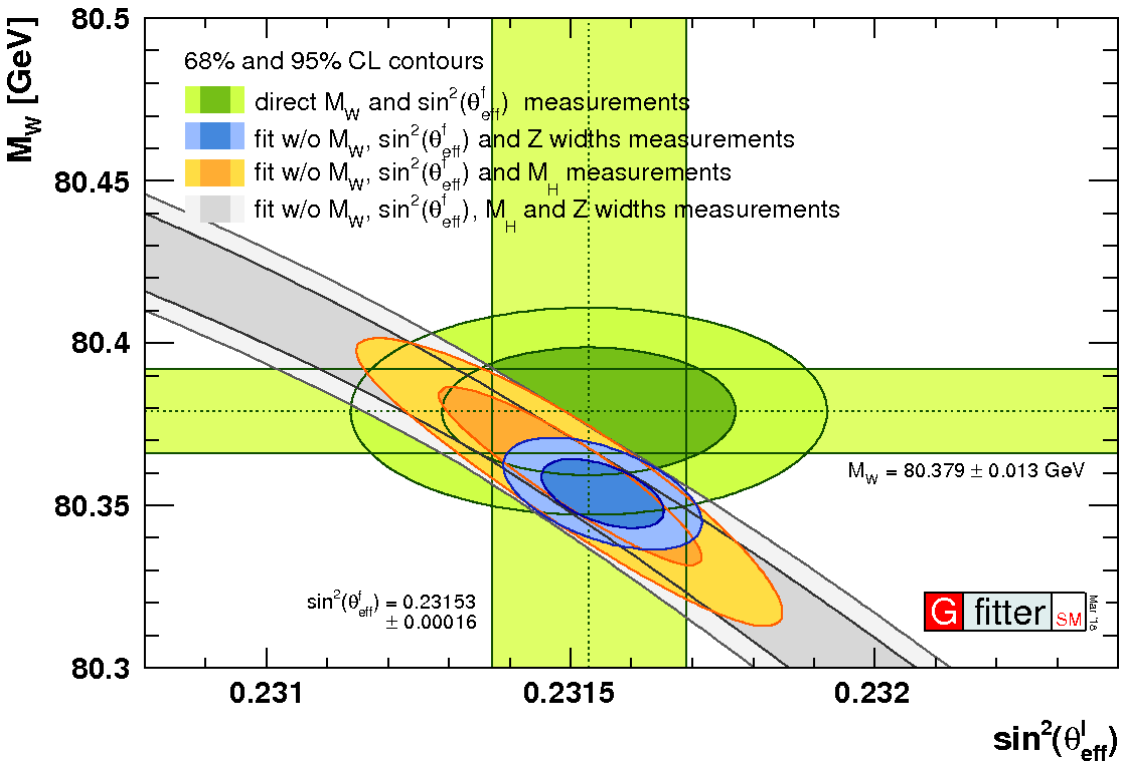
3 precision observables define the EW sector of the SM for example: α_{EM}, G_F, m_Z

—> define the other EW observables at ~~tree-level~~ loop-level:

$$m_W^2\left(1-\frac{m_W^2}{m_Z^2}\right)=\frac{\pi\alpha}{\sqrt{2}G_F}(1+\Delta r)$$

κ^l and Δr reflects loop corrections and depends on m_t^2 and $\ln(m_H)$

$\sin^2\theta_W = 1 - M^2_W/M^2_Z$ → $\sin^2\theta^l_{eff} = \kappa^l \sin^2\theta_W$



Eur.Phys.J.C74(2014)3046

EW fit: $\sin^2\theta^l_{eff} = 0.23149 +/- 0.00007$

$m_W = 80358 +/- 8$ MeV

Focus of this talk:

- Weak mixing angle: $\sin^2\theta_W$
- W-boson mass: m_W

Part I: Weak mixing angle

Data: 20.2 fb^{-1} of 8TeV

ATL-CONF-2018-037

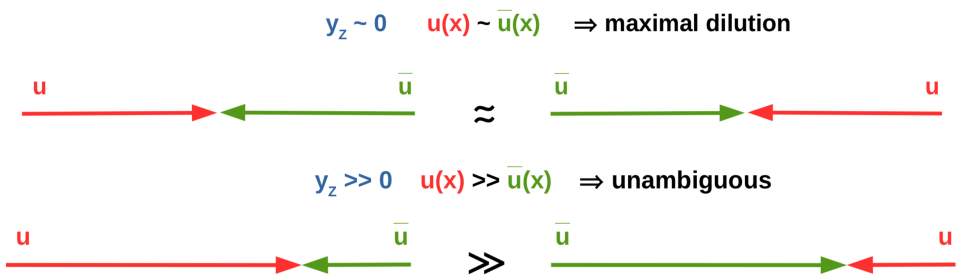
Neutral current: $q\bar{q} \to Z/\gamma^* \to \ell^+\ell^-$

Z couples differently with left and right handed fermions → Forward-backward asymmetry

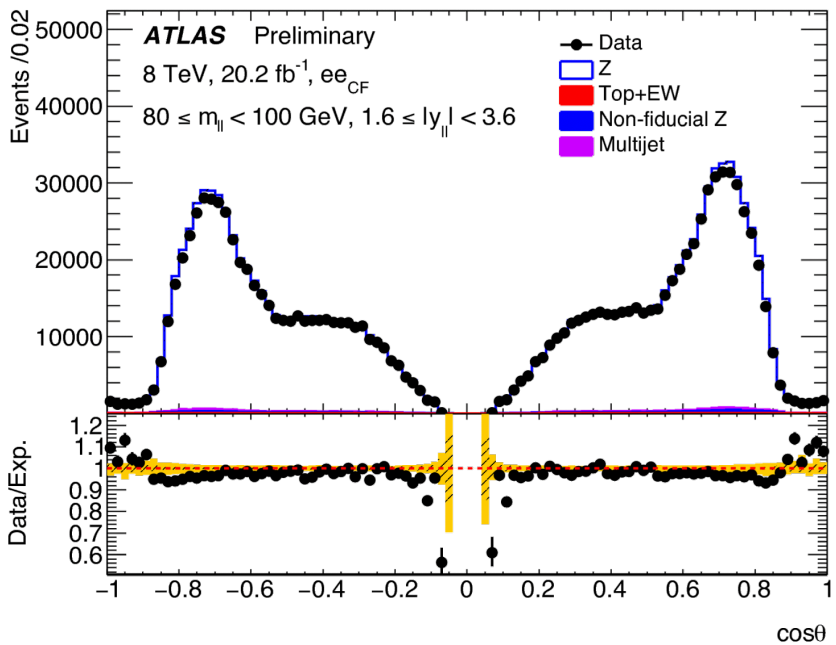
Drell-Yan cross-section factorisation in full lepton phase space:

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

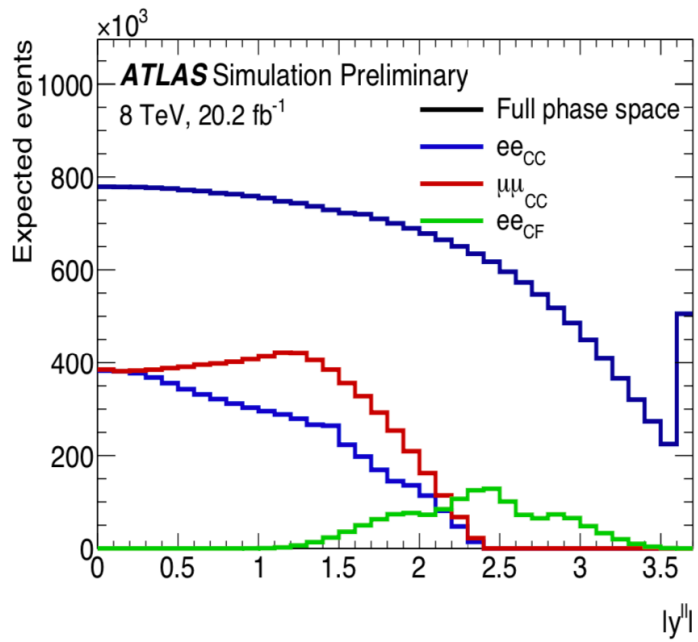
A_4 sensitive to $\sin^2\theta_W$ via coupling structure



Fold angular polynomials and fit to reco angular distributions binned in m_Z and $|y_Z|$



3 decay channels:
μμ$_{CC}$, ee$_{CC}$, ee$_{CF}$



Part I: Weak mixing angle

Data: 20.2 fb^{-1} of 8TeV

ATL-CONF-2018-037

$$\sin^2\theta^{\ell}_{\text{eff}} = 0.23140 \pm 0.00021\ (\text{stat.}) \pm 0.00024\ (\text{PDF}) \pm 0.00016\ (\text{syst.})$$

Channel	ee_{CC}	$\mu\mu_{CC}$	ee_{CF}	$ee_{CC}+\mu\mu_{CC}$	$ee_{CC}+\mu\mu_{CC}+ee_{CF}$
Central value	0.23148	0.23123	0.23166	0.23119	0.23140
			Uncertainties		
Total	68	59	43	49	36
Stat. **x10^{-5}**	48	40	29	31	21
Syst.	48	44	32	38	29

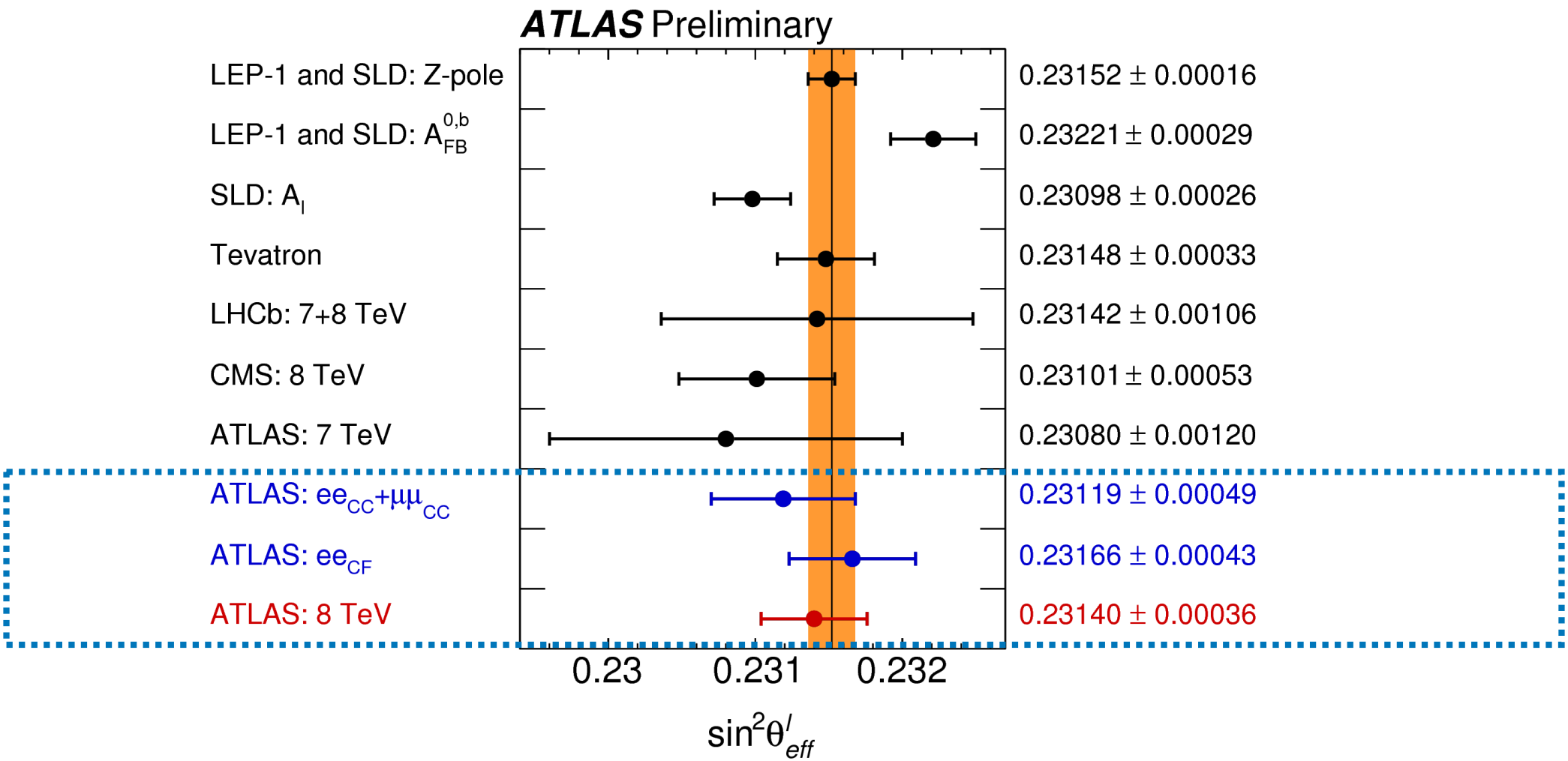
- Uncertainties dominated by statistics (including MC stat) and PDFs
- Most precise channel ee_{CF} – less dilution for high dilepton rapidity
- Spread between different recent PDFs~6x10^{-5} *(only CT10: 22x10^{-5} away from MMHT14)*
- Similar PDF uncertainties from eigenvectors / replicas

	CT10	CT14	MMHT14	NNPDF31
$\sin^2\theta^{\ell}_{\text{eff}}$	0.23118	0.23141	0.23140	0.23146
	Uncertainties in measurements			
Total	39	37	36	38
Stat.	21	21	21	21
Syst.	32	31	29	31

Part I: Weak mixing angle

Data: 20.2 fb^{-1} of 8TeV

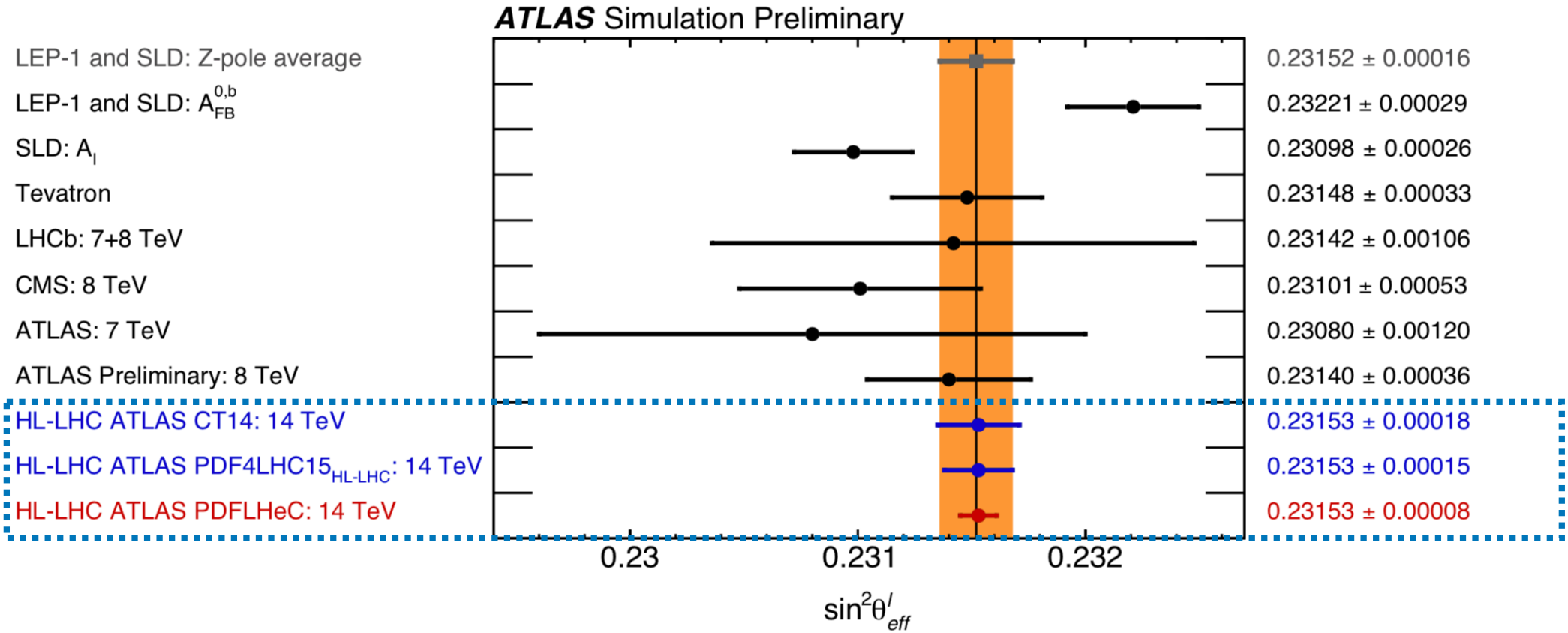
ATL-CONF-2018-037



- ATLAS results consistent with the mean value of LEP and SLD (~3σ discrepancy) and other available measurements.
- ee_{CF} is unique to ATLAS and is more sensitive than combined $ee_{CC}+\mu\mu_{CC}$ (49x10^{-5} ~ similar sensitivity to CMS measurement).

Part I: Weak mixing angle

ATL-PHYS-PUB-2018-037



Prospects @HL-LHC:

- reduction of statistical uncertainty (3000 fb^{-1})
- Extended pseudo-rapidity coverage ($|\eta|<4$)
- Expected reduction of PDF uncertainties

Including LHeC data: reduction of PDF (total) uncertainties by a factor of ~5 (2) wrt to HL-LHC PDFs.

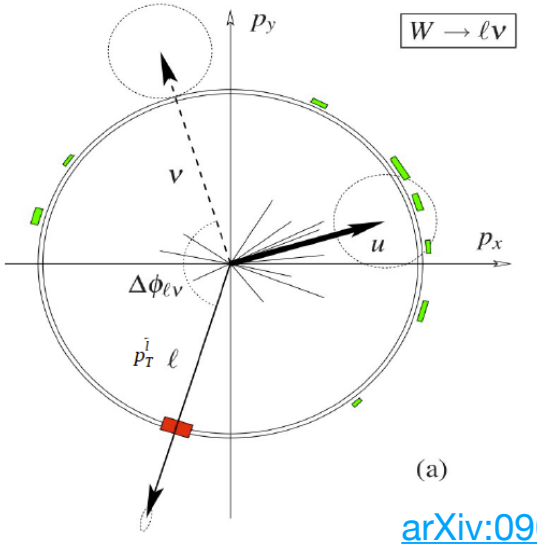
Part II: W-boson mass

Data: 4.6 fb^{-1} of 7 TeV

Eur. Phys. J. C (2018) 78:110

Very challenging: aim precision of 10 MeV using 40 GeV leptons —> knowledge of peak position @2*10^{-4}

High experimental precision & accurate theory modelling



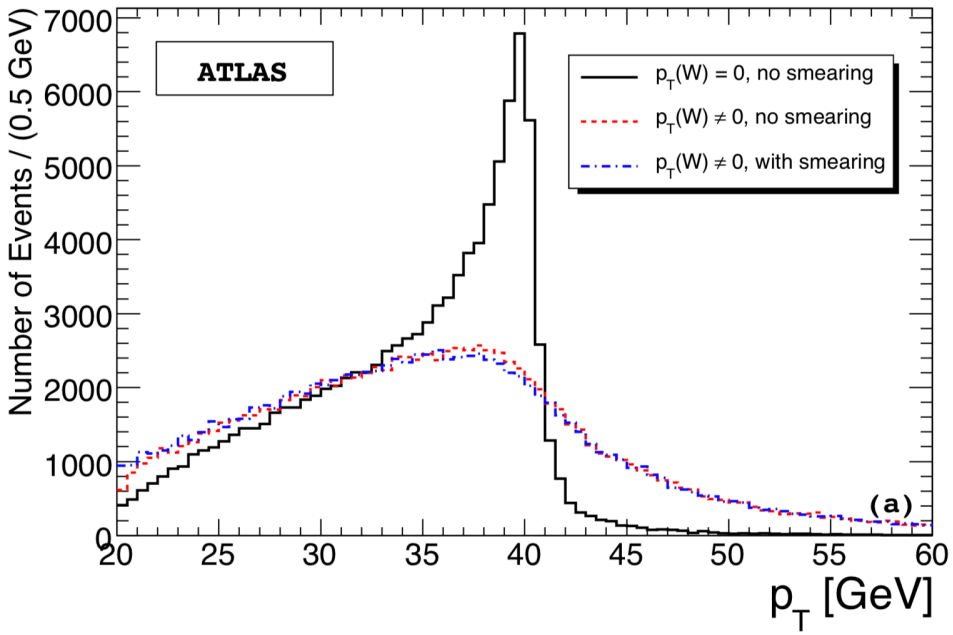
Not possible to fully reconstruct the invariant mass

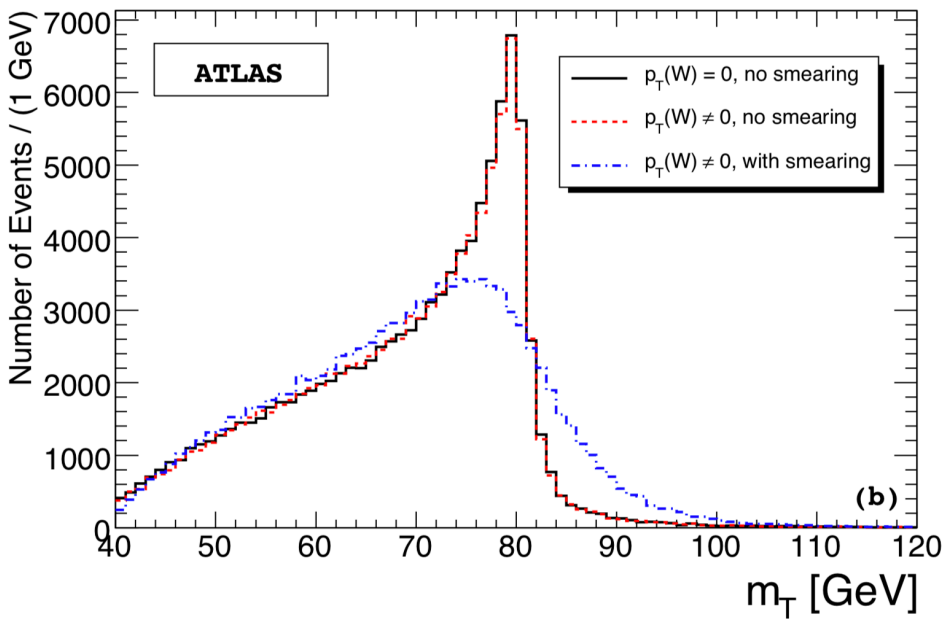
Sensitive final state distributions: **p_T^l, m_T**, p_T^{miss}

$$\vec{p}_T^{\,miss} = -\left(\vec{p}_T^{\,\ell} + \vec{u}_T\right), \quad m_T = \sqrt{2 p_T^{\ell} p_T^{miss}(1 - \cos\Delta\phi)}$$

u_T being the recoil

arXiv:0901.0512





Sensitive to p_T^W & PDFs

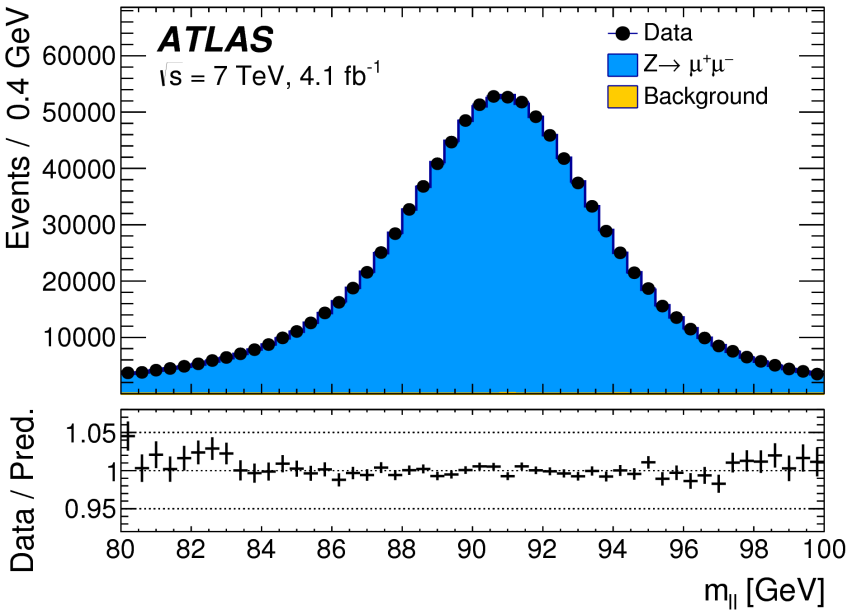
Sensitive to pile-up and UE

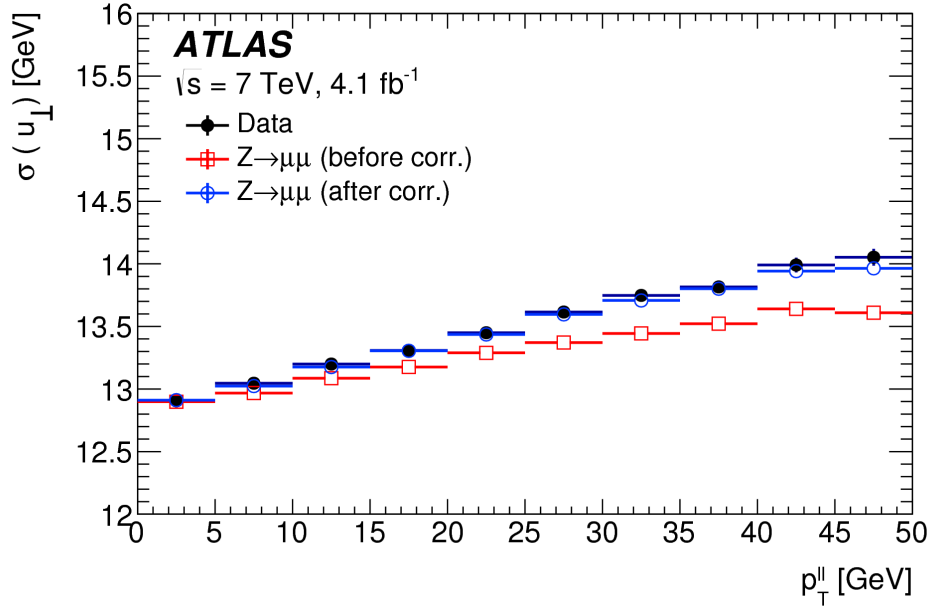
Part II: W-boson mass

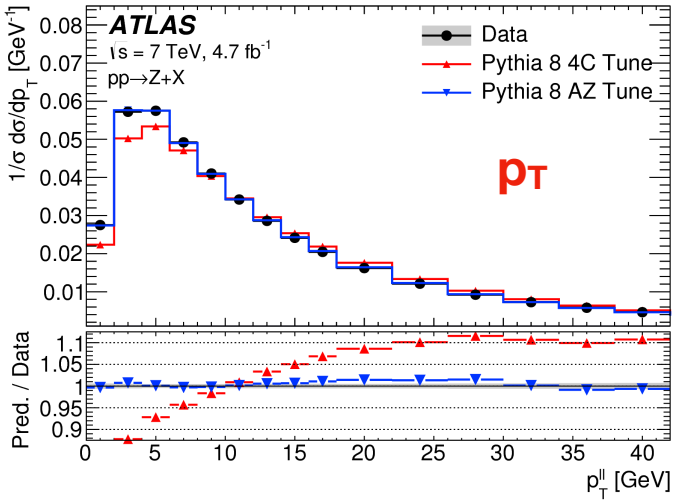
Data: 4.6 fb⁻¹ of 7 TeV

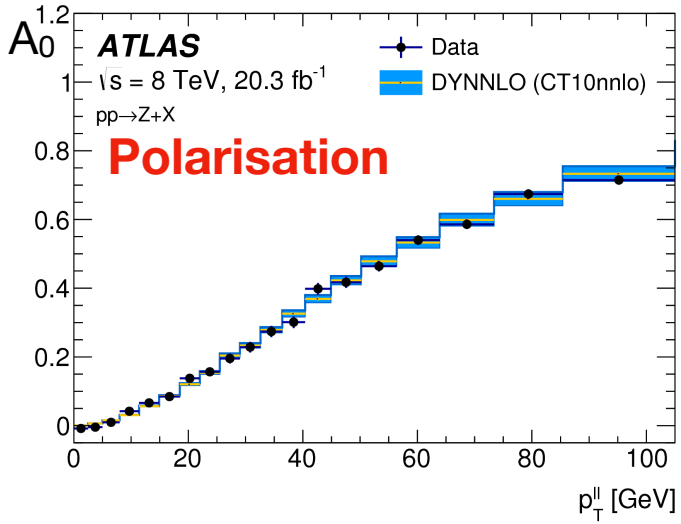
Eur. Phys. J. C (2018) 78:110

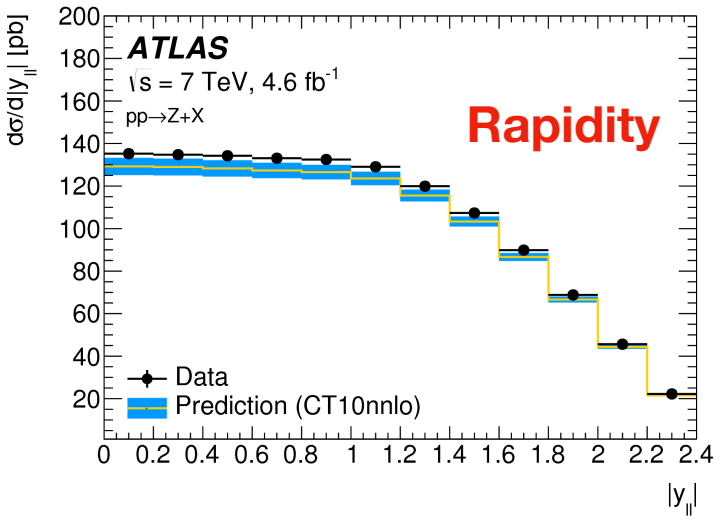
Lepton and Recoil calibration









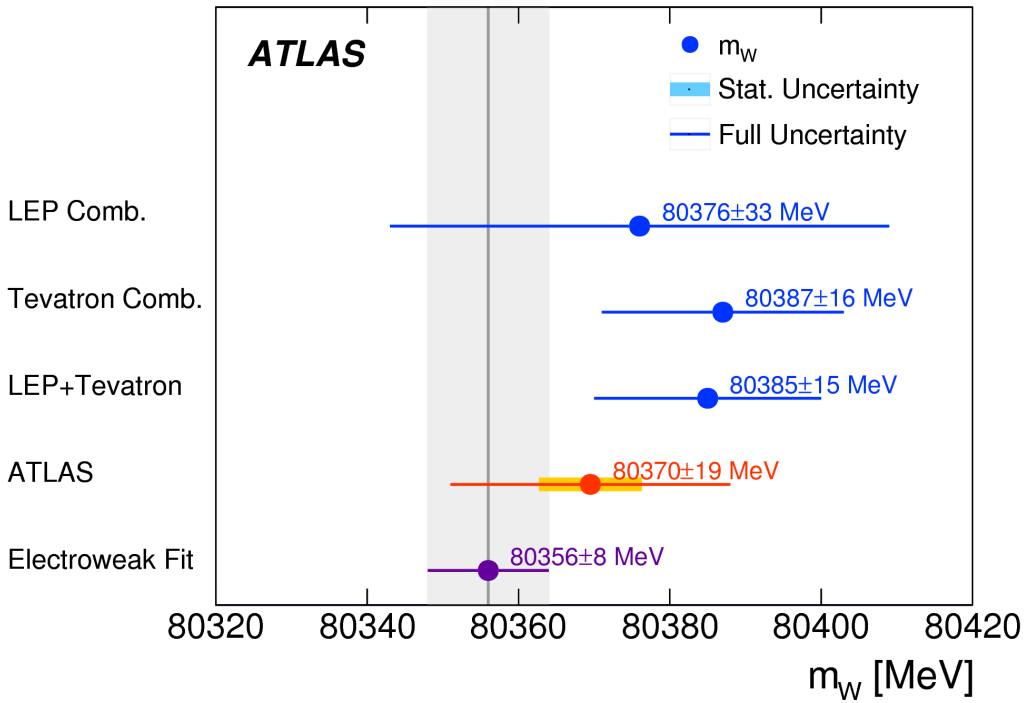


Use Z-boson sample for experimental and theoretical constraints —> Address Z to W extrapolation

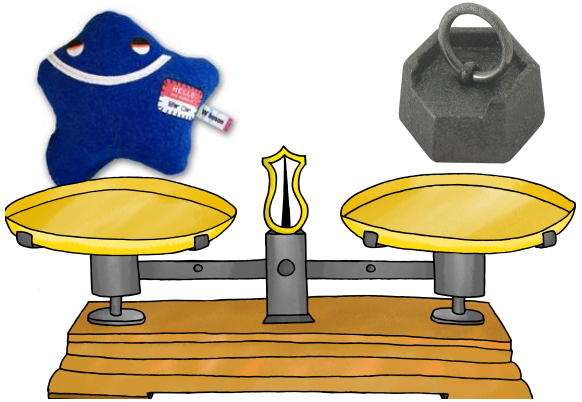
Part II: W-boson mass

Data: 4.6 fb^{-1} of 7 TeV

Eur. Phys. J. C (2018) 78:110



80370±19 MeV



86% p_T^l, 14% m_T

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

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

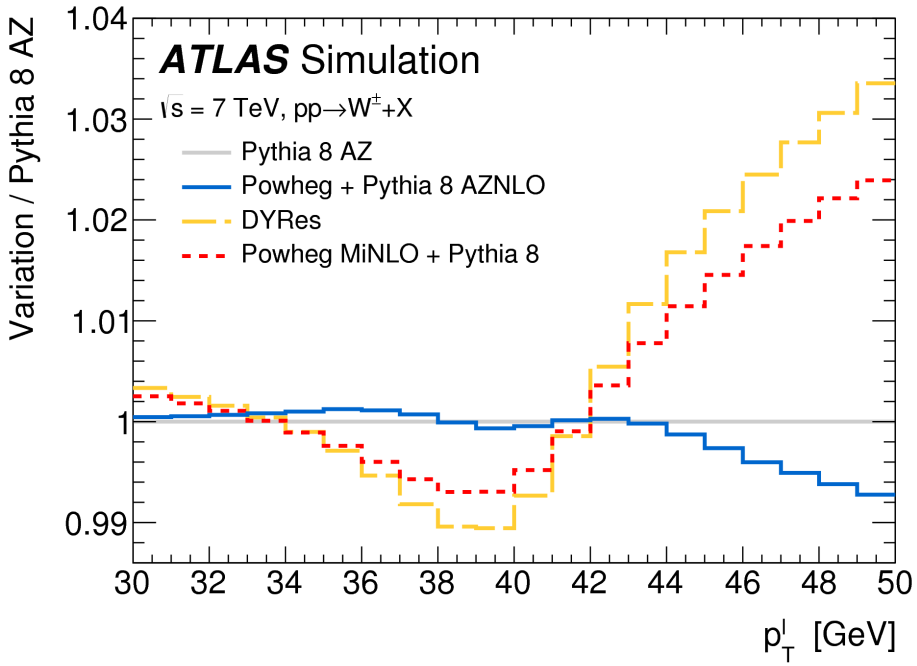
Consistent with the SM expectation, compatible with the world average and comparable in precision to the currently leading measurements by CDF

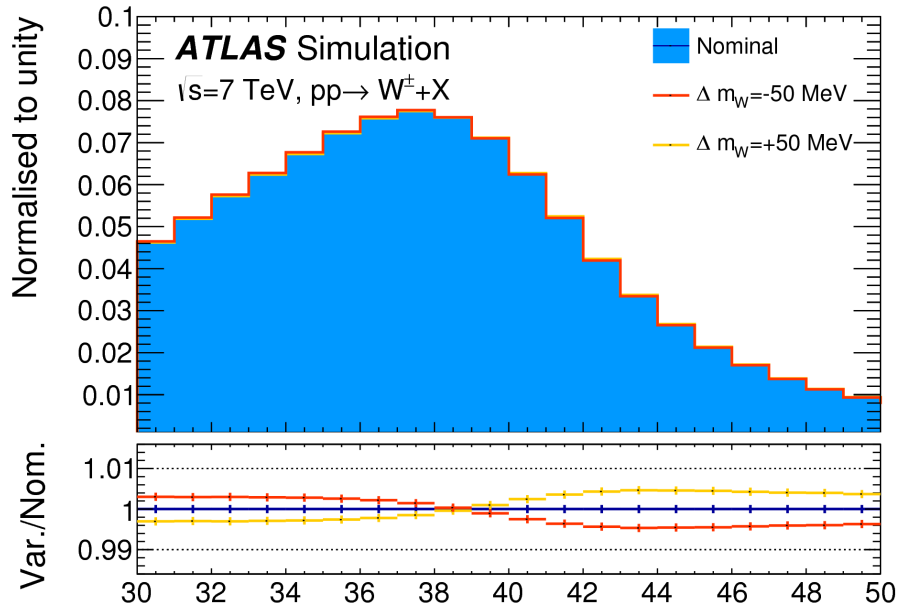
Dominated by PDF and QCD model uncertainties (mainly p_T^W)

Part II: W-boson mass

Eur. Phys. J. C (2018) 78:110

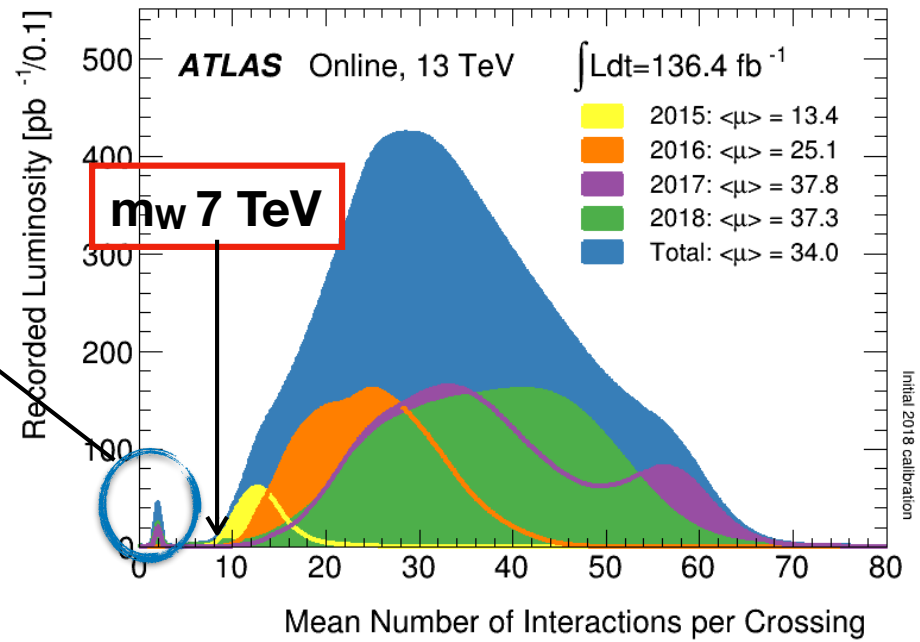
Impact of W-boson transverse momentum modelling





Low pile-up data: collected at √s= 5 TeV (~250 pb^{-1}) and at 13 TeV (~340 pb^{-1})

Target 1% uncertainty in bins of 5 GeV for low p_T^W
—> decrease p_T^W uncertainty in the W-boson mass measurement



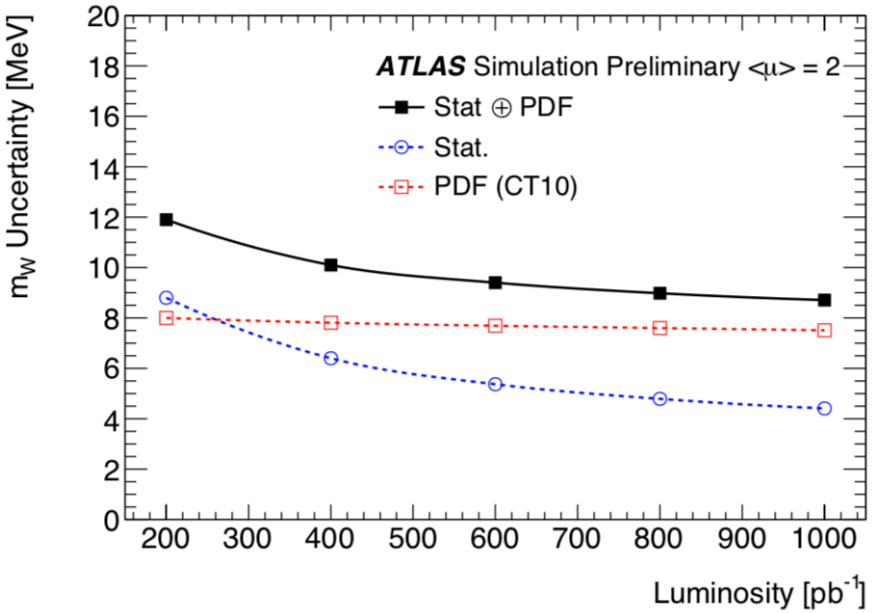
Part II: W-boson mass

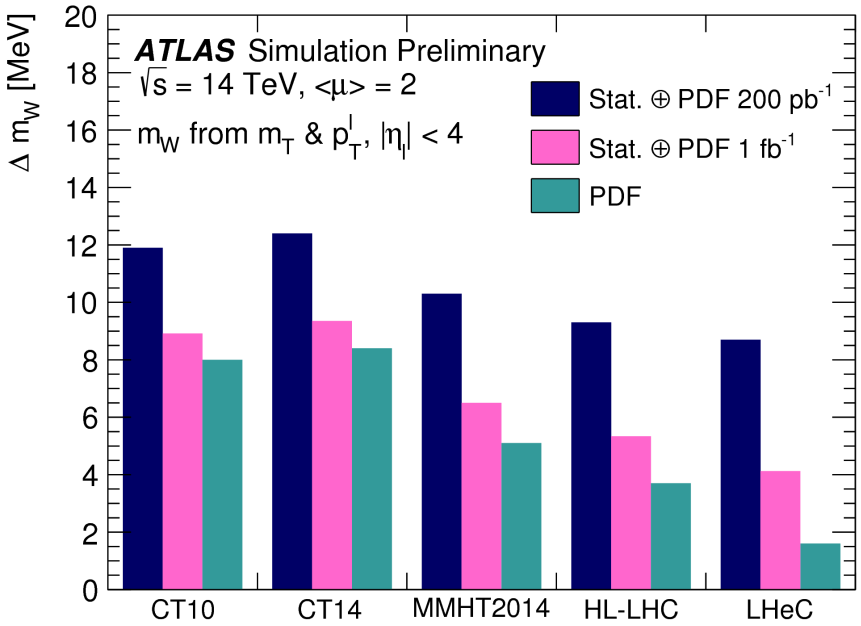
HL-LHC/HE-LHC prospects

ATL-PHYS-PUB-2018-026

Potential low pile-up runs at HL-LHC (14 TeV) and HE-LHC (27 TeV): 200 pb^{-1} per week

- Extended coverage with new tracking detector: $|\eta| < 4$ —> 30% reduction of PDF uncertainties





- The PDF uncertainties can be reduced to about 4 MeV using HL-LHC PDF sets and to 2 MeV using LHeC PDF sets.

Conclusions

- Precision measurement of the effective leptonic weak mixing angle: $\sin^2\theta_W = 0.23140 +/- 0.00036$ dominated by PDF and statistical uncertainties

- In preparation for full Run 2 measurements of $\sin^2\theta_W$: reduction of statistical uncertainty, higher level of dilution effects

- Prospects of $\sin^2\theta_W$@HL-LHC: 15×10^{-5} uncertainty can be achieved (at each experiment ATLAS, CMS and LHCb). 8×10^{-5} using LHeC.

- First LHC measurement of the W-boson mass: $m_W = 80370+/-19$ MeV comparable to precision at the Tevatron

- Low pile-up data: improve precision and measure transverse momentum up to 1% level

- Prospects of m_W@HL-LHC: 30% reduction of PDF uncertainty with extended tracker. 4 MeV with HL-LHC PDF sets. 2 MeV with LHeC.

More interesting results to come!