Electroweak precision measurements in ATLAS

LHCP 2020

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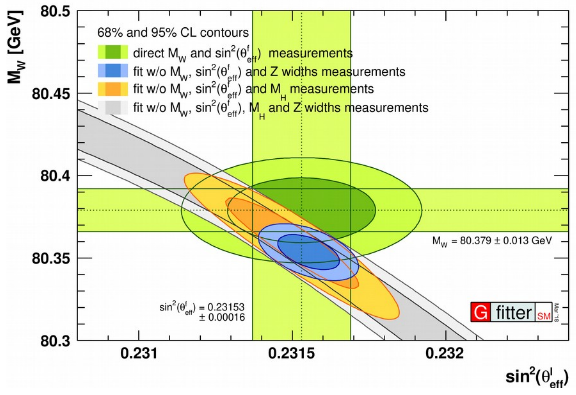
On behalf of the ATLAS collaboration

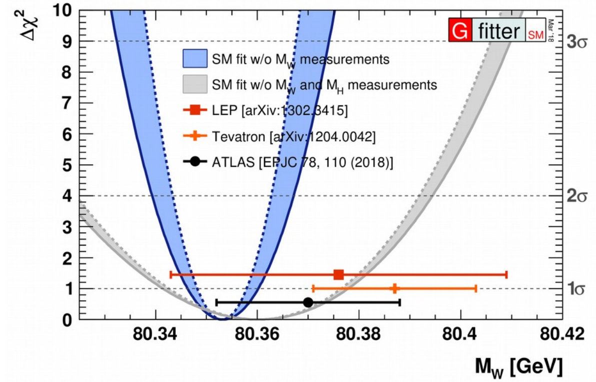
Electroweak precision measurements

- **Test self-consistency of Standard Model**
  - Can be indirect evidence for new physics
- **EW symmetry breaking sector can be better constrained, especially m_W and $\sin^2\theta_W$**
- **Direct measurement target uncertainties:**

	EW Fit	World Avg.
– δm_W at the level of **10 MeV**	7 MeV	13 MeV
– $\delta \sin^2\theta^l_{eff}$ at the level of $\mathbf{10.10^{-5}}$	6.10^{-5}	16.10^{-5}

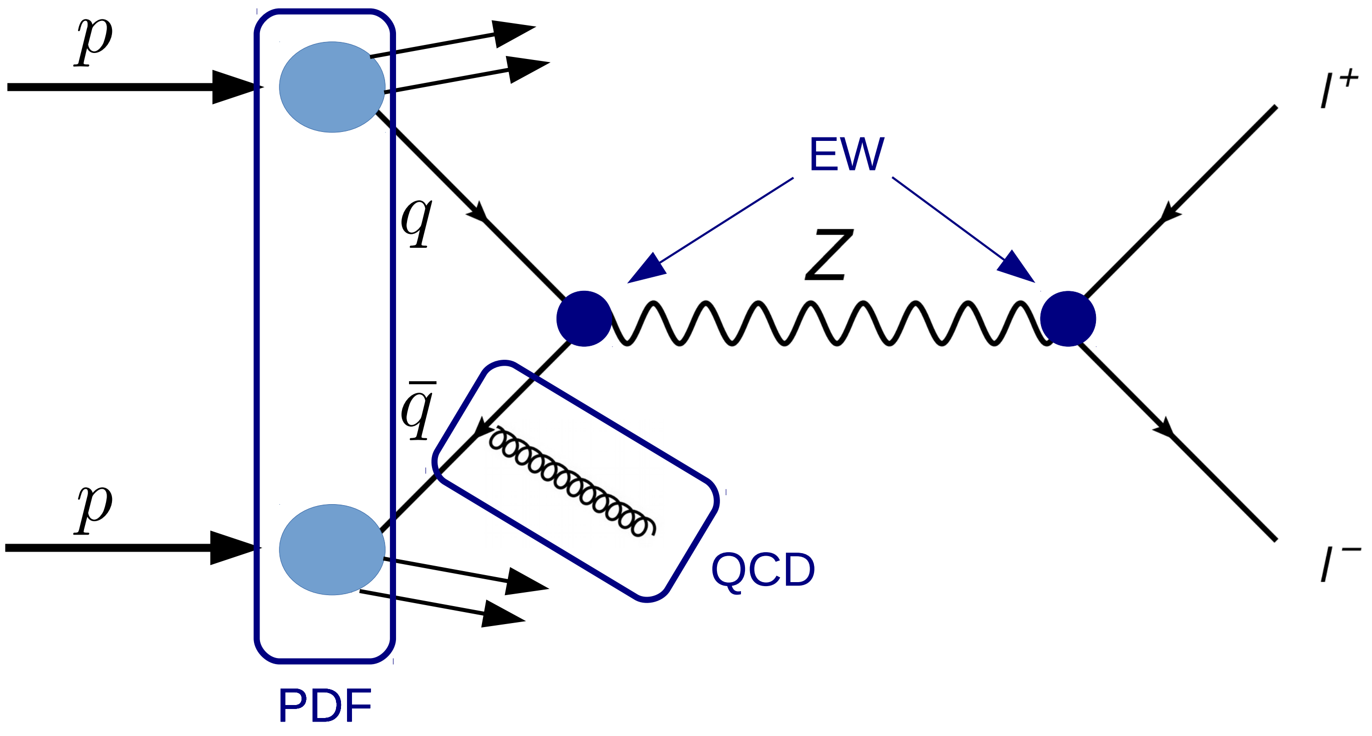
- **LHC measurements start to reach LEP/Tevatron precisions**





Gfitter

W/Z Production at LHC



Leptonic final state
= low background

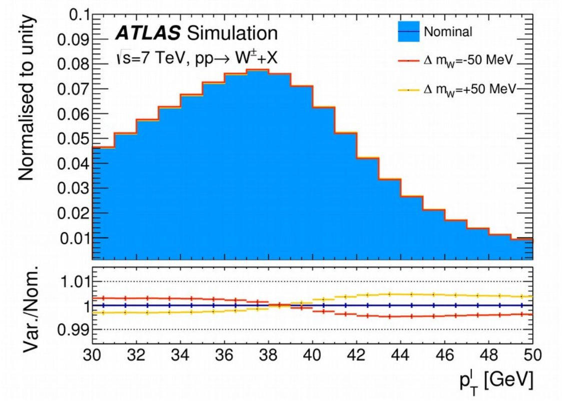
$p_T^{ll} \neq 0$:
- quark/gluon emissions
- Intrinsic parton p_T

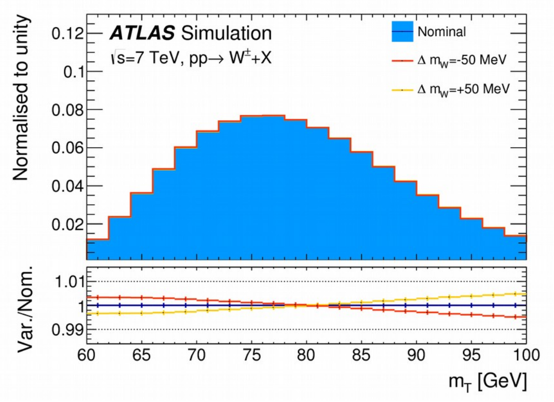
Low p_T^{ll} :
described with soft-gluon resummation & non perturbative models

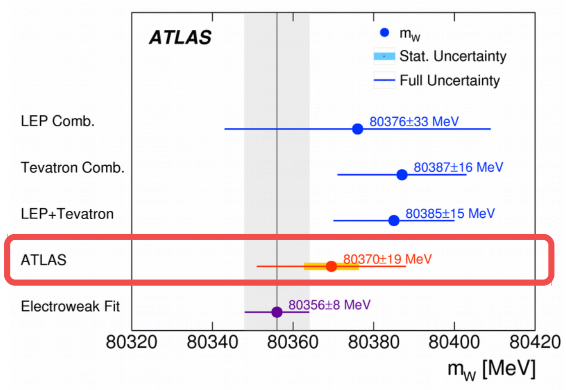
High p_T^{ll} : described with fixed-order pQCD with or w/o Parton Shower (PS)

W mass measurement at 7 TeV

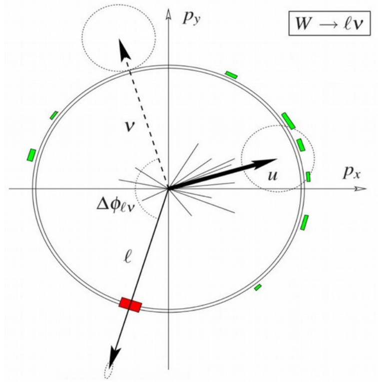
Eur. Phys. J. C 78 (2018) 110







- **Method : template fit to p_T^l and m_T**
  - p_T^l description depends on p_T^W modelling
    → large theory uncertainties
  - m_T sensitive to hadronic recoil u_T
    → resolution worsen with pile-up



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

$$\vec{p}_T^{\,\text{miss}} = -(\vec{p}_T^{\,l} + \vec{u}_T)$$

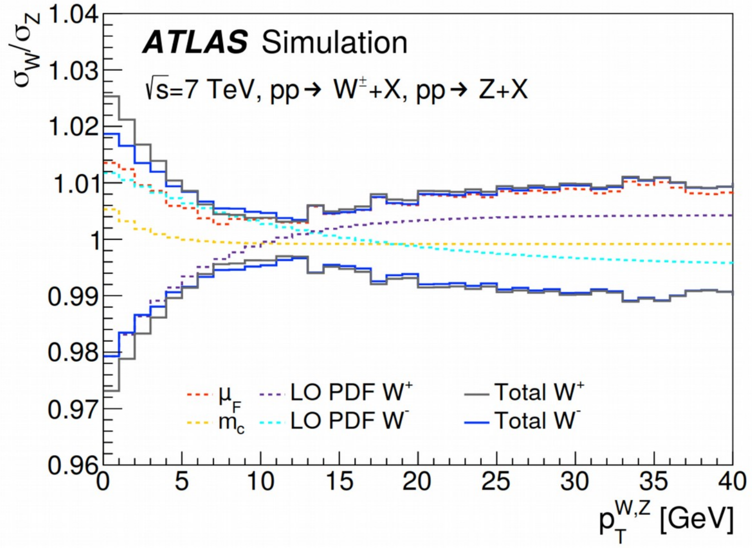
$$m_T = \sqrt{2p_T^l p_T^{\text{miss}} \cos(1 - \Delta\phi)}$$

W mass measurement : Uncertainties

Uncertainties in MeV

m_w [MeV]	Stat. Unc.	Muon Unc.	Elec. Unc.	Recoil Unc.	Bckg. Unc.	QCD Unc.	EW Unc.	PDF Unc.	Total Unc.	χ^2/dof
80369.5	6.8	6.6	6.4	2.9	4.5	8.3	5.5	9.2	18.5	29/27

- **Main uncertainties: QCD modeling and PDF**
- **PDF uncertainties large because W polarisation not well known**
- **QCD uncertainties mainly due to p_T^W modelling**
  - Uncertainty coming mainly from Z→W extrapolation
  - W/Z ratio predictions have large uncertainties



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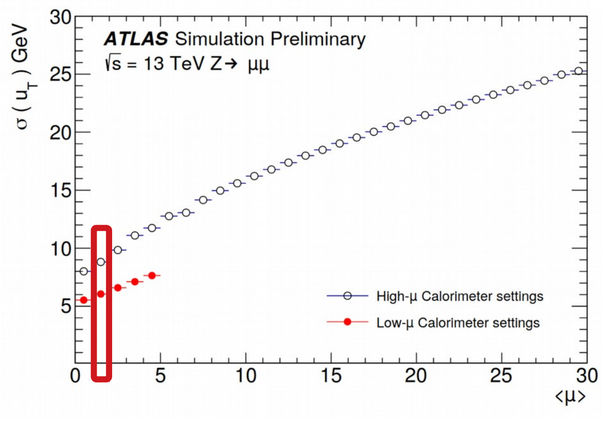
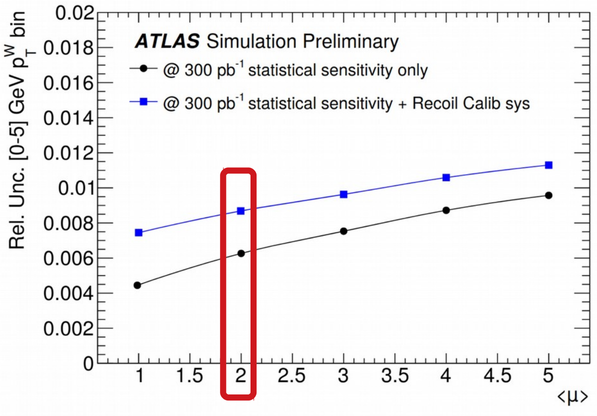
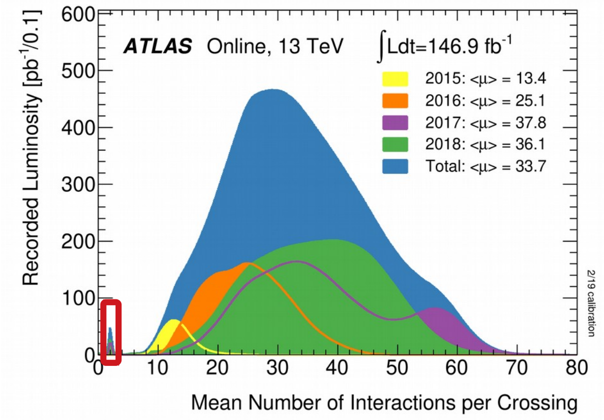
Prospects on p_T^W

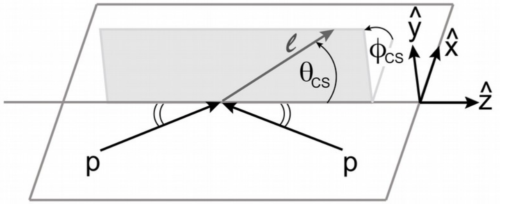






- **Low pile-up data : enhanced sensitivity to m_W**
  - Measure better m_T and p_T^W
- **Need to know better p_T^W , in 5 GeV bins → measure it with <μ>~2**
- **Use <μ>~2 data sets taken at 5 TeV (257pb^{-1}) and 13 TeV (335pb^{-1}) :**
  - Target 1% precision on p_T^W → should reduce by 2 p_T^W modelling uncertainty for W mass

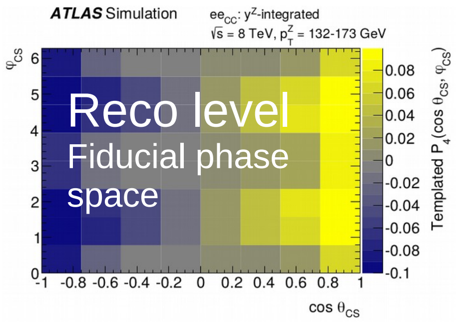
Weak mixing angle from Angular Coefficients



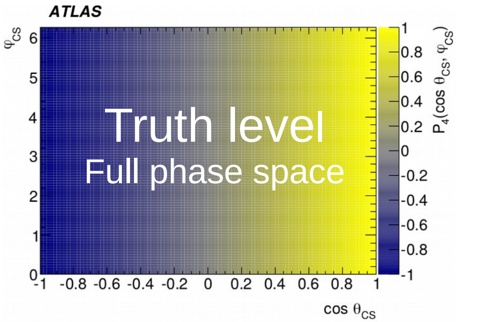
- **pp → Z → ll cross-section can be expanded in harmonic polynomial**
  - 9 polynomials $P_i(\cos\theta,\varphi)$ → Z decay kinematics (in Collins-Soper frame)
  - 8 angular coefficients A_i + unpolarised cross-section σ^{U+L} → Z production
  - A_4 function of $\sin^2\theta^l_{eff}$
- **Method : fit reconstructed $(\cos\theta,\varphi,m^{ll},y^{ll})$ in born level (m^Z,y^Z) bins**
  - Extract A_4 in full decay lepton phase space and infer $\sin^2\theta^l_{eff}$ using predictions

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

Fit



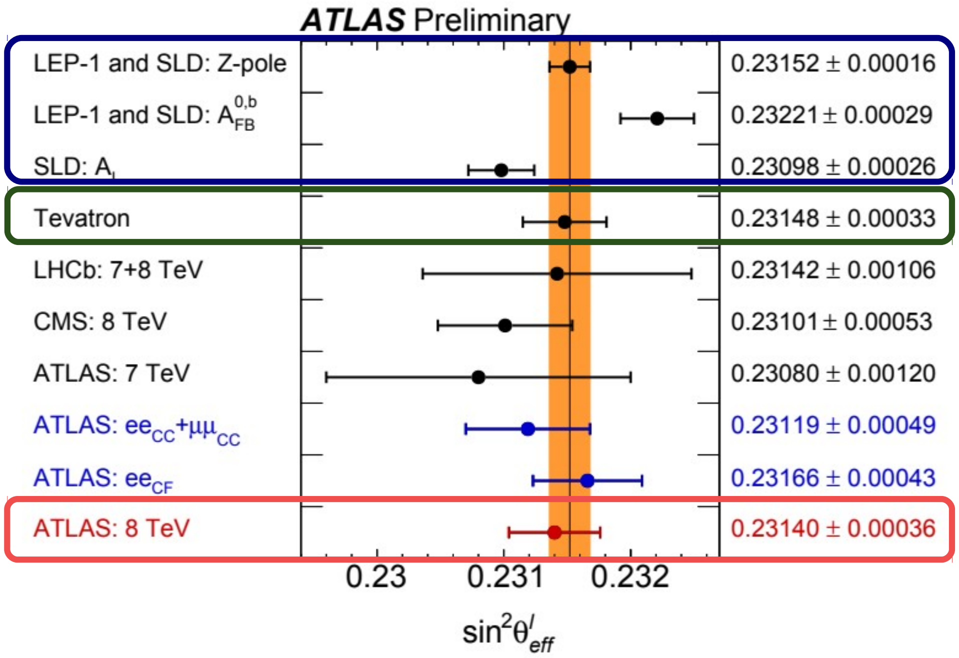
Fold



ATL-CONF-2018-037

$\sin^2\theta^l_{eff}$ at 8 TeV

ATL-CONF-2018-037



- **ATLAS measurement competitive with LEP, SLD and Tevatron results**
- **ATLAS benefits from improved sensitivity using forward electrons (2.5<|η|<4.9)**
  - Lower dilution at high $|y^Z|$
- **Total uncertainty 36x10^{-5}:**
  - 21 (stat) ± 24 (PDF) ± 16 (syst)
  - PDF uncertainties mitigated by profiling (exploit correlations in m^{ll} and y^{ll} bins)

Prospects on $\sin^2\theta^l_{eff}$

LHC Run-2

- **Compared to 8 TeV**
  - Luminosity : 20.2 $fb^{-1} \rightarrow$ 139 fb^{-1}
  - Higher cross-section

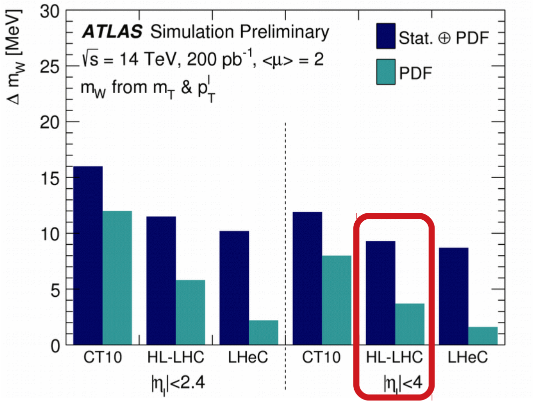
    $\rightarrow$ Much larger statistics
  - But higher dilution
- **Finer binning in y^Z : better constrain on PDF uncertainties**
- **Expected sensitivity on $\sin^2\theta^l_{eff}$ ~ 25.10^{-5}**

LHC Run-3

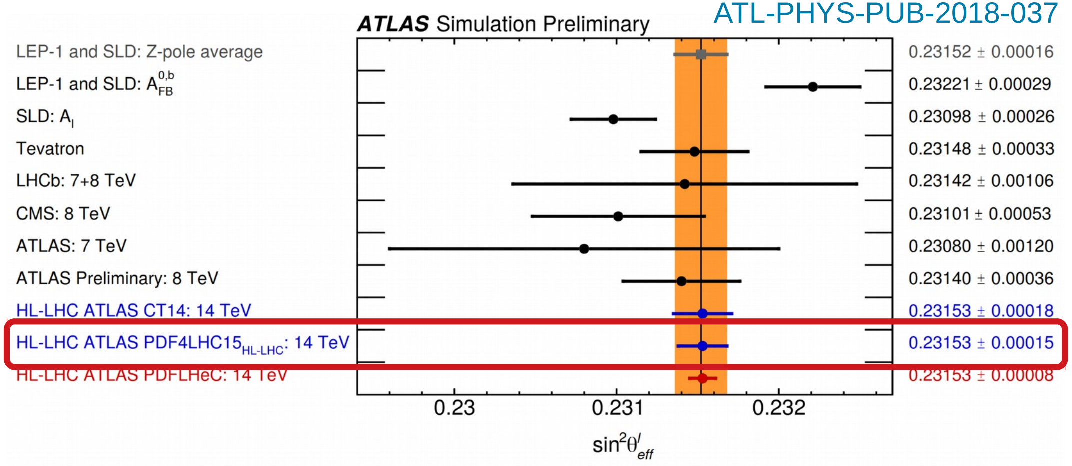
- **ATLAS upgrade its trigger system**
  - Improved trigger efficiencies on muons and electrons
  - Will be able to keep low p_T thresholds on leptons
  - Will have capabilities to trigger on forward electrons

Prospects with HL-LHC

ATL-PHYS-PUB-2018-026



ATL-PHYS-PUB-2018-037



- **Atlas detector upgraded at HL-LHC, including :**
  - New tracker ITk : extended coverage |η|< 2.5 → |η|< 4
  - Timing detector in forward region HGTD : pile-up background rejection
- **Expected sensitivity on m_W ~ 10 MeV (with 200 pb^{-1} of low-μ data)**
- **Expected sensitivity on $\sin^2\theta^l_{eff}$ ~ 15.10^{-5}**

Drell-Yan @ 13 TeV , 36.1 fb^{-1}

1912.02844

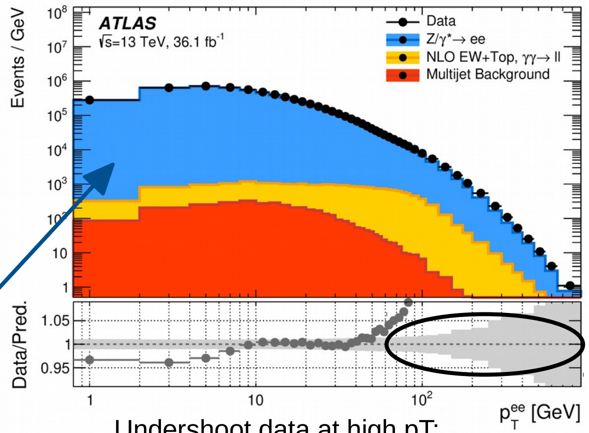
- **Study pp→Z/γ*→l⁺l⁻ (=e⁺e⁻ or μ⁺μ⁻) : p_T^{ll} and ϕ^*_η**
- **Important input for :**
  - Background prediction in BSM searches
  - SM precision measurement: e.g. m_W relies on W/Z pT ratio
- **13 TeV vs lower energies:**
  - different flavour composition
  - larger phase-space for hard QCD radiation
- **Fiducial volume : p_T^l > 27 GeV, $|\eta_l|$ <2.5, 66<m_{ll}<116 GeV**
- **Results unfolded at Born and Dressed levels**
- **Background fraction ~0.5% : mainly diboson & $t\bar{t}$**

$$\phi^*_\eta = \tan\left(\frac{\pi - \Delta\phi}{2}\right)\sin\theta^*_\eta$$

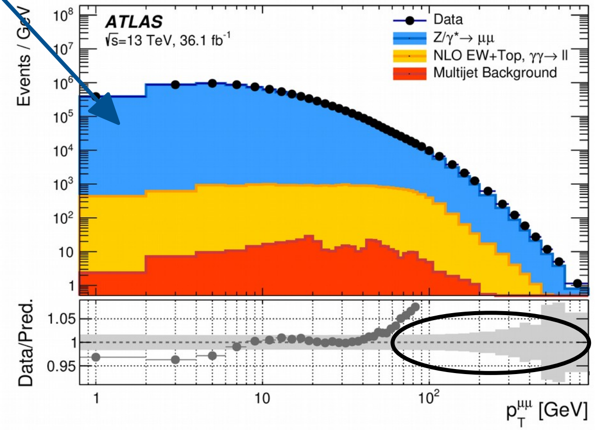
with $\cos\theta^*_\eta = \tanh\left(\frac{\eta^- - \eta^+}{2}\right)$

Depends only on leptons directions, not on momenta

Powheg+Pythia8 (NLO in α_S)



Undershoot data at high pT:
missing higher order corrections



		$Z/\gamma^* \to ee$	$Z/\gamma^* \to \mu\mu$
	Two reconstructed leptons within fiducial volume	13 649 239	18 162 641
From MC pred.	Electroweak background ($Z \to \tau\tau$, WW, WZ, ZZ)	40 000 ± 2000	39 000 ± 2000
From MC pred.	Photon-induced background	2900 ± 140	4100 ± 200
From MC pred.	Top-quark background	38 000 ± 1900	45 400 ± 2200
data-driven	Multijet background	8500 ± 4900	1000 ± 200

pp → Z/γ* → ll : Results

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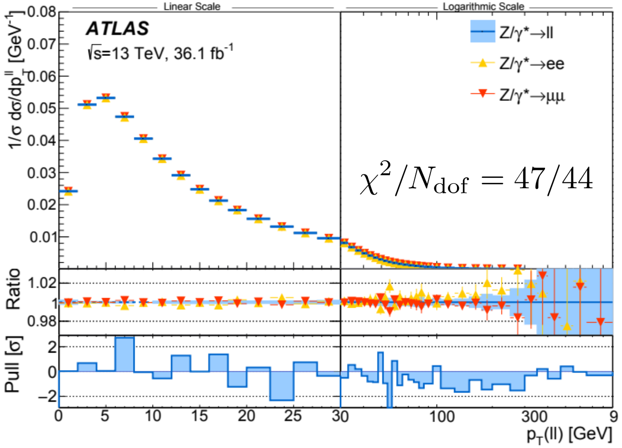
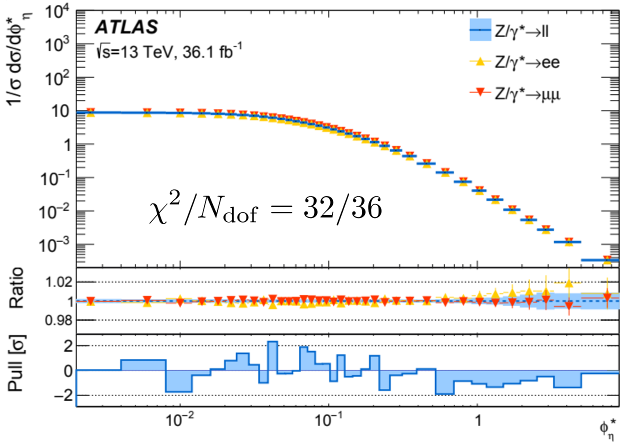


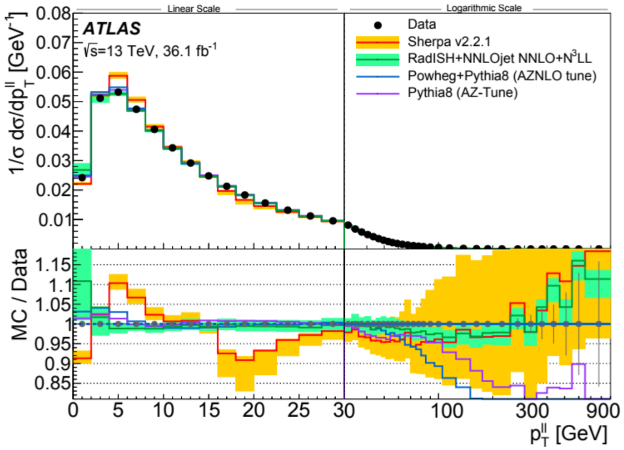


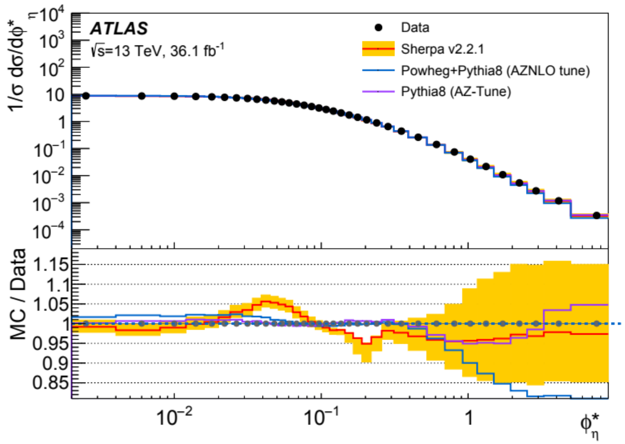
e/μ pull = (μ-e)/σ_{uncorr}

Channel	Measured cross-section × $\mathcal{B}(Z/\gamma^* \to \ell\ell)$ (value ± stat. ± syst. ± lumi.)	Predicted cross-section × $\mathcal{B}(Z/\gamma^* \to \ell\ell)$ (value ± PDF ± α_S ± scale ± intrinsic)
$Z/\gamma^* \to ee$	738.3 ± 0.2 ± 7.7 ± 15.5 pb	NNLO in α_s (DYTurbo)
$Z/\gamma^* \to \mu\mu$	731.7 ± 0.2 ± 11.3 ± 15.3 pb	
$Z/\gamma^* \to \ell\ell$	736.2 ± 0.2 ± 6.4 ± 15.5 pb	$703^{+19}_{-24}\,^{+6}_{-8}\,^{+4}_{-6}\,^{+5}_{-5}$ pb [69]

- **Results unfolded at Born and Dressed levels**
- **Good agreement between ee and μμ channels**
- **Combination with BLUE method**
  - Systematic uncertainties reduced in the combination (some uncorrelated sources)
  - **Precision of 0.2% for p_T^{ll}<30GeV**
- **Main uncertainties:**
  - Leptons **reconstruction and identification**
  - Leptons **momentum scale and resolution** (for p_T^{ll}) + **Luminosity** (Only for absolute cross-section)

Z/γ* → ll : Comparison to predictions





- **Sherpa : NLO up to 2 partons, LO up to 4 partons**
  - Describes data from p_T^{ll} > 30 GeV and ϕ^*_η>0.1 within 4%
  - This data can be useful to tune PS settings at low p_T^{ll}
- **RadISH : fixed-order NNLO (α_S^3) + resummation N³LL**
  - Agreement over the full spectrum (1-3 %)
- **Powheg+Pythia8 : NLO matrix elem. + PS AZNLO tune**
- **Pythia8 : LO matrix. Elem + PS AZ tune**
  - Both AZ & AZNLO tunes describe 13 TeV data within 2-4% at p_T^{ll} < 40GeV and ϕ^*_η < 0.5
  - At high p_T^{ll}, well below data → missing higher order corr.

Describe data at % level : need state of the art NNLO+N³LL

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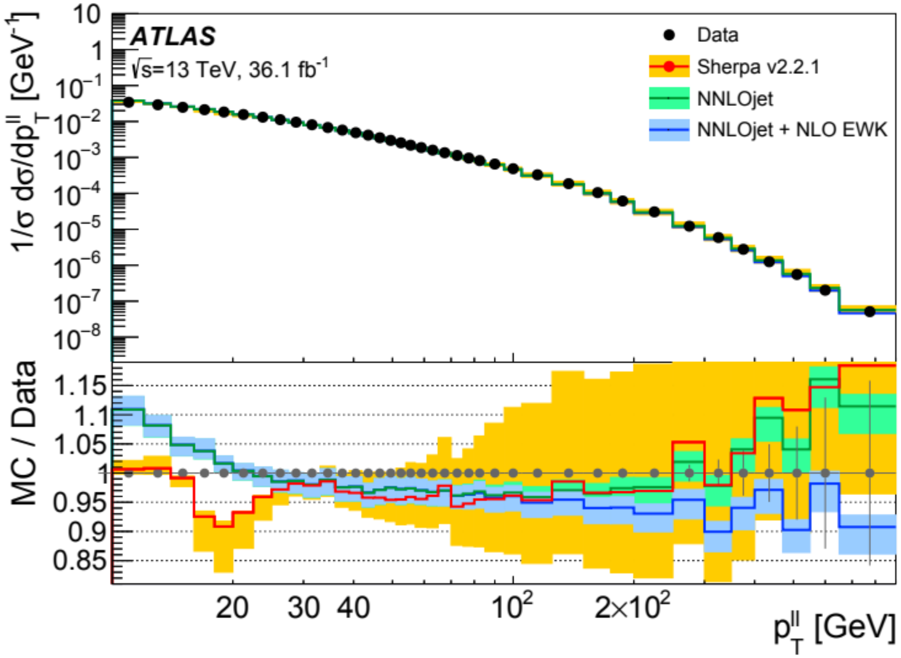
$Z/\gamma^* \rightarrow ll$: Comparison to predictions ($p_T^{ll} > 10$ GeV)



- **NNLOjet : order α_S^3**
  - Expected to describe well data only from $p_T^{ll} > 15$ GeV
  - Above data at high p_T^{ll}
- **NNLOjet + NLO Electroweak corr. (FEWZ)**
  - EW corrections → suppression at high p_T^{ll}
  - Below data at high p_T^{ll}
- **Both discrepancies not significant**
  - Within the measurement uncertainties

With current statistics, not yet sensitive to EW corrections

Conclusion

- **ATLAS experiment well suited to pursue precise measurements in electroweak sector**
- **Reaching LEP/SLD/Tevatron precision**
- **Main limitations in the future : precise predictions (esp. PDFs)**
- **Experimental and Theory communities need to work together to fully exploit the LHC data (up to HL-LHC)**

BACKUP

pp→ Z/γ* → ll : Uncertainties

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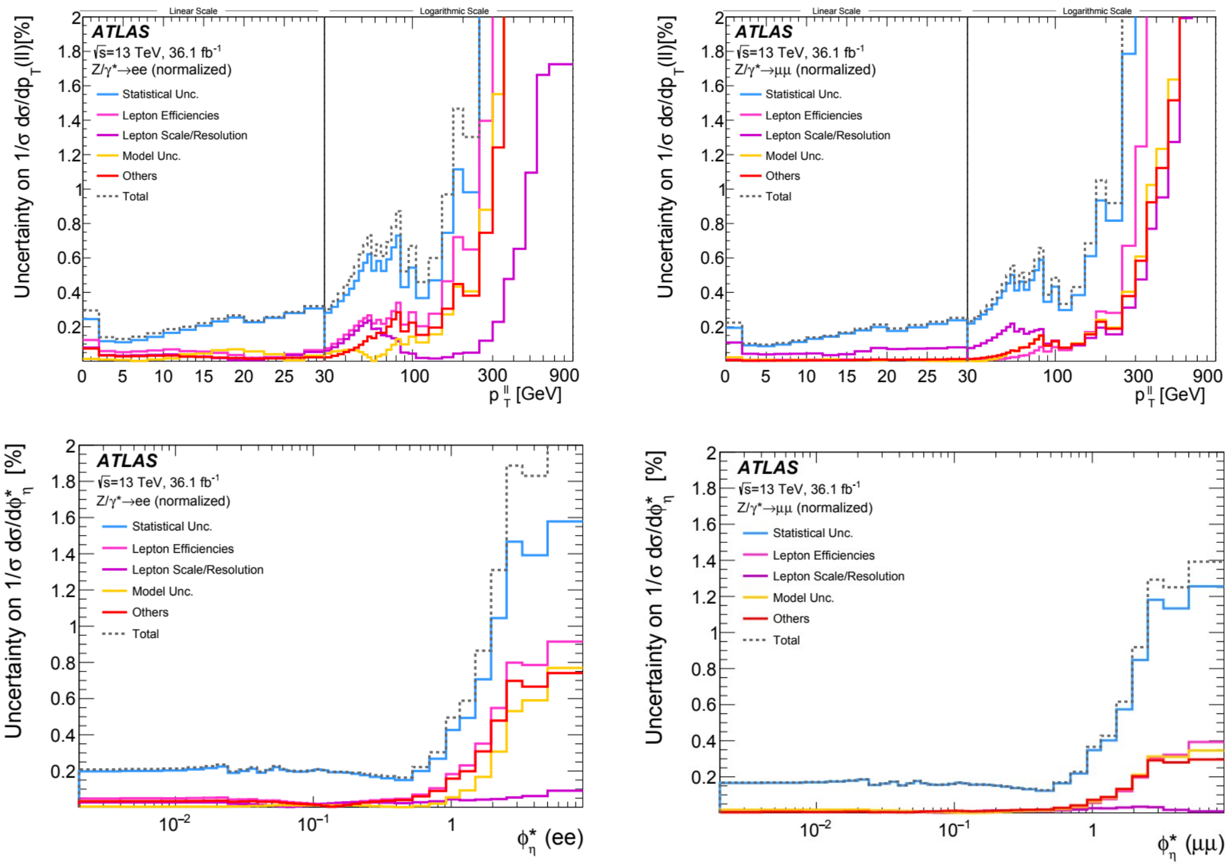
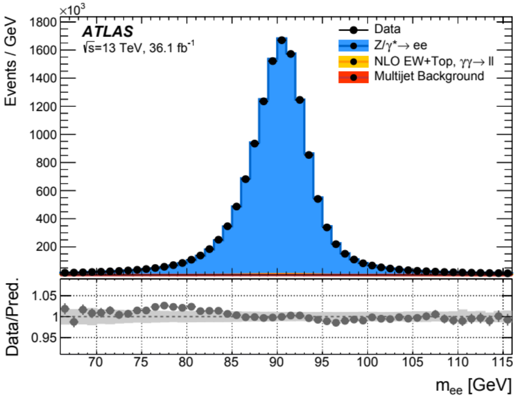
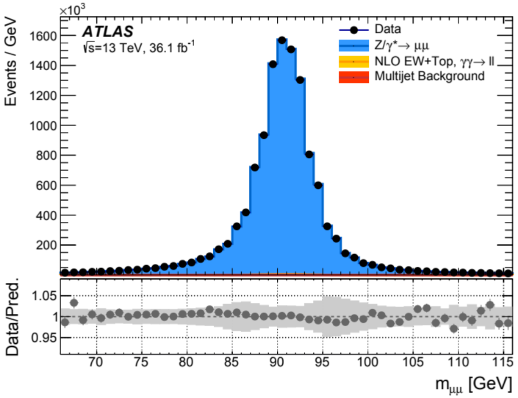
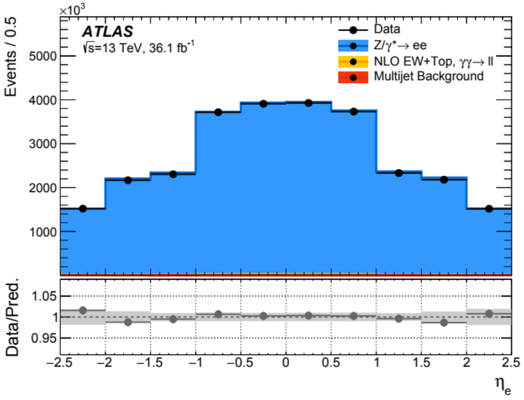
- **Main systematics on absolute cross-section:**
  - Leptons **momentum scale and resolution** (for p_T^{ll})
  - Leptons **reconstruction and identification** → Also for normalised cross-section
  - **Luminosity**
- **Normalised cross-section: precision of 0.2% for p_T^{ll}<30GeV**

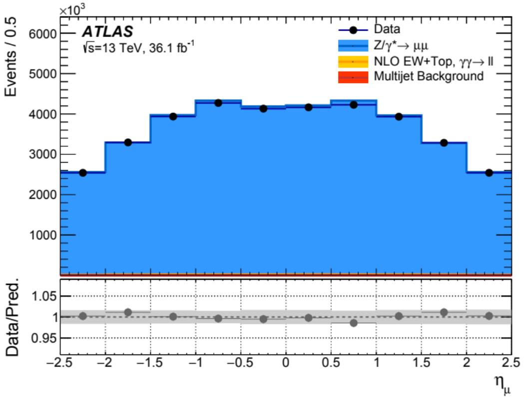


Drell-Yan @ 13 TeV , 36.1 fb^{-1} : Control plots









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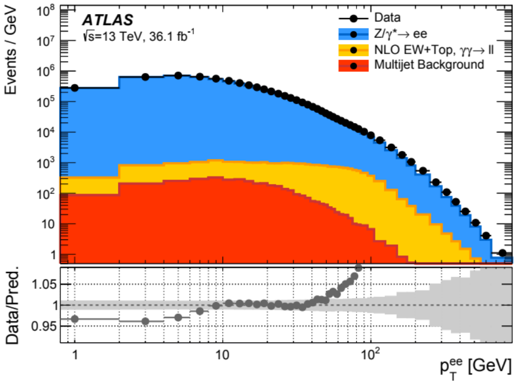
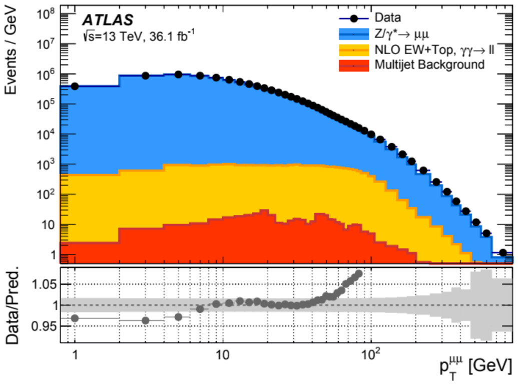
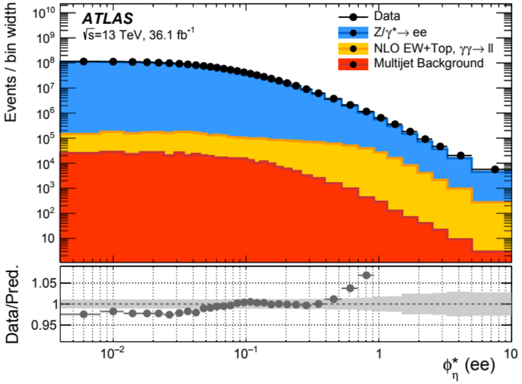
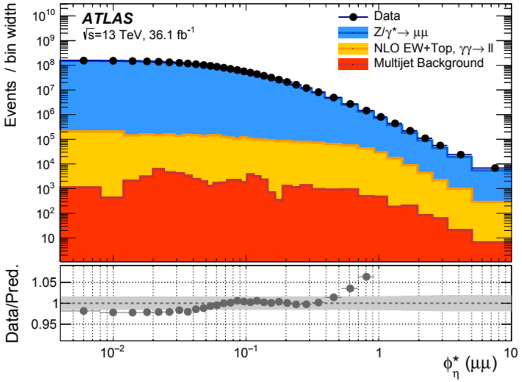
Drell-Yan @ 13 TeV , 36.1 fb^{-1} : Observables









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