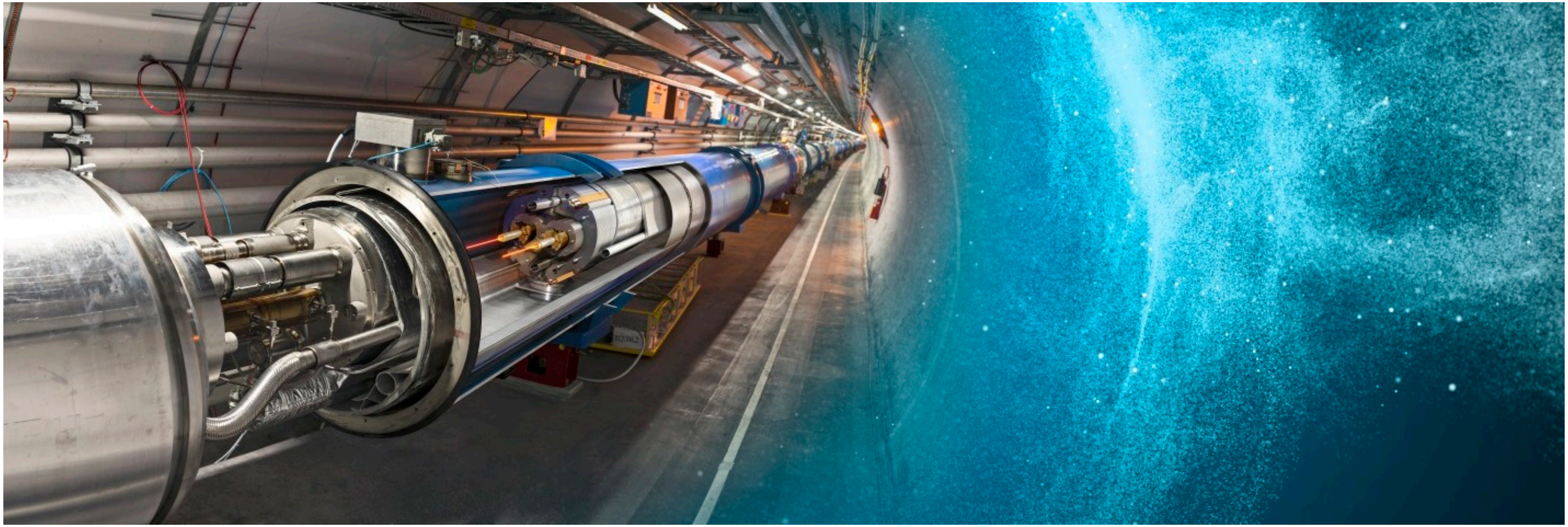
Tests of the EW sector with precision measurements and diboson final states at the ATLAS Experiment



DISCRETE 2018

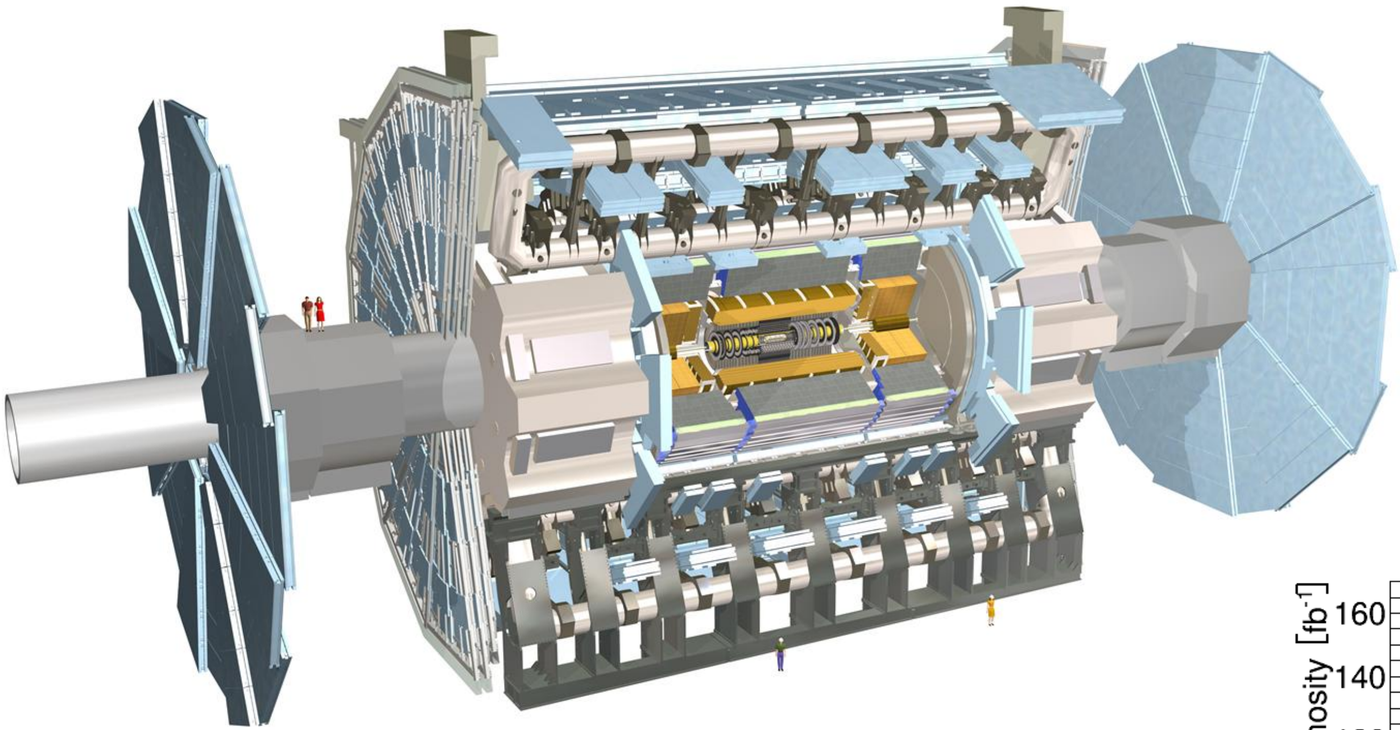
26-30 November 2018 **Wien**

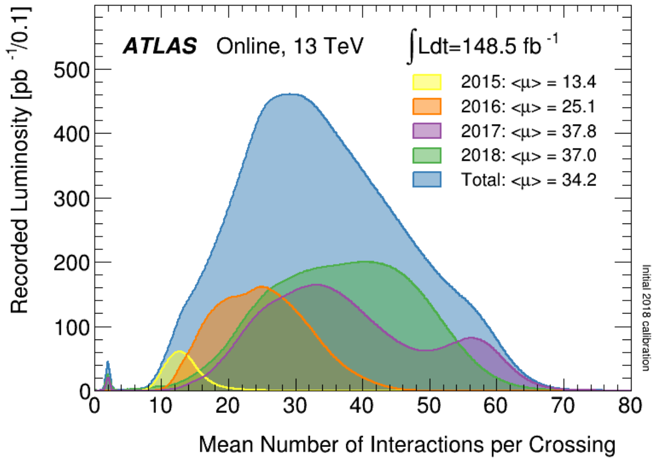
Laura Fabbri

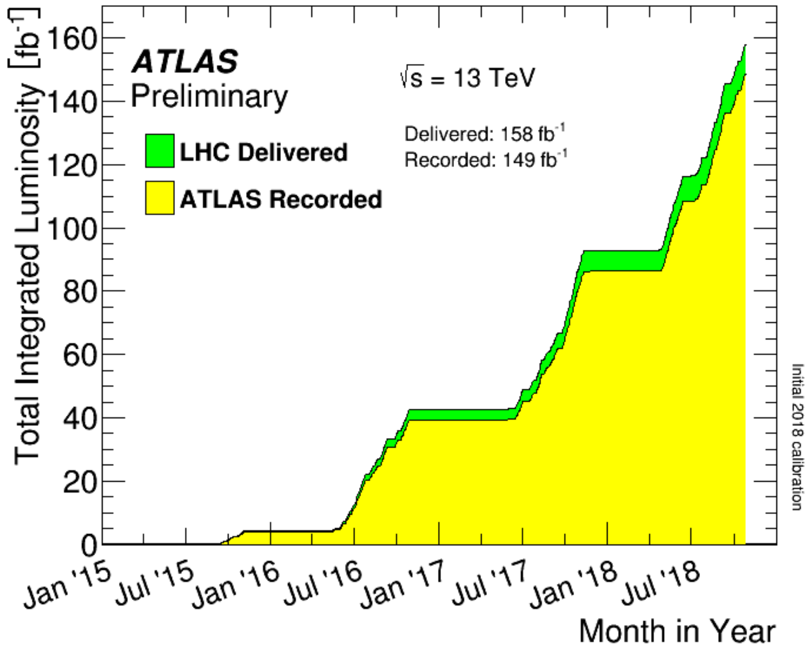
INFN and University of Bologna

on behalf of the ATLAS Collaboration

ATLAS Experimental Status







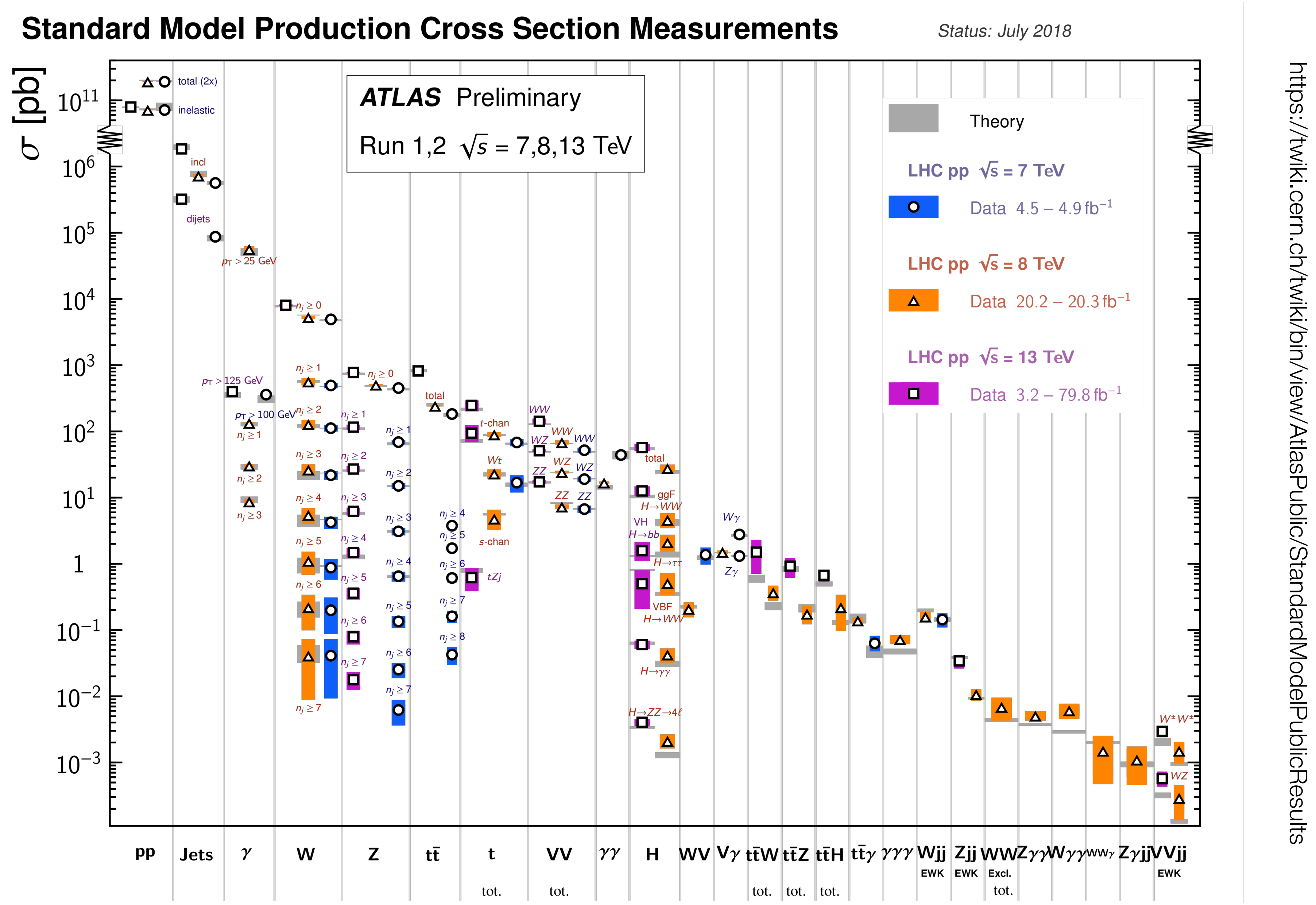
ATLAS has accumulated

~ 25 fb^{-1} at 7/8 TeV

~ 150 fb^{-1} at 13 TeV

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/LuminosityPublicResultsRun2

Standard Model measurements



Outline

- Precision WZ measurement at 13 TeV
  ATLAS-CONF-2018-034
- Electroweak VVjj Vector Boson Scattering at 13 TeV
  - $W^{\pm}W^{\pm}$ jj production
    ATLAS-CONF-2018-030
  - $W^{\pm}Z$ jj production
    ATLAS-CONF-2018-033
- Measurement of weak mixing angle at 8TeV
  ATLAS-CONF-2018-037

Precision WZ measurement at 13 TeV

ATLAS-CONF-2018-034

1. Integrated cross section:
   - fiducial phase space: $W^{\pm}Z$, $W^{+}Z$, $W^{-}Z$;
   - charge ratio $W^{+}Z/W^{-}Z$
   - total phase space: $W^{\pm}Z$
2. Differential cross sections: p_T^Z, p_T^W, m_T^{WZ}, p_T^{ν}, $|y_Z - y_{l,W}|$, $\Delta\phi(W,Z)$, N_{jets}, m_{jj},
3. First measurement of W and Z polarisation fractions in WZ events.

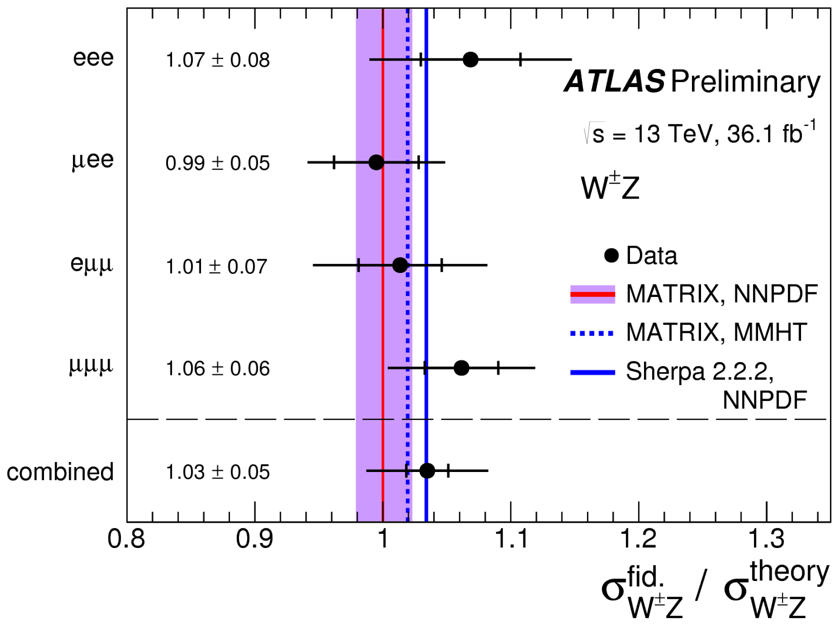
Event Selection: lll + E_T^{miss} + nj

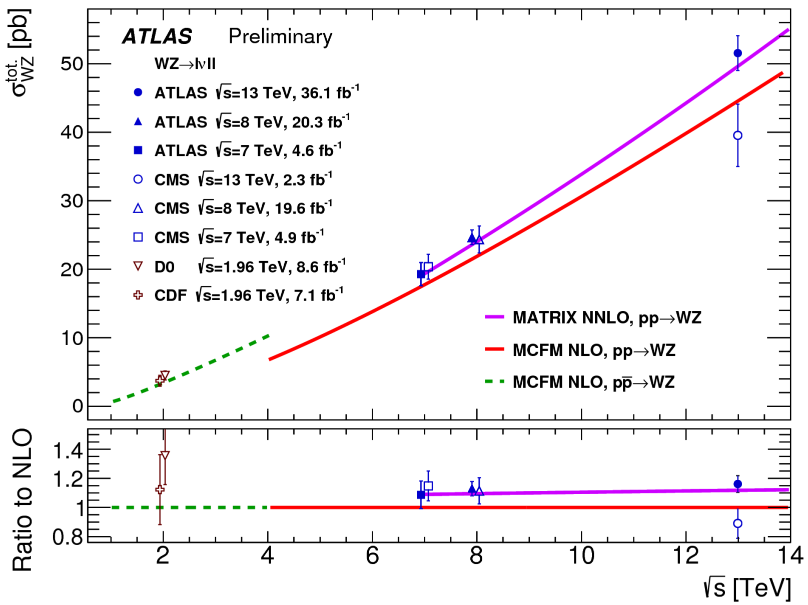
- *Medium* muons, p_T>15 GeV (except trigger), $|\eta_\mu| < 2.5$
- *Medium* electrons, p_T>15 GeV (except trigger), $|\eta_e|<1.37$ & $1.52<|\eta_e|<2.47$
- Leptons originate from a Primary Vertex: $|d_0/\sigma_{d0}| < 3(5)$ μ(e) $|z0 \sin(\theta)|<0.5$ mm
- Specific isolation cuts
- Jets: anti-k_T(R=0.4), p_T>25 GeV, $|\eta_j| < 4.5$
- $|m_{ll} - m_Z| < 10$ GeV ; $m_T^W > 30$ GeV

Signal categories:
$\mu^{\pm}\mu^{+}\mu^{-}$, $e^{\pm}\mu^{+}\mu^{-}$,
$\mu^{\pm}e^{+}e^{-}$, $e^{\pm}e^{+}e^{-}$

Cross section result in fiducial/total phase space

Integrated cross-section



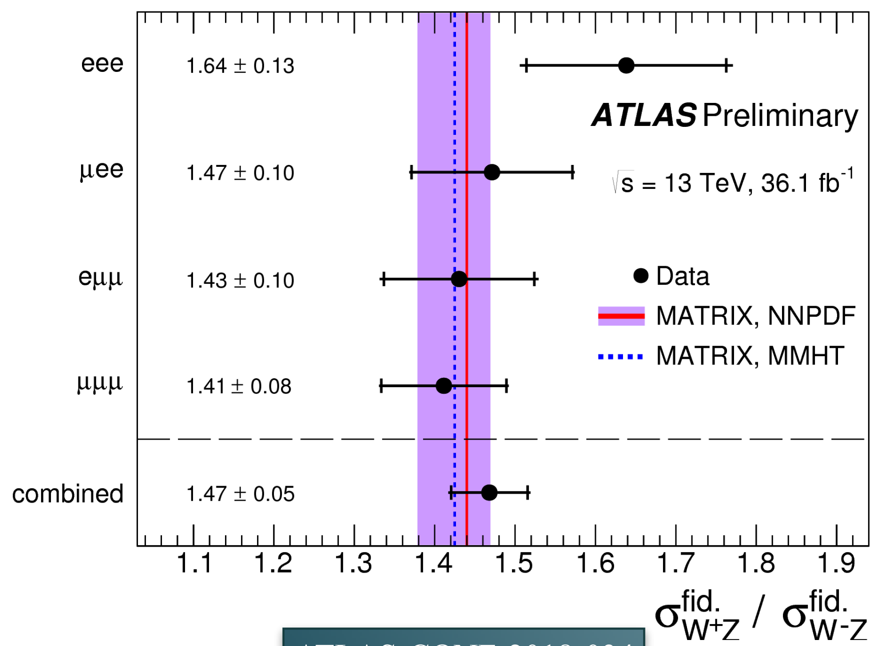


- Good agreement with NNLO prediction by MATRIX

$$\sigma^{tot.}_{W^\pm Z} = 51.0 \pm 0.8\,(\mathrm{stat.}) \pm 1.8\,(\mathrm{sys.}) \pm 0.9\,(\mathrm{th.}) \pm 1.2\,(\mathrm{lumi.})\,\mathrm{pb},$$

MATRIX NNLO: $49.1^{+1.1}_{-1.0}\,(\mathrm{scale})\,\mathrm{pb}$

W^+Z/W^-Z cross section ratio:



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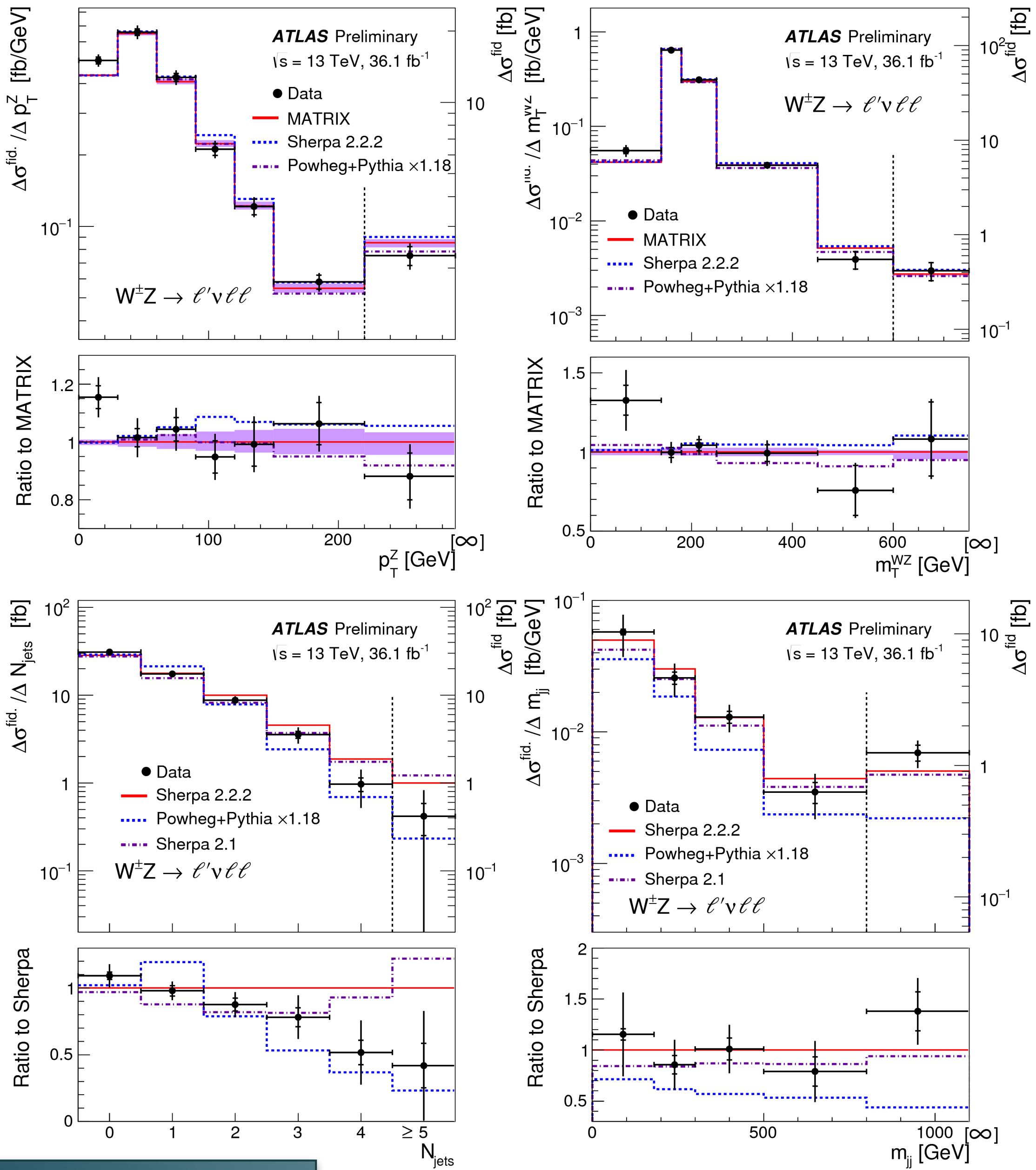
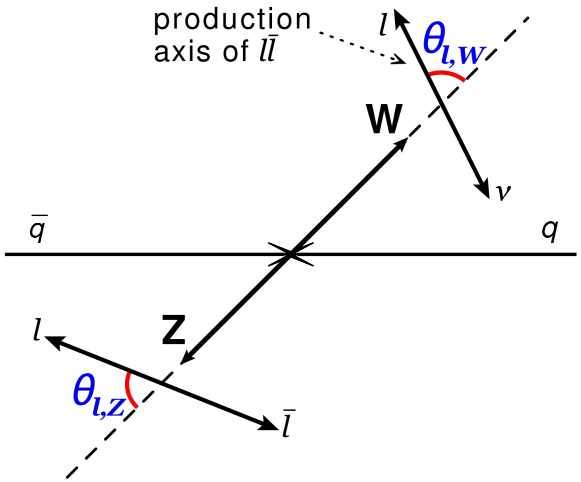
Differential cross sections

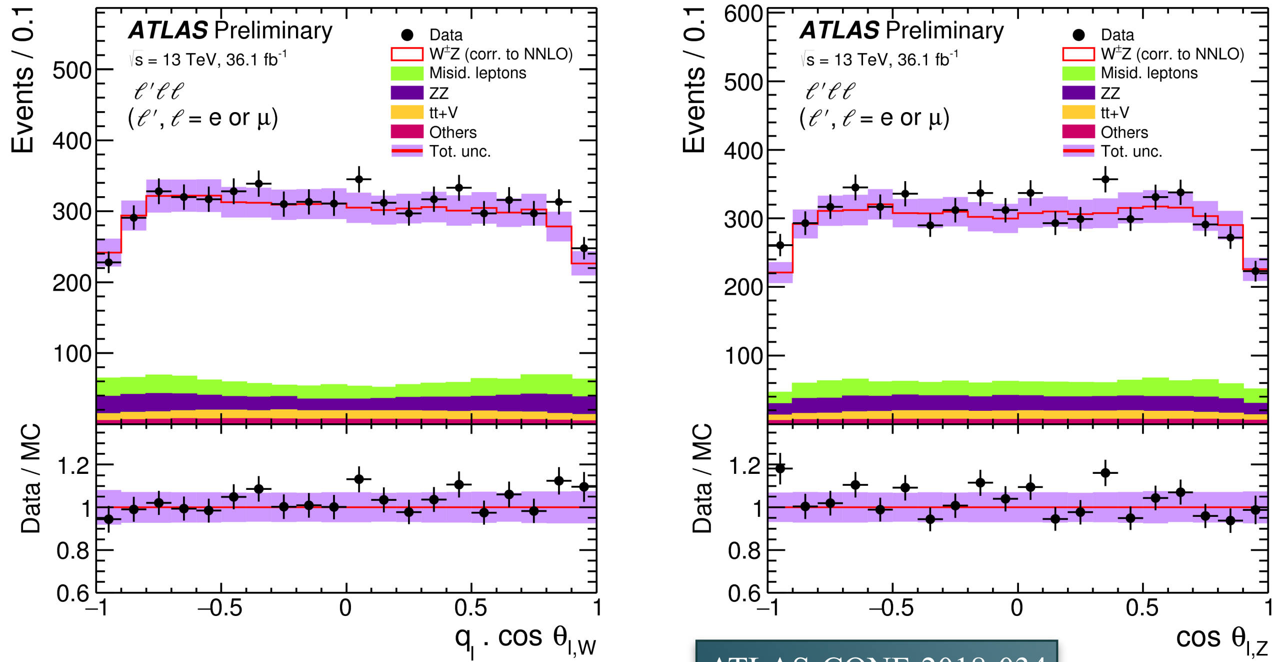


- Measure cross section as a function of: p_T^Z , p_T^W , m_T^{WZ} , $\Delta\phi(W,Z)$, p_T^{ν}, $|y_Z - y_{l,W}|$, N_{jets}, m_{jj};
- Differential cross section results are compared to the NNLO QCD predictions from MATRIX
- p_T^Z and m_T^{WZ} are sensitive to aTGCs: **no excess of data is observed**
- Jets-related distributions are compared to the Sherpa 2.2.2 predictions, that contains up to one parton at NLO and up to three partons at LO

First measurement of boson polarisation

purely longitudinal, transverse-left and transverse-right helicity components





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Fit angular distributions using analytical functions in total phase space to create templates with pure polarisation states.

Helicity fractions f_0 and $f_L - f_R$ measured using a binned profile-likelihood fit.

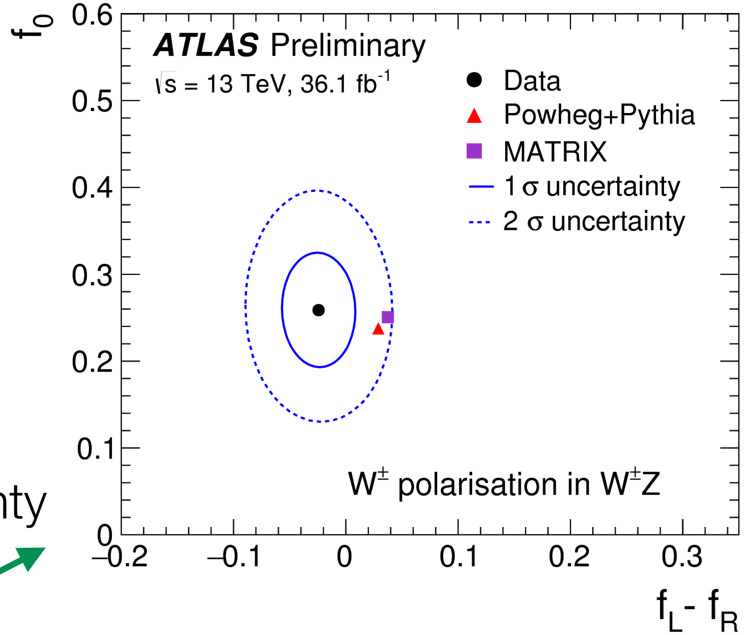
$$f_0 + f_R + f_L = 1$$

Born level leptons

Polarisation results

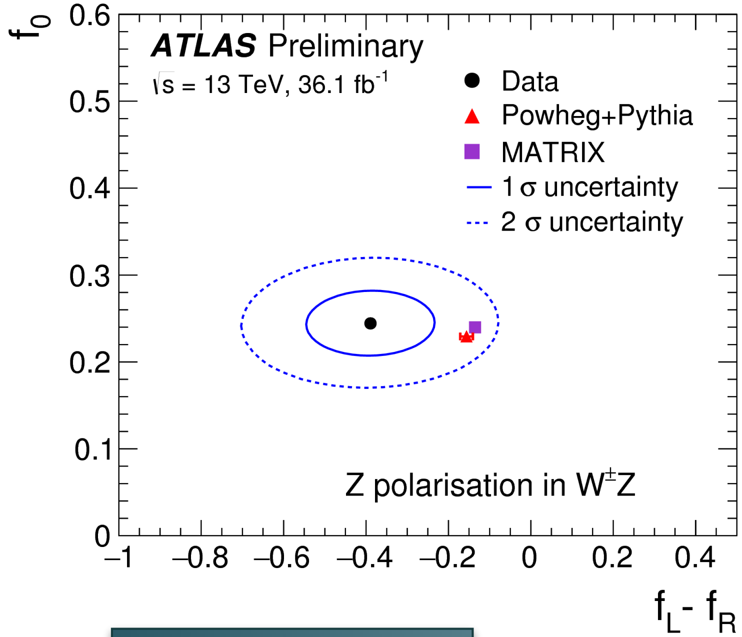
	f_0		$f_L - f_R$	
	Data	Prediction	Data	Prediction
W^+ in W^+Z	0.26 ± 0.08	0.233 ± 0.004	-0.02± 0.04	0.083 ± 0.004
W^- in W^-Z	0.32 ± 0.09	0.245 ± 0.005	-0.05± 0.05	-0.061 ± 0.006
$W^\pm$ in $W^\pm Z$	0.26 ± 0.06	0.2376 ± 0.0031	-0.024± 0.033	0.0249 ± 0.0022
Z in W^+Z	0.27 ± 0.05	0.225 ± 0.004	-0.32± 0.21	-0.269 ± 0.021
Z in W^-Z	0.21 ± 0.06	0.235 ± 0.005	-0.46 ± 0.25	0.034 ± 0.023
Z in $W^\pm Z$	0.24 ± 0.04	0.2294 ± 0.0033	-0.39± 0.16	-0.147 ± 0.016

Precision of the measurement is limited by statistical uncertainty



First evidence of longitudinally polarised W bosons

(4.2 σ observed significance)



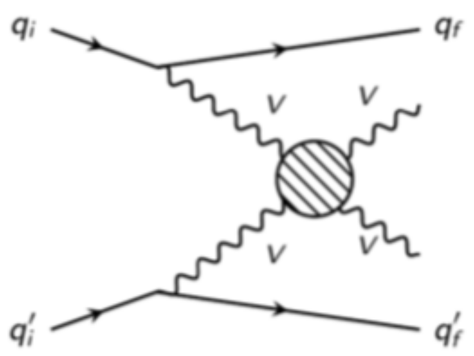
$f_L - f_R$ also measured even if with a lower sensitivity. Agreement with the SM predictions is within 2 σ

ATLAS-CONF-2018-034

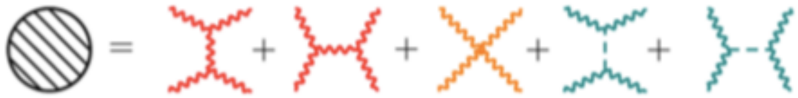
W±Z/W±W± jj final state

ATLAS-CONF-2018-030

ATLAS-CONF-2018-033



EW signal



α_{EW}^6

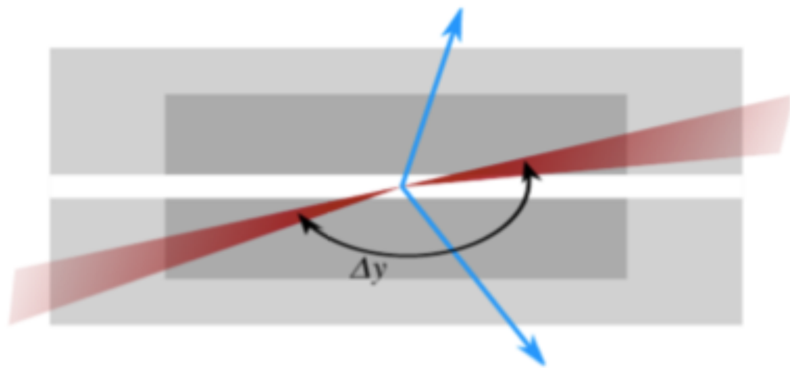
Motivation:

→ triple & quartic GC

→ Higgs, BSM

VBS VVjj production has a very characteristic kinematical signature

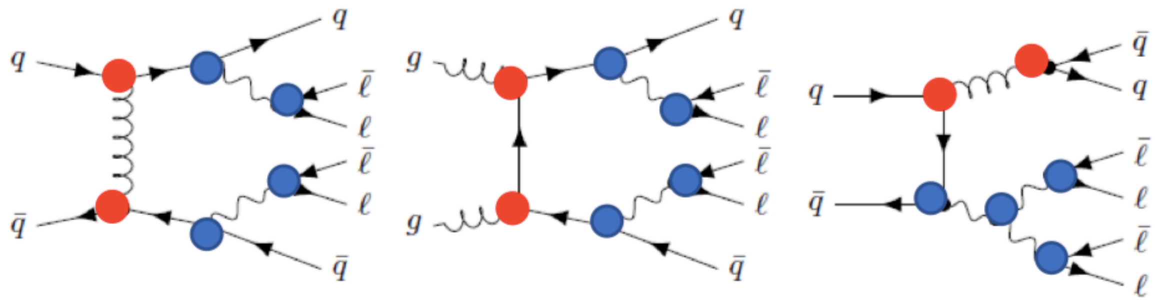
- Two high P_T forward jets
- W and Z products in the central region



Main Background

- QCD WZ production in association with two jets

$\alpha_S^2 \alpha_{EW}^4$



$W^{\pm}W^{\pm}$ jj final state

ATLAS-CONF-2018-030

Signal Extraction: SS 2l + 2j

- Two leptons $p_T > 27$ GeV, $|\eta_l| < 2.5$.
  (end-cap excluded in ee channel)
- Only $W^{\pm} \to e/\mu$

Signal categories: $e^{\pm}e^{\pm}$, $e^{\pm}\mu^{\pm}$, $\mu^{\pm}\mu^{\pm}$

- Two forward jets $p_T^j > 65/35$ GeV, $|\eta_j| < 4.5$
- $\Delta y_{jj} > 2.0$, $m_{jj} > 500$ GeV included in profile likelihood fit
- Additional kinematic cuts to remove tt+jets and WZ contributions (b-jet veto and 3rd lepton veto)

Major syst. unc.: jet energy scale

$W^{\pm}W^{\pm}$jj-EW	ee % Yield	$e\mu$ % Yield	$\mu\mu$ % Yield
Jet-related Uncertainties	2.28	2.22	2.28
b-tagging efficiency	1.81	1.76	1.74
Pile-up	0.48	0.97	2.42
Trigger efficiency	0.02	0.08	0.47
Lepton reconstruction and identification	1.45	1.14	1.83
MET reconstruction	0.26	0.17	0.21

Backgrounds

ATLAS-CONF-2018-030

- $W^\pm W^\pm jj$ processes involving strong interaction (**QCD processes**)
- processes with **prompt same-charge** leptons ($W^\pm Zjj$, $ZZjj$, $t\bar{t}V$)
  - ➡ Estimated using MC simulation normalised in a CR
- processes with at least one **non-prompt lepton** ($V\gamma$, W+jets)
  - ➡ the tight isolation requirements on leptons, the b-jet veto and the missing transverse energy selections
- processes with **electron charge mis-identification** ($t\bar{t}$, $W^\pm W^\mp jj$, $Z/\gamma^* jj$)
  - ➡ Z mass veto & b-jet veto

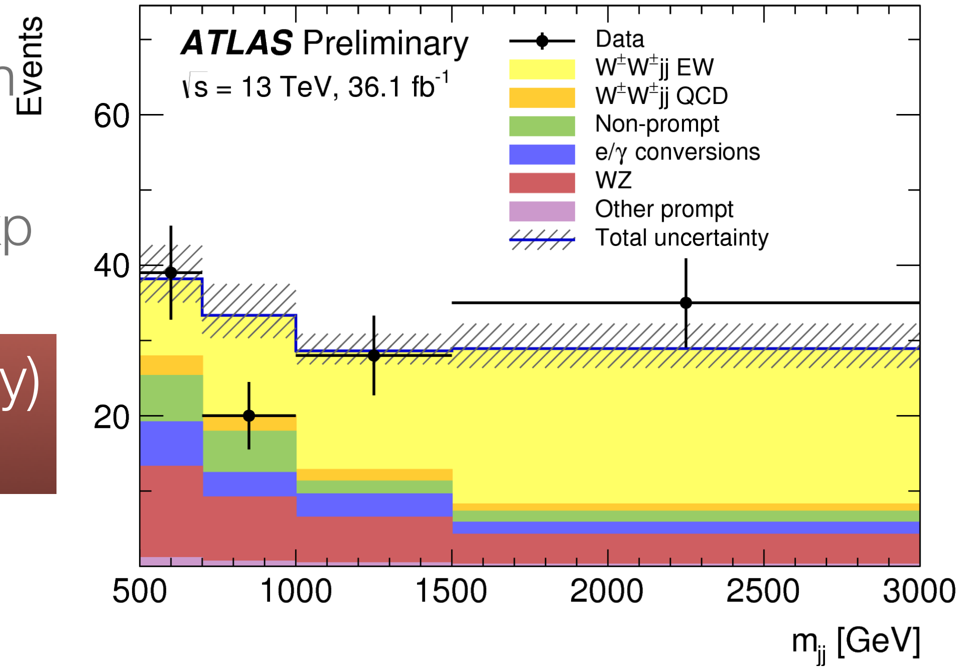
	e^+e^+	e^-e^-	$e^+\mu^+$	$e^-\mu^-$	$\mu^+\mu^+$	$\mu^-\mu^-$	combined
WZ	1.7 ± 0.6	1.2 ± 0.4	13 ± 4	8.1 ± 2.5	5.0 ± 1.6	3.3 ± 1.1	32 ± 9
Non-prompt	4.1 ± 2.4	2.3 ± 1.8	9 ± 6	6 ± 4	0.57 ± 0.16	0.67 ± 0.26	23 ± 12
e/γ conversions	1.74 ± 0.31	1.8 ± 0.4	6.1 ± 2.4	3.7 ± 1.0	-	-	13.4 ± 3.5
Other prompt	0.17 ± 0.06	0.14 ± 0.05	0.90 ± 0.24	0.60 ± 0.25	0.36 ± 0.12	0.19 ± 0.07	2.4 ± 0.5
$W^\pm W^\pm$jj strong	0.38 ± 0.13	0.16 ± 0.06	3.0 ± 1.0	1.2 ± 0.4	1.8 ± 0.6	0.76 ± 0.26	7.3 ± 2.5
Expected background	8.1 ± 2.4	5.6 ± 1.9	32 ± 7	20 ± 5	7.7 ± 1.7	4.9 ± 1.1	78 ± 15
$W^\pm W^\pm$jj electroweak	3.80 ± 0.30	1.49 ± 0.13	16.5 ± 1.2	6.5 ± 0.5	9.1 ± 0.7	3.50 ± 0.29	40.9 ± 2.9
Data	10	4	44	28	25	11	122

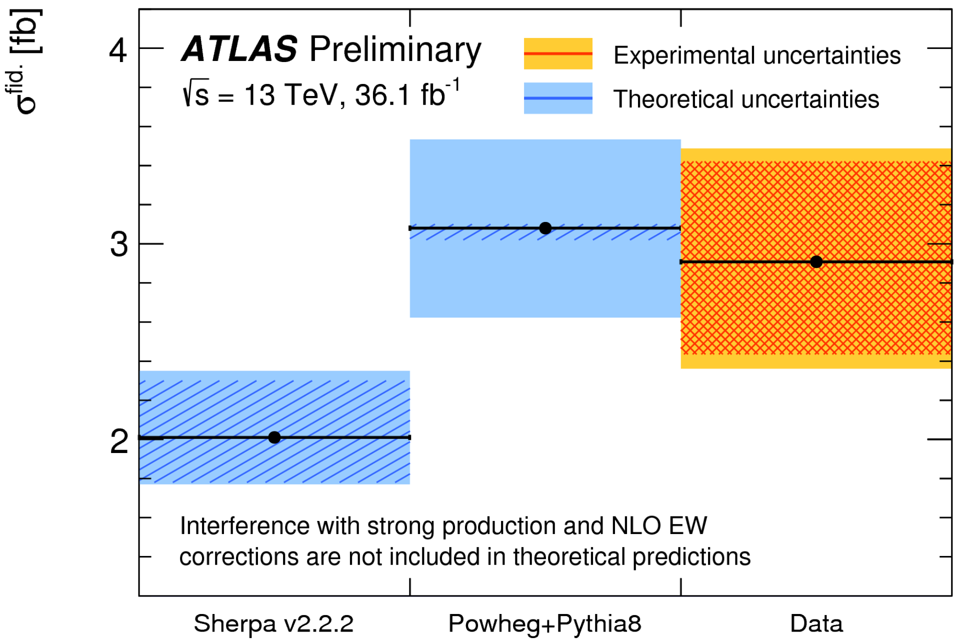
Results

An excess of data over backgrounds prediction is observed in most of the bins:

122 candidate events - 69±10 background exp

Observed significance: 6.9 σ (7.7 σ StatOnly)
Expected 4.6 σ (5.3 σ StatOnly)





$$\sigma^{fid} = 2.91^{+0.51}_{-0.47}(\text{stat.}) \pm 0.27(\text{sys.})\text{fb}$$

$$\sigma^{SHERPA} = 2.01^{+0.33}_{-0.23}(\text{sys.+stat.})\text{fb}$$

$$\sigma^{POWHEG+PYTHIA8} = 3.08^{+0.45}_{-0.46}(\text{sys.+stat.})\text{fb}$$

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WZjj final state - Signal and control regions

On top of the inherited WZ inclusive selection, **a region dedicated to WZjj is defined:**

- Exactly 3 leptons (only e/μ)
  - 2 of them: Z lepton selection (same flavour, oppositely charged, $|M_{ll}-M_Z| < 10$ GeV, …)
  - Remaining: W boson selection ($m_T^W > 30$ GeV, …)
- Two forward jets: $p_T^j > 40$ GeV, $|\eta_j| < 4.5$, $\eta_{j1} \cdot \eta_{j2} < 0$, $M_{jj} > 500$ GeV

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Then this region is separated into three orthogonal regions:

b-control region: Used to normalise the second irriducibile background

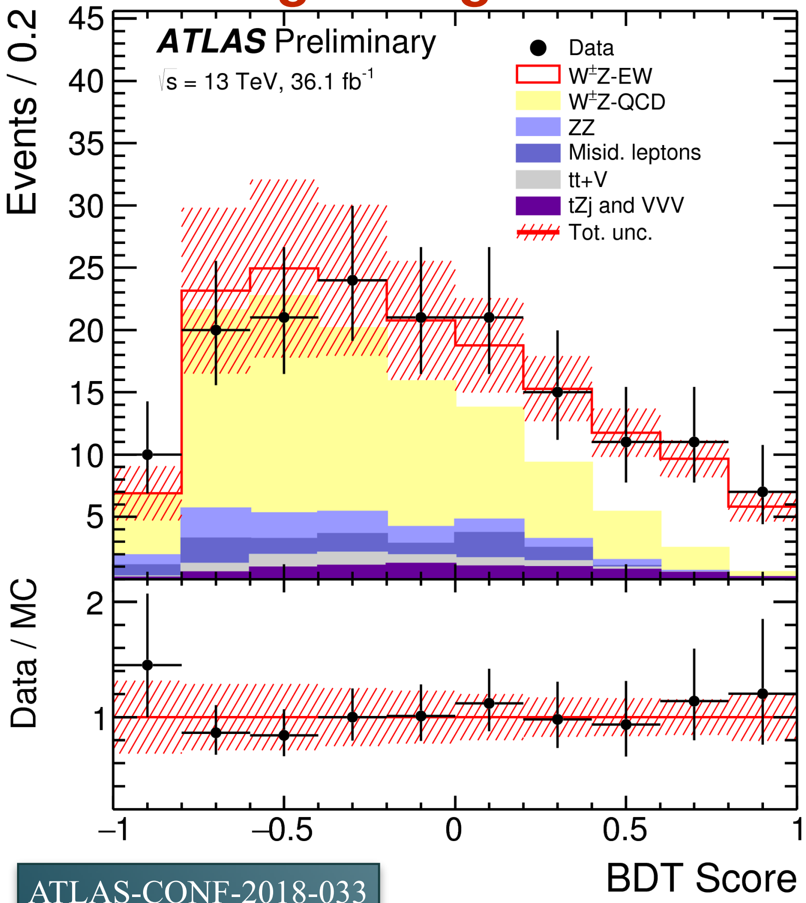
QCD control region: Used to normalise the main irriducibile background

b-CR ($t\bar{t}$+V) $N_{b\text{-jet}} > 0$	
QCD-CR(WZjj-QCD) M_{jj} <500 GeV $N_{b\text{-jet}} = 0$	SR (WZjj-EW) M_{jj} >500 GeV $N_{b\text{-jet}} = 0$

Signal region: Used for the cross-section measurement

Results

Signal region



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- **MultiVariate Analysis:**
  - BDT discriminant based on 15 variables
  - Cross training: train 2 BDTs and apply to each event the BDT for which it was not used

$$\mu_{EW} = 1.77 \pm 0.45$$

Observed significance: 5.6 σ (expected 3.3 σ)

$$\sigma_{EW}(W^{\pm}Zjj \to l'\nu lljj) = $$
$$= 0.57^{+0.14}_{-0.13}(\text{stat.})^{+0.05}_{-0.04}(\text{sys.})^{+0.04}_{-0.03}(\text{th.})\ \text{fb}$$

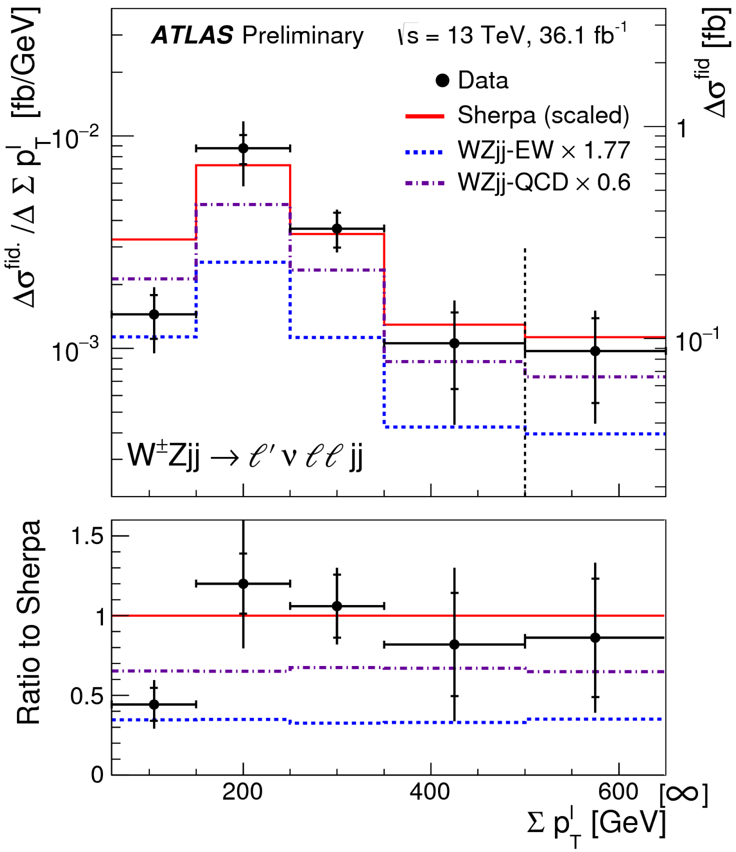
Predictions:

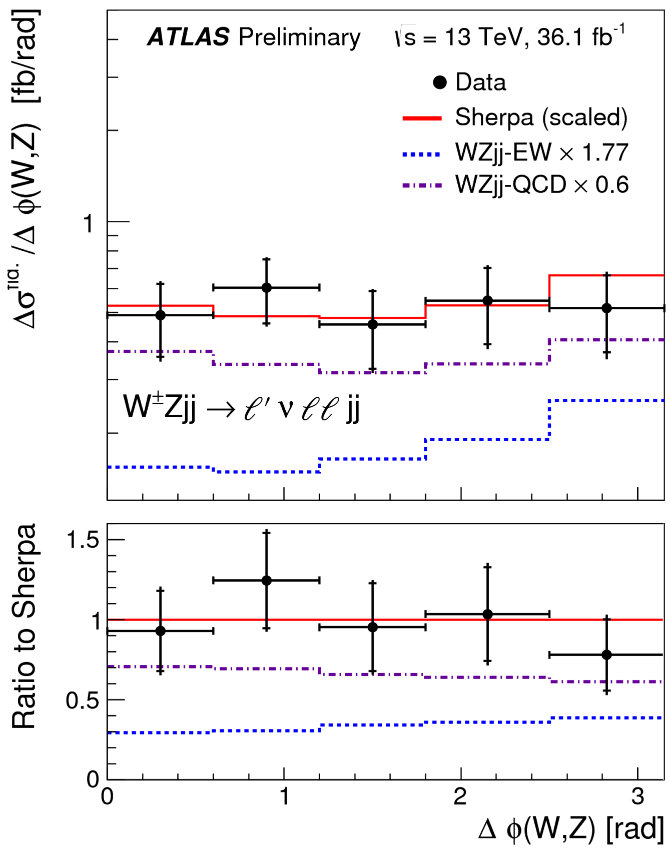
SM LO w/o interference effects nor NLO EW corrections

$$\sigma_{SHERPA} = 0.321 \pm 0.002(\text{stat.}) \pm 0.005(\text{PDF})^{+0.027}_{-0.023}(\text{scale})\ \text{fb}$$

$$\sigma_{MadGraph} = 0.366 \pm 0.004(\text{stat.})\ \text{fb}$$

Differential cross-section





- Kinematic distributions are unfolded as in the previous analysis
- Measure cross section as a function of: Σp^l_T, $\Delta\phi(W,Z)$, m_T^{WZ}, N_{jets}, Δy_{ll}, m_{jj}, N_{jets}^{gaps}, $\Delta\phi_{jj}$;
- Σp^l_T and $\Delta\phi(W,Z)$ are sensitive to aQGC

- **WZjj-QCD** and **WZjj-EW** SHERPA predictions are rescaled using μ_{EW} and $\mu_{WZ\text{-}QCD}$ obtained from the fit and combined in the **SHERPA(scaled)**

Good description of the measured cross sections

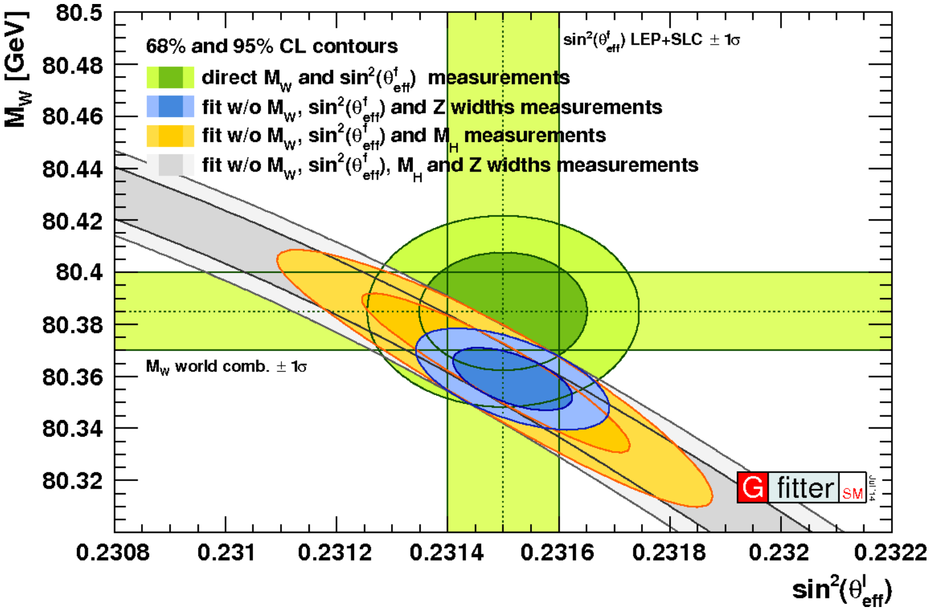
The weak mixing angle and the Standard Model

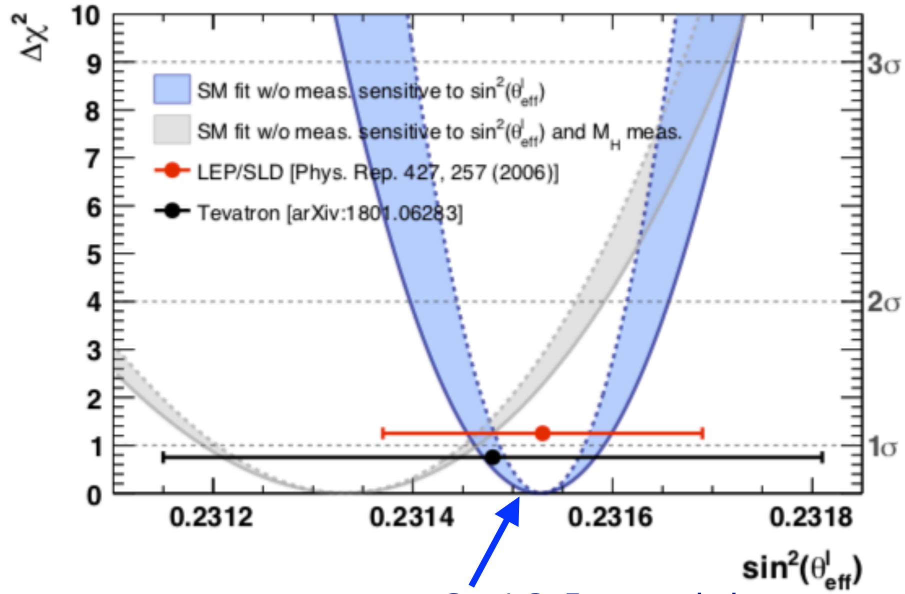
- **$\sin^2\theta_W$** is a parameter of the SM representing the mixing of the EM and weak fields
- Within the SM, it relates the W- and Z-boson coupling constants $g_{W,Z}$, and therefore $m_{W,Z}$
- Radiative corrections modify this relation, yielding the fermion-flavor dependent effective weak mixing angle: **$\sin^2\theta^l_{eff}$**

$$A_\mu = B_\mu \cos\theta_W + W^3_\mu \sin\theta_W$$
$$Z_\mu = -B_\mu \sin\theta_W + W^3_\mu \cos\theta_W$$

$$\sin^2\theta_W = 1 - \frac{g_W^2}{g_Z^2} = 1 - \frac{m_W^2}{m_Z^2}$$

$$\sin^2\theta^l_{eff} = (1 - \frac{m_W^2}{m_Z^2})(1 + \Delta r^l)$$





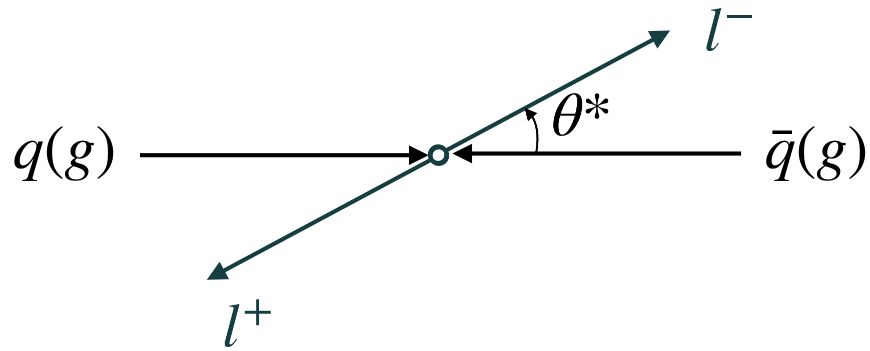
SM prediction, from fit w/out direct measurements, ~6x10^-5 precision

The weak mixing angle at hadron colliders

$q\bar{q} \rightarrow Z/\gamma* \rightarrow ll$ differential cross section at LO:

$$\frac{d\sigma}{dy^{ll}dm^{ll}d\cos\theta} = \frac{3}{16\pi}\frac{d\sigma^{U+L}}{dy^{ll}dm^{ll}}\left\{(1+\cos^2\theta) + A_4\cos\theta\right\}$$

- In the di-lepton CM, lepton angle with respect to axis of quark/gluon momentum is sensitive to **interference effects**: vector with axial-vector Z couplings, Z with photon (or Z with new physics)



- **The A_4 term odd in cosθ is very sensitive to the weak mixing angle when M = M_Z.**
- The odd term coefficient A_4 can be obtained from an angular fit or computed from the forward-backward asymmetry

$$A_{FB} = \frac{\sigma(\cos\theta > 0) - \sigma(\cos\theta < 0)}{\sigma} = \frac{3}{8}A_4$$

A_4 measurement strategy

$$\frac{d\sigma}{dp_T^Z\, dy^Z\, dm^Z\, d\cos\theta\, d\phi} = \frac{3}{16\pi}\frac{d\sigma^{U+L}}{dp_T^Z\, dy^Z\, dm^Z}$$

→ unpolarized cross-section

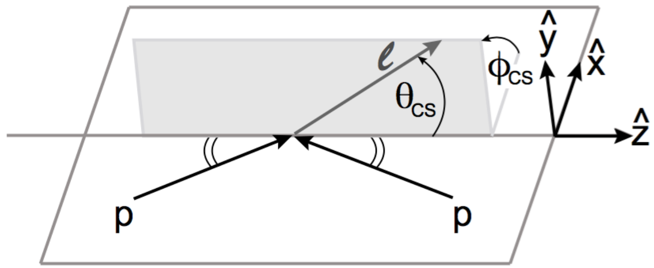
$$\Big\{(1+\cos^2\theta) + \frac{1}{2}A_0(1-3\cos^2\theta) + A_1 \sin 2\theta \cos\phi + \frac{1}{2}A_2 \sin^2\theta \cos 2\phi + A_3 \sin\theta \cos\phi + A_4 \cos\theta + A_5 \sin^2\theta \sin 2\phi + A_6 \sin 2\theta \sin\phi + A_7 \sin\theta \sin\phi\Big\}$$

- Angular distributions parametrized by coefficients **$A_i(p_T^Z, y^Z, m^Z)$**
  - ➤ Extracted **from the shape of angular distributions**

- **Five-dimensional differential cross-section**: 9 harmonic polynomials **$P_i(\cos\theta,\phi)$**

LO QCD: only $A_4 \neq 0$
NLO QCD $O(\alpha_s)$: $+A_{1\text{-}3} \neq 0$
$A_0 - A_2 = 0$ due to spin-1 of gluon (Lam-Tung)
NNLO QCD $O(\alpha_s^2)$: $+A_{5,6,7} \neq 0$

Collins-Soper Frame



- Rest frame of di-lepton system
- z-axis bisecting directions of incoming protons

Event selection and categorisation

- **ee_{CC}**: two electrons in the central tracking and calorimetry (|η|<2.4)
  - p_T >25 GeV
  - Exactly 2 opposite sign electrons
- **$\mu\mu_{CC}$**: two muons in the central tracking and muon systems (|η|<2.4)
  - p_T >25 GeV P_T
  - Exactly 2 opposite sign muons

- 3 bins in m_{ll}
  - $70 < m_{ll} < 80$ GeV
  - $80 < m_{ll} < 100$ GeV
  - $100 < m_{ll} < 125$ GeV
- 3 bins in $|y_{ll}|$
  - $|y_{ll}| < 0.8$
  - $0.8 < |y_{ll}| < 1.6$
  - $1.6 < |y_{ll}| < 2.5$

- **ee_{CF}**: one electron in central tracking/ calorimetry (|η|<2.4), one in endcap/forward calorimetry (2.5 < |η| < 4.9)
  - p_T >25/20 GeV C/F
  - requirement with tighter ID than ee_{CC}

- 1 bin in m_{ll} $80 < m_{ll} < 100$ GeV
- 2 bins in $|y_{ll}|$ $2.5 < |y_{ll}| < 3.6$, $1.6 < |y_{ll}| < 2.5$

	$80 < m_{ll} < 100$ GeV			
$\lvert y_{ll}\rvert$	Data	Top+EW	Multijets	Non-fiducial Z
1.6-2.5	702 142	0.001	0.010	0.017
2.5-3.6	441 104	0.001	0.011	0.013

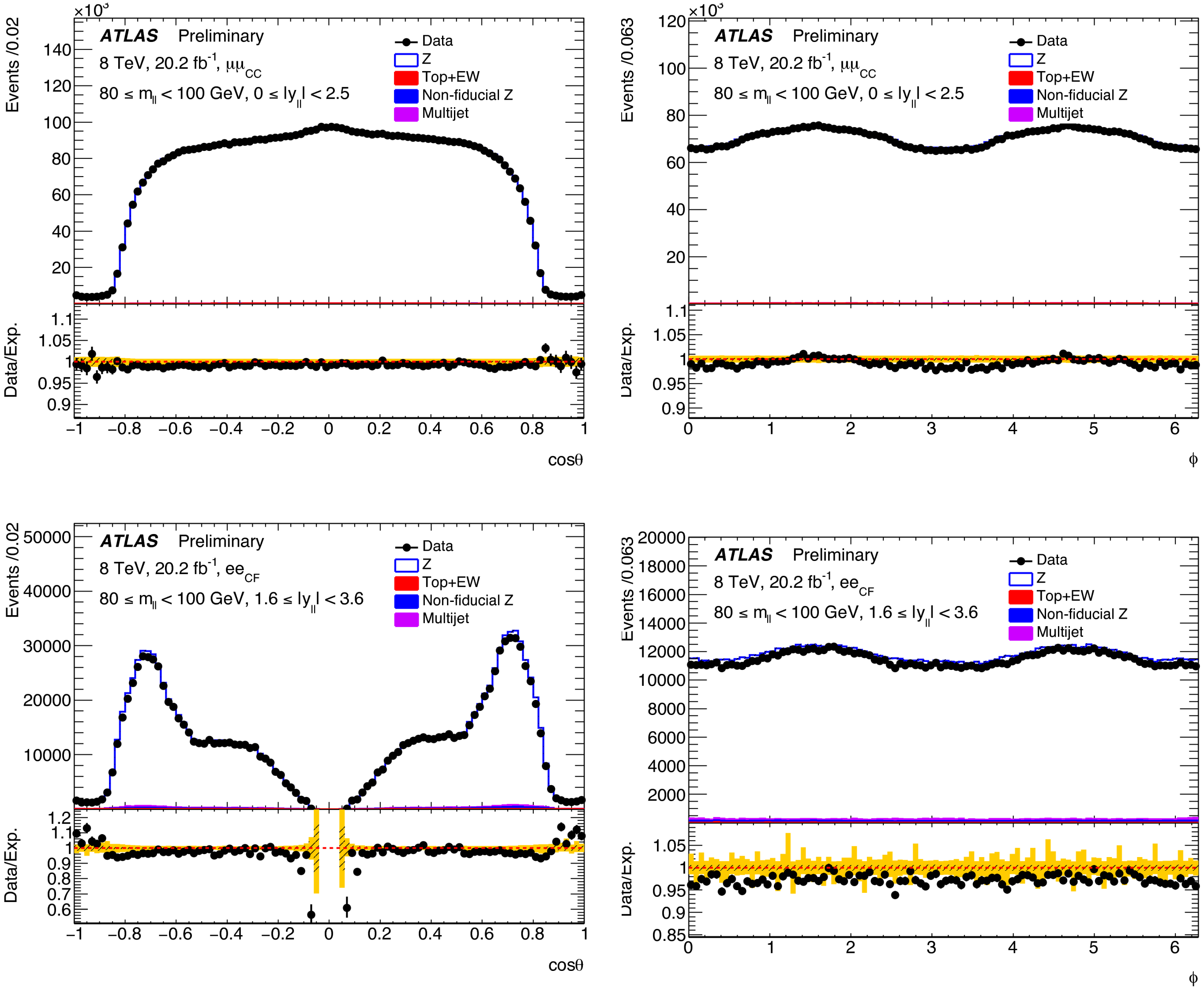
About 6-7M events each for CC categories

1M for CF

ATLAS-CONF-2018-037

Angular distributions

- Data/MC agreement for $\mu\mu_{CC}$ and ee_{CF} in the Z pole mass region for all y.
- Only a small raw AFB is visible for CC; a larger one emerges for CF, as expected.
- S/B at the Z pole is very high
- cos2ϕ modulation from A_2 can be clearly seen



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Fit results and uncertainties

Channel	ee_{CC}	$\mu\mu_{CC}$	ee_{CF}	$ee_{CC} + \mu\mu_{CC}$	$ee_{CC} + \mu\mu_{CC} + ee_{CF}$
Total	65	59	42	48	34
Stat.	47	39	29	30	21
Syst.	45	44	31	37	27
	Uncertainties in measurements				
PDF (meas.)	7	7	7	7	4
p_T^Z modelling	< 1	< 1	1	< 1	< 1
Lepton scale	5	4	6	3	3
Lepton resolution	3	1	3	1	2
Lepton efficiency	1	1	1	1	1
Electron charge misidentification	< 1	0	< 1	< 1	< 1
Muon sagitta bias	0	4	0	2	1
Background	1	1	1	1	1
2 MC. stat.	25	22	18	16	12
	Uncertainties in predictions				
1 PDF (predictions)	36	37	21	32	22
QCD scales	5	5	9	4	6
EW corrections	3	3	3	3	3

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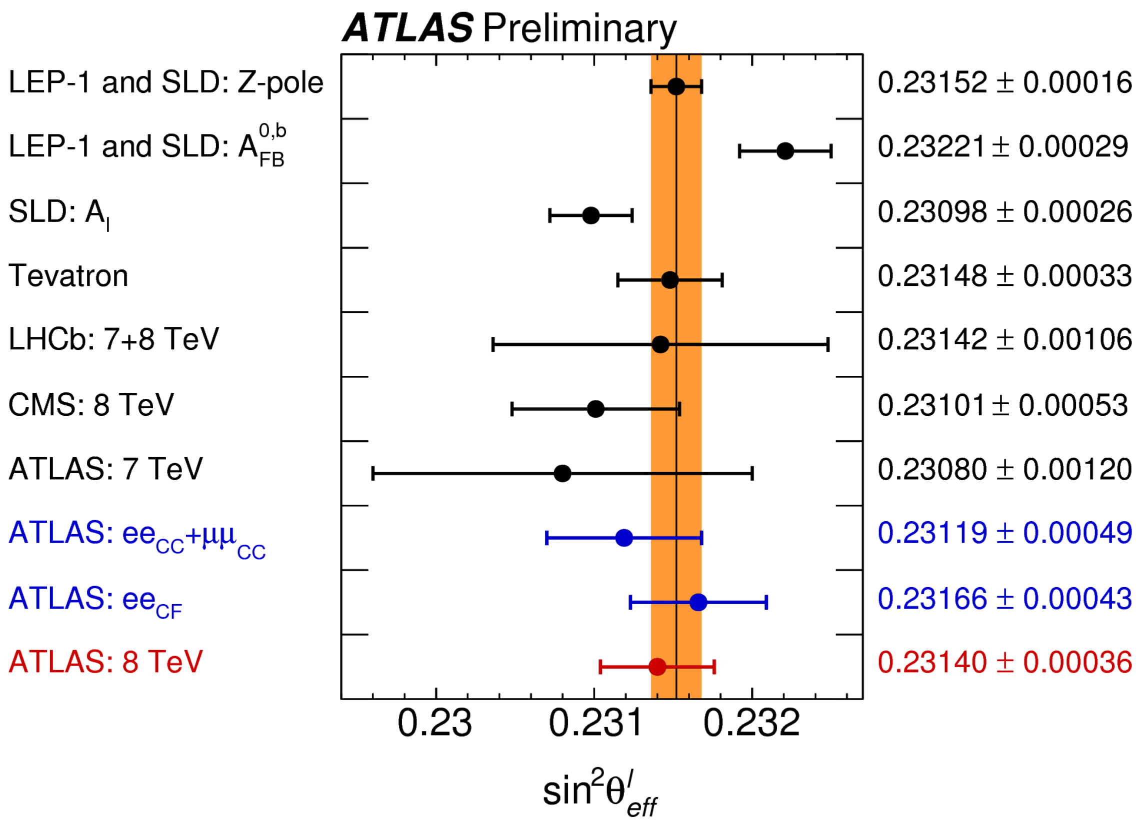
x 10^{-5}

assuming $\sin^2\theta_W = 0.23152$

- Consistent results for all three categories
- ee_{CF} is as powerful as $ee_{CC} + \mu\mu_{CC}$
- All three categories systematics limited, predominantly by PDF uncertainty affecting relation between A_4 and mixing angle

Result: $\sin^2\theta^l_{eff}$



- More than 2 times less precise than LEP/SLD
- Comparable to Tevatron final results
- Superior to CMS 8 TeV, which does not include ee_{CF} category.
- Superior to LHCb due to luminosity/statistics (LHCb has lower PDF unc.!)

0.23140 ± 0.00021 (stat.) ± 0.00024 (PDF) ± 0.00016 (syst.)

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Conclusions

- Precise measurement of SM quantities preformed both at 8 and 13 TeV by the ATLAS Collaboration:
  - ★ **13 TeV**
    - Integrated and differential cross section of $W^{\pm}Z$
    - Cross section of $W^{+}Z/W^{-}Z$
    - Measurement of boson polarisation: first evidence of W longitudinal polarisation
    - Observation of $W^{\pm}W^{\pm}jj$ and $W^{\pm}Zjj$ production via VBS
  - ★ **8 TeV**
    - Precise polarisation study of Z boson
    - Best LHC's measurement of $\sin^2\theta^{l}_{eff}$

Conclusions

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Thank you for your attention

BACKUP

$W^{\pm}Z \rightarrow l\nu ll$ (l = e or μ) production

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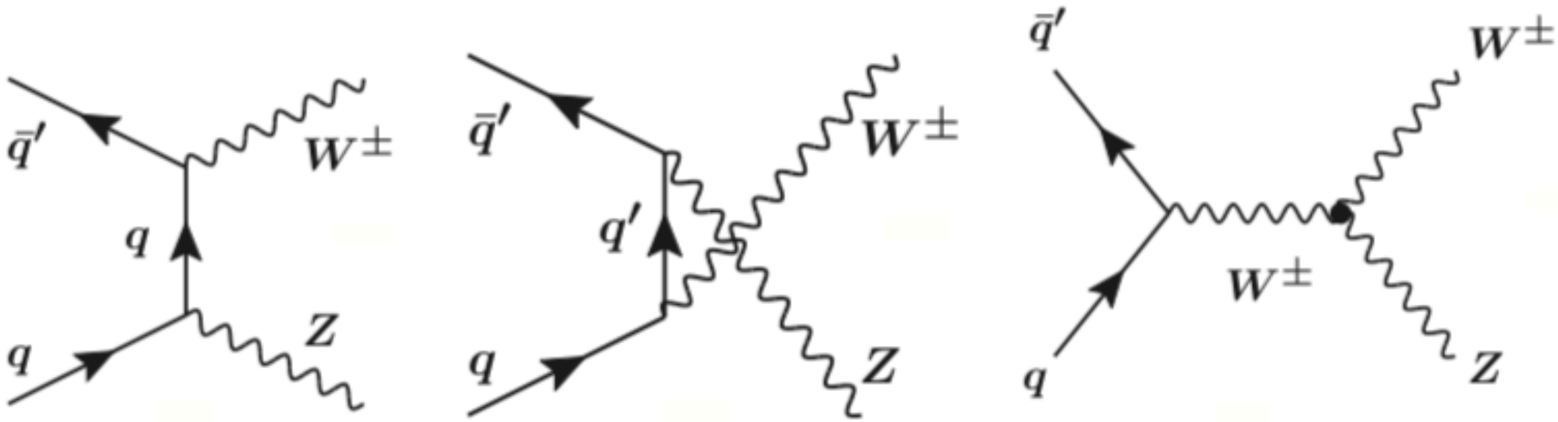
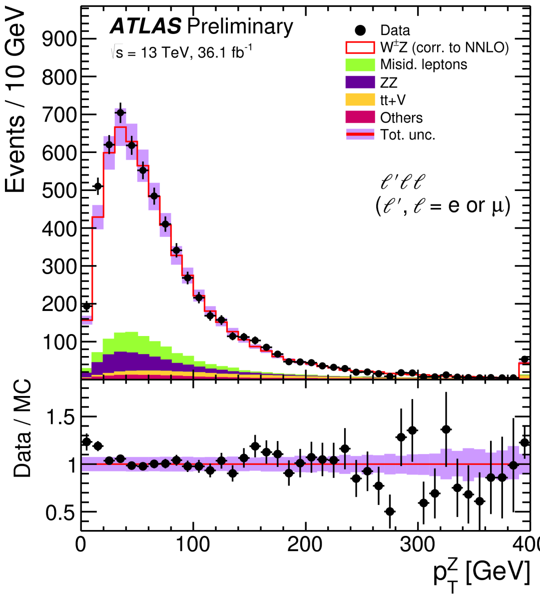
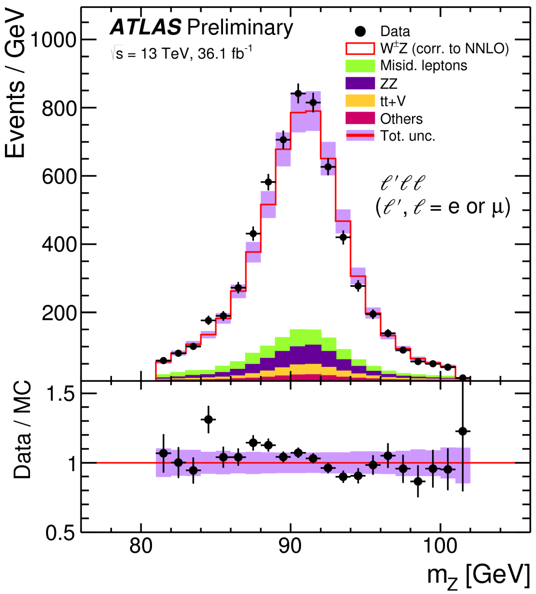
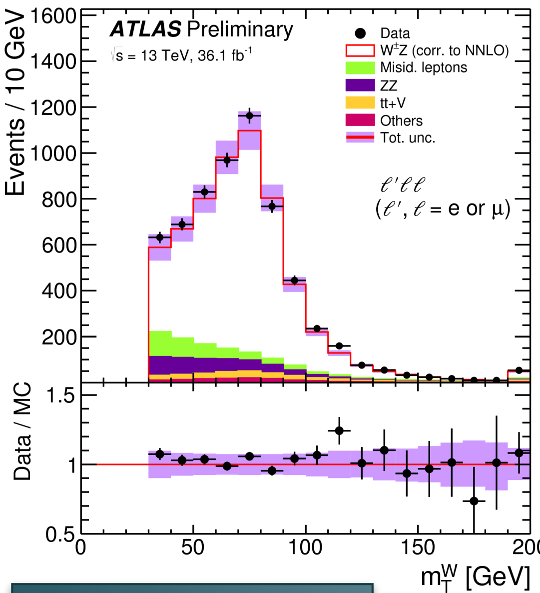


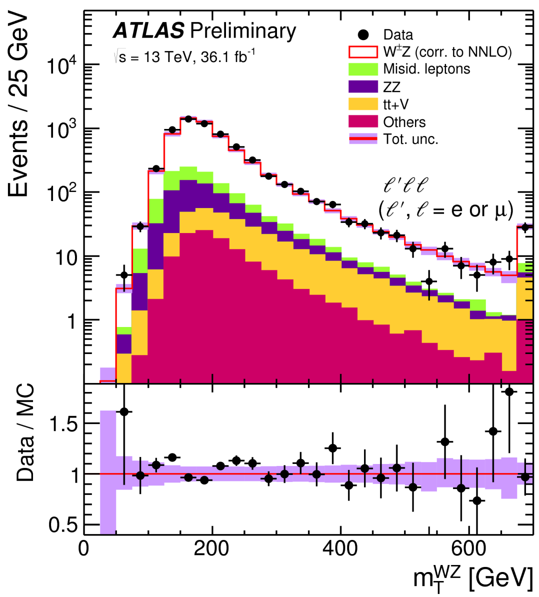
- Diboson processes include vertices with gauge boson self-interactions
  => sensitive to searches of anomalous triple gauge couplings
  → The searches are based on precision measurements.
- Fully leptonic WZ production - clean experimental signature:
  → good signal-to-background ratio, objects systematics are well under control
- Important test of NNLO QCD calculations.
- Important background for many searches in ATLAS.

Kinematical distributions









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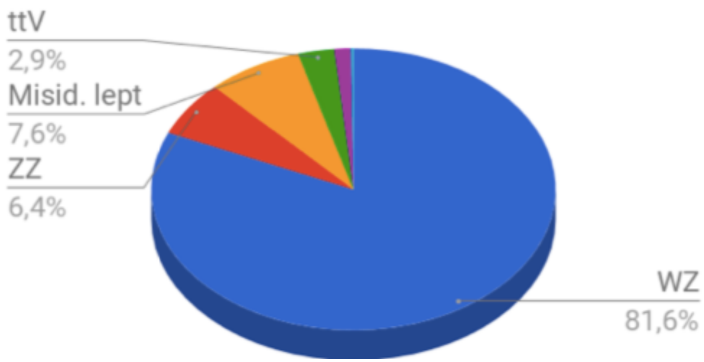
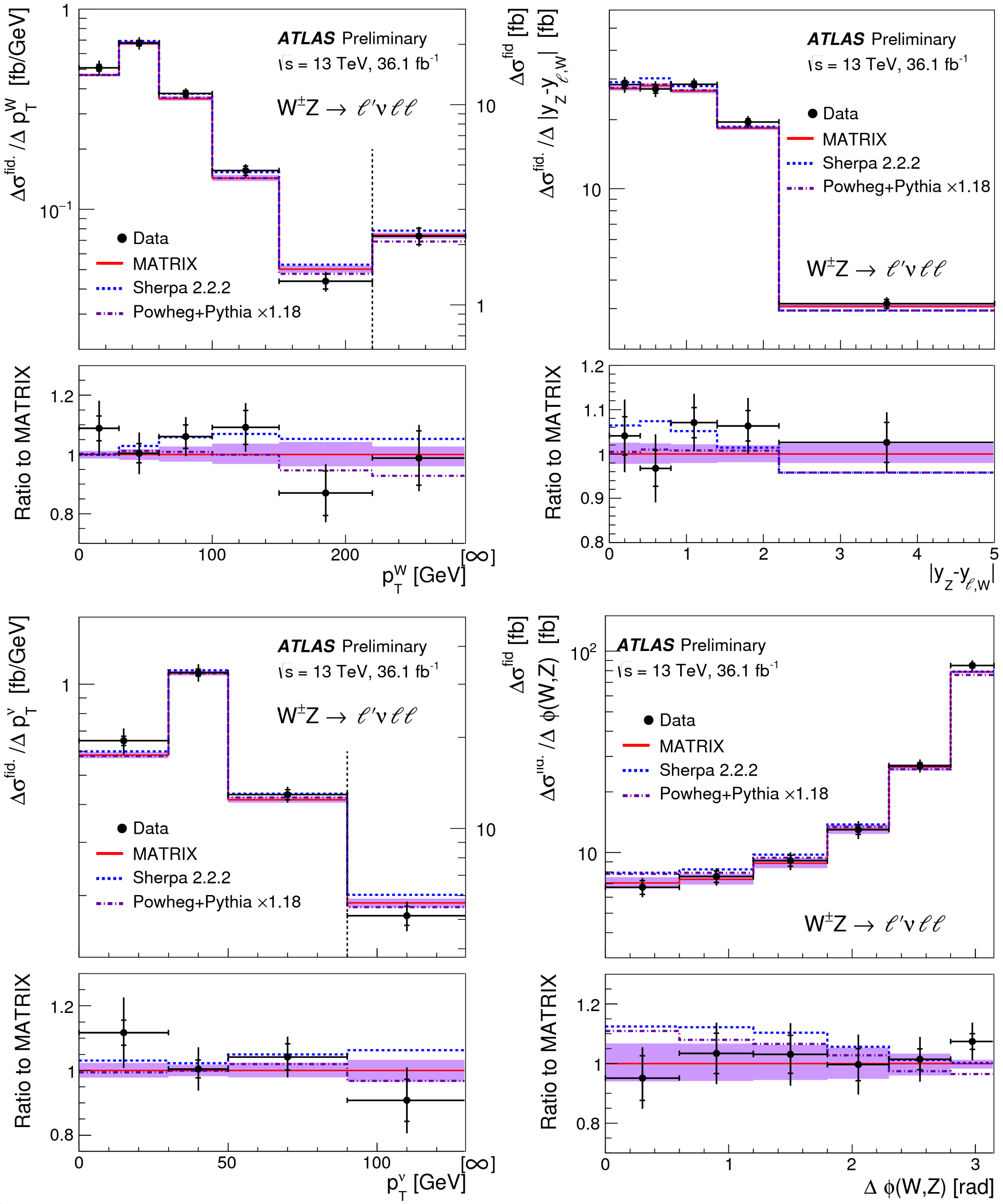
- Observed **6160** WZ data events, compared to an expectation of **5986** events
- WZ Monte Carlo prediction is scaled to **NNLO cross-section**
- Background estimated using data driven technics and MC simulation



- Total uncertainty 4.6%
- Dominant sources of uncertainty:
  - data-driven background determination,
  - pileup,
  - lepton ID efficiencies.
- Measurement is not dominated any more by statistics.

Differential cross sections



- Kinematic distributions are unfolded with a response matrix computed using a Powheg+Pythia MC using Bayesian iterative approach.
- Measure cross section as a function of: p_T^Z , p_T^W , m_T^{WZ} , $\Delta\phi(W,Z)$, p_T^ν, $|y_Z - y_{l,W}|$, N_{jets}, m_{jj};
- Differential cross section results are compared to the NNLO QCD predictions from MATRIX

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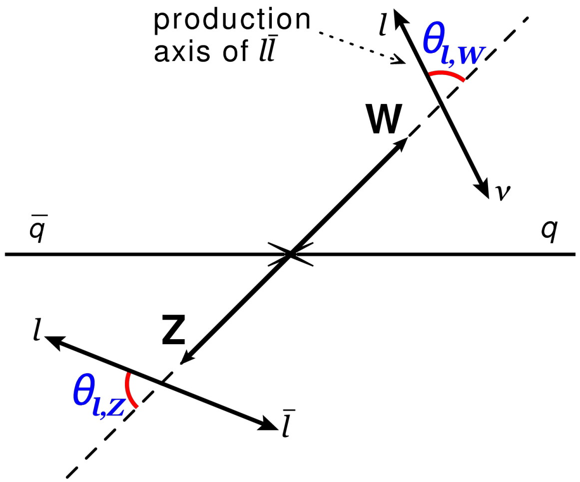
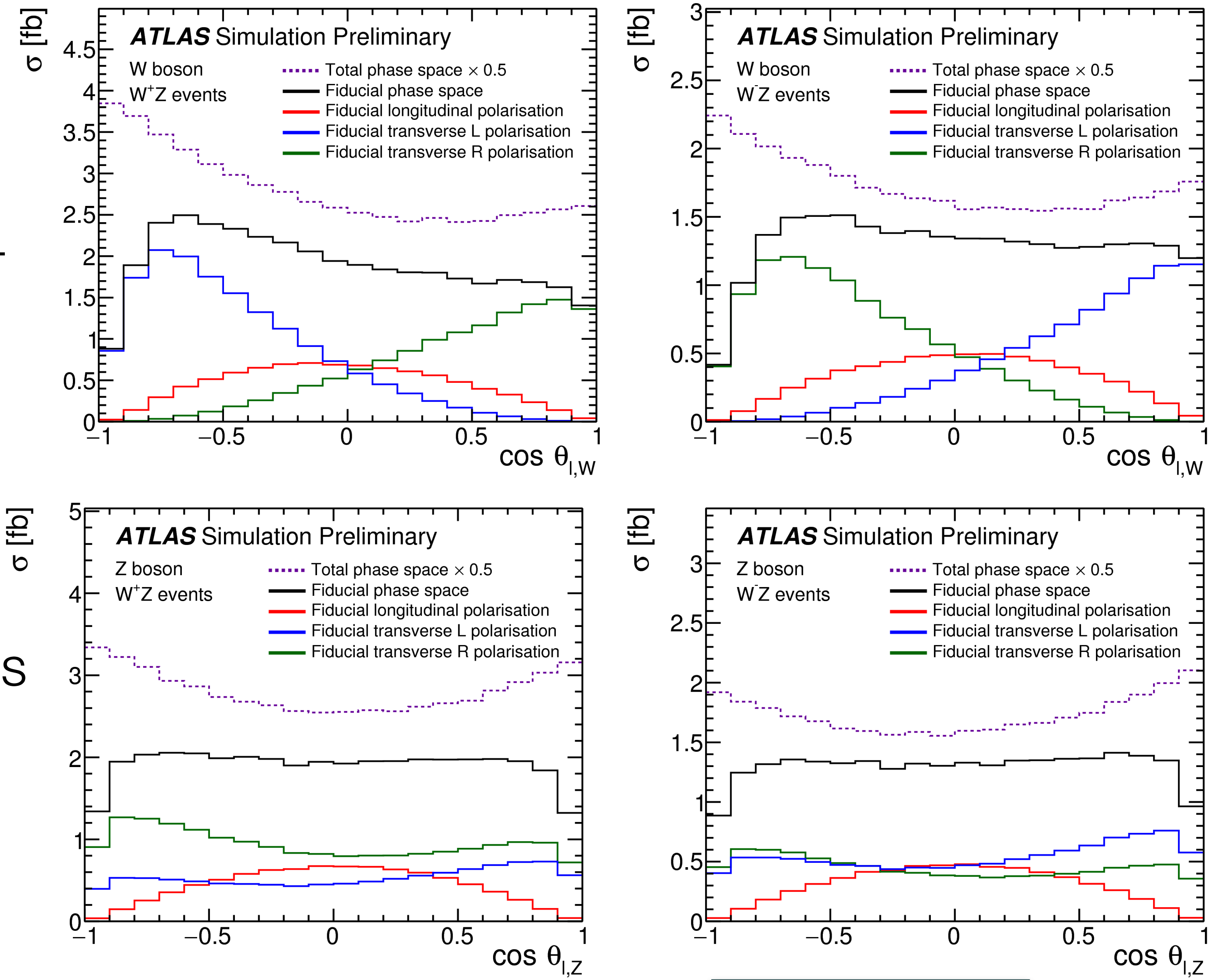
First measurement of boson polarisation

purely longitudinal, transverse-left and transverse-right helicity components





Fit angular distributions using analytical functions in total phase space to create templates with pure polarisation states.

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WZjj Signal extraction

	SR	QCD-CR	b-CR	ZZ-CR
Data	161	213	141	52
Total MC	199.2 ± 1.4	289.4 ± 1.9	159.2 ± 1.8	44.7 ± 6.4
$WZjj$-EW (signal)	24.93 ± 0.18	8.46 ± 0.10	1.36 ± 0.05	0.21 ± 0.12
$WZjj$-QCD	144.17 ± 0.85	231.2 ± 1.1	24.44 ± 0.29	1.43 ± 0.69
Misid. leptons	9.2 ± 1.1	17.7 ± 1.5	29.7 ± 1.6	0.50 ± 0.32
ZZ-QCD	8.10 ± 0.19	14.98 ± 0.34	1.96 ± 0.08	35.0 ± 5.9
tZ	6.46 ± 0.18	6.56 ± 0.19	36.19 ± 0.45	0.18 ± 0.09
$t\bar{t} + V$	4.21 ± 0.18	9.11 ± 0.23	65.36 ± 0.64	2.8 ± 1.3
ZZ-EW	1.50 ± 0.10	0.44 ± 0.05	0.10 ± 0.08	3.4 ± 1.6
VVV	0.59 ± 0.03	0.93 ± 0.04	0.13 ± 0.01	1.0 ± 1.0

Source	Uncertainty [%]
$WZjj$-EW theory modelling	5.0
$WZjj$-QCD theory modelling	2.3
$WZjj$-EW and $WZjj$-QCD interference	1.9
Jets	6.7
Pileup	2.2
Electrons	1.6
Muons	0.7
b-tagging	0.3
MC statistics	2.1
Misid. lepton background	1.0
Other backgrounds	0.1
Luminosity	2.1

WZjj Results

$\mu_{EW} = 1.77 \pm 0.45$

Observed significance: 5.6 σ (expected 3.3 σ)

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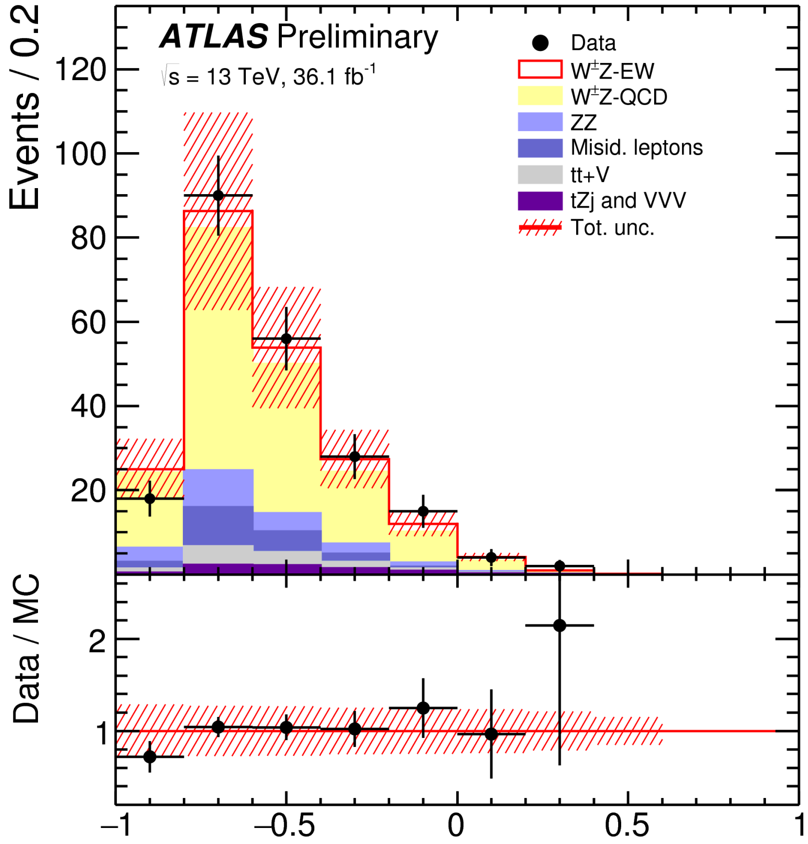
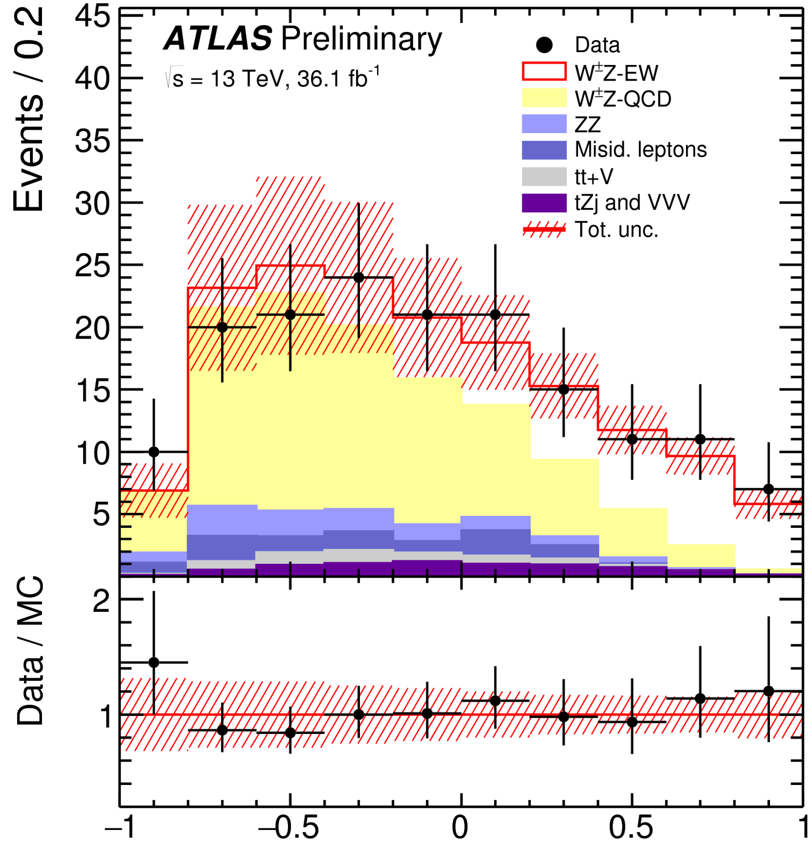


QCD control region



Signal region

$$\sigma_{EW}(W^{\pm}Zjj \rightarrow l'\nu lljj) = 0.57^{+0.14}_{-0.13}(\text{stat.})^{+0.05}_{-0.04}(\text{sys.})^{+0.04}_{-0.03}(\text{th.})$$

$W^{\pm}W^{\pm}$ jj Selection

Electrons	p_T	$\lvert\eta\rvert$	ID	Isolation	Author	$\lvert z_0 \sin\theta \rvert$	$\lvert d_0/\sigma_{d_0} \rvert$
Baseline	> 6 GeV	< 2.47	`Loose+BLayer`	–	–	< 0.5 mm	< 5
Analysis Level		*ee*: < 1.37	`Tight`	`Gradient`	$= 1$	✓	✓
	> 27 GeV	others: < 2.47					
Anti-ID		crack veto	`!Tight`	`!Gradient`	–	✓	✓

Muons	p_T	$\lvert\eta\rvert$	Quality	Isolation	$\lvert z_0 \sin\theta \rvert$	$\lvert d_0/\sigma_{d_0} \rvert$
Baseline	> 6 GeV	< 2.7	`Loose`	–	< 0.5 mm	10
Analysis Level	> 27 GeV	< 2.5	`Medium`	`Gradient`	✓	< 3
Anti-ID			`!Medium`	`!Gradient`	✓	✓

Jets	p_T	$\lvert\eta\rvert$	*b*-tag eff.	JVT
Baseline	> 25 GeV, $\lvert\eta\rvert < 2.4$ > 30 GeV, $\lvert\eta\rvert < 4.5$	< 4.5	85 %	if $p_T^j \in (25\ \text{GeV}, 60\ \text{GeV})$
Analysis Level	$p_T^{j1(2)} > 65(35)$ GeV	✓	✓	✓

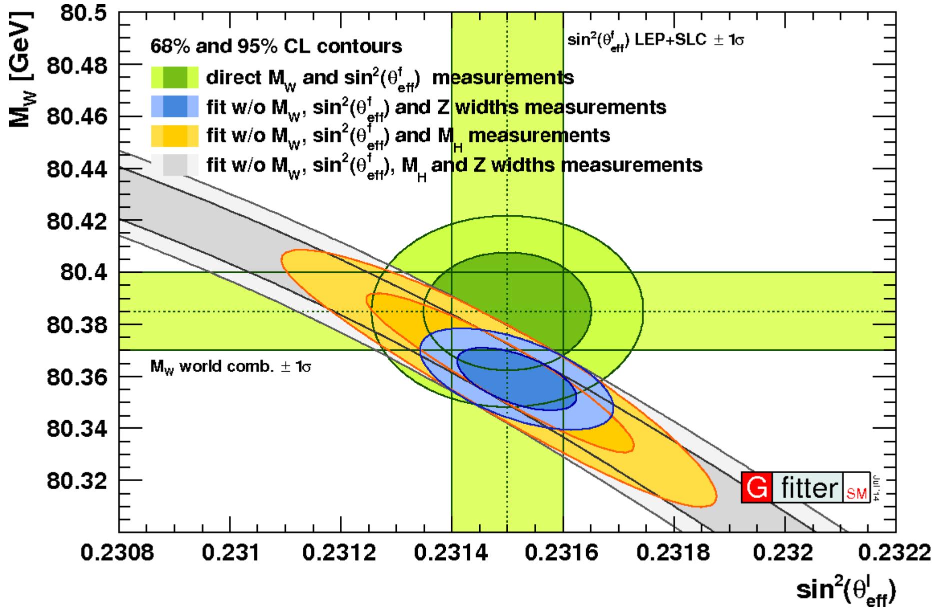
The weak mixing angle and the Standard Model

- **$\sin^2\theta_W$** is a parameter of the SM representing the mixing of the EM and weak fields
- Within the SM, it relates the W- and Z-boson coupling constants $g_{W,Z}$, and therefore $m_{W,Z}$
- Radiative corrections modify this relation, yielding the fermion-flavor dependent effective weak mixing angle: **$\sin^2\theta^l_{eff}$**

$$A_\mu = B_\mu \cos\theta_W + W^3_\mu \sin\theta_W$$
$$Z_\mu = -B_\mu \sin\theta_W + W^3_\mu \cos\theta_W$$

$$\sin^2\theta_W = 1 - \frac{g_W^2}{g_Z^2} = 1 - \frac{m_W^2}{m_Z^2}$$

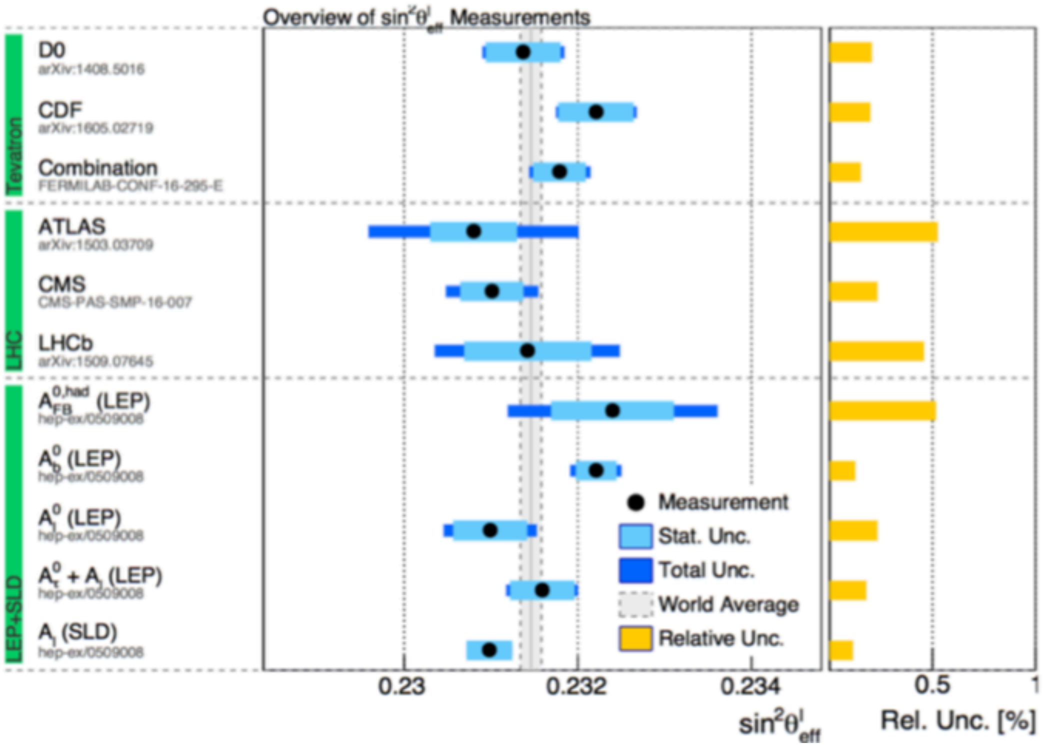
$$\sin^2\theta^l_{eff} = (1 - \frac{m_W^2}{m_Z^2})(1 + \Delta r^l)$$

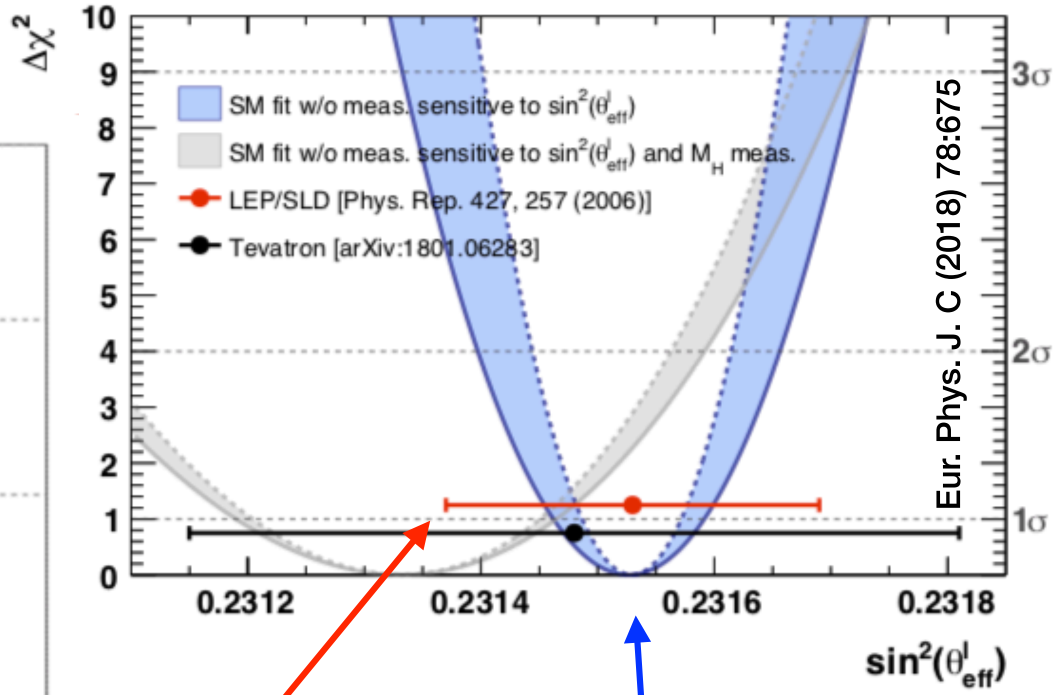


➡ Direct measurements of $\sin^2\theta^l_{eff}$ and m_W can indirectly predict each other

➡ Precise measurements of both enable strict tests for the internal consistency of the SM as a probe of new physics

Previous measurements





Direct measurements, average ~16x10^{-5} precision

SM prediction, from fit w/out direct measurements, ~6x10^{-5} precision

Likelihood fit design

1280 bins in (m, y) x θ x ϕ = 20x8x8

Nuisance priors

$$\mathscr{L}(A,\sigma,\theta|N_{obs}) = \prod_{n}^{N_{bins}} \left\{ P(N^n_{obs}|N^n_{exp}(A,\sigma,\theta)P(N^n_{eff}|\gamma^n N^n_{eff}) \right\} \times \prod_{n}^{M} G(0|\beta^m,1)$$

Poisson probability for data Nobs

Poisson probability for template MC Neff

$$N^n_{exp}(A,\sigma,\theta) = \left\{ \sum_{j=0}^{N_{bins}} \sigma_j \times L \times \left[t^n_{8j}(\beta) + \sum_{i=0}^{7} A_{ij} \times t^n_{ij}(\beta) \right] \right\} \times \gamma^n + \sum_{B}^{bkgs} T^n_B(\beta)$$

Cross section x lumi in bin j

Ang. Coeff. i in bin j

9 angular templates for bin j and their nuisance parameter dependence

Backgrounds and their nuisance parameter dependence

$$A_{4,j}(\sin^2\theta^l_{eff},\theta) = a_j(\theta) \times \sin^2\theta^l_{eff} + b_j(\theta)$$

A4 mixing angle dependence (linear interpolation in each bin j, w/nuisances)

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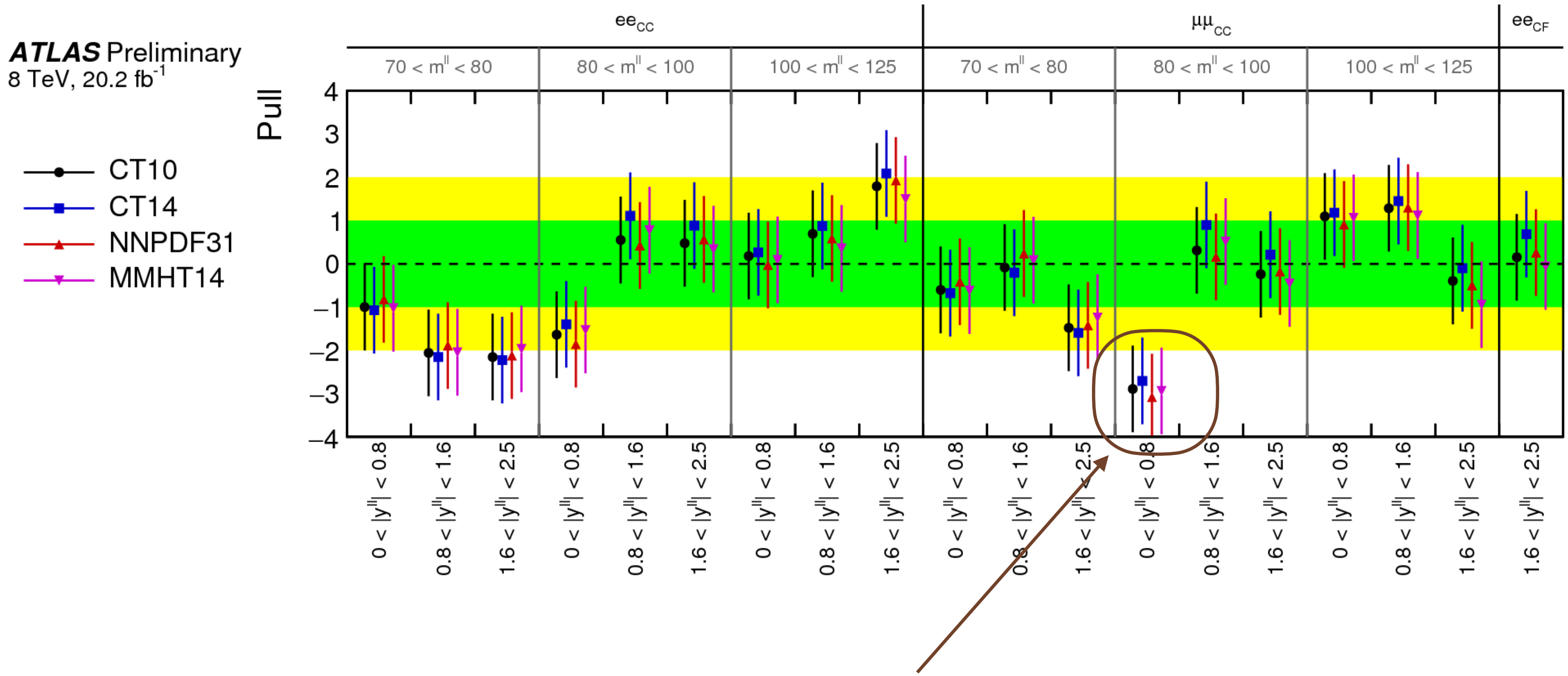
Internal consistency across categories

- Using ee_{CF} outermost bin as a reference, compute pulls of other categories



- Sensitivity is much lower than in the higher bins
- Dominated by statistics

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Outline

- "Observation of electroweak production of a same-sign W boson pair in association with two jets in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector"

  ATLAS-CONF-2018-030

- "Measurement of W ± Z production cross sections and gauge boson polarisation in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector"

  ATLAS-CONF-2018-034

- "Measurement of the effective leptonic weak mixing angle using electron and muon pairs from Z-boson decay in the ATLAS experiment at $\sqrt{s}$ = 8 TeV"

  ATLAS-CONF-2018-037