Recent diboson and polarization measurements at ATLAS

LHCP 2023

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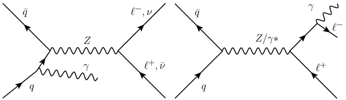
Overview

- Probe self-couplings between massive vector bosons in the Standard Model
- Important test of perturbative QCD and electroweak corrections and resummation schemes
- Higgs mechanism provides mass and longitudinal polarization to gauge vector bosons
- Sensitivity to new physics via anomalous couplings or preferential couplings to polarization modes

$Z\gamma$+jets cross-sections

[arXiv:2212.07184] (Accepted by JHEP)

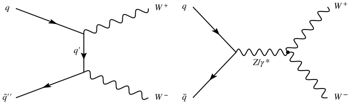
- Anomalous triple gauge couplings
- Sensitive to PDFs



W^+W^- cross-sections

[ATLAS-CONF-2023-012]

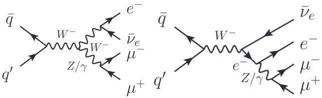
- Triple gauge couplings
- Important background for $H \to WW$ and BSM searches



WZ joint polarization

[arXiv:2211.09435] (Accepted by PLB)

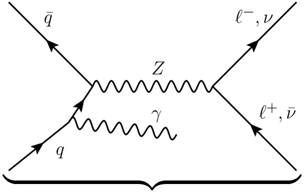
- First observation joint $W^{\pm}Z$ polarization



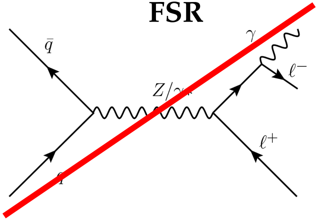
[arXiv:2212.07184]

$Z\gamma$+jets: including jet activity

ISR ✓

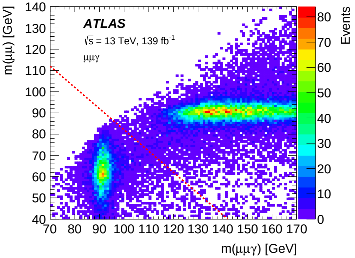


FSR



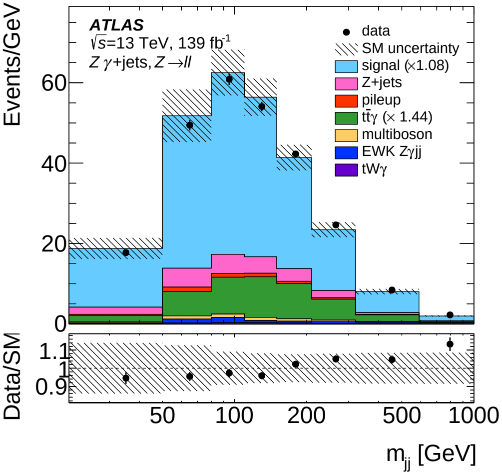
Sensitive to γ content of p

- `Tight` photon p_T >30 GeV.
- $Z \to \ell\ell$, with $\ell = e$, μ and $m_{\ell\ell} > 40$ GeV
- $m_{\ell\ell} + m_{\ell\ell\gamma} > 182$ GeV (enrich ISR)
- No requirements on N_{jets}
- Pile-up and Z+jets contributions estimated using data-driven techniques

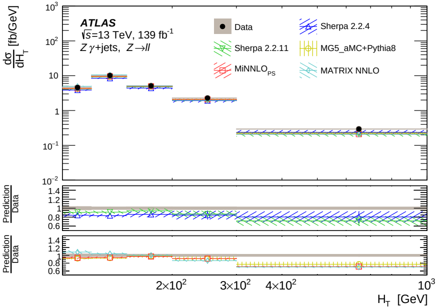


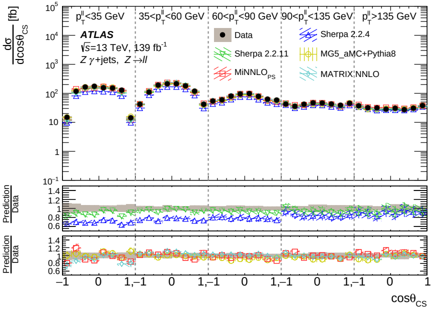
(From [arXiv:1911.04813])

Study jet activity and 2D differential distributions



$Z\gamma$+JETS CROSS-SECTIONS





- Fiducial differential cross-sections across
  - 13 observables related to lepton, jet and E_T^{miss} kinematics
  - 3 2D distributions sensitive to pQCD
  - 2 2D distributions sensitive to polarization effects in [Collins-Soper frame]
- Integrated fiducial cross section

$$\sigma_{\text{fid}}^{\text{exp}} = 533.7 \pm 2.1\,(\text{stat}) \pm 12.4\,(\text{syst}) \pm 9.1\,(\text{lumi}),$$

versus predictions $\sigma_{\text{fid}}^{\text{Sherpa 2.2.11}} = 479.5 \pm 0.3$ and $\sigma_{\text{fid}}^{\text{MiNNLO}} = 493.0 \pm 3.0$.

- Total uncertainty of 2.9% on $\sigma_{\text{fid}}^{\text{exp}}$.
  - 4% (0 jet) up to 10% ($\geq$2 jets), dominated by pile-up and jet-related uncertainties.
- Good agreement between Data and theory predictions

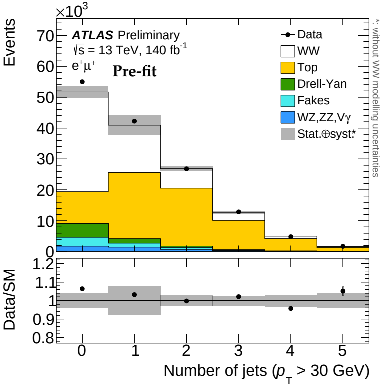
W^+W^- jet-inclusive measurement

- ✓ Largest diboson production cross-section + clean signature $\Longrightarrow$ **Precision**
- ✗ Large contributions from irreducible backgrounds, especially $t\bar{t}$

First W^+W^- differential cross-section measurements in fully jet-inclusive phase space

Accurate top-quark and lepton misID background estimates using **data-driven techniques**

High precision in **fully jet-inclusive phase space**



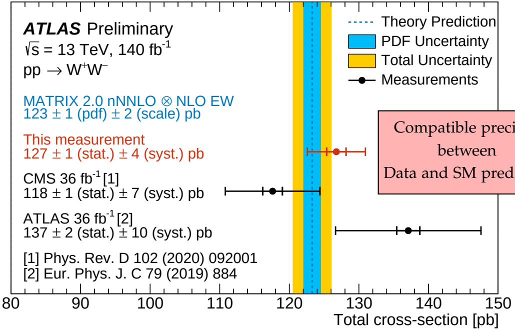
- Fully leptonic final states, different flavor and opposite charge, $WW \to e^{\pm}\mu^{\mp}\nu_e\nu_\mu$
- Suppress $Z \to \tau\tau$ and $H \to WW$ by $m_{e\mu} > 85$ GeV
- Reduce top-quark contributions using b-jet veto

b-jet counting method [arXiv:1910.08819]

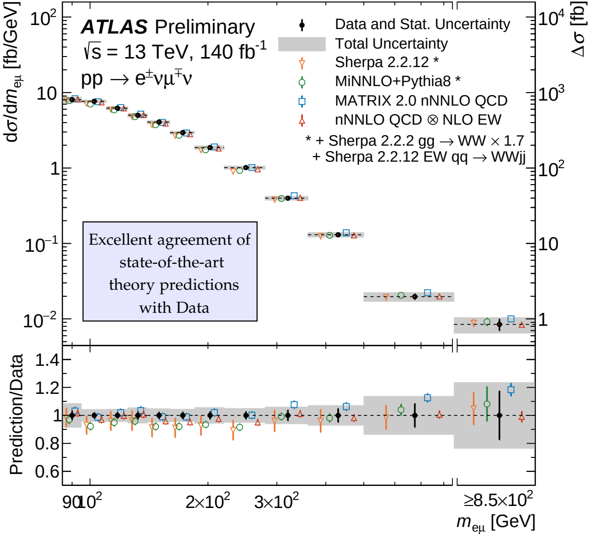
- Measure $N^{t\bar{t}}_{1b,2b}$ in 1 b-jet and 2 b-jet regions
- Determine both $t\bar{t}$ effective cross-section and b-jet reconstruction efficiency ε_b *bin-by-bin*
- Estimate differential $N^{t\bar{t}}_{0b}$ (SR)

W^+W^- Jet-inclusive: Results

- Precision measurement of WW production in fully leptonic final state across 12 observables on lepton, jet and E_T^{miss} kinematics
- **Fiducial** (integrated and differential) **and total cross-sections**
- **Precision of 3.1%**, dominated by top modelling and fake background estimate



Compatible precision between Data and SM prediction



Excellent agreement of state-of-the-art theory predictions with Data

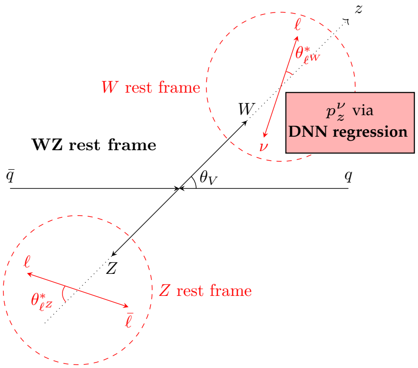
[arXiv:2211.09435]

WZ joint polarization

Polarization states measured in

Modified helicity coordinate system

Helicity fractions f_{00}, f_{0T}, f_{T0}, f_{TT} are *not* Lorentz invariant



- Maximize decorrelation of 00 and TT polarization modes

Joint polarizations at NLO-QCD using DNN

Predictions of WZ joint polarization states available

- LO + real corrections at reco level (MadGraph+Pythia)
  $\Longrightarrow$ Insufficient [arXiv:2010.07149]
- NLO-QCD at particle level (MoCaNLO)

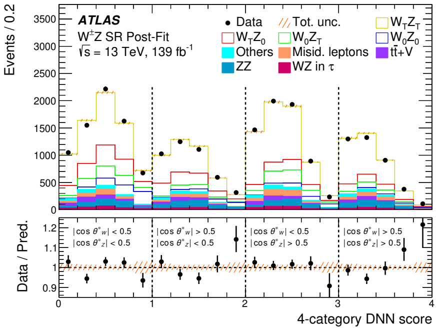
Methodology

- Virtual corrections via DNN reweighting

Validation

- Closure to folded fixed-order predictions

- DNN classifies each joint polarization state
- 4 categories to disentangle mixed states (0T,T0)

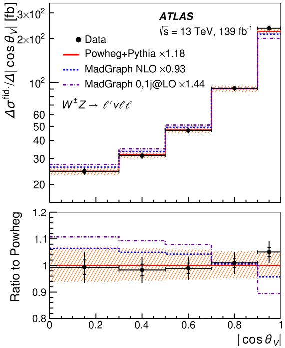


WZ joint polarization: Results

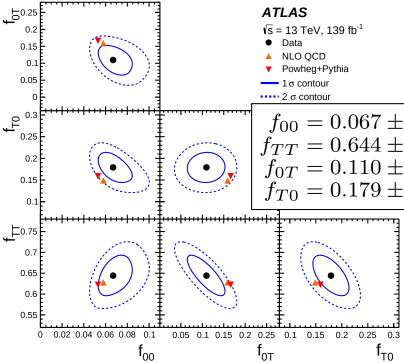
- **First observation** of f_{00} state: 7.1σ obs (6.2σ exp)
  $\Longrightarrow$ f_{0T}, f_{T0} and f_{TT} with 3.4σ (5.4σ), 7.1σ (6.6σ) and 11σ (9.7σ), respectively
- Joint and individual WZ polarization measurements compared to predictions
- Differential cross-sections across observables sensitive to polarization states
- $\sigma^{\text{fid}}_{\text{exp}} = 64.6 \pm 0.5\,(\text{stat}) \pm 1.8\,(\text{syst}) \pm 1.1\,(\text{lumi})$ fb ($\sigma^{\text{fid}}_{\text{MATRIX}} = 64.0 \pm 1.4\,(\text{scale})$)

Dominated by theory uncertainties

Differential cross-sections

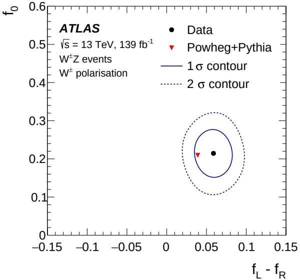


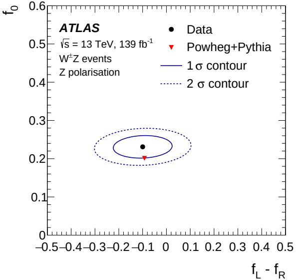
Joint WZ polarization



$$f_{00} = 0.067 \pm 0.010$$
$$f_{TT} = 0.644 \pm 0.032$$
$$f_{0T} = 0.110 \pm 0.029$$
$$f_{T0} = 0.179 \pm 0.023$$

Individual polarization





Conclusions

- Recent experimental results on diboson production cross-sections and polarization measurements with the ATLAS detector were presented
- Overall, excellent agreement with state-of-the-art SM predictions is observed

$Z\gamma$+jets cross-sections

[arXiv:2212.07184] (Accepted by JHEP)

- Differential cross-section measurements across 13 observables, **including jet activity and kinematics**
- 5 **2D distributions** sensitive to pQCD and polarization effects
- Fiducial cross-section up to 4% (0 jet) and 10% ($\geq$2 jets) precision

W^+W^- cross-sections

[ATLAS-CONF-2023-012]

- **Fully jet-inclusive measurement** of W^+W^-, benefited from **data-driven top-quark background** estimation
- Differential cross-sections across 12 observables related to lepton, jet and E_T^{miss} kinematics
- Integrated cross-section with precision of 3.1%

WZ joint polarization

[arXiv:2211.09435] (Accepted by PLB)

- **First observation** of f_{00} state: 7.1σ obs (6.2σ exp)
- Joint and individual WZ polarization measurements in agreement with predictions
- Differential cross-sections of angular observables sensitive to polarization states
- Integrated cross-section with 3.4% precision

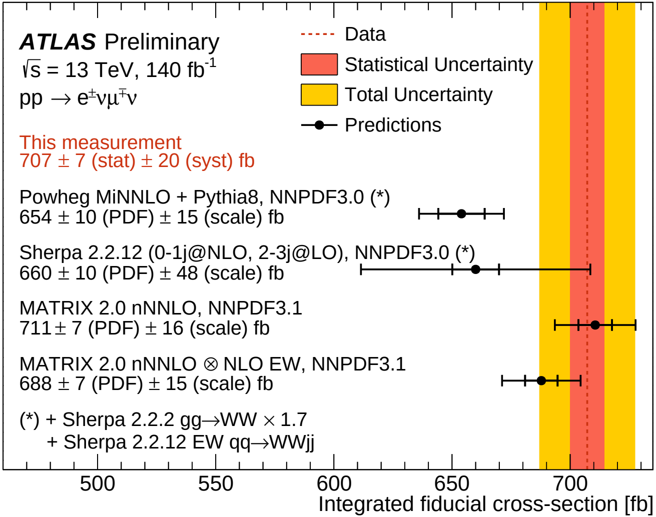
Thank you for your attention

Backup slides

$Z\gamma$+jets uncertainties

N_{jets}	0	1	2	> 2
Source	Uncertainty [%]			
Electrons	1.0	0.9	0.8	0.8
Muons	0.3	0.3	0.3	0.4
Jets	1.7	1.7	4.5	8.8
Photons	1.4	1.3	1.3	1.2
Pile-up	2.1	0.8	0.2	0.3
Background	1.8	1.8	3.0	4.4
MC statistical	0.1	0.2	0.3	0.4
Data statistical	0.8	1.5	1.8	1.9
Luminosity	1.7	1.7	1.7	1.7
Theory	0.6	0.2	1.4	1.0
Total	4.2	3.8	6.3	10.3

WW Integrated fiducial cross-sections



WW Uncertainties

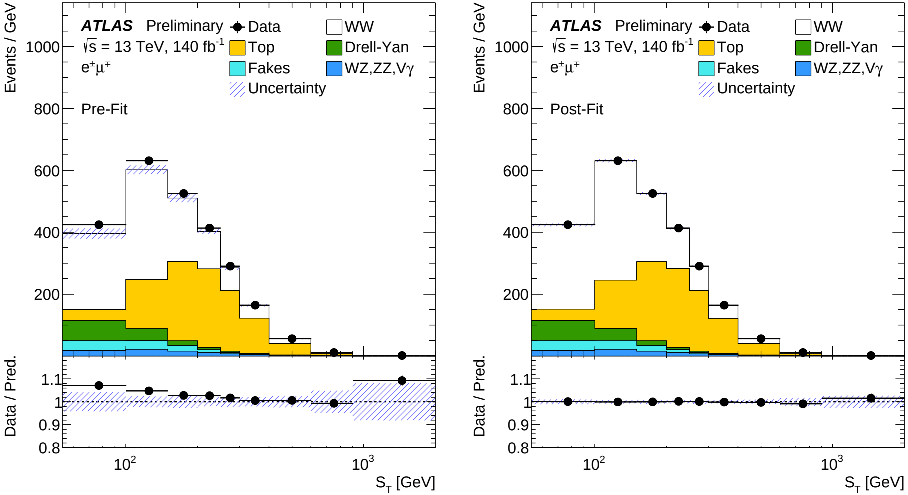
Uncertainty source	Effect
Total uncertainty	3.1%
Stat. uncertainty	1.1%
Top modelling	1.6%
Fake lepton background	1.5%
Flavour tagging	0.7%
Other background	0.9%
Signal modelling	1.0%
Jet calibration	0.6%
Luminosity	0.8%
Other systematic uncertainties	0.9%

WW theory predictions

Process	Code	PDF	Perturbative order	Fid. cross-section	
$q\bar{q} \to WW$	MATRIX2.0.1	NNPDF3.1	NNLO QCD	674 fb	$\pm 1.8\,\%$
$q\bar{q} \to WW$	MiNNLO + Pythia8	NNPDF3.0	NNLO QCD + PS	624 fb	$\pm 1.1\,\%$
$q\bar{q} \to WW$	Sherpa2.2.12	NNPDF3.0	NLO QCD + PS †	630 fb	$\pm 7.2\,\%$
$gg \to WW$	MATRIX2.0.1	NNPDF3.1	NLO QCD	32 fb	$\pm 13\,\%$
$gg \to WW$	Sherpa2.2.2	NNPDF3.0	LO QCD + PS †	15 fb	$\pm 30\,\%$
$\gamma\gamma \to WW$	MATRIX 2.0.1	NNPDF3.1	LO	5 fb	$\pm 2.3\,\%$
$\gamma\gamma \to WW$	MATRIX 2.0.1	NNPDF3.1	NLO EW	11 fb	$\pm 2.3\,\%$
$q\bar{q} \to WWjj$ (EW)	Sherpa2.2.12	NNPDF3.0	LO + PS	4 fb	$\pm 7.0\,\%$
For calculation of NLO EW correction:					
$q\bar{q} \to WW$	MATRIX2.0.1	NNPDF3.1	LO	436 fb	$\pm 5.1\,\%$
$q\bar{q} \to WW$	MATRIX2.0.1	NNPDF3.1	NLO EW	418 fb	$\pm 5.1\,\%$

†: Includes matrix elements with additional parton emissions, matched and merged with the parton shower, which increases the accuracy of the simulation of high jet multiplicity events but also increases the nominal scale uncertainty.

WW pre-fit and post-fit distributions



WZ Uncertainties

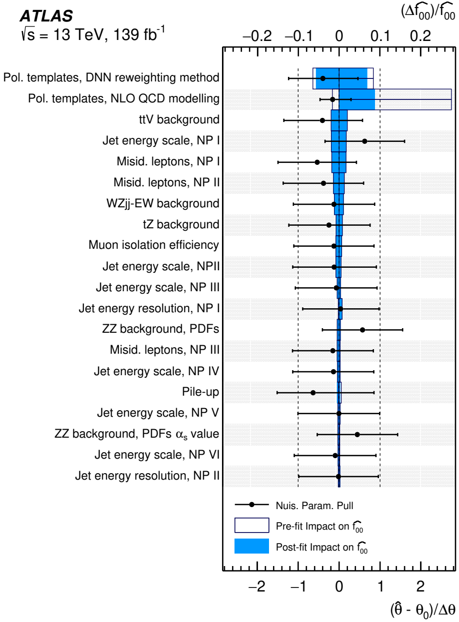
Absolute uncertainties joint polarizations

	f_{00}	$f_{0\mathrm{T}}$	$f_{\mathrm{T}0}$	f_{TT}
e energy scale and id. efficiency	0.00018	0.0009	0.0012	0.0019
μ energy scale and id. efficiency	0.0004	0.0004	0.0004	0.0008
$E_{\mathrm{T}}^{\mathrm{miss}}$ and jets	0.0017	0.0021	0.0020	0.0023
Pile-up	0.00031	0.00027	0.0007	0.0010
Misidentified lepton background	0.0012	0.0026	0.0013	0.0016
ZZ background	0.0005	0.00028	0.0005	0.0004
Other backgrounds	0.0016	0.0025	0.0021	0.0025
Parton Distribution Function	0.00025	0.0029	0.00014	0.0028
QCD scale	0.00010	0.014	0.0014	0.012
Modelling	0.005	0.007	0.005	0.008
Total systematic uncertainty	0.006	0.017	0.006	0.016
Luminosity	0.00019	0.0004	0.0004	0.00034
Statistical uncertainty	0.007	0.016	0.019	0.019
Total	0.010	0.029	0.023	0.032

Absolute uncertainties individual polarizations

	$W^{\pm}$ in $W^{\pm}Z$		Z in $W^{\pm}Z$	
	f_0	$f_{\mathrm{L}} - f_{\mathrm{R}}$	f_0	$f_{\mathrm{L}} - f_{\mathrm{R}}$
e energy scale and id. efficiency	0.0029	0.00030	0.0027	0.0007
μ energy scale and id. efficiency	0.004	0.0018	0.0015	0.0005
$E_{\mathrm{T}}^{\mathrm{miss}}$ and jets	0.004	0.0011	0.0006	0.0028
Pile-up	0.0028	0.0015	0.0024	0.0029
Misidentified lepton background	0.007	0.00032	0.0033	0.0011
ZZ background	0.0015	0.00025	0.0012	0.0023
Other backgrounds	0.0020	0.0005	0.0013	0.0012
Parton Distribution Function	0.0011	0.0011	0.00011	0.0005
QCD scale	0.012	0.0025	0.0004	0.005
Modelling	0.025	0.0012	0.004	0.018
Total systematic uncertainty	0.030	0.004	0.007	0.019
Luminosity	0.0005	0.00004	0.00012	0.00018
Statistical uncertainty	0.028	0.015	0.018	0.08
Total	0.04	0.016	0.019	0.08

Pulls f_{00} fit



WZ fid. cross section uncertainties

Relative uncertainty [%]	
e energy scale and id. efficiency	0.8
μ energy scale and id. efficiency	1.1
$E_{\mathrm{T}}^{\mathrm{miss}}$ and jets	0.4
Pile-up	1.6
Misidentified lepton background	1.3
ZZ background	0.09
Other backgrounds	0.9
Parton Distribution Function	0.05
QCD scale	0.09
Modelling	0.04
Total systematic uncertainty	2.8
Luminosity	1.7
Statistical uncertainty	0.9
Total	3.4

p_Z^ν REGRESSION