

Drell-Yan Precision Measurements In ATLAS

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On behalf of the ATLAS Collaborations

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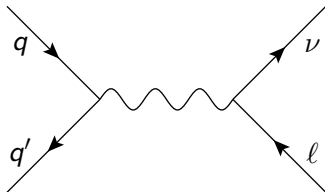
Oxford

28th September 2026



Introduction

- NC and CC Drell-Yan processes provide an excellent environment for probing QCD
- Simplest LO QCD process in $pp/p\bar{p}$ collisions
- Clean, fully-leptonic final state to measure
- This talk focusses on a recent ATLAS measurement of CC DY using low pile-up data at $\sqrt{s} = 13$ TeV ([Eur.Phys.J.C 86 \(2026\) 5, 483](#)):
 - Extract W -boson Angular coefficients
 - Measure as a function of p_T^W



A_i formalism I

This measurement primarily aims to measure the angular coefficients A_i :

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

These A_i are related to the nature of the Electroweak processes, the W polarisation, and to the presence of QCD effects

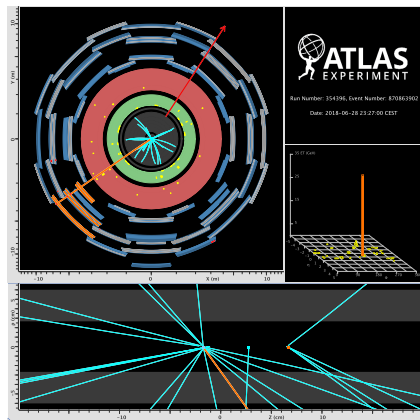
A_i formalism II

- A_4 the only non-zero coefficient if the W is produced with no transverse momentum, polarised along the z -axis with pure $V - A$ interaction
- A_{0-3} become non-zero if the W is produced with transverse momentum balanced by associated production of one or more jets
- A_{5-7} become non-zero if gluon loops of $\mathcal{O}(\alpha_s^2)$ are present in the production of the W
- The Lam-Tung relation $A_0 - A_2 = 0$ is a consequence of the spin-1 nature of the gluon and expected to hold up to $\mathcal{O}(\alpha_s)$

ATLAS DY measurement

This ATLAS measurement uses a special low pile-up pp data collected in 2017 and 2018:

- Centre-of-mass energy:
 $\sqrt{s} = 13 \text{ TeV}$
- Mean number of interactions per bunch crossing: $\langle \mu \rangle = 2$
- Integrated Luminosity:
 $\mathcal{L} = 338.1 \pm 3.1 \text{ pb}^{-1}$



(Example $W^- \rightarrow \mu^- \nu$ candidate in this dataset from [Eur. Phys. J. C 84 \(2024\) 1126](#))

Selection

Signal Region (SR) Selection:

- Require a single isolated lepton originating from the primary vertex:
 - $p_T^e > 15 \text{ GeV}$ or $p_T^\mu > 14 \text{ GeV}$
 - Central pseudorapidity: $|\eta^e| < 2.47$, $|\eta^\mu| < 2.4$
- Reduce multijet backgrounds by requiring large missing transverse momentum¹ and transverse mass
 - $E_T^{\text{miss}} > 25 \text{ GeV}$
 - $m_T > 50 \text{ GeV}$ ²

Reconstruct angles in the Collins-Soper (CS) frame where the z-axis is defined in the W -boson rest frame as the external bisector of the angle between the momenta of the two leptons

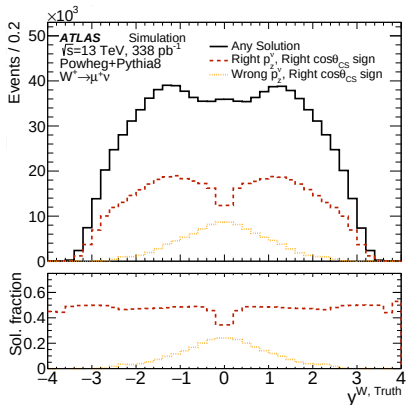
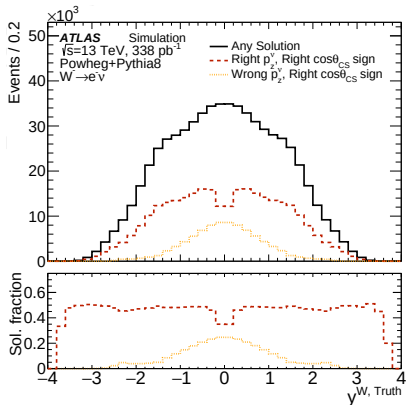
¹Here the missing transverse momentum is reconstructed using the vector sum of transverse momenta of the lepton and the hadronic recoil u_T

²This is the usual experimental transverse mass: $m_T = \sqrt{2p_T E_T^{\text{miss}}(1 - \cos \Delta\phi_{\ell\nu})}$

W Reconstruction I

- p_Z^ν is inferred by imposing an $m_{\ell\nu} = m_W$ constraint
- This gives a quadratic equation in p_Z^ν which yields two real solutions
- In this analysis one of the real solutions is picked at random
- In the CS frame events where two solutions have opposite signed $y^{\ell\nu}$ (usually at central rapidities) have unambiguous $\cos\theta_{CS}$ enabling a direct measurement of the forward backward-asymmetry (hence A_4)
- If there is no real solution (due to resolution effects) events are kept and a momentum balance is applied to ensure a real solution
- Ambiguity in $\cos\theta_{CS}$ dilutes sensitivity to A_0 and A_4

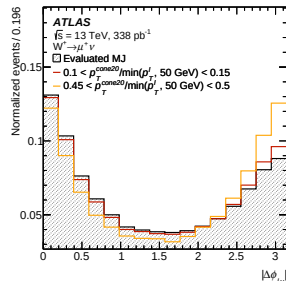
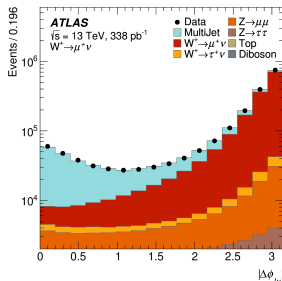
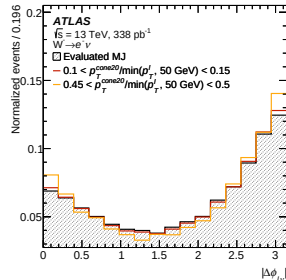
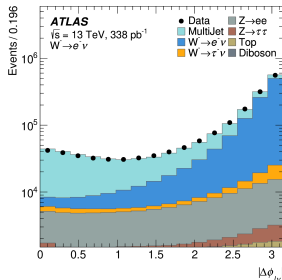
W Reconstruction II



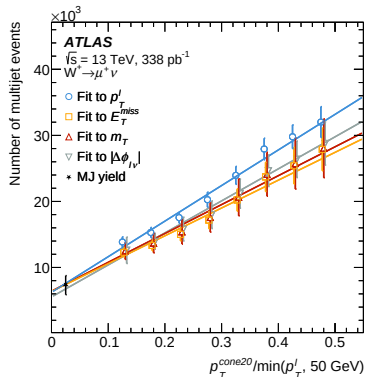
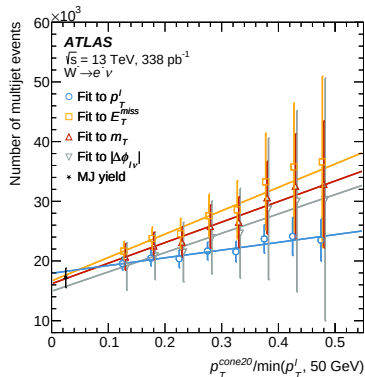
- Unambiguous $\cos \theta_{CS}$ events are those labelled as "Right $\cos \theta_{CS}$ " in the figures above

Background Estimation I

- Multijet (MJ) background from template fit to p_T^ℓ , E_T^{miss} , m_T and $|\Delta\phi_{\ell\nu}|$
- Fit Region (FR), same as the signal region except E_T^{miss} and m_T selections are removed
- Set of orthogonal lepton anti-isolation cuts used to extrapolate to the signal isolation requirements



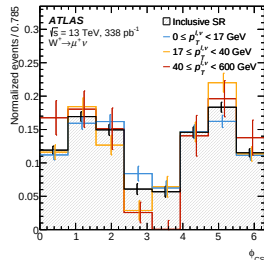
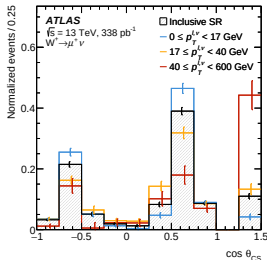
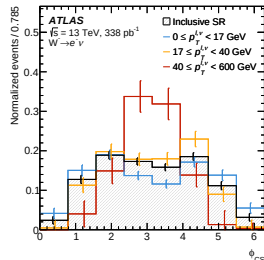
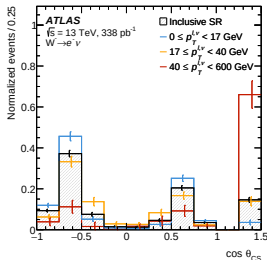
Background Estimation II



- Figures above illustrates the MJ yield extrapolation
- 10% (20%) uncertainty in the e (μ)-channel MJ yield
- dominant uncertainties: extrapolation, signal/bkg subtraction and soft activity modelling in anti-iso regions

Background Estimation III

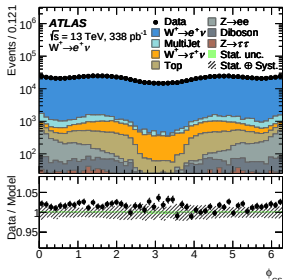
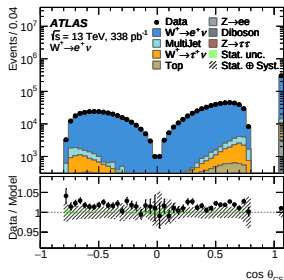
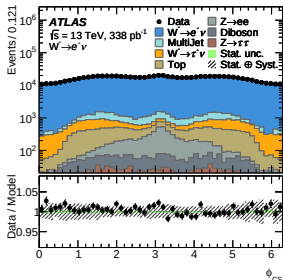
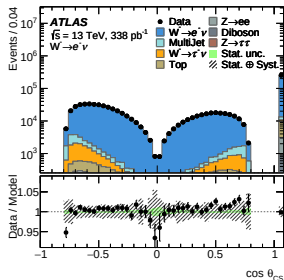
- Similar procedure to model MJ background in SR kinematic distributions
- Extra corrections needed for angular distributions due to strong p_T^ℓ dependence of 2-D $(\cos\theta_{CS}, \phi_{CS})$ distributions
- Dominant uncertainties from data+MC stats and MC modelling of non-prompt backgrounds



Parameter Extraction II

Projections of angular distributions shown here for $e\nu$ channel:

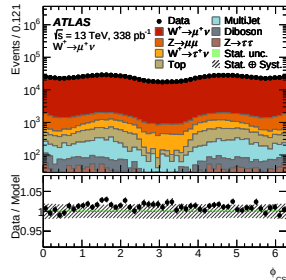
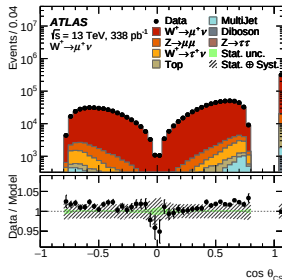
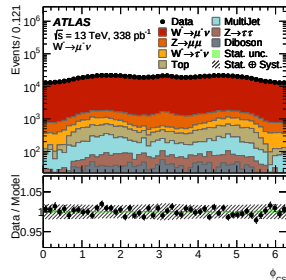
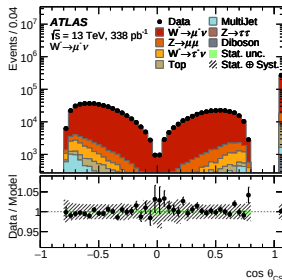
- Good agreement observed in all distributions
- small normalisation differences observed, consistent with uncertainties
- Extraction of angular coefficients is independent of normalisation



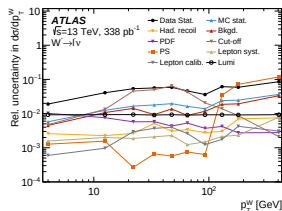
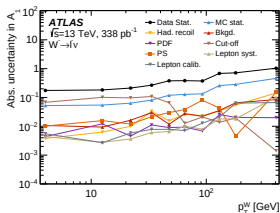
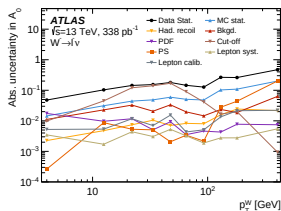
Parameter Extraction III

Projections of angular distributions shown here for $\mu\nu$ channel:

- similar level of agreement to $e\nu$ channel observed in all distributions
- Differences between distributions in e, μ channels reflect different lepton reconstruction and selection efficiencies



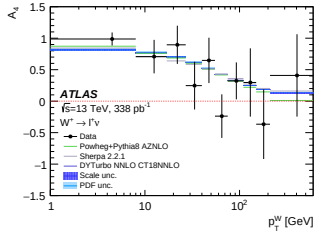
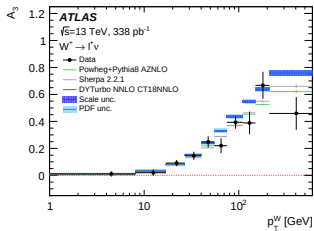
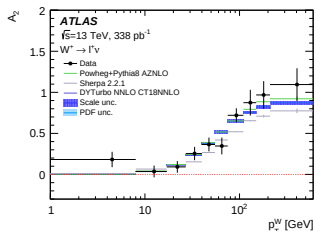
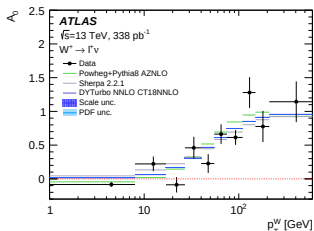
Uncertainties



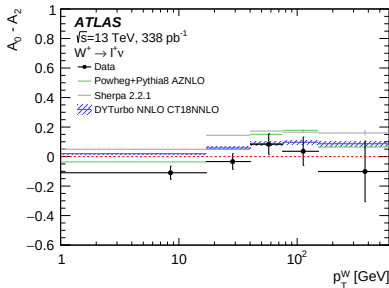
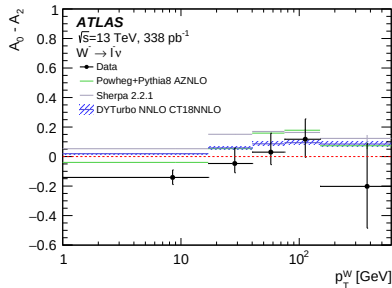
- Data Statistical uncertainties are dominant
- MC statistics generally the next largest
- Largest experimental uncertainties ($\lesssim 1\%$) come from hadronic recoil
- Theory uncertainties such as PDF and Parton shower also significant in some p_T regions

Comparison to Theory I

- A_0, A_{2-4} clearly determined and agree well with theory
- First direct measurements of A_0 and A_4 in both W^- and W^+ production
- World's most precise A_3 determination



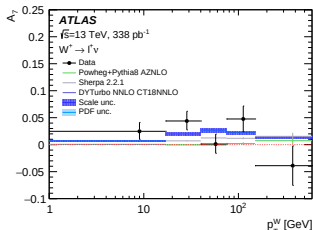
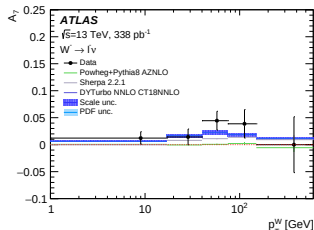
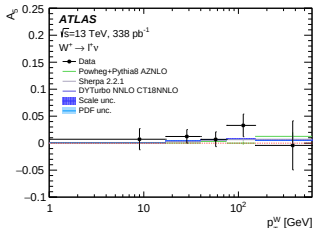
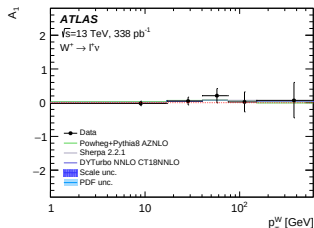
Comparison to Theory II



- The Lam-Tung relation is studied using the combined fit results
- Precision not yet high enough to probe potential deviations from zero expected from calculations including higher-order diagrams

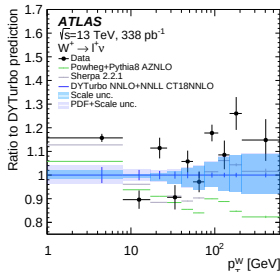
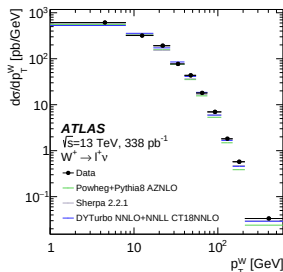
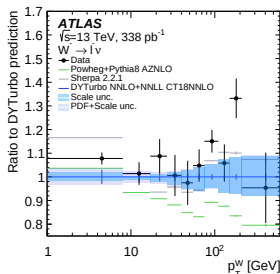
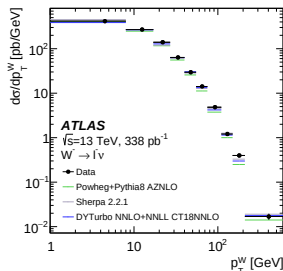
Comparison to Theory III

- Measured $A_{1,5-7}$ coefficients do not significantly differ from 0
- Slight deviation of A_7 from 0 is visible in the intermediate p_T range



Comparison to Theory IV

- $\frac{d\sigma}{dp_T^W}$ in full lepton phase space is compared to different predictions
- DYTURBO shows best agreement across the spectrum
- SHERPA 2.2.1 also shows overall good agreement
- POWHEG+PYTHIA8 has worse agreement for $p_T^W > 40$ GeV



Summary

- ATLAS has completed the first measurement of the full set of angular coefficients for W production at the LHC
- It is produced simultaneously with a differential measurement of p_T^W in the full phase space of the leptons
- Measurement uses low pile-up data and benefits from improved hadronic recoil resolution compared to standard running
- Dominant uncertainties are statistical in nature with experimental and theoretical uncertainties usually at the percent level
- $A_{0,2-4}$ are found to be significantly different from zero
- Theory predictions from DYTURBO at NNLO (including transverse momentum resummation at NNLL) accuracy in QCD are found to give good agreement with data

Back-up

Event Yields

Channel	$W^- \rightarrow e^- \nu$	$W^+ \rightarrow e^+ \nu$	$W^- \rightarrow \mu^- \nu$	$W^+ \rightarrow \mu^+ \nu$
$W \rightarrow e \nu$	802370 ± 260	1019420 ± 290	—	—
$W \rightarrow \mu \nu$	—	—	893900 ± 270	1153450 ± 310
$W \rightarrow \tau \nu$	14950 ± 110	18260 ± 130	14670 ± 110	18210 ± 130
$Z \rightarrow ee$	4953 ± 17	5227 ± 17	—	—
$Z \rightarrow \mu\mu$	—	—	33469 ± 42	37148 ± 44
$Z \rightarrow \tau\tau$	1106 ± 32	1183 ± 32	1705 ± 51	1663 ± 49
Top	11928 ± 47	12372 ± 49	11948 ± 47	12516 ± 49
Diboson	1581 ± 43	1605 ± 46	1617 ± 43	1718 ± 44
Multijet	17200 ± 1600	18600 ± 1900	6800 ± 1300	7400 ± 1400
Total expected	854000 ± 1700	1076600 ± 2000	964100 ± 1400	1232100 ± 1500
Data	857807	1093356	964514	1245755

- The uncertainty in the expected yields for simulation includes only the statistical uncertainty
- The total uncertainty is given for the multijet background.

Theory Configuration/Accuracy

- DYTURBO
 - CT18NNLO PDFs
 - Fixed order $\mathcal{O}(\alpha_s^2)$
 - Also includes resummation of logarithmically-enhanced contributions in the small transverse momentum region of the lepton pairs at NNLL accuracy
- SHERPA 2.2.1
 - NNPDF3.0 NNLO PDFs
 - COMIX and OPENLOOPS doing MEPS@NLO merging
 - NLO for $W+0,1,2$ partons, LO for $W+3,4$ partons
- POWHEG+PYTHIA8
 - CT10 NLO PDFs
 - AZNLO tune
 - PHOTOS++ for QED radiation