Measurements of Drell–Yan processes with ATLAS

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on behalf of the ATLAS Collaboration
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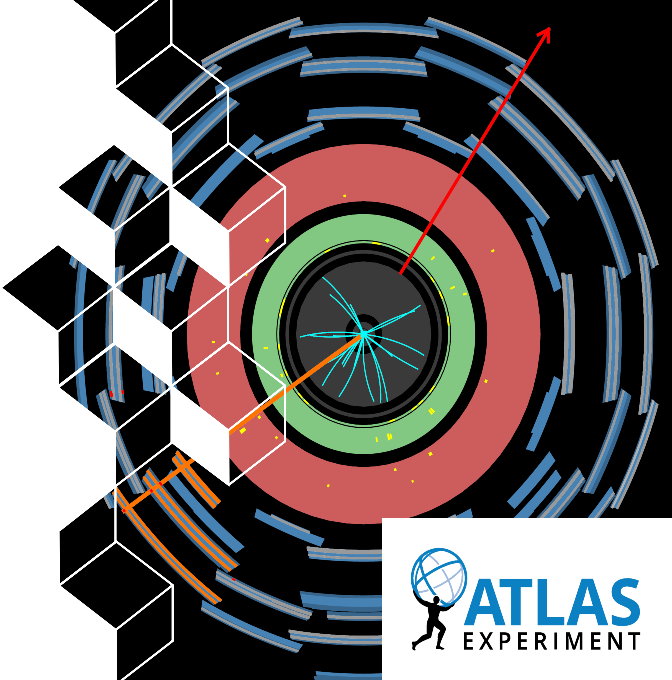
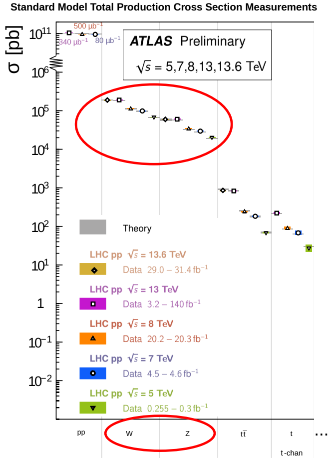


Drell–Yan process measurements at the LHC



- Drell–Yan: experimentally and theoretically clean and well-known
  - Very large cross sections
  - Clean experimental signature (isolated leptons), low backgrounds
  - Theory up to N^4LO_{QCD} + NLO_{EW} + N^4LL_{QCD}...
- Precision checks of the Standard Model
  - Fundamental parameters of the SM: m_W, $\sin^2\theta_W$, ...
  - pQCD calculations
  - Non-perturbative QCD (parton distribution functions, q_T resummation / parton shower...)
- Searches beyond the SM (Effective Field Theories, background to direct searches, etc.)

Outline

1. **W cross sections with low pile-up data (2502.09403)**

2. **Charged-current Drell–Yan at high m_T^W (2502.21088)**

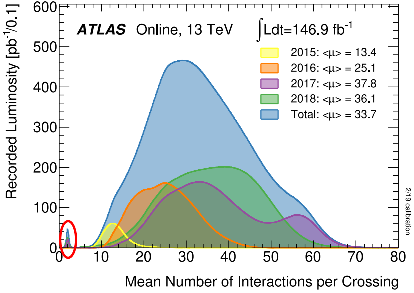
3. **High-mass Drell–Yan to $\tau\tau$ (2503.19836)**

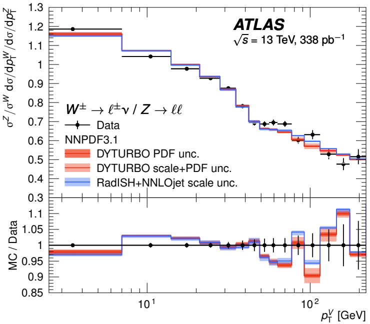
All ATLAS Standard Model results: `https://twiki.cern.ch/twiki/bin/view/AtlasPublic/StandardModelPublicResults`

1. W cross sections with low pile-up data

W cross sections with low pile-up data

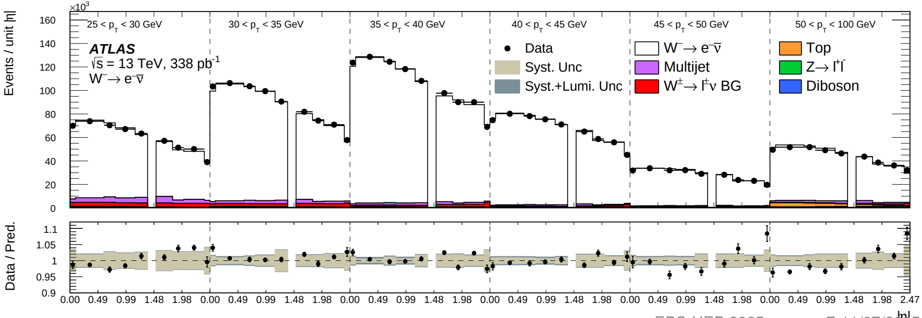
- Sensitive probe of QCD, especially PDFs
  - Strong correlation between boson rapidity y and Bjorken x: $x \propto \frac{M_W e^{\pm y}}{\sqrt{s}}$
- Cross sections as functions of the charged lepton p_{T} and η (1D and 2D)
- Low pile-up data at $\sqrt{s} = 5.02$ and 13 TeV: excellent experimental conditions
  - Same dataset as precise W and Z p_{T} measurement (EPJC 84 (2024) 1126)



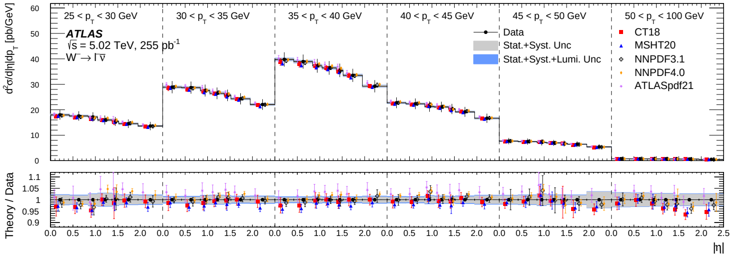


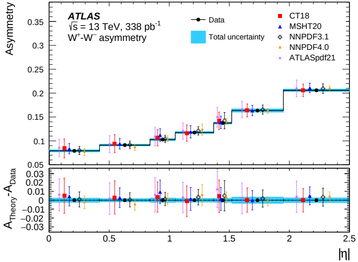
Experimental procedure

- Electron and muon channels
  - $W \to \tau\nu$ treated as background
- Fiducial region (Born-level kinematics): $p_T > 25\,\text{GeV}$, $|\eta| < 2.5$, $m_T^W > 50\,\text{GeV}$, $p_T^\nu > 25\,\text{GeV}$
- Detector effects unfolded (iterative Bayesian unfolding)
- Dominant systematic uncertainties: MC generator choice for $W^\pm$ (up to 5%)
  - Sherpa (alt.) vs Powheg+Pythia (nom.)



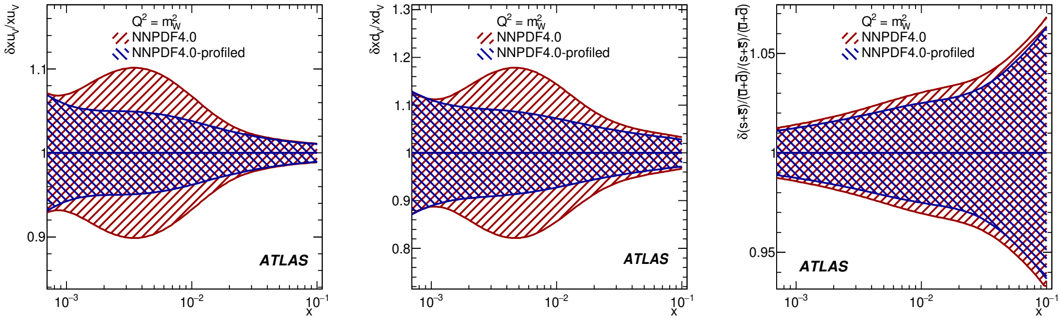
Results





- Predictions from DYTURBO (NNLO$_{QCD}$ + NNLL)
  - Good agreement overall (except high p_T tail)
- Comparison with CT18, MSHT20, NNPDF3.1, NNPDF4.0, ATLASpdf21 (all NNLO)
  - Best description by NNPDF3.1 and NNPDF4.0
- Measurement more precise than predictions (esp. charge asymmetry) → potential for additional constraints on the PDFs

PDF profiling



- PDF profiling done using xFitter
  - Grids from MadGraph5_aMC@NLO + NNLO K-factors from DYTurbo
- Sizeable reduction of uncertainties (up to factor of two for $x \approx 0.004$)

2. Charged-current Drell–Yan at high m_T^W

Charged-current Drell–Yan at high m_T^W

First measurement of CCDY above the W-boson resonance region

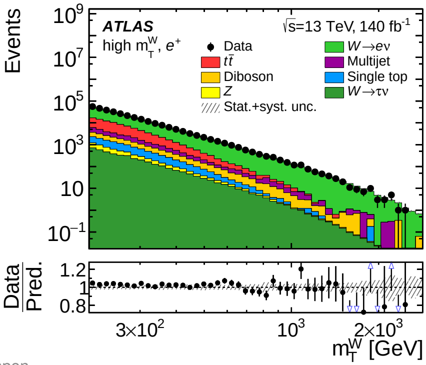
- Drell–Yan measurements at the LHC usually performed at the resonance peak
- Going beyond this opens up the (x, Q^2) range accessible (where $Q = m_{\ell\ell}$ or $m_{\ell\nu}$)
- High Q particularly interesting for sensitivity to physics beyond the SM (e.g. Effective Field Theory) and high-x anti-quark PDFs
- $m_{\ell\nu}$ not accessible experimentally: use m_T^W instead

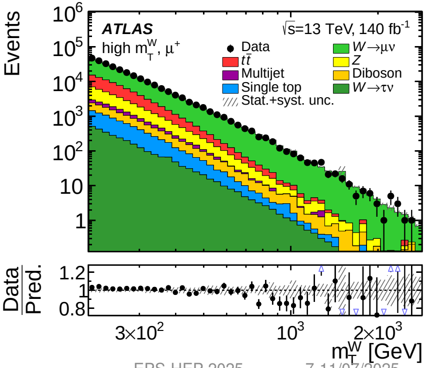
$$m_T^W = \sqrt{2 p_T^\ell p_T^\nu (1 - \cos\Delta\phi(\ell, \nu))}$$

- Using full Run-2 (2015–2018, 140 fb^{-1})

Experimental procedure

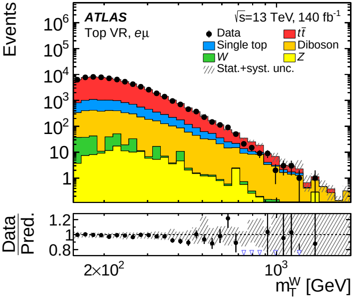
- Electron and muon channels
  - $W \to \tau\nu$ treated as background
- Fiducial region (Born-level kinematics): $p_{\mathrm{T}} > 65\,\mathrm{GeV}$, $|\eta| < 2.4$, $200 \leq m_{\mathrm{T}}^{\mathrm{W}} \leq 5000\,\mathrm{GeV}$ (2D: $m_{\mathrm{T}}^{\mathrm{W}} \leq 2000\,\mathrm{GeV}$), $p_{\mathrm{T}}^{\nu} > 85\,\mathrm{GeV}$
- Iterative Bayesian unfolding to Born or "dressed" particle level

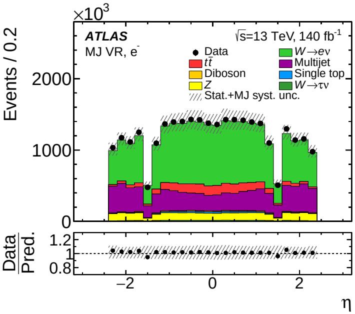


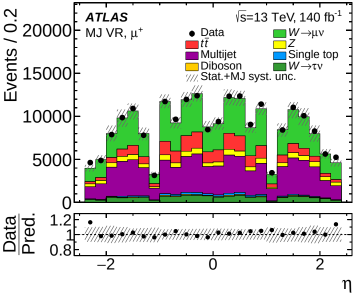


Validation regions

- Non-resonant signal $\rightarrow$ background estimation is crucial
- Dedicated validation regions for backgrounds:
  - Top (MC-driven): $e\mu$ selection
  - Multijet (data-driven, matrix method): no m_T^W selection, $E_T^{miss} < 65\,\text{GeV}$
  - Good agreement between data and predictions



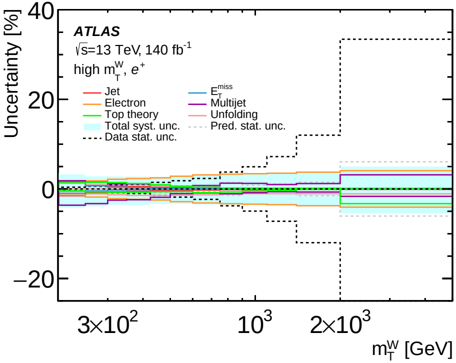


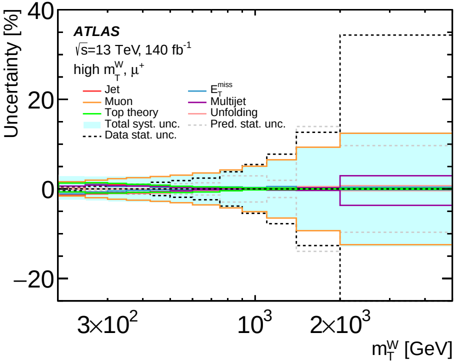


Systematic uncertainties

Dominated by lepton energy / momentum scale (both channels) and multijet estimation (electron only)

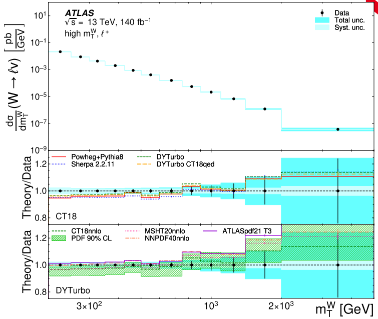
- Measurement systematically limited up to $m_T^W = 900\,\text{GeV}$

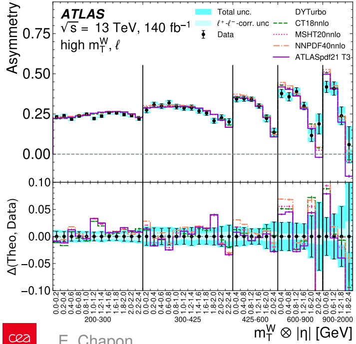


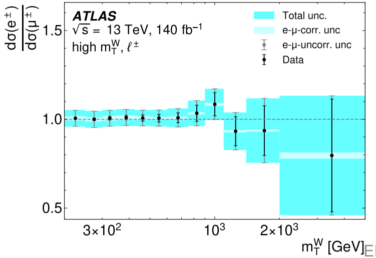


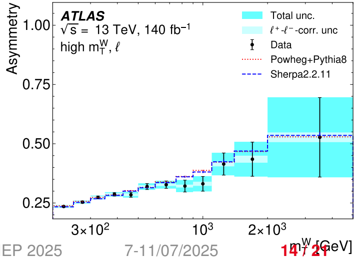
Results

- Fall over $>$ 7 orders of magnitude!
- Good agreement with POWHEG+PYTHIA and SHERPA
  - POWHEG+PYTHIA (nom.): NLO QCD, QED FSR using PHOTOS++, mass-dependent k-factors to NNLO_{QCD} + NLO_{EW}
  - SHERPA (alt.): NLO up to 2 additional partons (LO up to 5), including NLO EW, k-factor scaling to NNLO
- 1D and 2D cross sections, $d\sigma(e^{\pm})/d\sigma(\mu^{\pm})$ ratio, charge asymmetry









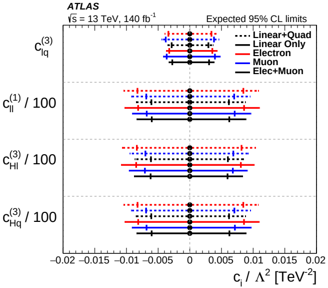
Effective field theory

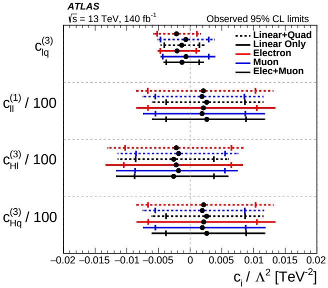
Considering the SMEFT Lagrangian:

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_i \frac{c_i^{(d)}}{\Lambda^{d-4}} O_i^{(d)}$$

- 4 relevant dim-6 operators (Warsaw basis): $O_{lq}^{(3)}$, $O_{ll}^{(1)}$, $O_{Hl}^{(3)}$, $O_{Hq}^{(3)}$
- World-leading limits on $c_{lq}^{(3)}$

Wilson Coefficient	Operator
$c_{lq}^{(3)}$	$O_{lq}^{(3)} = (\bar{l}\tau^I\gamma_\mu l)(\bar{q}\tau^I\gamma^\mu q)$
$c_{ll}^{(1)}$	$O_{ll}^{(1)} = (\bar{l}\gamma_\mu l)(\bar{l}\gamma^\mu l)$
$c_{Hl}^{(3)}$	$O_{Hl}^{(3)} = (H^\dagger i \overleftrightarrow{D}^I_\mu H)(\bar{l}\tau^I\gamma^\mu l)$
$c_{Hq}^{(3)}$	$O_{Hq}^{(3)} = (H^\dagger i \overleftrightarrow{D}^I_\mu H)(\bar{q}\tau^I\gamma^\mu q)$





3. High-mass Drell–Yan to $\tau\tau$

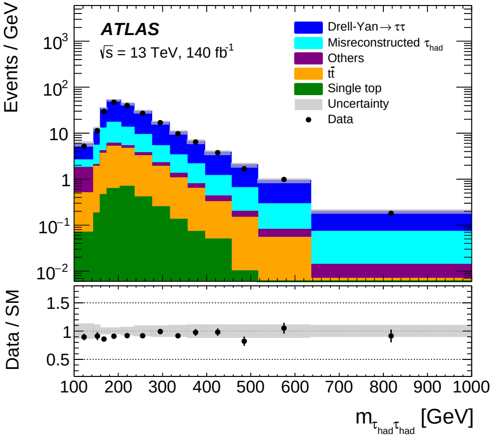
High-mass Drell–Yan to $\tau\tau$

First measurement of inclusive $\tau\bar{\tau}$ production vs $m_{\tau\tau}$

- Study of NC DY lead to historic discoveries of J/ψ, Υ, Z
- Many models predict enhanced couplings to third-generation fermions
- Measurement done in bins of *b*-jet multiplicity to enhance BSM sensitivity
- Using full Run-2 (2015–2018, $140\,\text{fb}^{-1}$)

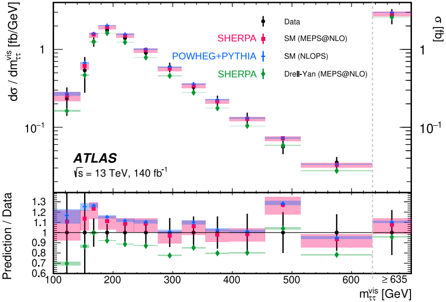
Selection and systematic uncertainties

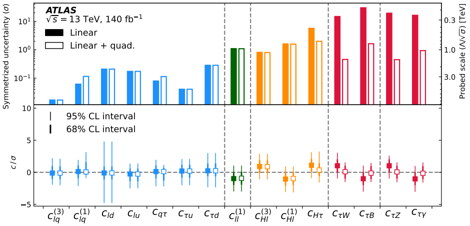
- Using only hadronic τ decays for higher purity (leptonic decays used for validation)
- Fiducial phase space:
  - Hadronically-decaying τ-leptons with visible decay products $p_{\mathrm{T}} > 20\,\mathrm{GeV}$, $|\eta| < 2.47$
  - $p_{\mathrm{T}}^{\tau} > 90\,(60)\,\mathrm{GeV}$
  - Measurement presented in visible mass $m_{\mathrm{vis}}^{\tau\tau}$
  - b-jets: $p_{\mathrm{T}} > 25\,\mathrm{GeV}$, $|\eta| < 2.5$
- All processes included as signal (Drell–Yan but also $t\bar{t}$, multi-boson, tW, etc.)
- Unfolding to particle level using the iterative Bayesian method

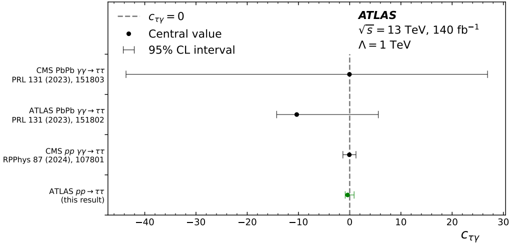


Results

- Cross section: good agreement with SM predictions (SHERPA and POWHEG+PYTHIA)
  - “SM”: inclusive $\tau\tau$ vs “Drell–Yan”: DY only
- Limits on Wilson coefficients for 15 SMEFT operators
  - Limits on $c_{\tau\gamma}$ translated into limits on the τ-lepton anomalous magnetic moment a_τ, comparable with CMS $pp\,\gamma\gamma \to \tau\tau$
- Limits also set on leptoquark and Z' models







Summary

- W-boson differential cross sections with low pile-up data (2502.09403)
  - Measurements more precise than predictions: potential constraining power on quark PDFs
- Charged-current Drell–Yan at high transverse masses (2502.21088)
  - First measurement
  - Measurements more precise than predictions: potential constraining power on quark PDFs
  - World-leading constraints on the Wilson coefficient $c_{lq}^{(3)}$
- High-mass $\tau\bar{\tau}$ measurement (2503.19836)
  - First measurement
  - SMEFT constraints, leptoquark and Z' searches

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Thank you for your attention !

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