Measurement of electroweak boson production in pp, p+Pb and Pb+Pb collisions with the ATLAS detector.

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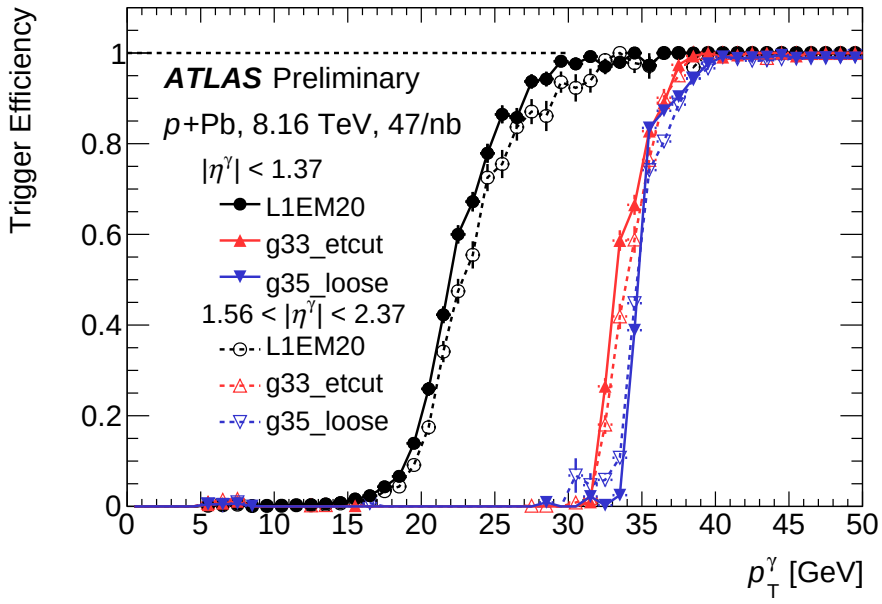
Introduction

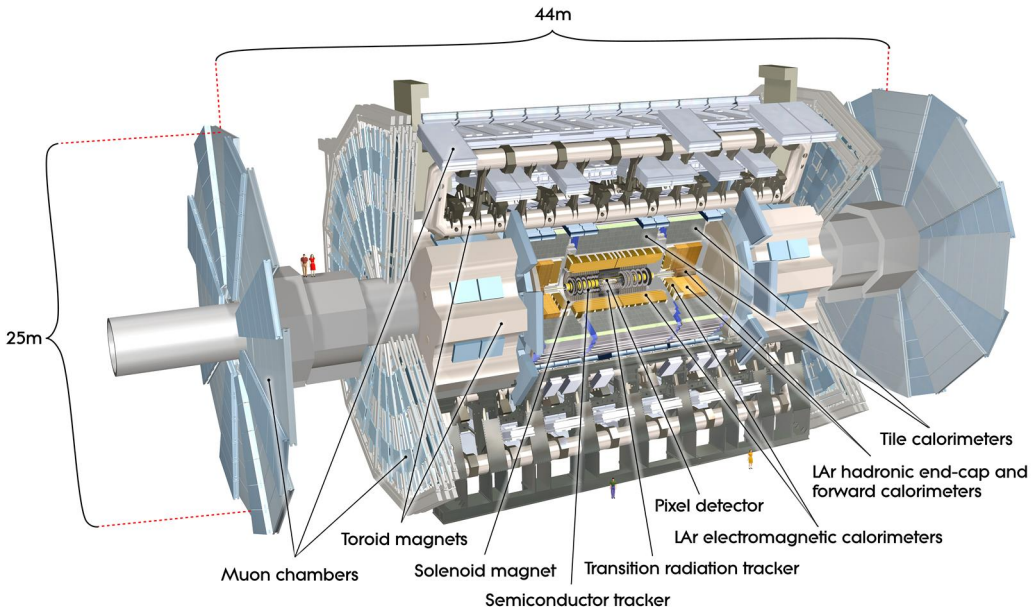
Electroweak bosons:

- high-precision test of pQCD (pp),
- the nuclear modifications to PDF can be investigated (p+Pb, Pb+Pb),
- provides information on centrality and geometry of p+Pb and Pb+Pb systems (T_{AA} scaling) as EW bosons are insensitive to final state interactions,
- with LHC energies, a range of photon spectra can be measured in a broader scope.

ATLAS detector & data

- Muon, electron and photon triggers are designed to collect high-p_{T} objects.
- Measurements of electroweak bosons are based on:
  - pp: $\sqrt{s} = 5.02$ TeV ($25\ \mathrm{pb}^{-1}$)
  - p+Pb: $\sqrt{s} = 8.16$ TeV ($0.16\ \mathrm{pb}^{-1}$)
  - Pb+Pb: $\sqrt{s} = 5.02$ TeV ($0.49\ \mathrm{nb}^{-1}$)

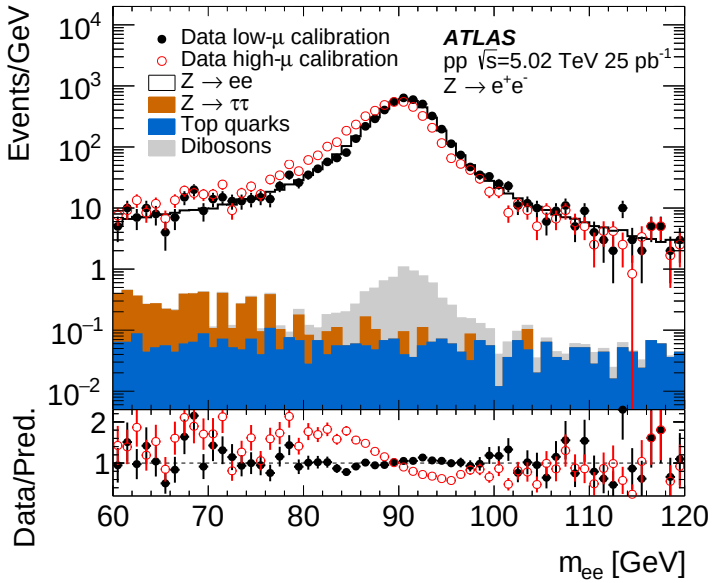


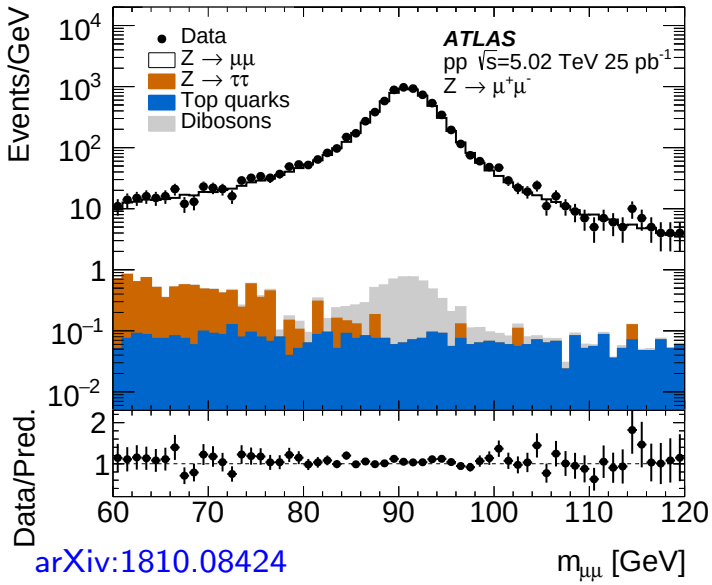


Z bosons in *pp* at 5.02 TeV

NEW

- 15 GeV single electron trigger and 14 GeV single muon trigger
- isolated and good quality leptons
- $p_{\mathrm{T}}^{e(\mu)} > 20$ GeV, $|\eta_e| < 1.37$ or $1.52 < |\eta_e| < 2.47$, $|\eta_\mu| < 2.4$
- opposite-charge dilepton pairs in mass range: $66 < m_{\ell\ell} < 116$ GeV
- $\sim$ 4800 (7400) $Z \to e^+e^-$ ($Z \to \mu^+\mu^-$) candidates
- subtracted backgrounds ($Z \to \tau^+\tau^-$, $t\bar{t}$ and dibosons from MC, multi-jet from data) at the level of 0.3%
- corrections for trigger, reconstruction and isolation efficiencies



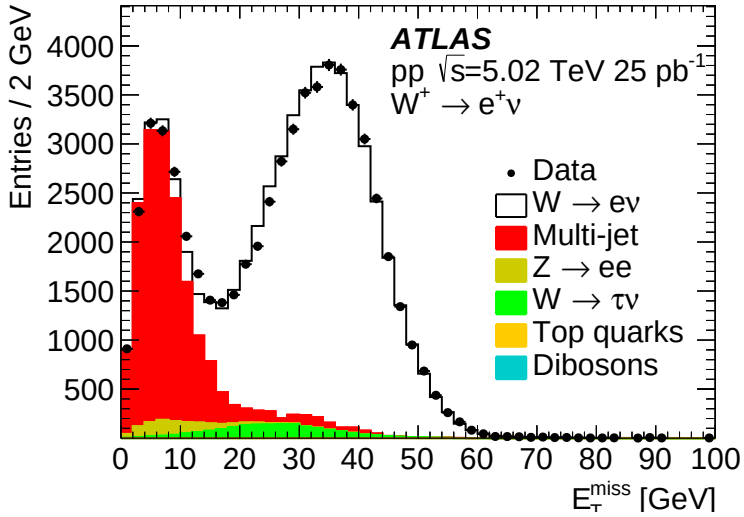


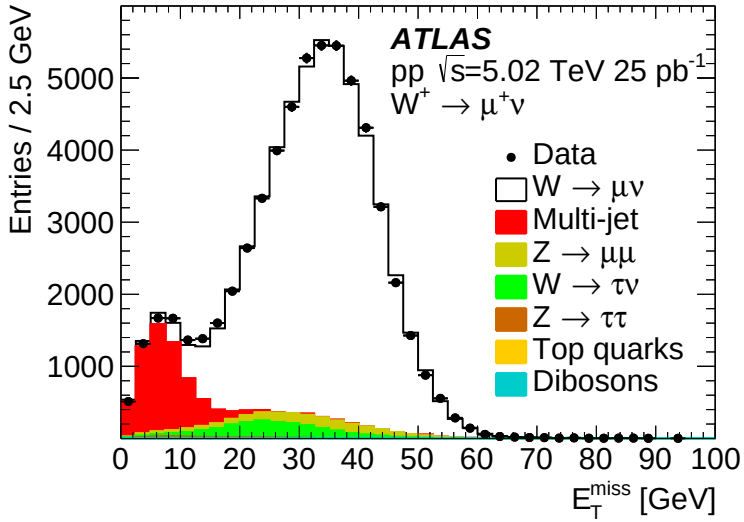
arXiv:1810.08424

W bosons in *pp* at 5.02 TeV

NEW

- 15 GeV single electron trigger and 14 GeV single muon trigger
- isolated and good quality leptons (exactly one per event - veto on Z boson candidates)
- $p_{\mathrm{T}}^{e(\mu)} > 25$ GeV, $|\eta_e| < 1.37$ or $1.52 < |\eta_e| < 2.47$, $|\eta_\mu| < 2.4$
- $E_{\mathrm{T}}^{miss} > 25$ GeV, $m_{\mathrm{T}} > 40$ GeV
- $\sim$ 38000 (44000) $W^+ \to e^+\nu$ ($W^+ \to \mu^+\nu$) candidates
- $\sim$ 24000 (27000) $W^- \to e^-\nu$ ($W^- \to \mu^-\nu$) candidates
- subtracted backgrounds: 2-6% EW, top-quark and diboson estimated from MC, 0.1-1.4% multi-jet estimated with data-driven method
- corrections for trigger, reconstruction and isolation efficiencies, as well as missing energy calibration





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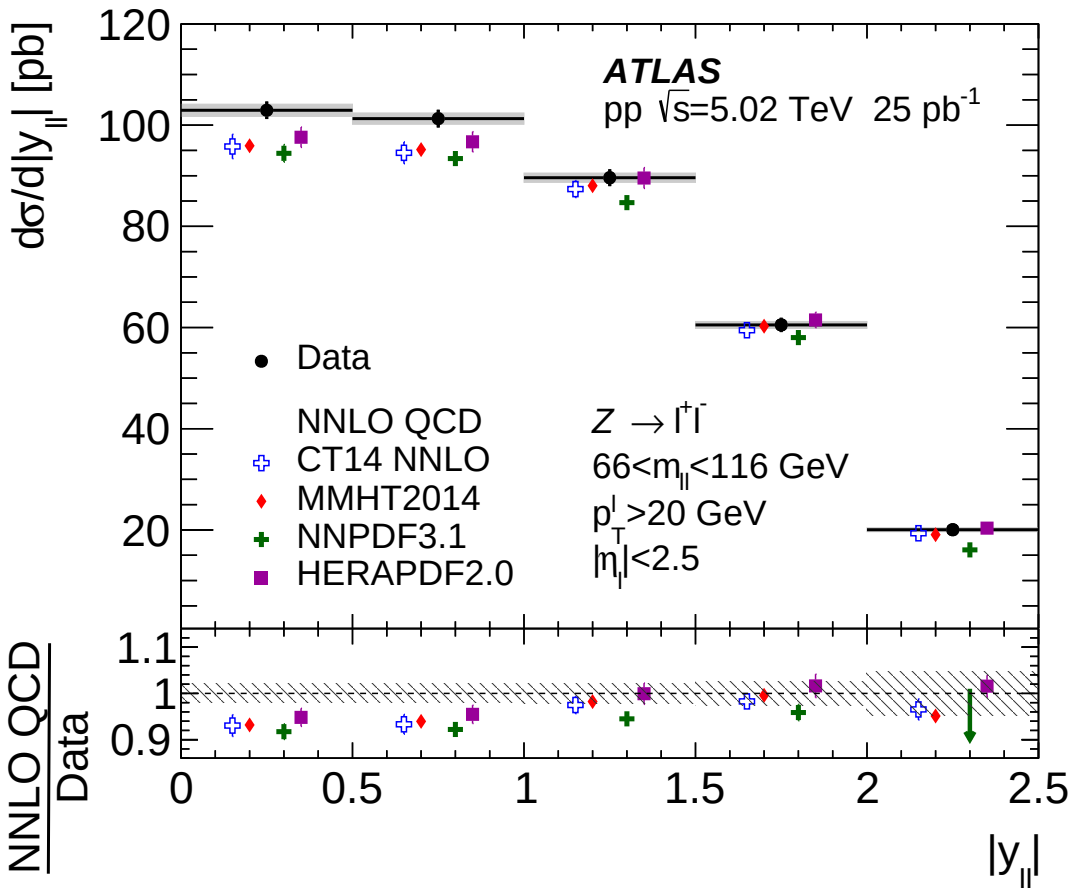
Z bosons in *pp* - differential cross section

NEW

- Rapidity differential cross-sections measured in fiducial phase-space volume.
- Combined results are compared with several theory predictions (different PDF sets) calculated at NNLO using an optimised version of DYNNLO 1.5.
- At central rapidities ($|y_{\ell\ell}| < 1$) all predictions tend to underestimate measured cross-sections.
- At larger rapidities good agreement with most considered PDF sets.
- **High precision measurement.**



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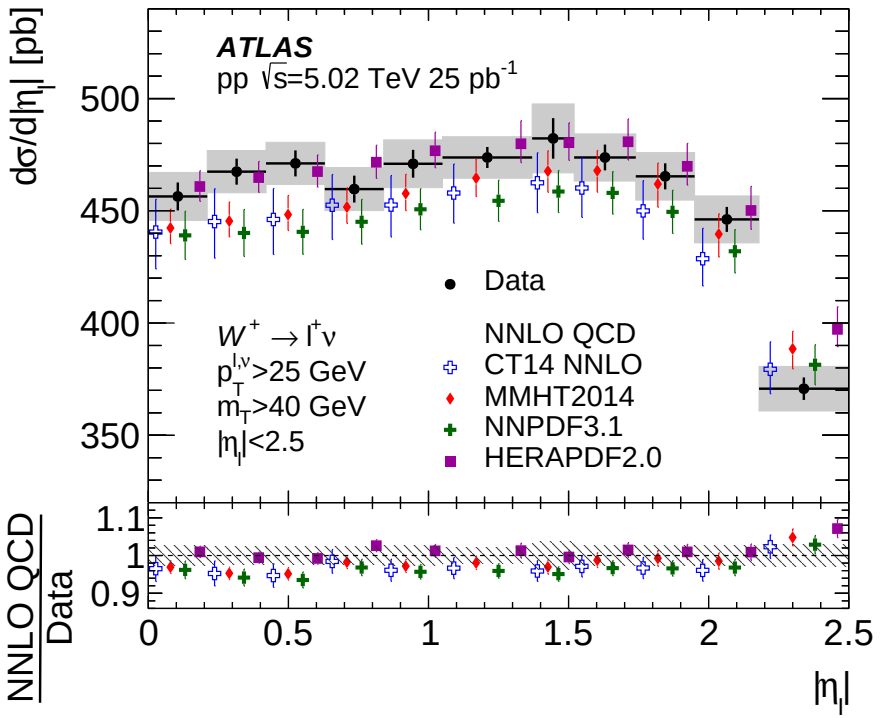
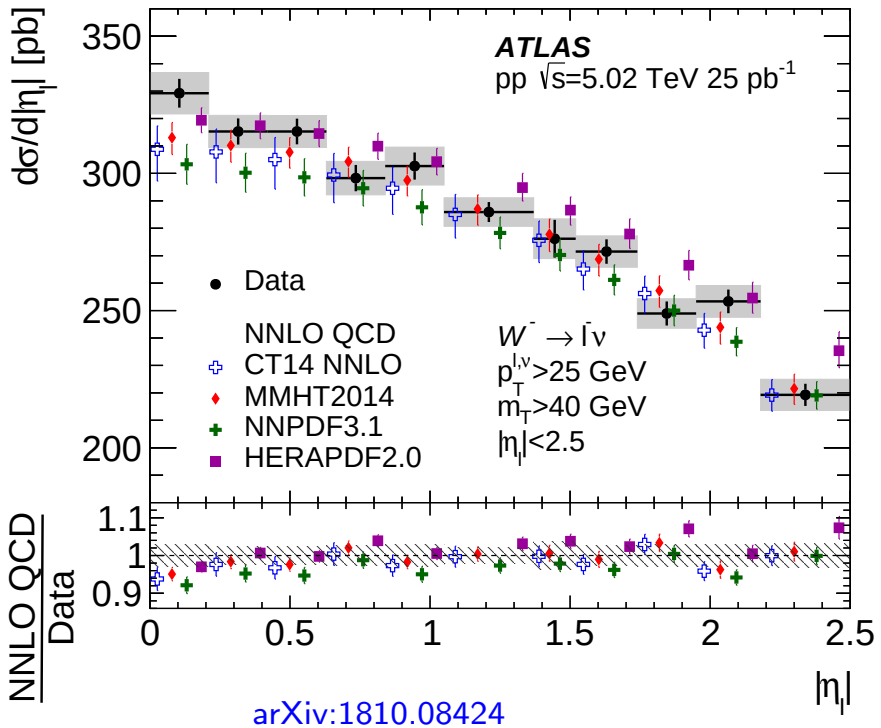
W bosons in *pp* - differential cross section

NEW

- Lepton pseudorapidity differential cross-sections measured in fiducial phase-space volume.
- Predictions (except using HERAPDF 2.0) systematically tend to underestimate measured cross-sections, but deviations are at the level of 1-2σ.
- Similar observations made in previous ATLAS measurements at 7 and 13 TeV.
- **High precision measurement.**





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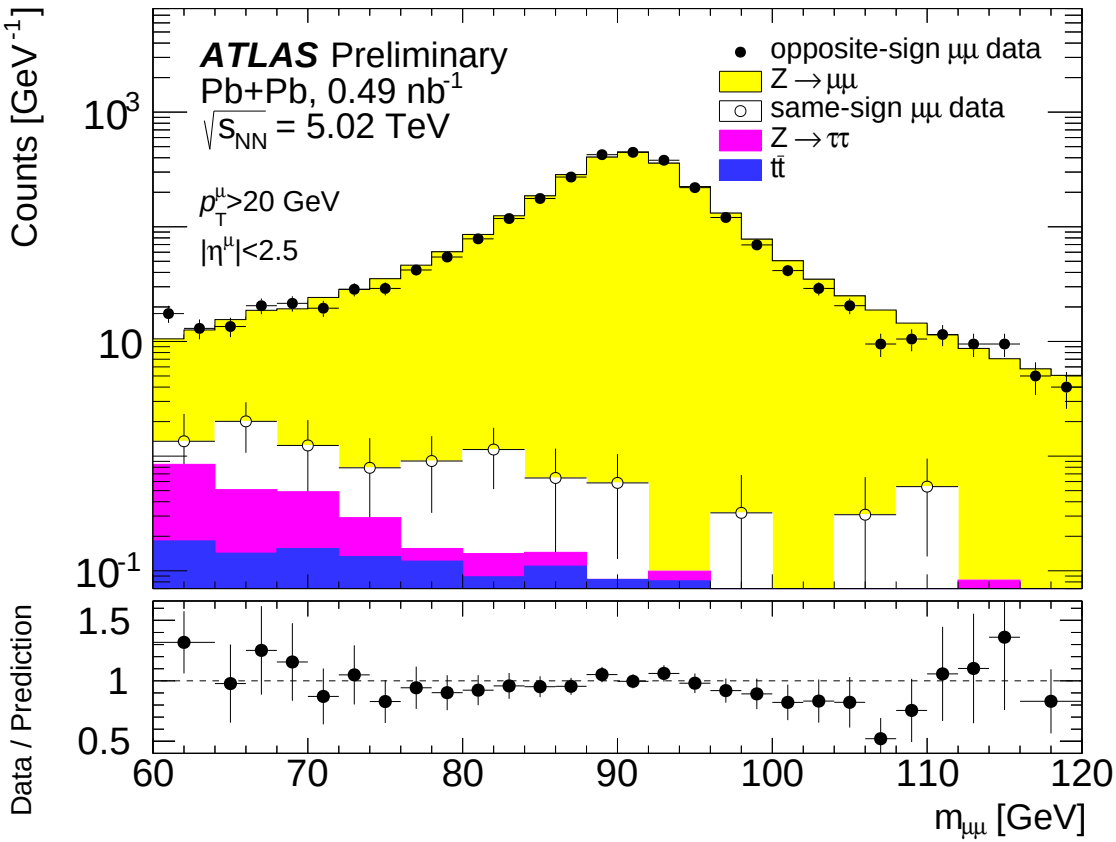
Z bosons in Pb+Pb at 5.02 TeV

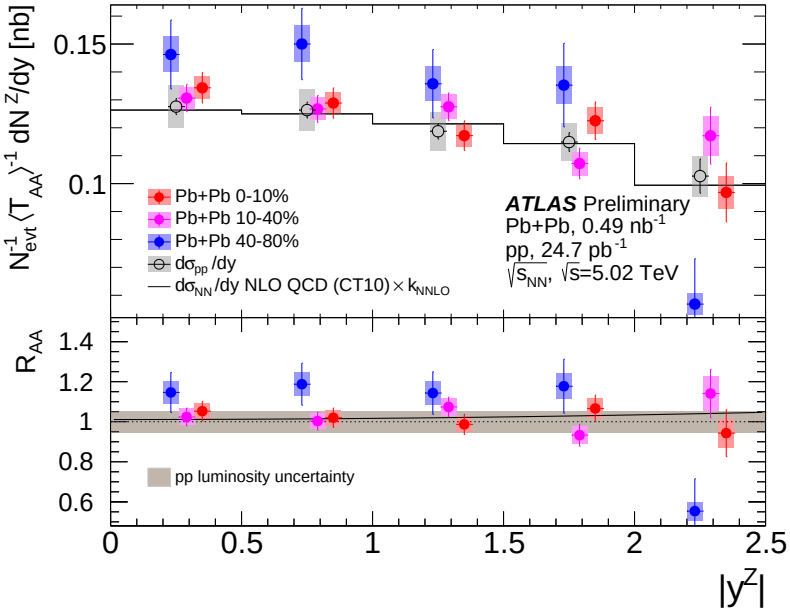
- 8 GeV single muon trigger
- good quality muons
- $p_{\mathrm{T}} > 20$ GeV, $|\eta| < 2.5$
- opposite-charge dilepton pairs in mass range: $66 < m_{\mu^+\mu^-} < 116$ GeV
- ~ 5500 $Z \to \mu^+\mu^-$ candidates
- subtracted backgrounds ($Z \to \tau^+\tau^-$, $t\bar{t}$ and dibosons from MC, multi-jet from data) at the level of 0.5%
- corrections for trigger and reconstruction efficiencies



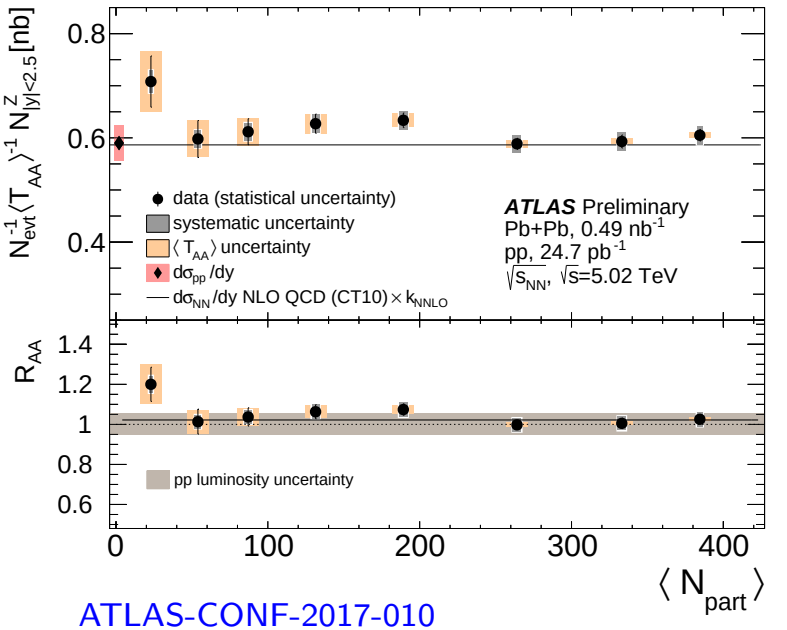
ATLAS-CONF-2017-010

Z bosons in Pb+Pb - rapidity and centrality yields

- Rapidity differential yields per minimum-bias event divided by $\langle T_{\mathrm{AA}} \rangle$ to compare with *pp* cross-sections.
- Mostly consistent with $\langle T_{\mathrm{AA}} \rangle$ scaling - only peripheral bin is somewhat high ($\sim 1.5\sigma$).
- Caveat: preliminary results on *pp* cross-sections used to construct R_{AA}.



- Yields per minimum-bias event divided by $\langle T_{\mathrm{AA}} \rangle$ as a function of N_{part} integrated in $|y_Z| < 2.5$.
- High-precision measurement: uncertainties related to Z bosons smaller than normalisation uncertainties.
- Most peripheral bin shows a hint of excess, otherwise no significant dependence of scaled yields or R_{AA} on centrality observed.



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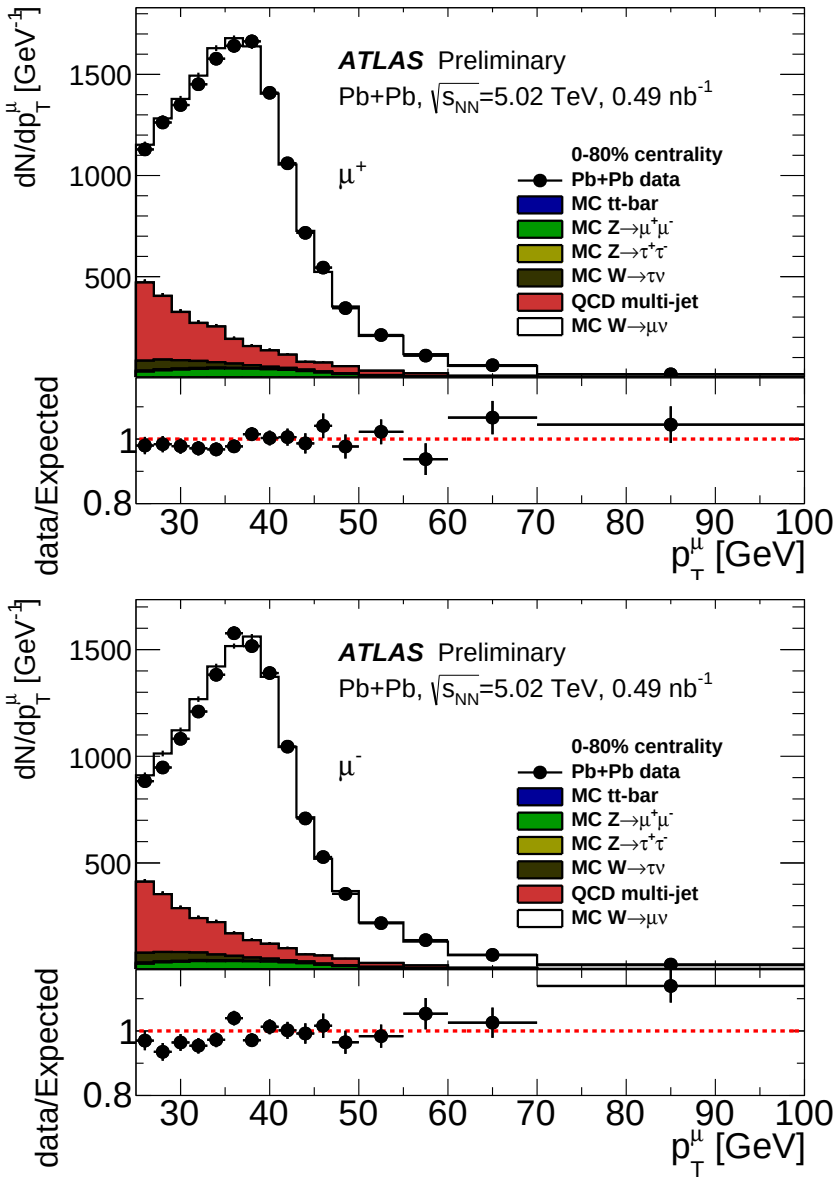
W bosons in Pb+Pb at 5.02 TeV

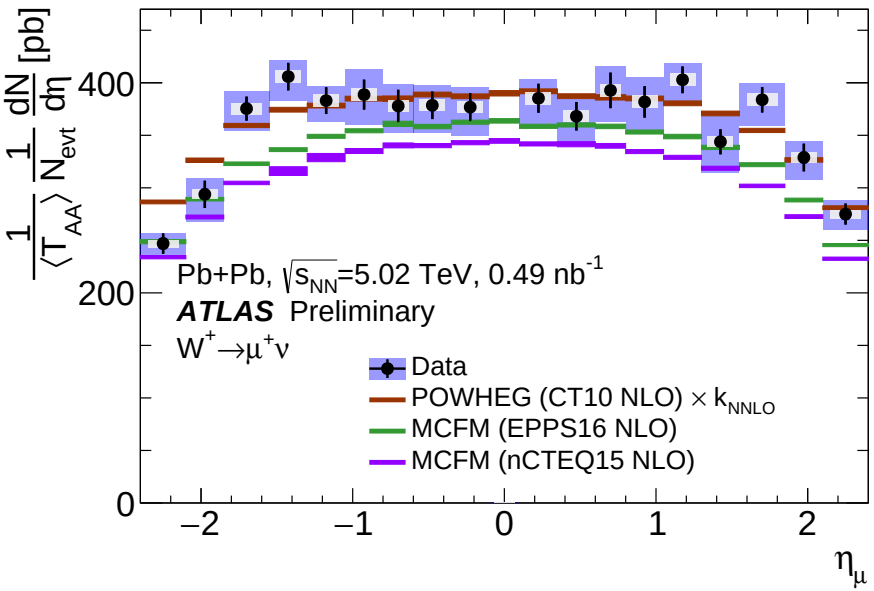
- 15 GeV single muon trigger
- isolated and good quality muons
- $p_{\mathrm{T}} > 25$ GeV, $0.1 < |\eta| < 2.4$
- $p_{\mathrm{T}}^{\mathrm{miss}} > 25$ GeV
- $m_{\mathrm{T}} > 40$ GeV, where $m_{\mathrm{T}} = \sqrt{2 p_{\mathrm{T}}^{\mu} p_{\mathrm{T}}^{\mathrm{miss}} (1 - \cos(\Delta\phi))}$
- $\sim$ 25000 (23000) $W^+ \to \mu^+ \nu$ ($W^- \to \mu^- \nu$) candidates
- subtracted backgrounds: 2-3% EW and $t\bar{t}$ estimated from MC, 6-12% multi-jet estimated with data-driven method
- corrections for trigger, reconstruction and isolation efficiencies, as well as MET resolution effects

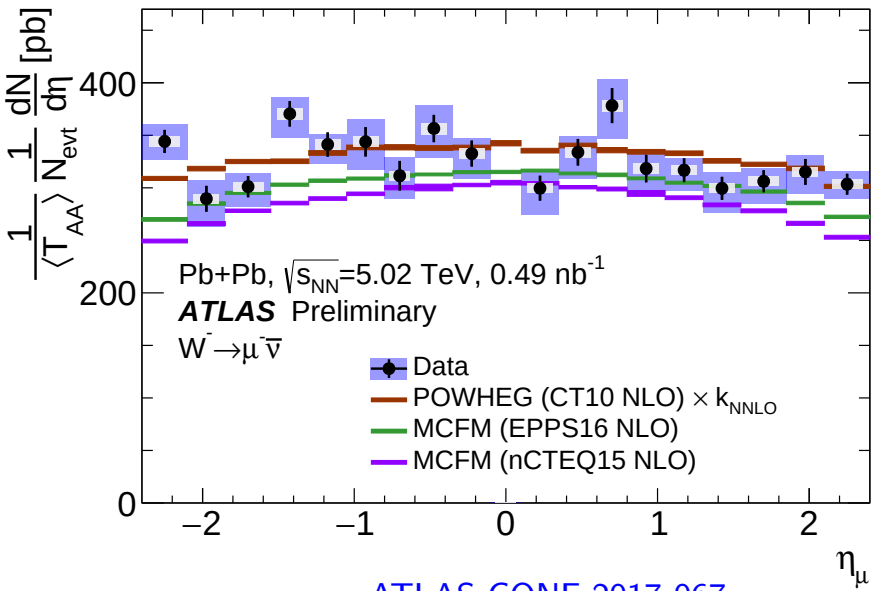


ATLAS-CONF-2017-067

W bosons in Pb+Pb - rapidity yields

- Lepton pseudorapidity differential yields per minimum-bias event divided by $\langle T_{\mathrm{AA}} \rangle$ for fiducial phase-space volume: $p_{\mathrm{T}} > 25$ GeV, $p_{\mathrm{T}}^{\mathrm{miss}} > 25$ GeV, $m_{\mathrm{T}} > 40$ GeV.
- Comparisons with several theory predictions:
  - CT10 free-nucleon PDFs (Powheg+Pythia8, NLO scaled to NNLO)
  - EPPS16 and nCTEQ15 nPDFs (both MCFM, NLO)
- Best agreement with NLO calculation obtained with free-nucleon PDFs scaled to NNLO results, while NLO calculations with nPDFs are somewhat below data.





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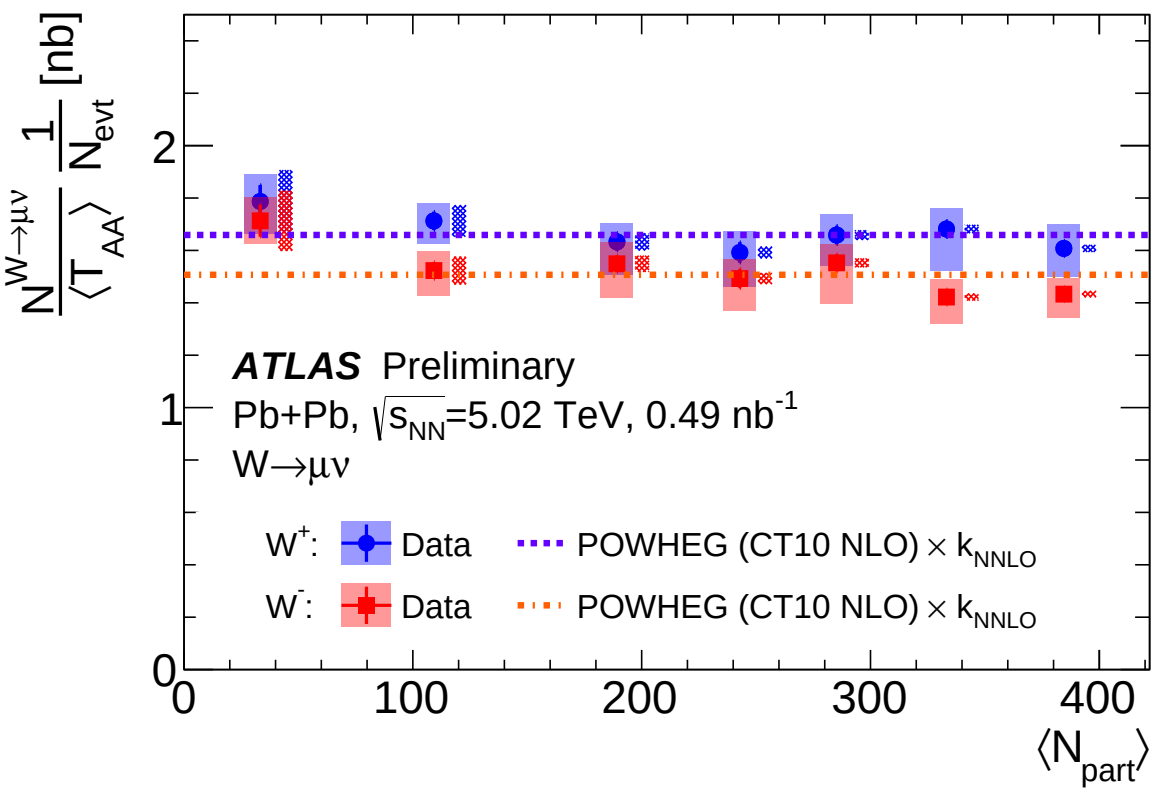
W bosons in Pb+Pb - centrality yields

- Fiducial yields per minimum-bias event divided by $\langle T_{\mathrm{AA}} \rangle$ (integrated in $0.1 < |\eta_\mu| < 2.4$).
- Similarly to Z bosons, most peripheral bin shows a hint of excess.
- Otherwise no significant dependence of scaled yields on centrality observed.
- Predictions from Powheg+Pythia8 including isospin effect and scaled to NNLO agree with data.



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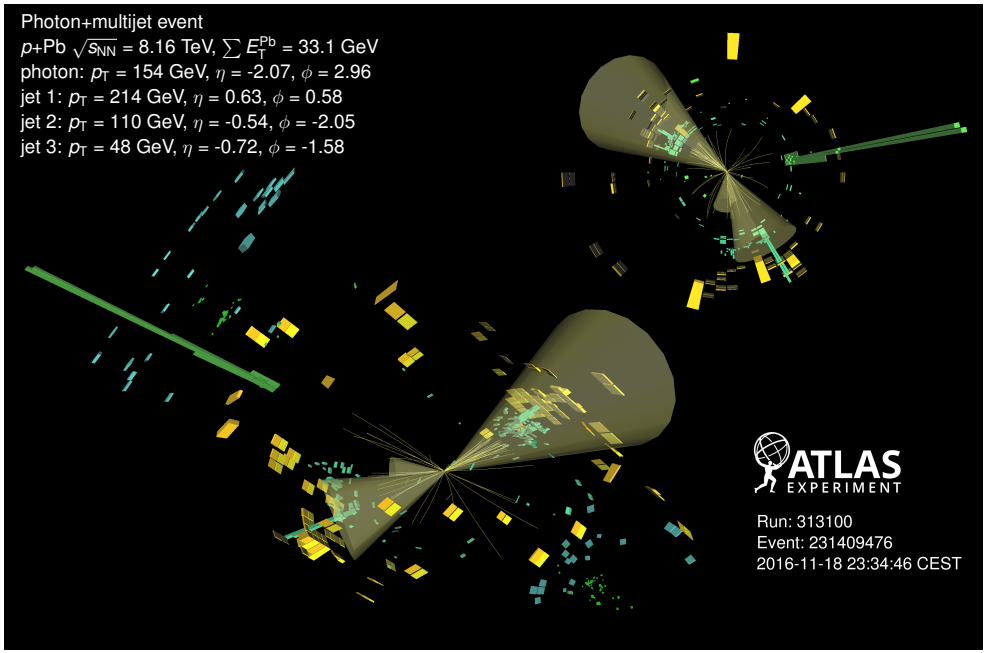
Prompt photons in p+Pb at 8.16 TeV

- single photon triggers with 4 thresholds from 20 to 35 GeV
- good quality photons and passing isolation criterion:
  $E_{\mathrm{T}}^{\mathrm{iso}} < 4.8\ \mathrm{GeV} + 4.2 \times 10^{-3} E_{\mathrm{T}}^{\gamma}/GeV$
- $E_{\mathrm{T}}^{\gamma} > 25$ GeV
- $|\eta^{\gamma}| < 1.37,\ 1.56 < |\eta^{\gamma}| < 2.37$
- rapidity boost by $\Delta y = \pm 0.465$
- corrections for trigger, reconstruction and isolation efficiencies, as well as bin migration in E_{T}^{γ}

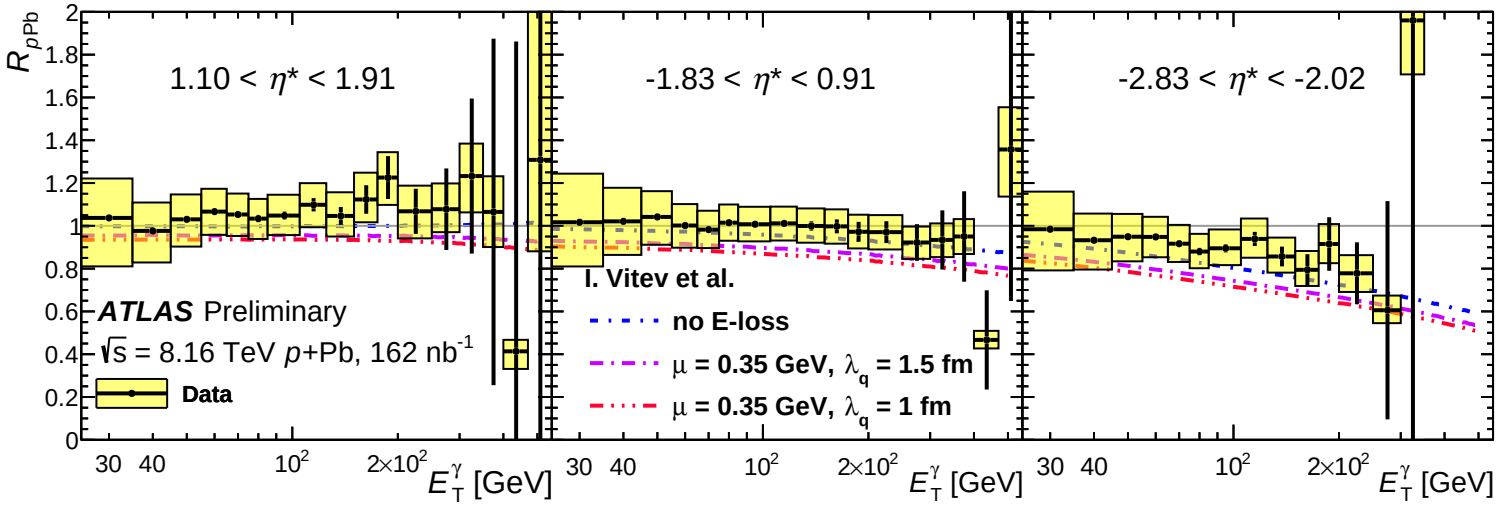


$R_{p\mathrm{Pb}}$ (I)

- $R_{p\mathrm{Pb}}$ as a function of E_{T}^{γ} and η^{*}
- At mid-rapidity, the $R_{p\mathrm{Pb}}$ is consistent with unity (isospin or other nuclear effects are small).

$$R_{p\mathrm{Pb}} = \frac{d\sigma^{p+\mathrm{Pb}\to\gamma+X}/dE_{\mathrm{T}}^{\gamma}}{A \cdot d\sigma^{pp\to\gamma+X}/dE_{\mathrm{T}}^{\gamma}}$$

- At high E_{T}^{γ} at backward pseudorapidity, the $R_{p\mathrm{Pb}}$ is significantly lower than unity.
- This effect is driven by the different isospin composition of pp and p+Pb systems.
- Comparison to initial state energy loss model. Data disfavour a large suppression due to energy loss effects.



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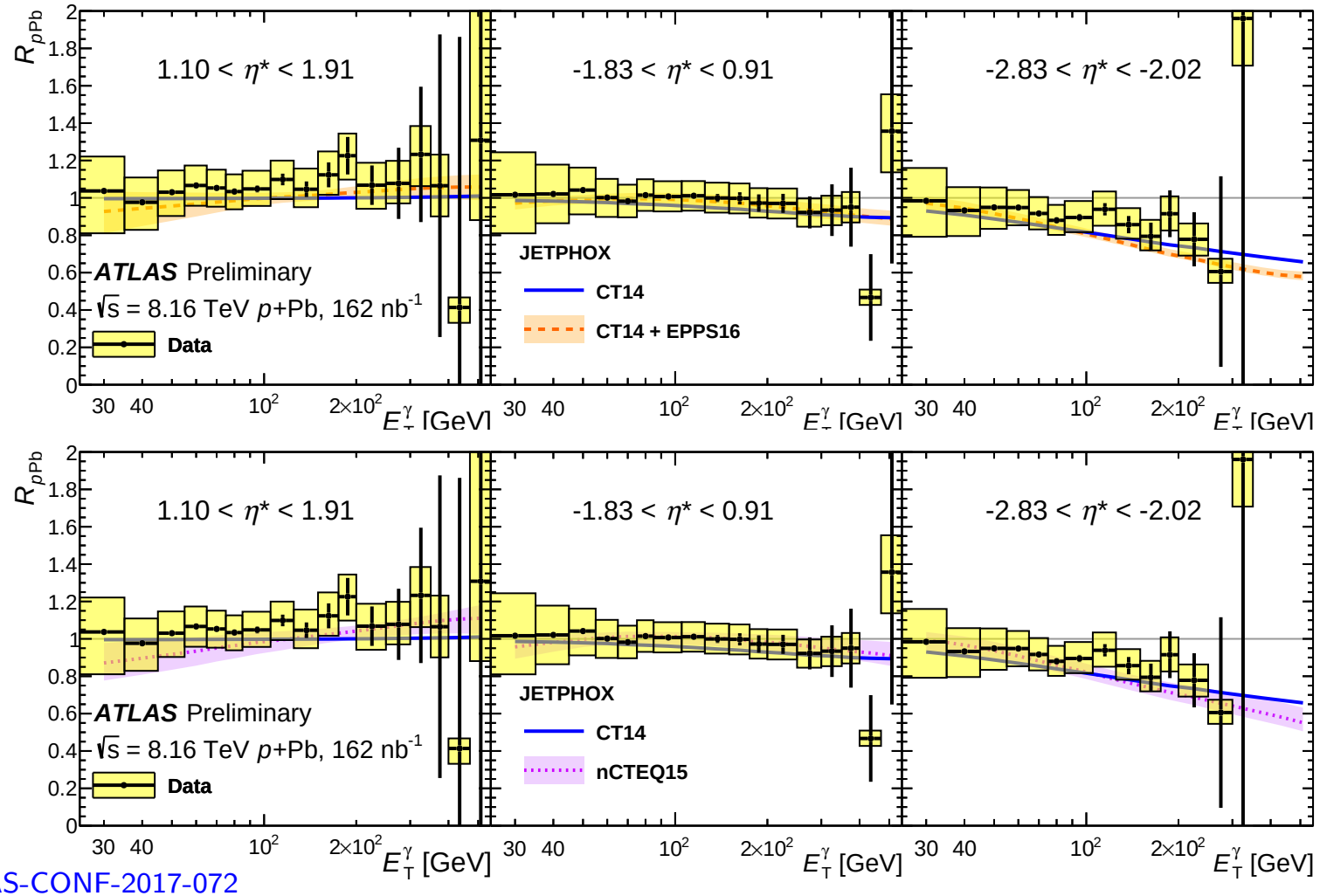
$R_{p\mathrm{Pb}}$ (II)

- Comparison to CT14, nCTEQ15 and EPPS16.
- Data are consistent with the free proton PDFs and with the small effects expected from a nuclear modification of the parton densities.



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Summary

- Presented ATLAS measurements of electroweak boson production in *pp*, *p*+Pb and Pb+Pb collsions.
- *pp* collisions:
  - New measurement will serve as high-precision baseline for Pb+Pb results.
  - Expect improved R_{AA} measurements.
  - Theory predictions calculated with different PDF sets at NNLO tend to systematically understimate measured cross-sections - similar behaviour observed in ATLAS measurements at 7 and 13 TeV.
- *p*+Pb collisions:
  - $R_{p\mathrm{Pb}}$ consistent with unity at mid-rapidity range.
  - It is in agreement with JETPHOX with the EPPS16/nCTEQ15 nPDFs while data disfavour large suppression due to energy loss effects.
- Pb+Pb collisions:
  - Measurements consistent with expectations from T_{AA} scaling, no significant dependence of yields on centrality (except most peripheral collisions).
  - With current uncertainties there is little experimental sensitivity to nPDFs.

Backup slides

Fiducial and total cross-section predictions for W^+, W^- and Z

PDF set	$\sigma^{\text{fid}}_{W^+}$ [pb]	$\sigma^{\text{fid}}_{W^-}$ [pb]	σ^{fid}_{Z} [pb]	$\sigma^{\text{tot}}_{W^+}$ [pb]	$\sigma^{\text{tot}}_{W^-}$ [pb]	σ^{tot}_{Z} [pb]
CT14 NNLO	2203^{+62}_{-64}	1379^{+34}_{-42}	356^{+8}_{-10}	4299^{+112}_{-113}	2862^{+63}_{-77}	648^{+14}_{-16}
MMHT2014	2244^{+40}_{-39}	1393^{+24}_{-28}	363^{+6}_{-5}	4357^{+75}_{-73}	2902^{+49}_{-57}	660^{+11}_{-10}
NNPDF3.1	2186 ± 45	1344 ± 29	355 ± 7	4301 ± 87	2828 ± 62	645 ± 13
HERAPDF2.0	2291^{+92}_{-61}	1440^{+42}_{-27}	369^{+14}_{-7}	4459^{+180}_{-108}	3042^{+94}_{-56}	675^{+24}_{-13}
Additional uncertainties						
α_{S}	± 17	$^{+13}_{-11}$	$^{+3}_{-2}$	$^{+31}_{-29}$	$^{+27}_{-22}$	± 5
μ_{R}, μ_{F} scales	$^{+18}_{-11}$	$^{+11}_{-8}$	± 1	$^{+25}_{-36}$	$^{+13}_{-15}$	$^{+3}_{-4}$
Data	2266 ± 53	1401 ± 33	374.5 ± 8.6	–	–	–

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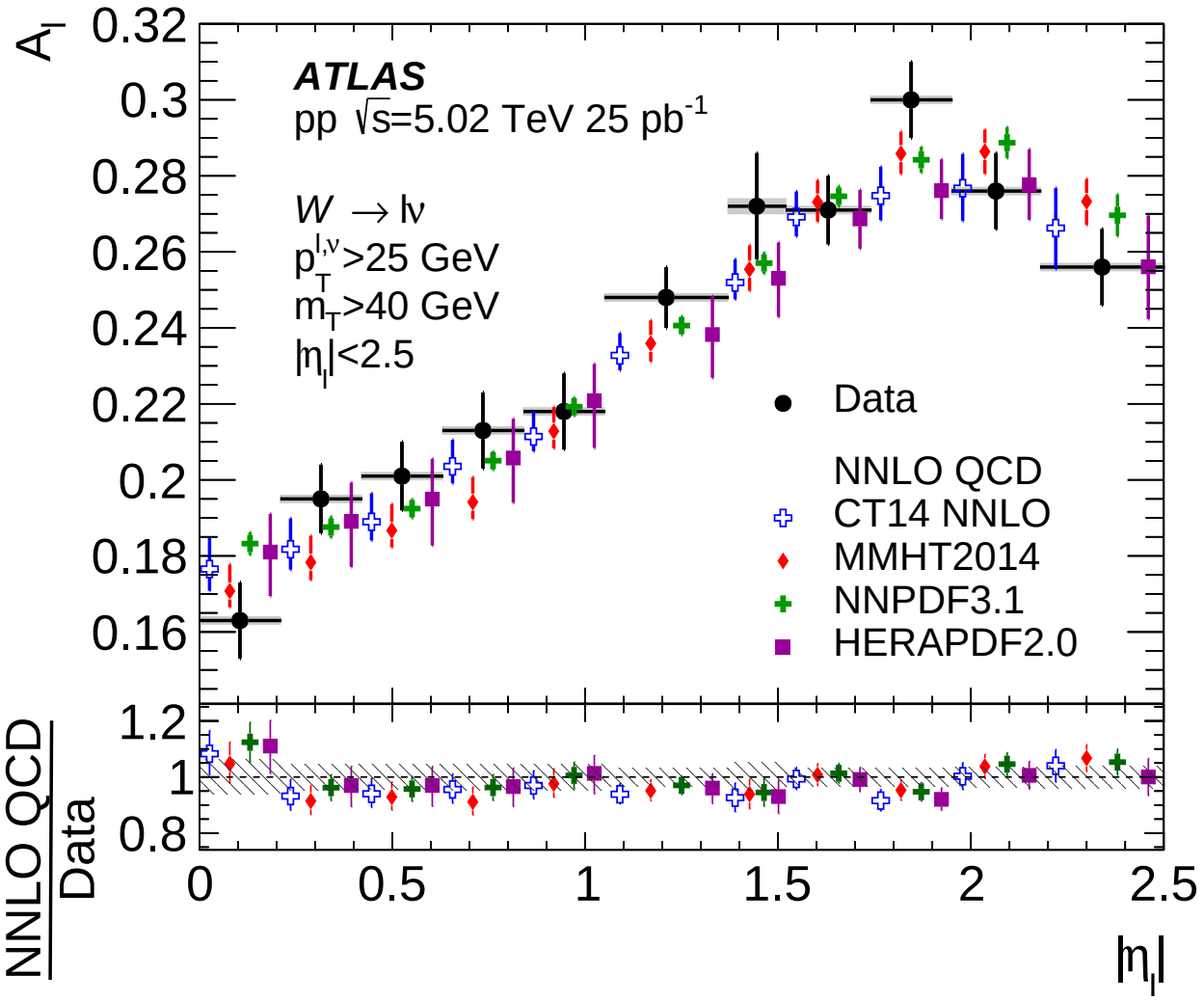
Charge asymmetry for W bosons



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