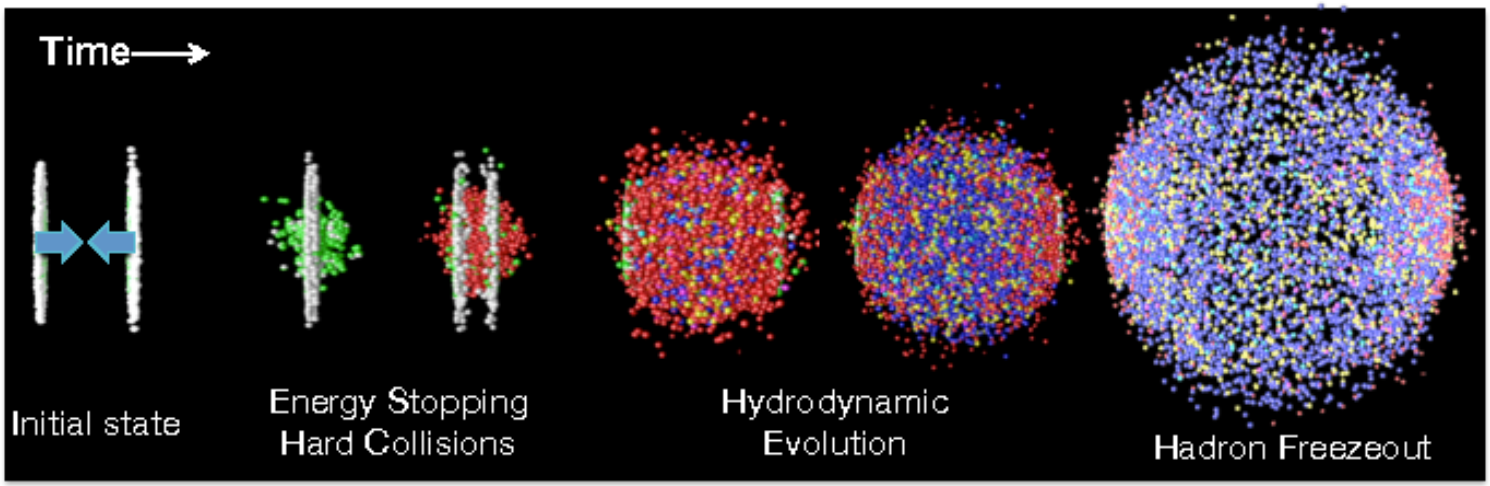
Measurement of W and Z boson production in 5 TeV pp, p+Pb and Pb+Pb collisions with the ATLAS detector.

Piotr Janus
on behalf of the ATLAS Collaboration

AGH University of Science and Technology, Cracow, Poland

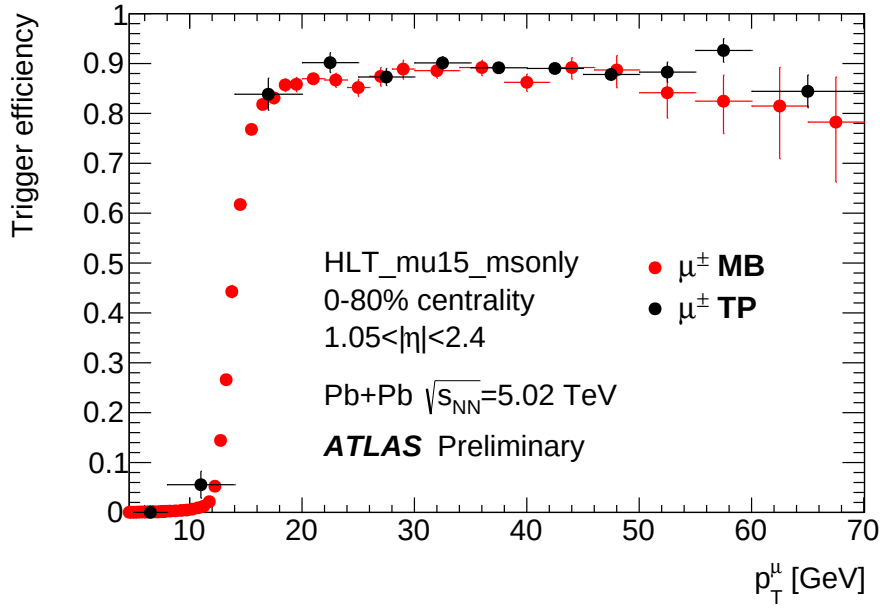
W and Z bosons

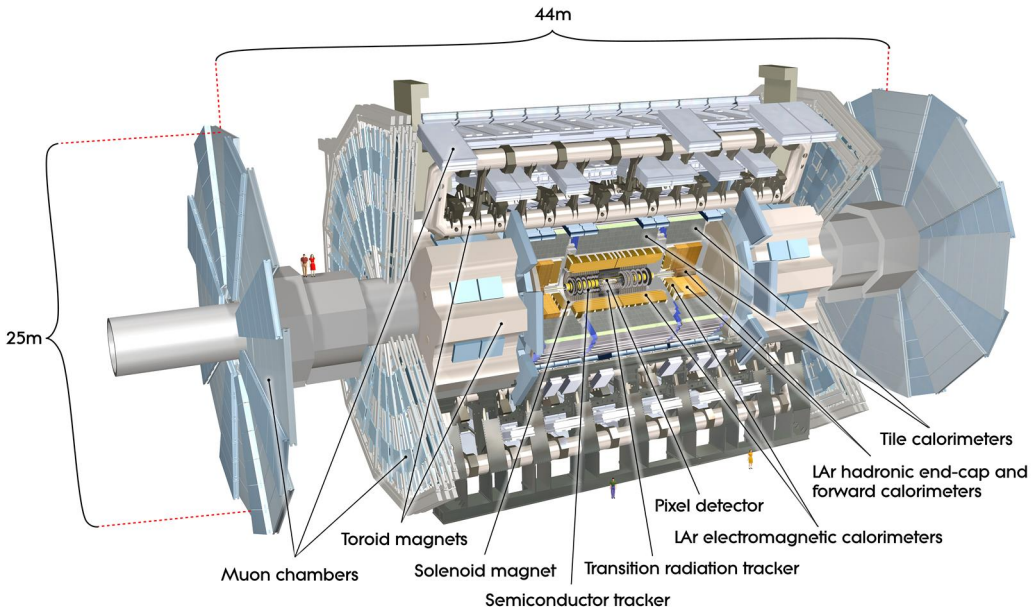
- In pp collisions W and Z bosons allow for constraining/tuning the pQCD calculations and investigation of parton distribution function (PDF).
- The collisions of heavy ions (HI):
  - enable to investigate QCD in the limit of high densities and temperatures reached in deconfined medium - the Quark Gluon Plasma (QGP),
  - the nuclear modifications to PDF can be investigated (p+Pb, Pb+Pb),
  - one can study initial state effects (p+Pb) and impact of interaction with nuclear medium formed in nucleus–nucleus collisions,
  - 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.



ATLAS detector & data

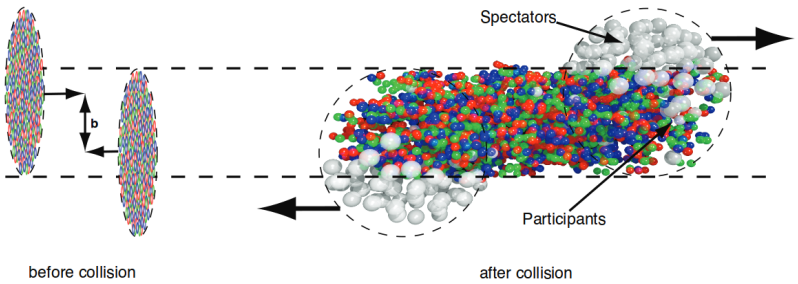
- Muon and electron triggers designed to collect high-p_{T} objects.
- Measurements of electroweak bosons based on:
  - pp: $\sqrt{s} = 5.02$ (24.7 pb^{-1})
  - p+Pb: $\sqrt{s} = 5.02$ (28.1 nb^{-1})
  - Pb+Pb: $\sqrt{s} = 5.02$ TeV (0.49 nb^{-1})

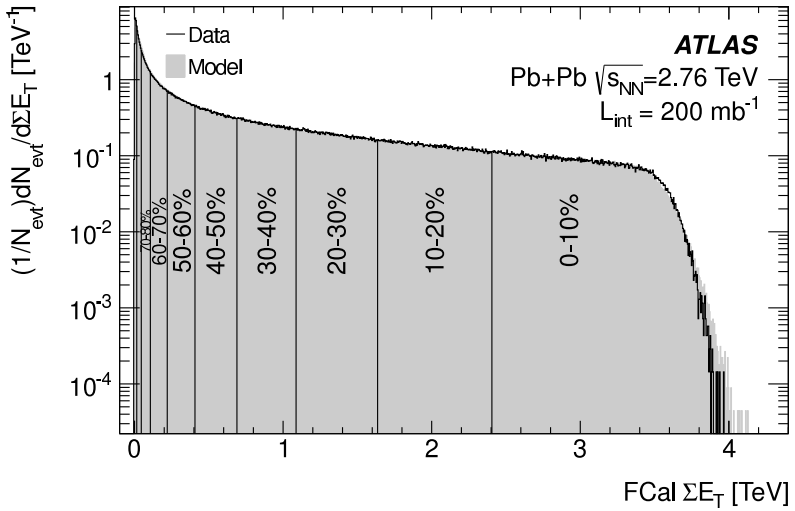




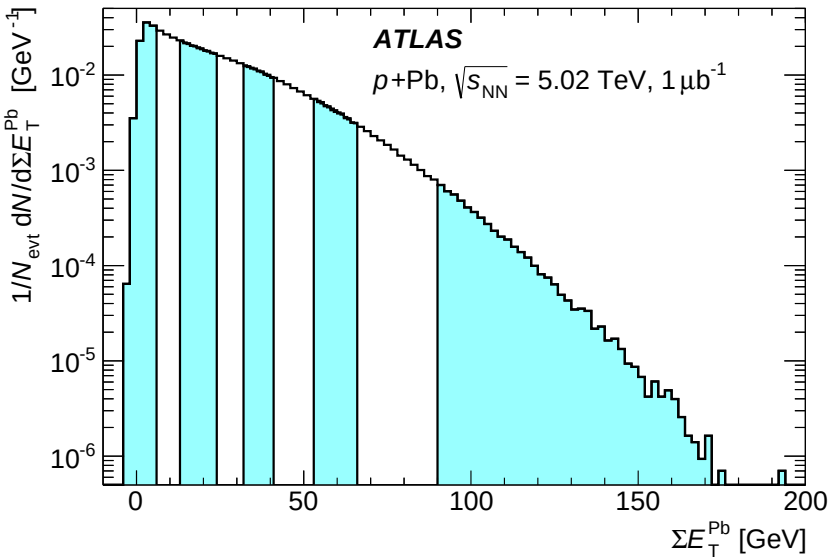
Centrality

- The centrality of a collision is related to the impact parameter b.
  - peripheral: low number of N_{part}
  - central: high number of N_{part}





- The Glauber model allows to connect experimental quantity with a geometric quantity (impact parameter, N_{part}, N_{coll}).
- Centrality is measured using forward calorimeters (FCal) which covers $3.2 < |\eta| < 4.9$
- In p+Pb it is challenging due to asymmetry and less activity compared to Pb+Pb system.



Nuclear modification factor

- The nuclear modification factor compares Pb+Pb to *pp*:

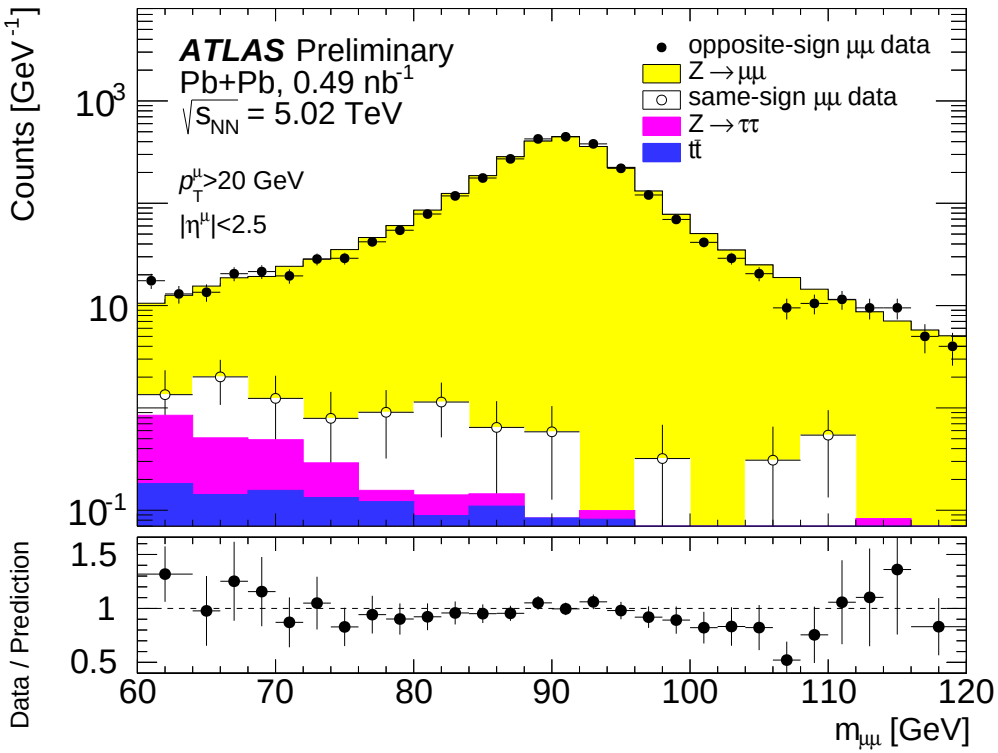
$$R_{\mathrm{AA}} = \frac{dN_{\mathrm{Pb+Pb}}/dp_T}{\langle T_{\mathrm{AA}} \rangle N_{\mathrm{evt}}} \frac{1}{d\sigma_{pp}/dp_T}$$

- $\langle T_{\mathrm{AA}} \rangle = \langle N_{\mathrm{coll}} \rangle / \sigma_{\mathrm{tot}}^{pp}$, where N_{coll} is a number of binary collisions.
- blue term corresponds to HI results (QCD in medium) while the green is *pp* measurement (QCD in vacuum).
- R_{AA} close to unity indicates small nuclear effects, meaning that PbPb scales as $d\sigma_{pp}/dp_T \times \langle N_{\mathrm{coll}} \rangle$.
- In the very similar way one can define R_{pPb} for p+Pb collisions:

$$R_{\mathrm{pA}} = \frac{dN_{\mathrm{p+Pb}}/dp_T}{\langle T_{\mathrm{pA}} \rangle N_{\mathrm{evt}}} \frac{1}{d\sigma_{pp}/dp_T}$$

Z bosons in Pb+Pb at 5.02 TeV

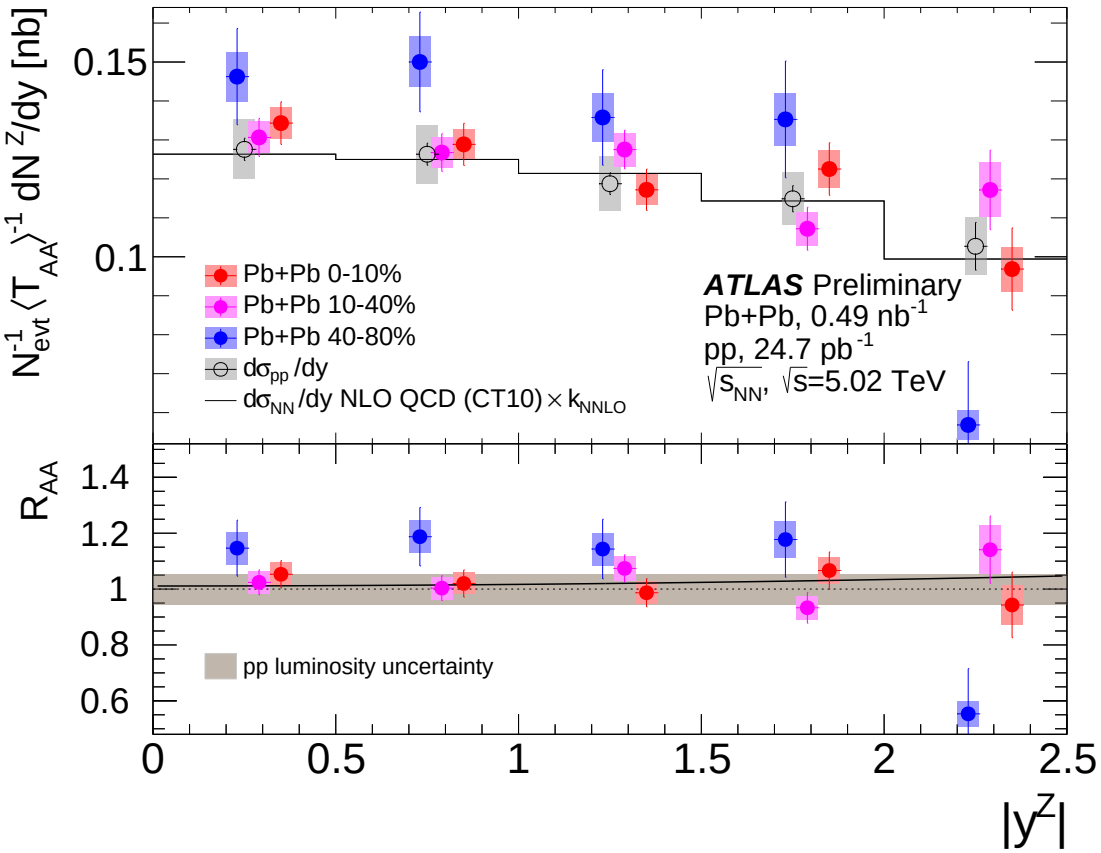
- 0.49 nb^{-1} of data
- 8 GeV single muon trigger
- Opposite charge muons
- $p_{\mathrm{T}} > 20$ GeV, $|\eta| < 2.5$
- $66 < m_{\mu\mu} < 116$ GeV
- $\sim$ 5500 counts
- Background:
  - $Z \to \tau^+\tau^-$ and $t\bar{t}$ were simulated and normalized to the cross section
  - QCD multi-jet background was extracted with data driven method.
  - $\sim$ 0.5%



ATLAS-COM-2017-010

Rapidity differential yields in centrality

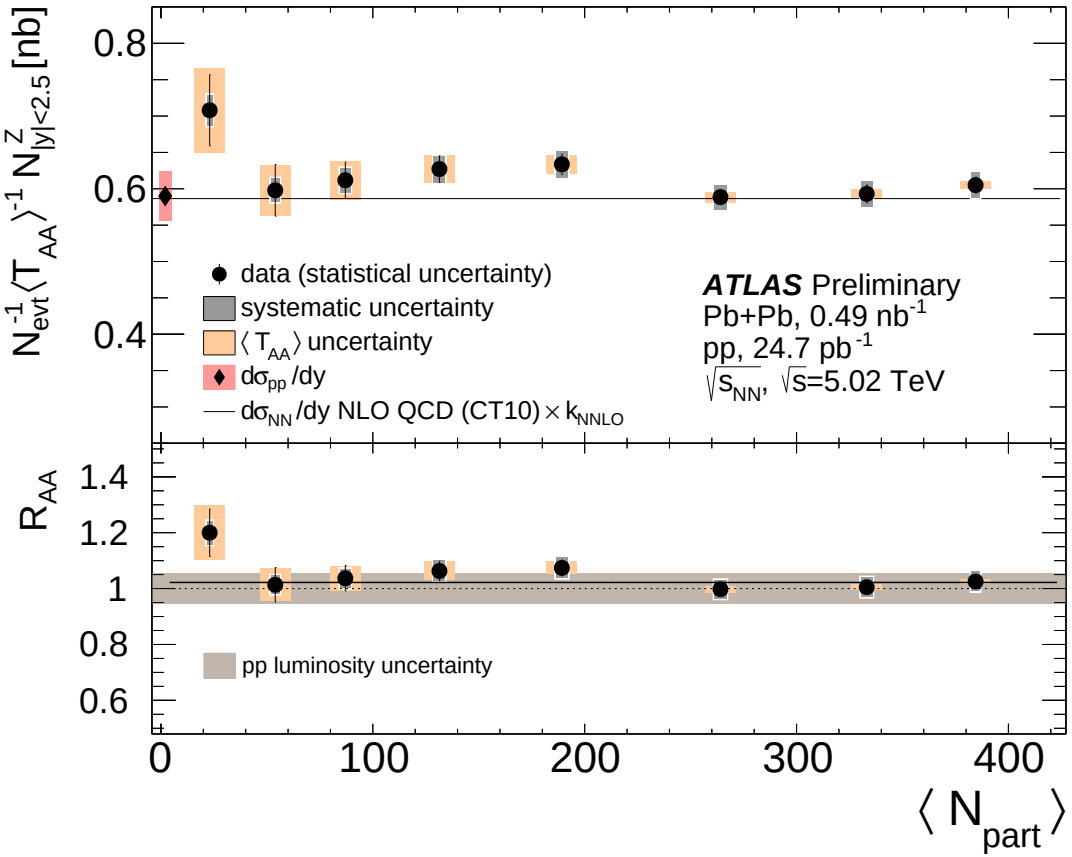
- Corrected to fiducial volume:
  - $66 < m_Z < 116$ GeV, $|y_Z| < 2.5$
- Corrected for detector/trigger efficiency and background.
- Divide by $\langle T_{\mathrm{AA}} \rangle$.
- Shown with comparison to *pp* data.
- Expect $R_{\mathrm{AA}} \approx 1.02$ because of *pn* and *nn* collisions (**isospin effect**).
- Largely consistent with expectations. The most peripheral bin is different from unity by $\sim 1.5\sigma$



ATLAS-COM-2017-010

Normalized yield as a function of $\langle N_{\mathrm{part}} \rangle$

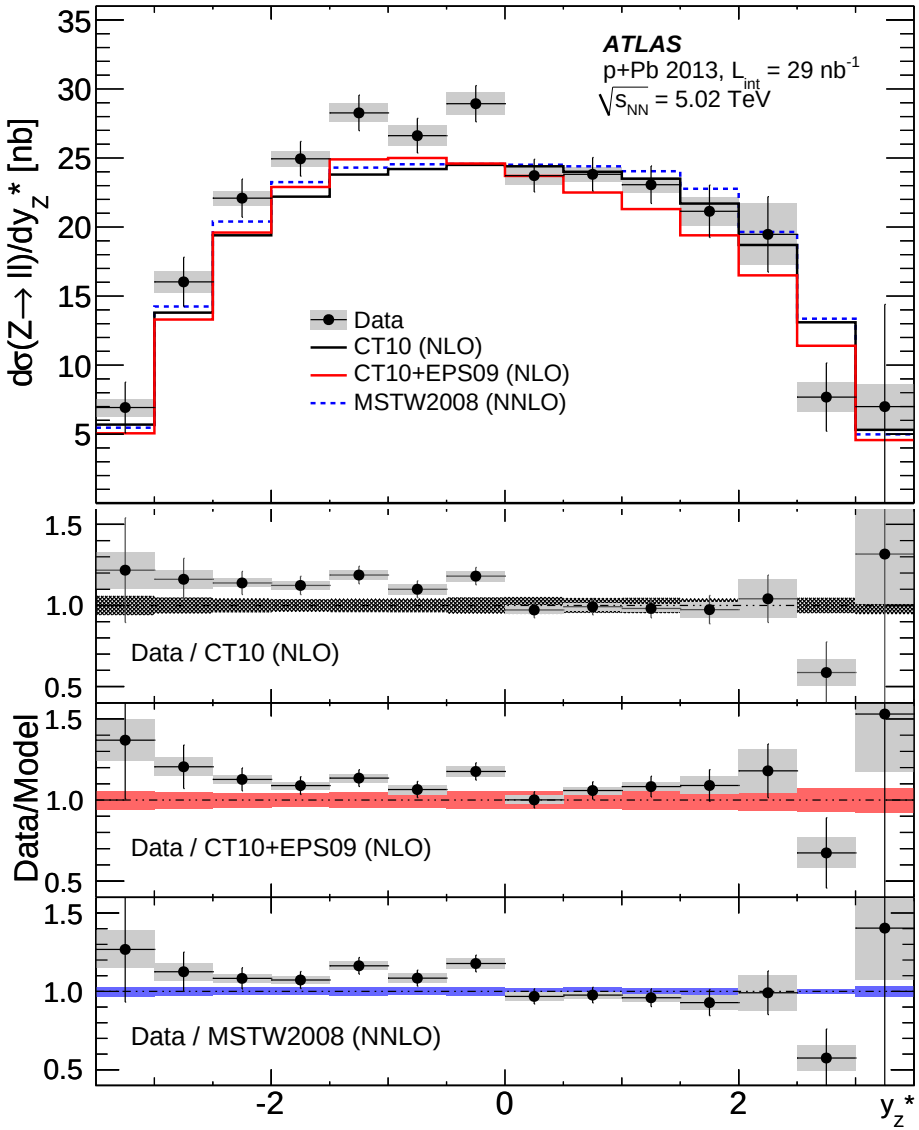
- Yield per min-bias (MB) event divided by T_{AA} of Z bosons as a function of N_{part} inside $|y_Z| < 2.5$
- Normalized yields are consistent with independence of centrality.
- High precision result - uncertainties are smaller on measuring Z bosons than on T_{AA} and luminosity.



ATLAS-CONF-2017-010

Z bosons in p+Pb at 5.02 TeV

- Cross sections asymmetric in y_Z^*.
- Sensitive to nPDF.
- Models underestimate total cross section.
- Shape better described by model with nuclear modifications (CT10+EPS09).
- Differences for $y_Z^* < 0$ in agreement with W results (next slide).



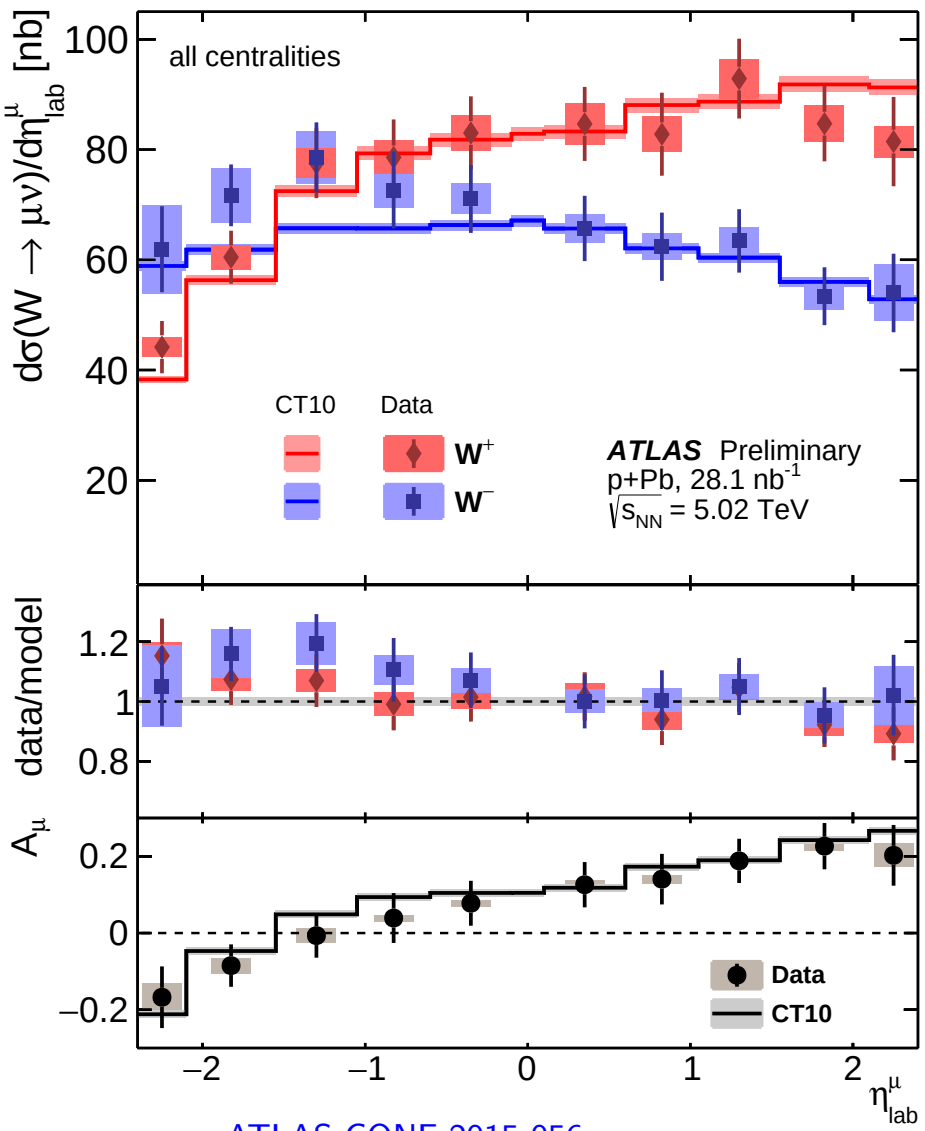
Phys.Rev. C92 (2015)

W bosons in p+Pb at 5.02 TeV

- Differential cross section as a function of $\eta^{\mu}_{\mathrm{lab}}$.
- Shift of centre-of-mass has impact on distributions.
- The isospin effect is visible in charge asymmetry:

$$A_{\mu} = \frac{N^{+} - N^{-}}{N^{+} + N^{-}}$$

- POWHEG with CT10 works well for $\eta^{\mu}_{\mathrm{lab}} > 0$ while for Pb-going side ($\eta^{\mu}_{\mathrm{lab}} < 0$) is below data.
- Similar disagreement for ($\eta^{\mu}_{\mathrm{lab}} < 0$) seen in Z result (previous slide).



ATLAS-CONF-2015-056

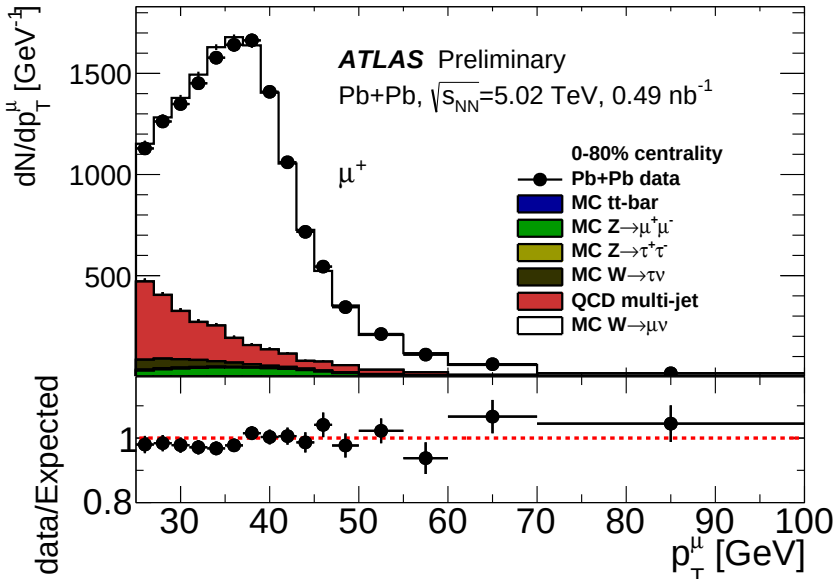
W bosons in Pb+Pb at 5.02 TeV

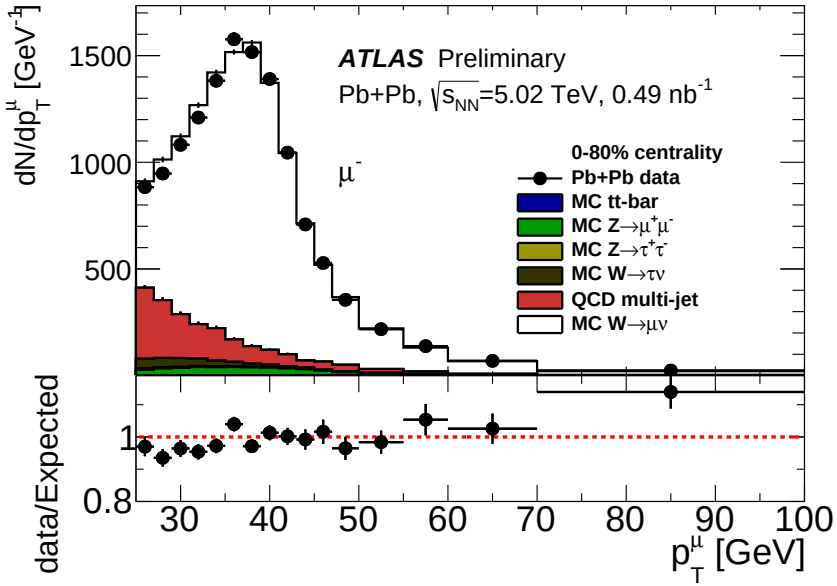
NEW

- 0.49 nb^{-1} of data
- 15 GeV single muon trigger
- $p_{\mathrm{T}} > 25$ GeV, $0.1 < |\eta| < 2.4$
- isolated muon
- $p_{\mathrm{T}}^{\mathrm{miss}} > 25$ GeV, where $p_{\mathrm{T}}^{\mathrm{miss}}$ is a negative vector sum of transverse momenta of tracks which pass a minimum p_{T} requirement
- $m_{\mathrm{T}} > 40$ GeV, where $m_{\mathrm{T}} = \sqrt{2 p_{\mathrm{T}}^{\mu} p_{\mathrm{T}}^{\mathrm{miss}} (1 - \cos(\Delta\phi))}$
- ~ 48000 $W^{+,-}$ boson candidates

Background:

- Electroweak backgrounds and $t\bar{t}$ were simulated and normalized to the cross section.
- QCD multi-jet background was extracted with data driven method.

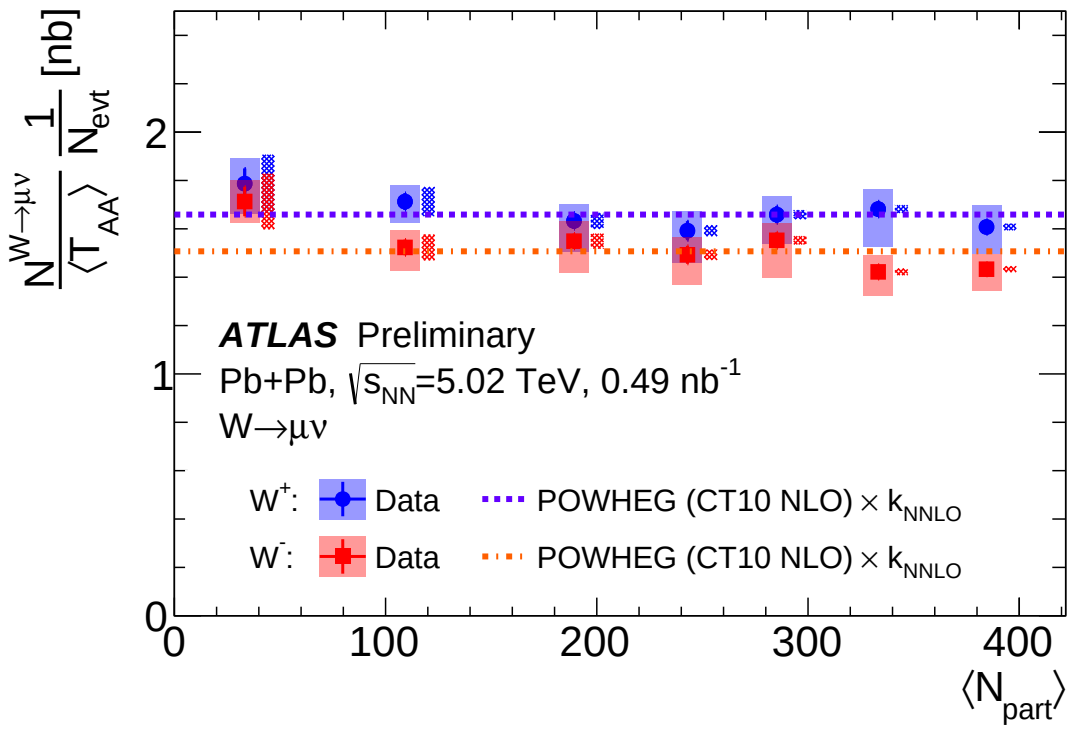




ATLAS-CONF-2017-067

Normalized yield as a function of $\langle N_{\mathrm{part}} \rangle$

- Corrected to fiducial volume:
  - $p_{\mathrm{T}}^{\mu} > 25$ GeV, $0.1 < |\eta_{\mu}| < 2.4$
  - $p_{\mathrm{T}}^{\nu} > 25$ GeV, $m_{\mathrm{T}} > 40$ GeV.
- Corrected for detector/trigger efficiency and background
- Divide by $\langle T_{\mathrm{AA}} \rangle$ and N_{evt}
- Uncertainty on $\langle T_{\mathrm{AA}} \rangle$: 1-7%
- Covered $0 - 80\%$ centrality range.
- Observed normalized yields are independent of centrality as they are expected to scale with N_{coll}.
- POWHEG including isospin effects and scaled by k_{NNLO} agrees with data.

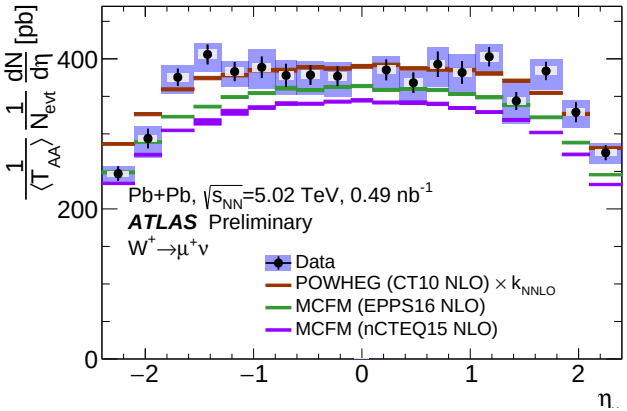


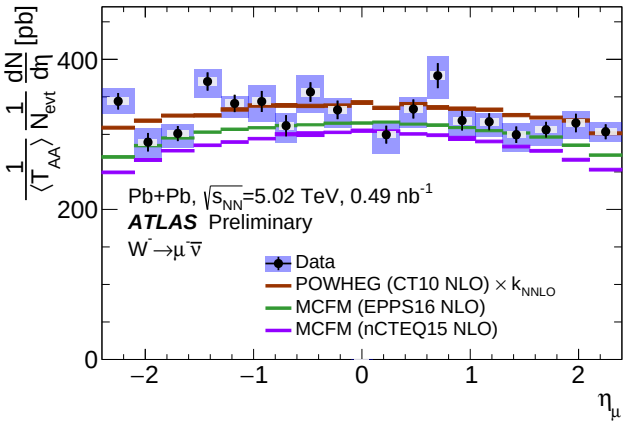
ATLAS-CONF-2017-067

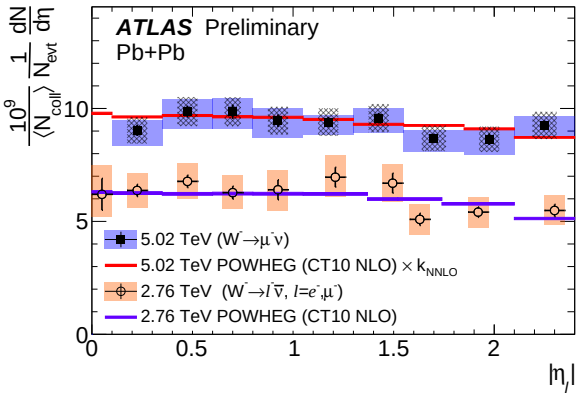
Differential yields as a function of η

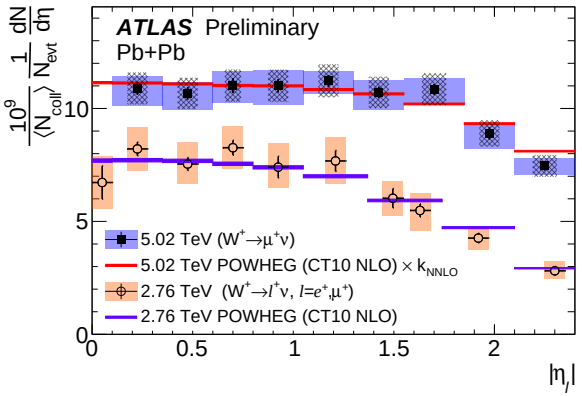
- Differential yields as a function of η_μ and $|\eta_\mu|$
- Extracted from $0-80\%$ centrality range.
- Uncertainty on $\langle T_{\mathrm{AA}} \rangle$: 1.5%
- Other systematics: 3-7%
- POWHEG (CT10) scaled by k_{NNLO} agrees with data
- MCFM using nPDF (EPPS16 and nCTEQ15) differ in normalization.

- Results at 2.76 TeV and 5.02 TeV are compared.
- W boson yields grow with collision energy.
- Shapes tend to be similar at both energies.





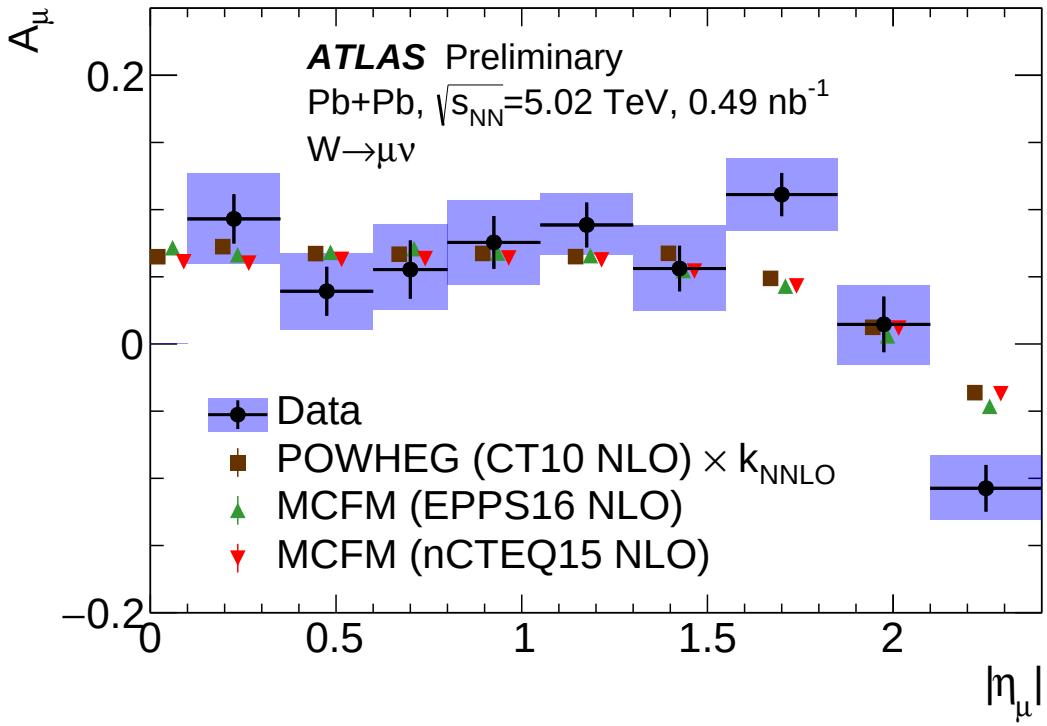




2.76 TeV - Eur. Phys. J. C (2015) 75:23
5.02 TeV - ATLAS-CONF-2017-067

Lepton charge asymmetry

- Charge asymmetry as a function of $|\eta_\mu|$:
  $A_\mu = \frac{N^+ - N^-}{N^+ + N^-}$
- It allow to reduce correlated systematic uncertainties between both charges.
- Extracted from $0 - 80\%$ centrality range.
- Predictions from POWHEG (CT10) and MCFM nPDF (EPPS16 and nCTEQ15) are comparable in whole η_μ range. No sensitivity to nPDF.
- Central range ($|\eta_\mu| < 1.6$) well described by MC.
- Small differences appear in forward range ($1.6 < |\eta_\mu| < 2.4$).



ATLAS-CONF-2017-067

Summary

- The electroweak boson production has been studied in three different systems: *pp*, *p*+Pb, Pb+Pb.
- *W* and *Z* bosons allow to investigate nuclear effects in heavy ion collisions.
- Predictions for *W* and *Z* bosons mostly agree with data with small deviations in some kinematic regions.
- Significant impact of isospin effect is visible on lepton charge asymmetry.
- New result was presented.
- The *W* boson yields in Pb+Pb at 5.02 TeV integrated over η_μ are found to scale with $\langle T_{\mathrm{AA}} \rangle$ in all centralities.
- Lepton charge asymmetry in the forward direction slightly deviates from predictions.

More information can be found in
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HeavyIonsPublicResults

Thank you for your attention