Electroweak boson production in heavy ion collisions with the ATLAS detector

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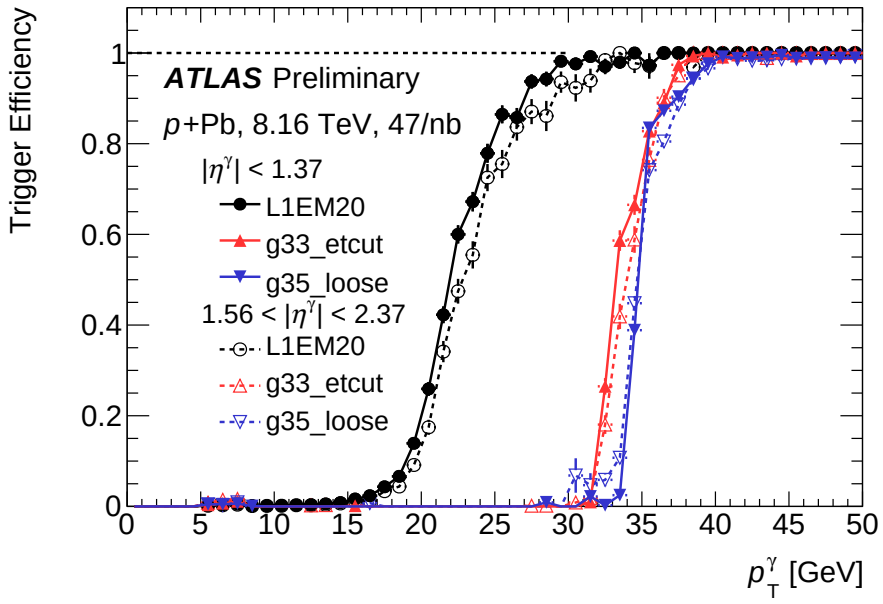
Motivation

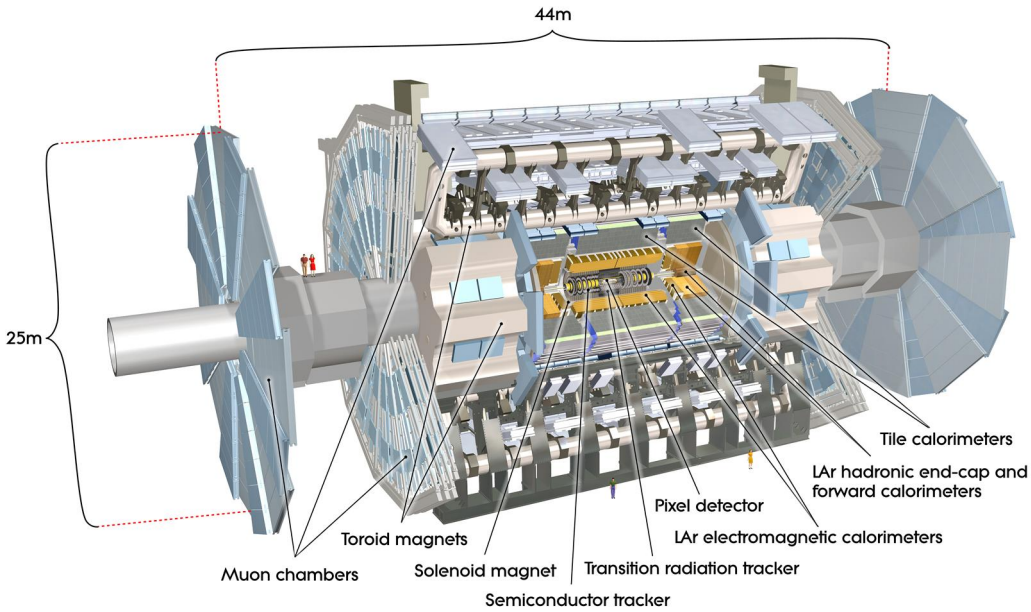
Electroweak bosons:

- high-precision test of pQCD (pp),
- parton distribution function (PDF) and nuclear modifications (nPDF) can be investigated,
- 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,
- with LHC energies, a range of photon spectra can be measured in broader scope.

ATLAS detector & data

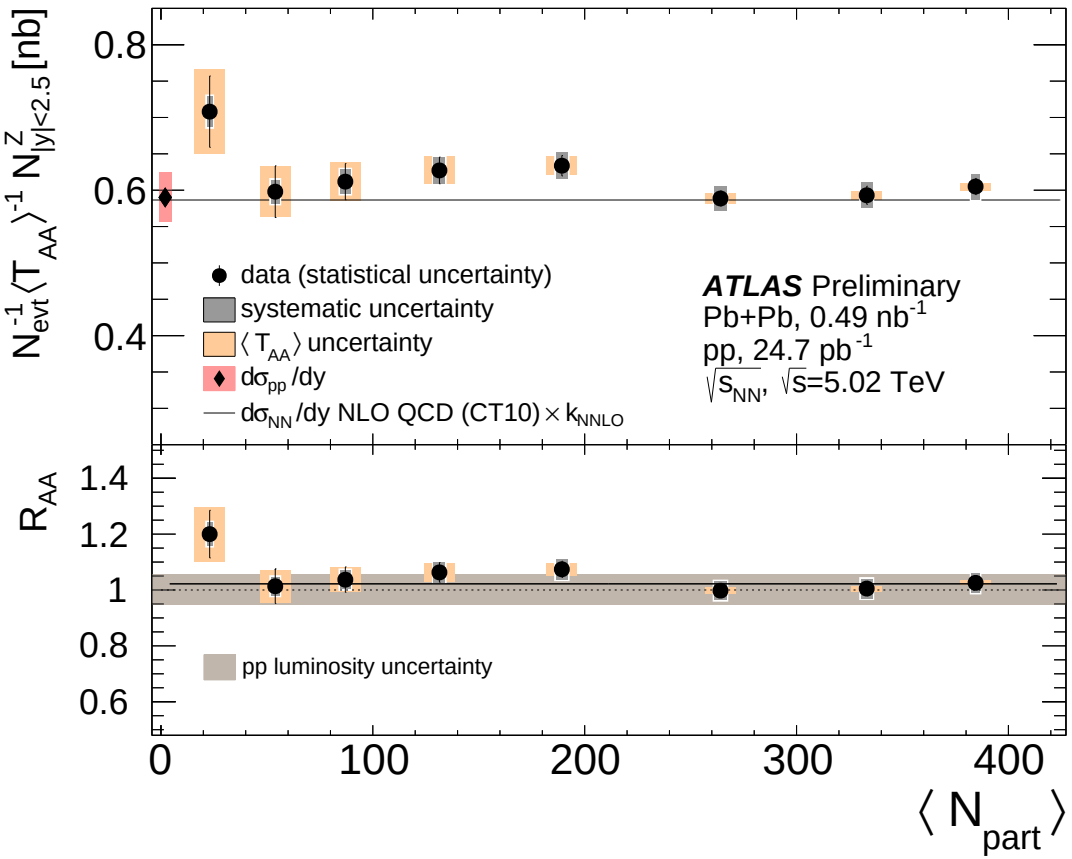
- Muon, electron and photon triggers designed to collect high-p_{T} objects.
- Measurements of electroweak bosons based on:
  - pp: $\sqrt{s} = 5.02$ (24.7 pb^{-1}), 8 TeV (20.2 fb^{-1})
  - p+Pb: $\sqrt{s} = 5.02$ (28.1 nb^{-1}), 8.16 TeV (0.16 pb^{-1})
  - Pb+Pb: $\sqrt{s} = 5.02$ TeV (0.49 nb^{-1})





Z bosons in Pb+Pb at 5.02 TeV

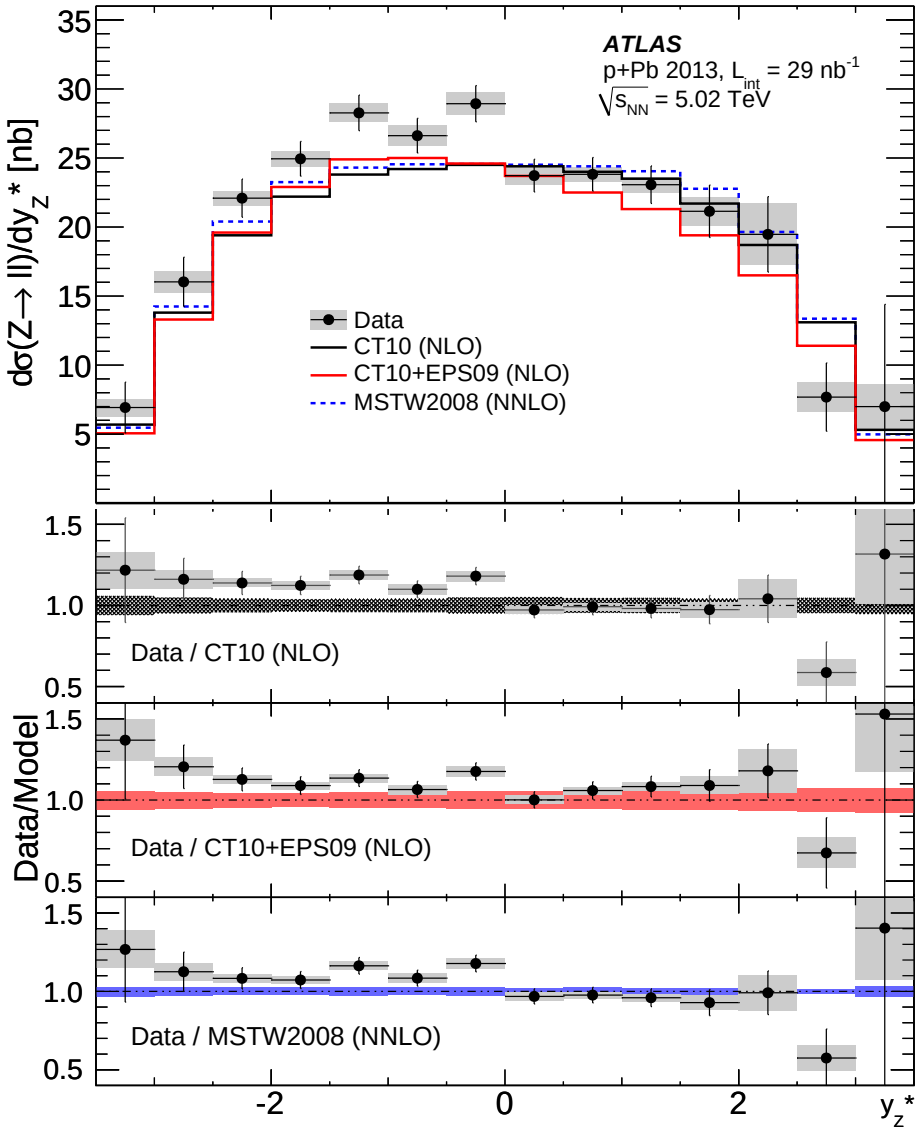
- Yield per min-bias (MB) event divided by T_{AA} of Z bosons as a function of N_{part} inside $|y_Z| < 2.5$
- Normalized yields are consistent with independence of centrality.
- The most peripheral point slightly deviates.
- High precision result - uncertainties are smaller on measuring Z bosons than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



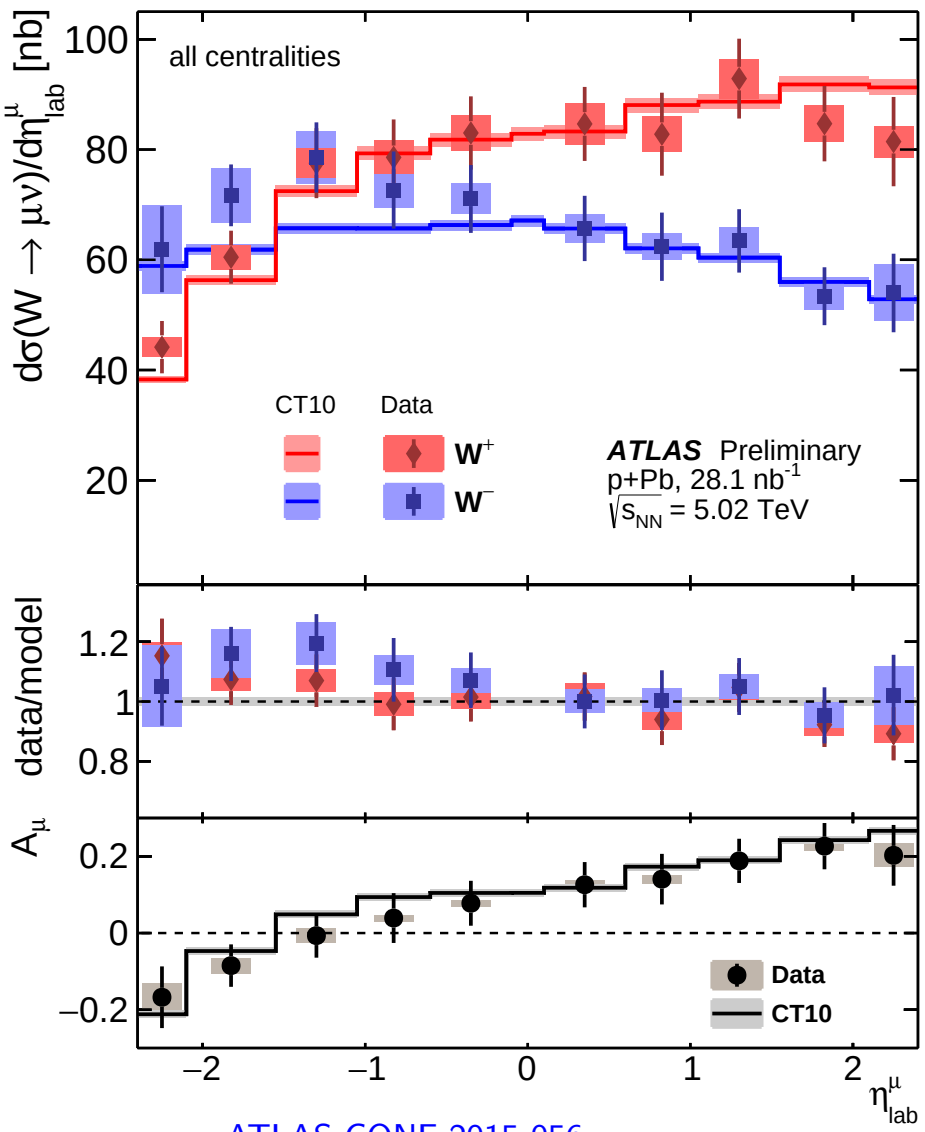
Phys.Rev. C92 (2015)

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:

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

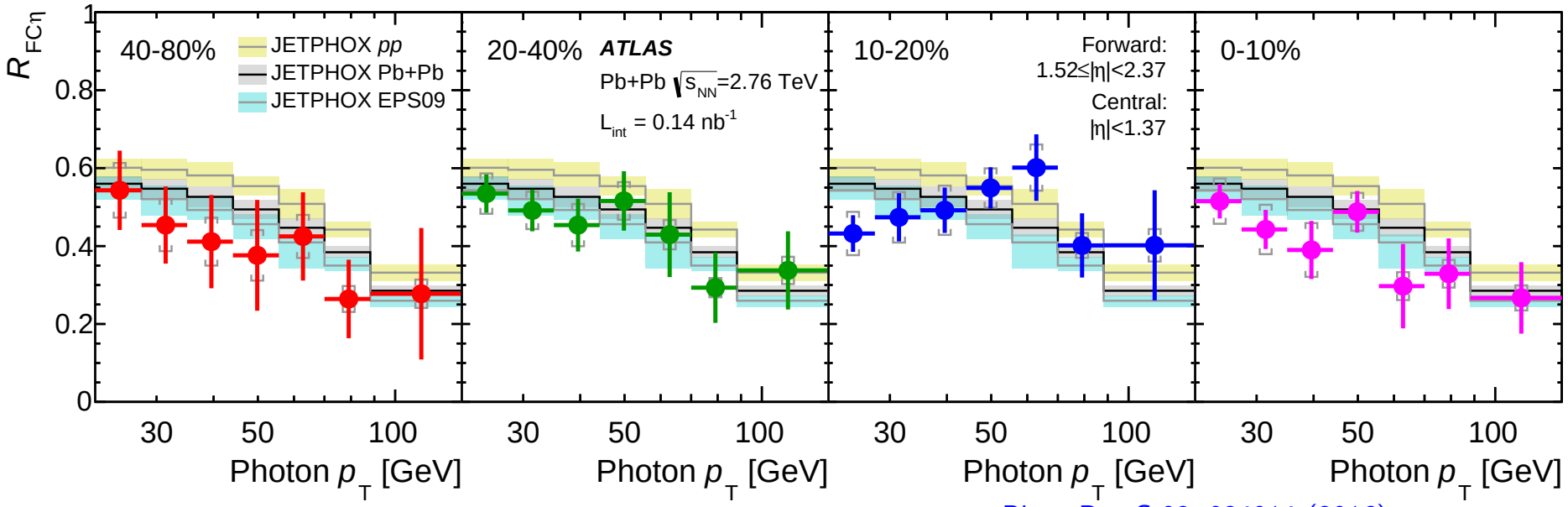
- POWHEG with CT10 works well for $\eta^{\mu}_{\mathrm{lab}} > 0$ while for Pb-going side ($\eta^{\mu}_{\mathrm{lab}} < 0$) is below data.
- Similar disagreement for ($\eta^{\mu}_{\mathrm{lab}} < 0$) seen in Z result (previous slide).



ATLAS-CONF-2015-056

Prompt photon production in Pb+Pb at 2.76 TeV

- Ratios of forward and central yields.
- Clear sensitivity to nuclear effects: JETPHOX *pp* is above JETPHOX EPS09.
- Statistical and systematic uncertainties on data are too large to distinguish between models.
- Slight preference for the calculations incorporating nuclear effects.



Phys. Rev.C 93, 034914 (2016)

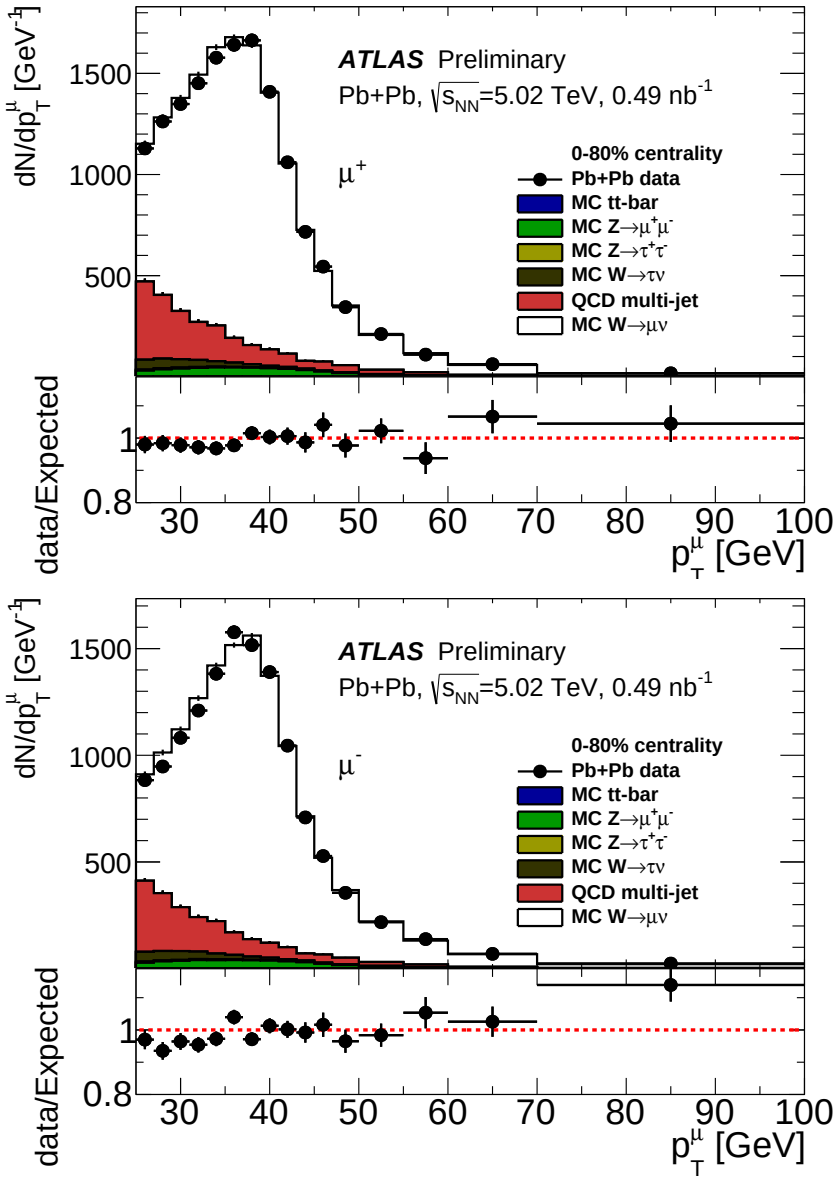
W bosons in Pb+Pb at 5.02 TeV

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:

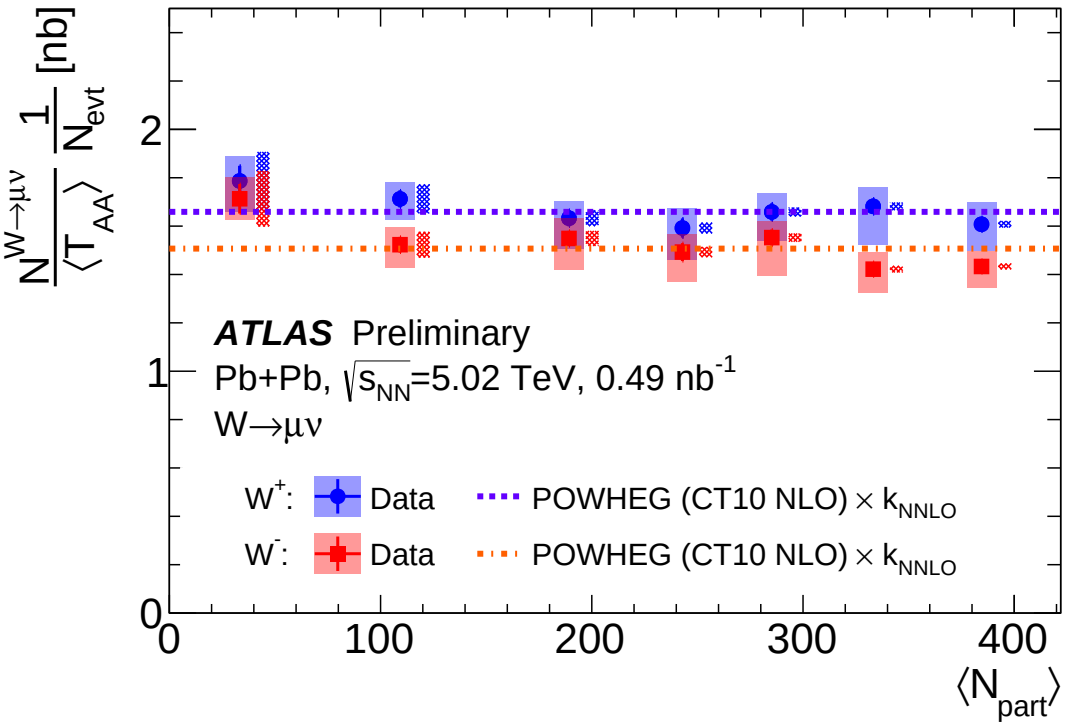
- Electroweak backgrounds and $t\bar{t}$ were simulated and normalized to the cross section.
- QCD multi-jet background was extracted with data driven method.



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.
- Peripheral measurements slightly deviate. Similar effect seen in Z measurement (slide 4).
- POWHEG including isospin effects and scaled by k_{NNLO} agrees with data.

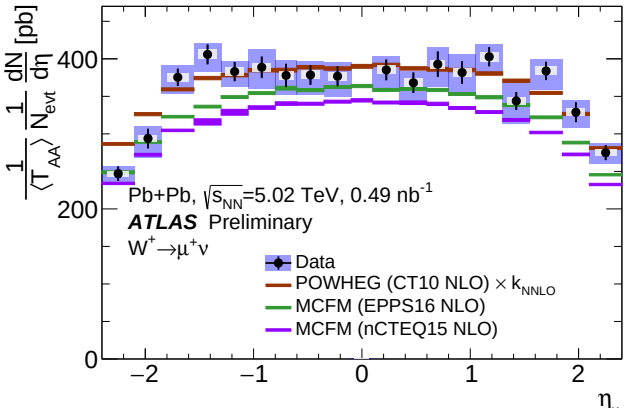


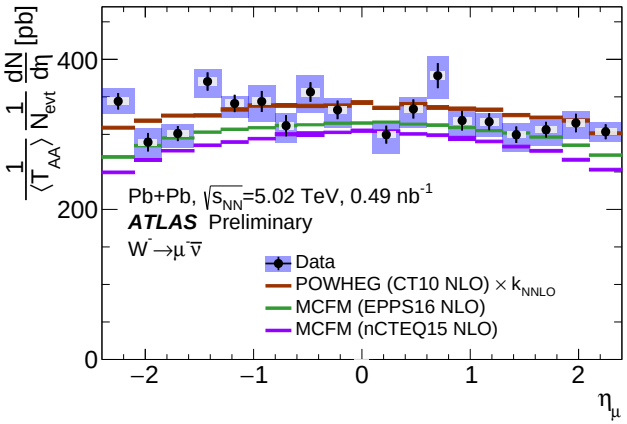
ATLAS-CONF-2017-067

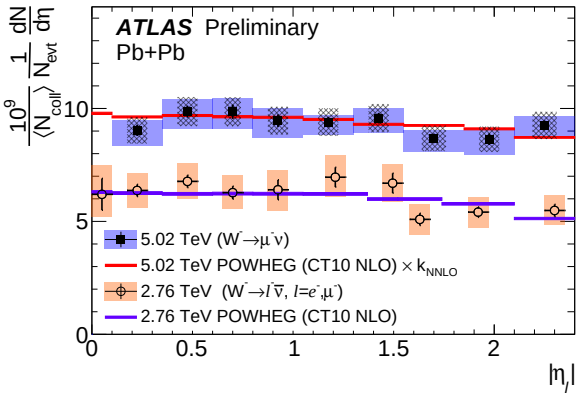
Differential yields as a function of η

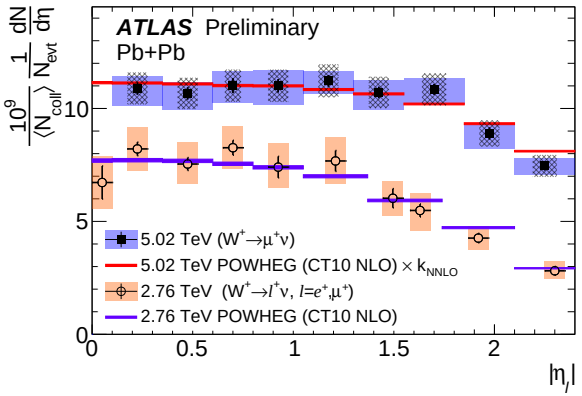
- Differential yields as a function of η_μ and $|\eta_\mu|$
- Extracted from $0-80\%$ centrality range.
- Uncertainty on $\langle T_{\mathrm{AA}} \rangle$: 1.5%
- Other systematics: 3-7%
- POWHEG (CT10) scaled by k_{NNLO} agrees with data
- MCFM using nPDF (EPPS16 and nCTEQ15) differ in normalization.

- 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.





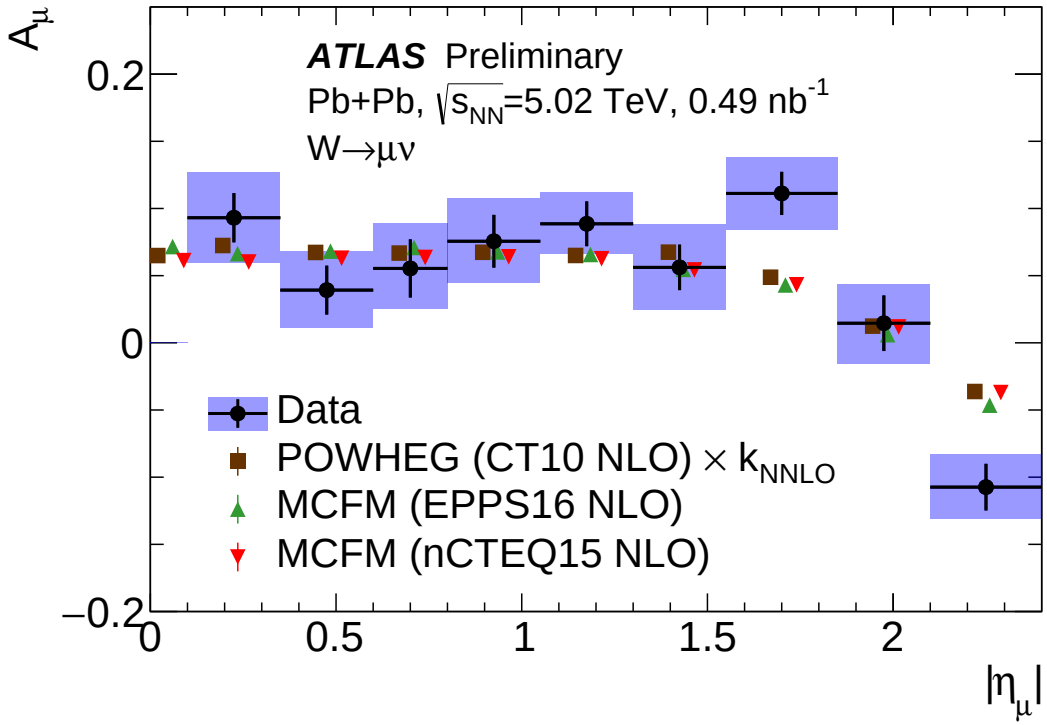




2.76 TeV - Eur. Phys. J. C (2015) 75:23
5.02 TeV - ATLAS-CONF-2017-067

Lepton charge asymmetry

- Charge asymmetry as a function of $|\eta_\mu|$: $A_\mu = \frac{N^+ - N^-}{N^+ + N^-}$
- 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.
- Discrepancies appear in forward range ($1.6 < |\eta_\mu| < 2.4$).

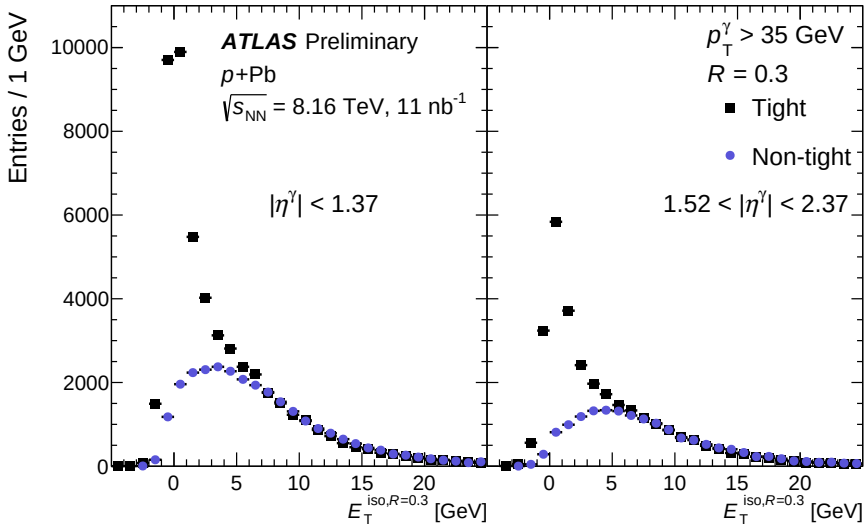


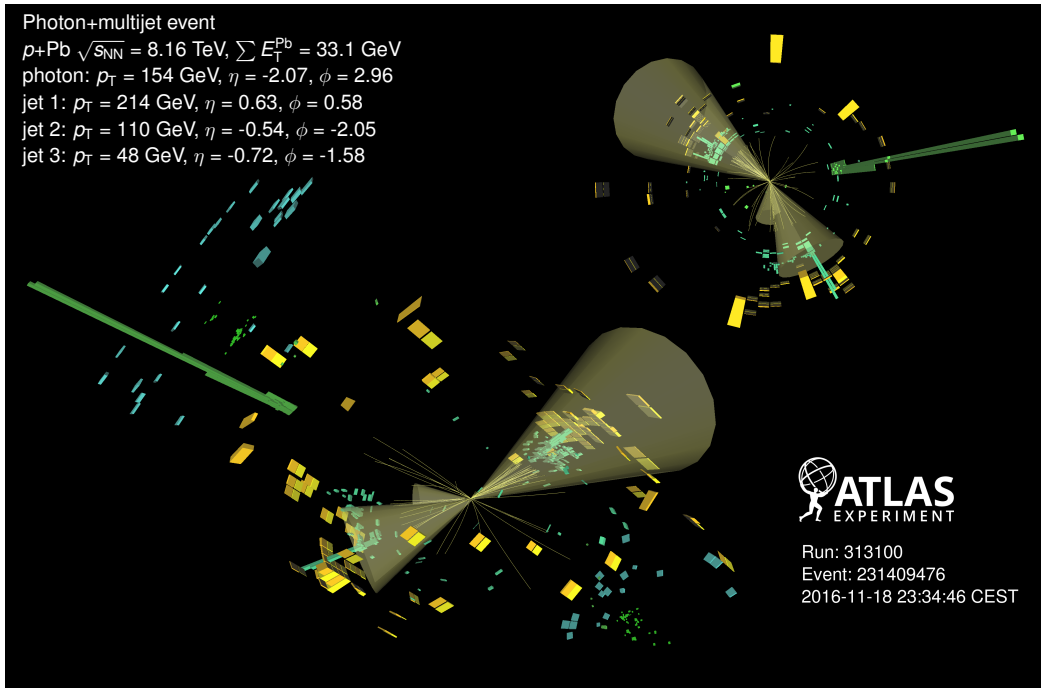
ATLAS-CONF-2017-067

Prompt photons in p+Pb at 8.16 TeV

NEW

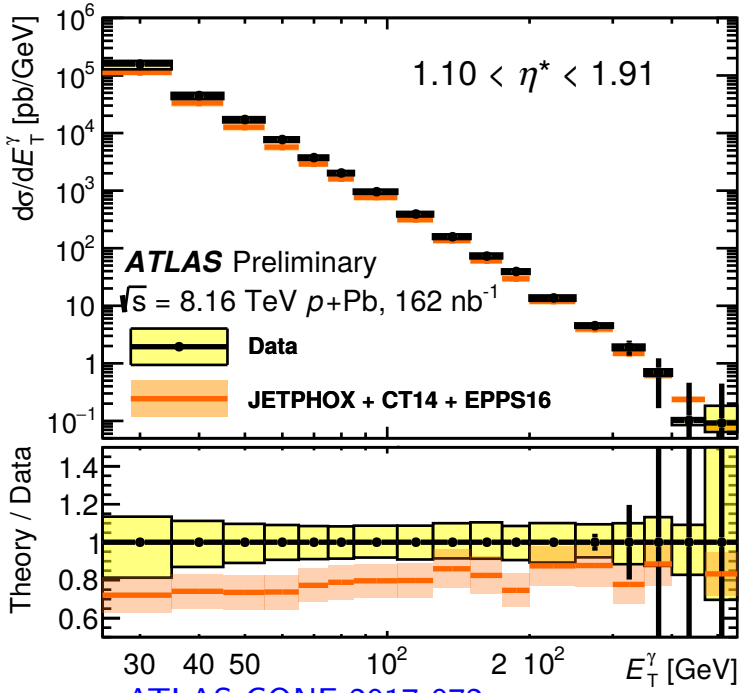
- 0.16 pb^{-1} of data
- $E_{\mathrm{T}}^{\gamma} > 25$ GeV
- $E_{\mathrm{T}}^{\mathrm{iso}} < 4.8$ GeV $+ 4.2 \times 10^{-3} E_{\mathrm{T}}^{\gamma}/GeV$
- $|\eta^{\gamma}| < 1.37$, $1.56 < |\eta^{\gamma}| < 2.37$
- rapidity boost by $\Delta y = \pm 0.465$



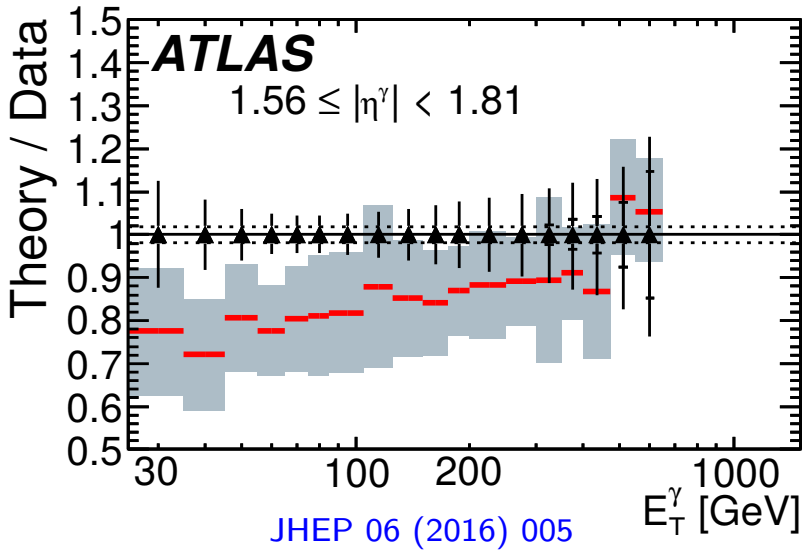


Prompt photon spectra

- $d\sigma/dE_{\mathrm{T}}^{\gamma}$ decreases by five orders of magnitude.
- Observed yield up to $E_{\mathrm{T}}^{\gamma} \approx 500$ GeV at mid-rapidity.
- Uncertainties range from 6% to 10%.
- JETPHOX calculation underpredicts the data by up to 20% (consistent with the results of such comparisons in pp).



ATLAS-CONF-2017-072



JHEP 06 (2016) 005

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$\sqrt{s}$ = 8 TeV, 20.2 fb^{-1}

Data 2012

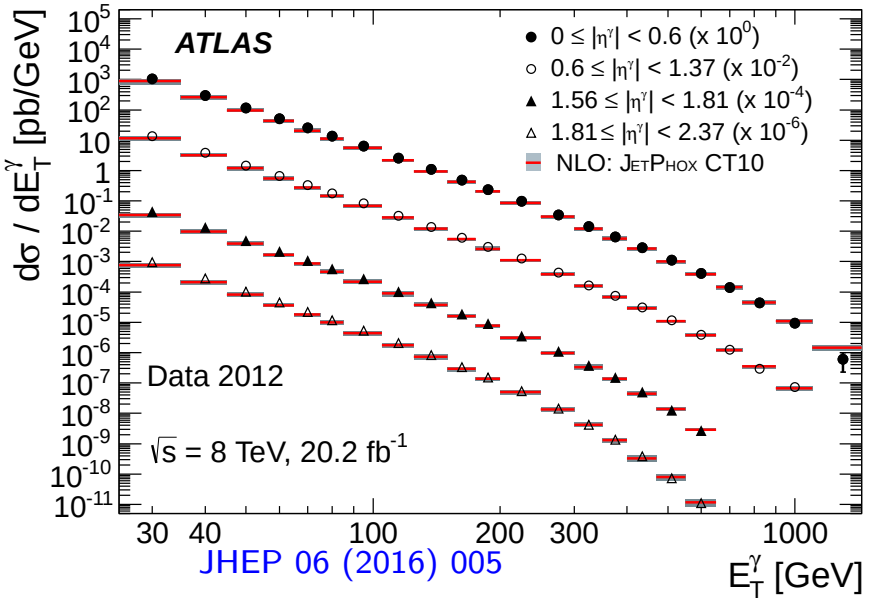
·· Lumi Uncert.

NLO:

JETPHOX CT10

Reference for p+Pb at 8.16 TeV

- Differential cross section was measured in pp at 8 TeV (same isolation and kinematic range as in p+Pb at 8.16 TeV).
- To construct a correct reference one needs to extrapolate the 8TeV measurement (w/o boost) to 8.16TeV (w/ boost).
- The ratio $\sigma_{8.16\mathrm{TeV}}/\sigma_{8\mathrm{TeV}}$ using JETPHOX and PYTHIA8 calculation is determined.
- The extrapolation factors become large at large E_{T}^{γ}.
- Majority of correction comes from the boost of the p+Pb system.



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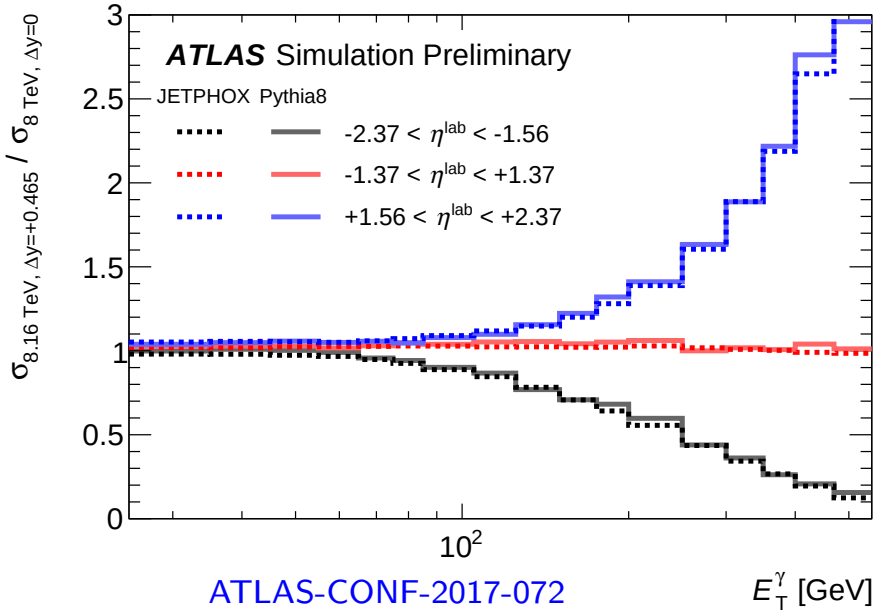


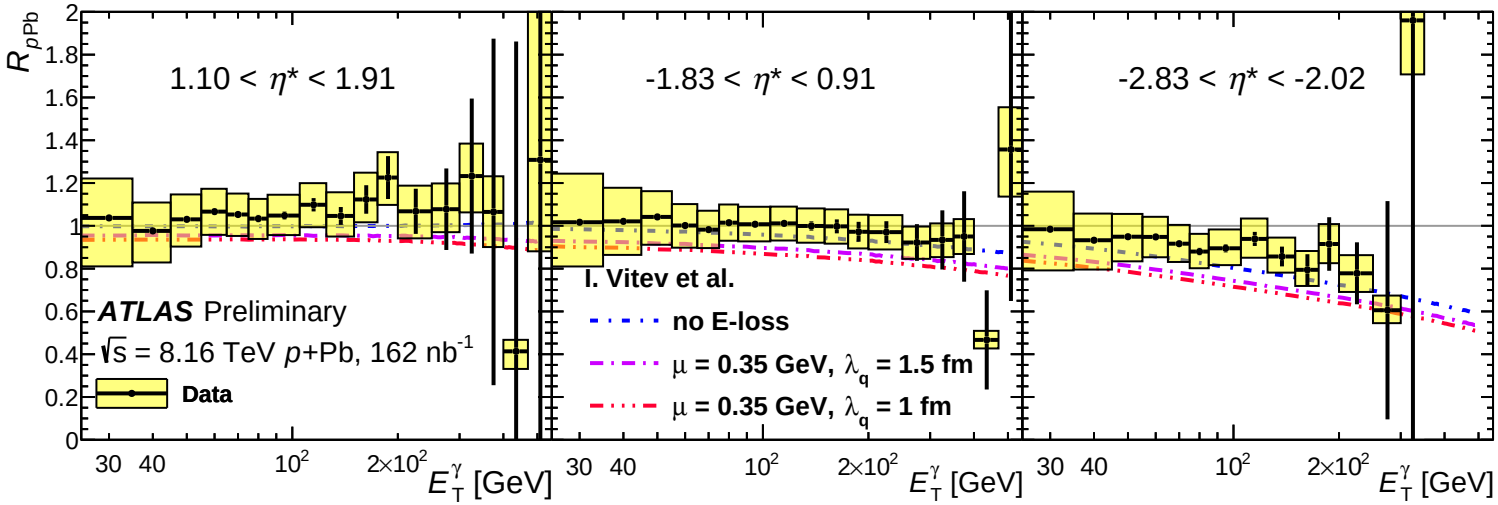
ATLAS-CONF-2017-072

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

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

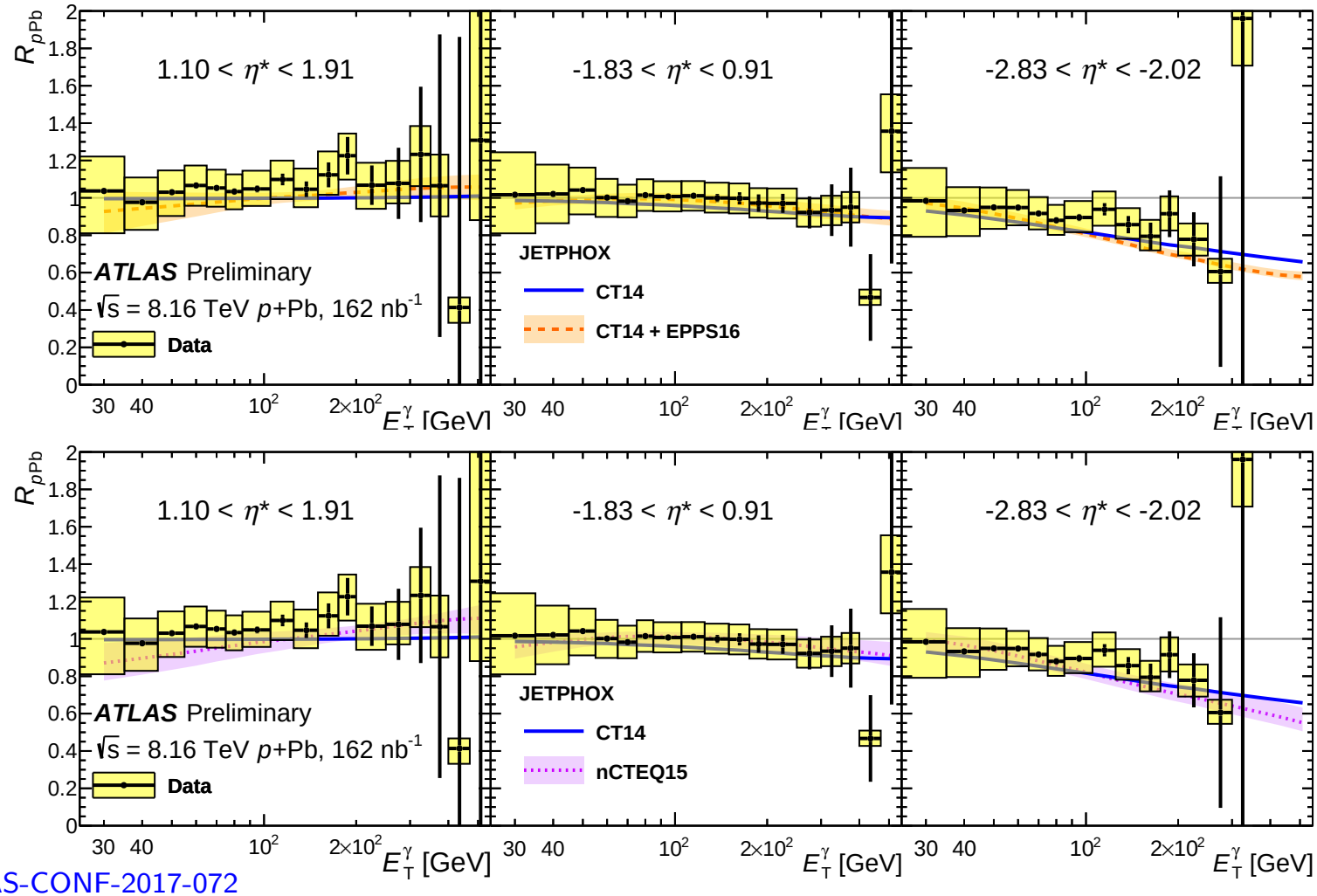
- At high E_{T}^{γ} at backward pseudorapidity, the $R_{p\mathrm{Pb}}$ is significantly lower than unity.
- This effect is driven by the different isospin composition of pp and p+Pb systems.
- Comparison to initial state energy loss model. Data disfavour a large suppression due to energy loss effects.



ATLAS-CONF-2017-072

$R_{p\mathrm{Pb}}$ (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.



ATLAS-CONF-2017-072

Summary

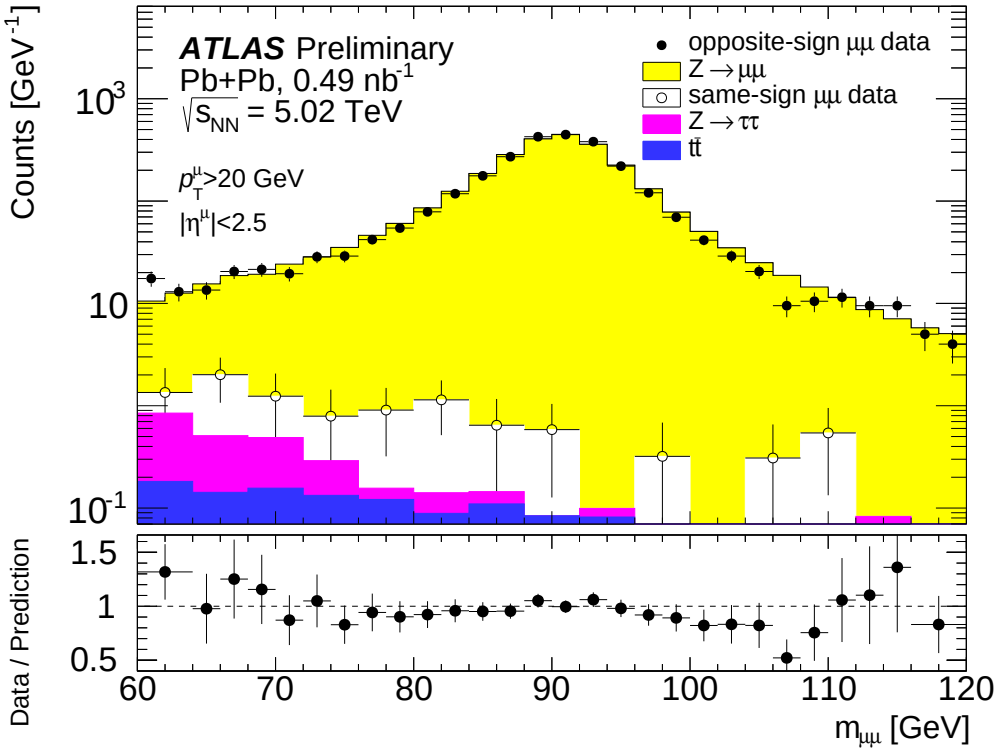
- The electroweak boson production has been studied in three different systems: *pp*, *p*+Pb, Pb+Pb.
- Predictions for W and Z bosons mostly agree with data with small deviations in some kinematic regions.
- Two new results were presented.
- The W boson yields in Pb+Pb at 5.02 TeV integrated over η_μ are found to scale with $\langle T_{\mathrm{AA}} \rangle$ in all centralities.
- Lepton charge asymmetry in the forward direction slightly deviates from predictions.
- Inclusive prompt photon cross-section in *p*+Pb at 8.16 TeV was measured in broad E_{T}^{γ} range.
- $R_{p\mathrm{Pb}}$ consistent with unity at mid-rapidity range.
- It is in agreement with JETPHOX with the EPPS16/nCTEQ15 while data disfavour large suppression due to energy loss effects.

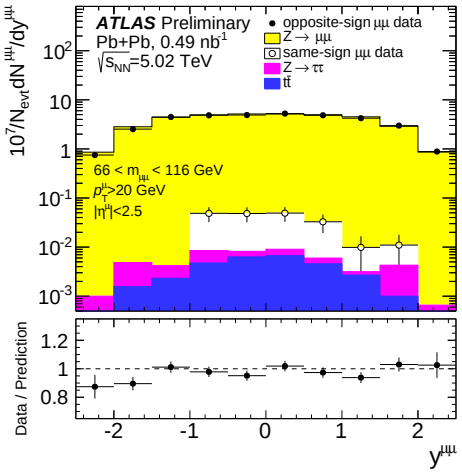
More information can be found in
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HeavyIonsPublicResults

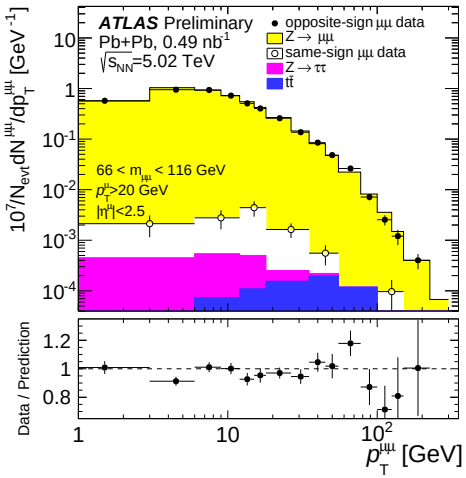
Backup slides

Z Bosons in Pb+Pb at 5.02 TeV - Event selection

- 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%



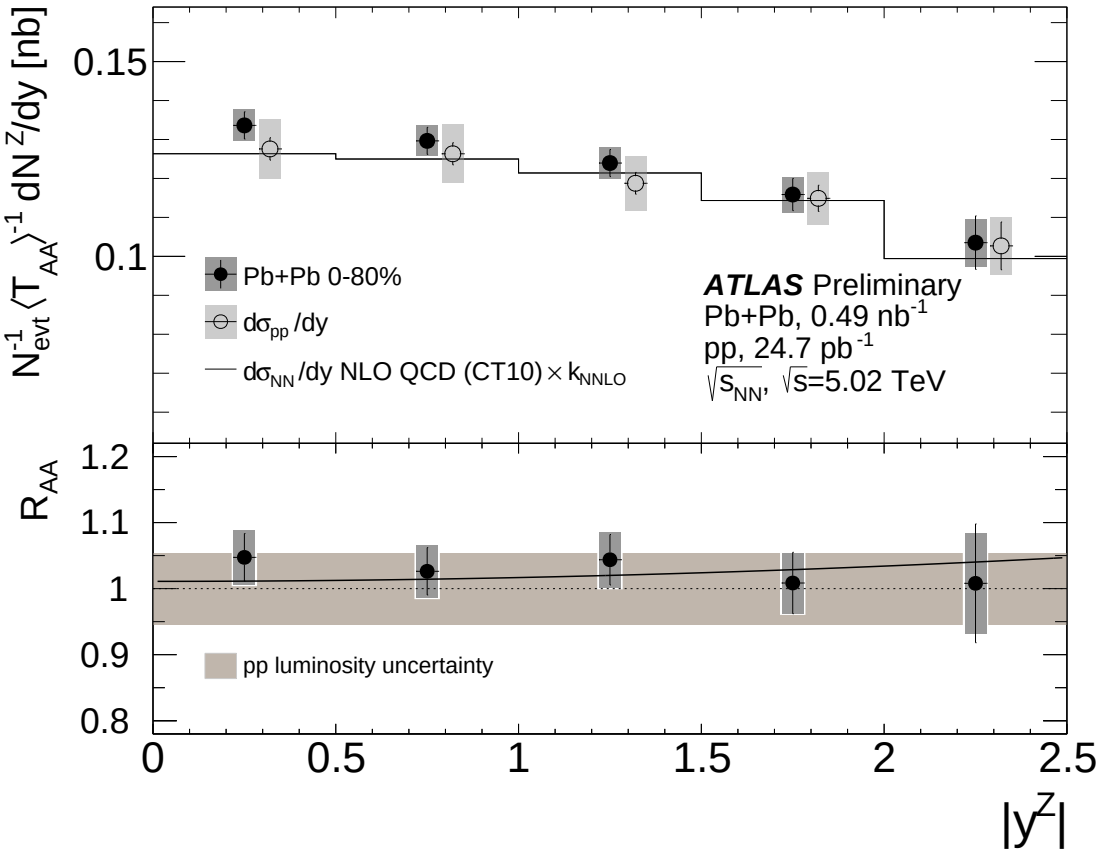




ATLAS-COM-2017-010

Rapidity differential yields

- Corrected to fiducial volume:
  - $66 < m_Z < 116$ GeV, $|y_Z| < 2.5$
  - $p_{\mathrm{T}}^{\mu} > 20$ GeV, $|\eta_\mu| < 2.5$
- Corrected for detector/trigger efficiency and background.
- Divide by $\langle T_{\mathrm{AA}} \rangle$.
- Extracted from $0 - 80\%$ centrality range.
- Shown with comparison to *pp* data.
- POWHEG (CT10) scaled by k_{NNLO} agree with data.
- Expected $R_{AA} \approx 1.02$ due to isospin effects consistent with expectations.

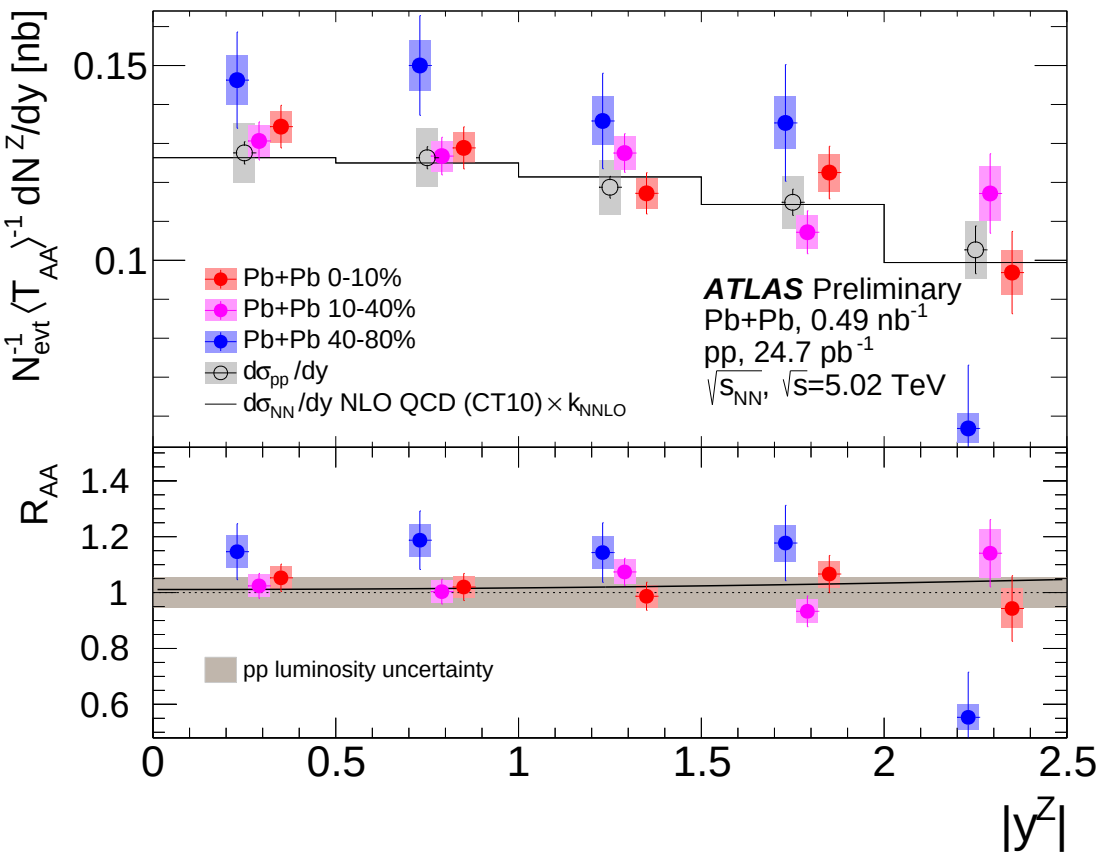


$$R_{\mathrm{AA}} = \frac{1}{\langle T_{\mathrm{AA}} \rangle N_{\mathrm{evt}}} \frac{dN_{\mathrm{Pb+Pb}}/dy}{d\sigma_{pp}/dy}$$

ATLAS-COM-2017-010

Rapidity differential yields in centrality

- Corrected to fiducial volume:
  - $66 < m_Z < 116$ GeV, $|y_Z| < 2.5$
  - $p_{\mathrm{T}}^{\mu} > 20$ GeV, $|\eta_\mu| < 2.5$
- Corrected for detector/trigger efficiency and background.
- Divide by $\langle T_{\mathrm{AA}} \rangle$.
- Shown with comparison to *pp* data.
- Largely consistent with expectations. The most peripheral bin is different from unity by $\sim 1.5\sigma$



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