

Vector boson and Charmonium production in p+Pb and Pb+Pb collisions with ATLAS at the LHC



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on behalf of the ATLAS Collaboration

Weizmann Institute of Science

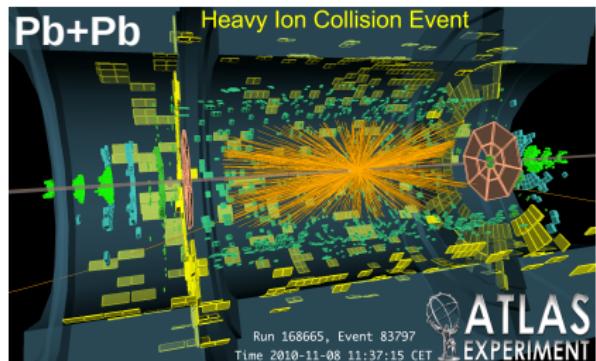
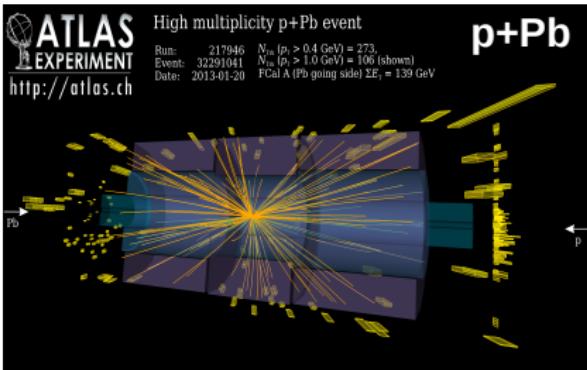
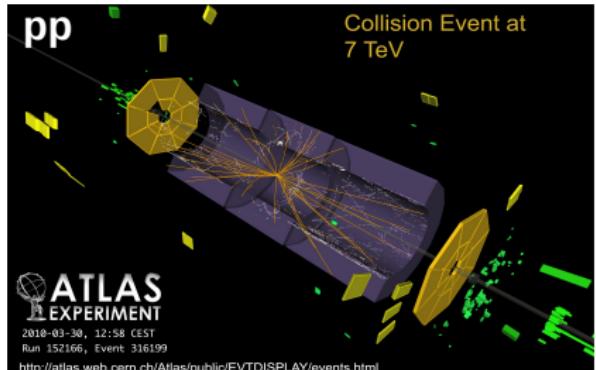
April 13th, 2016



24th International Workshop on Deep-
Inelastic Scattering and Related Subjects

11-15 April 2016, DESY, Hamburg

Heavy-ion collisions



Pb+Pb

p+Pb

pp

Study the Quark-Gluon Plasma
Disentangle initial from final state effects
Reference measurement

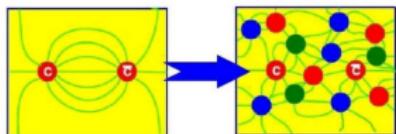
Vector bosons and Charmonia in heavy-ion collisions

- ▶ Electroweak (EW) bosons, as well as heavy-flavor quarks, are produced in early stages of a heavy-ion collision
- ▶ Leptonic decay products do not interact strongly
→ Excellent messengers from a strongly interacting medium

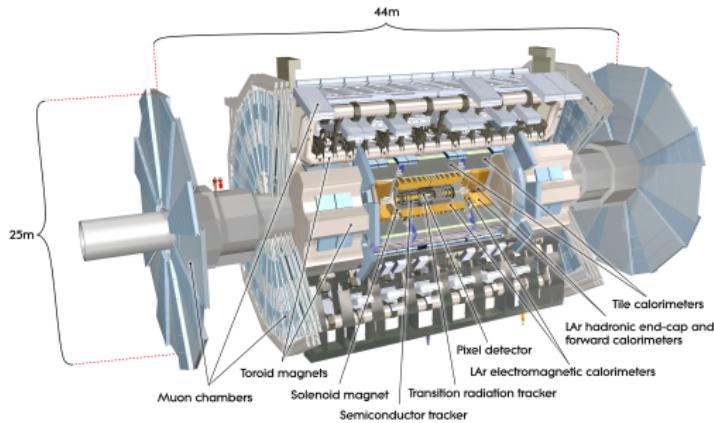
EW bosons

- ▶ Assumption of the binary nucleon-nucleon collision scaling
- ▶ Standard candles for energy-loss in QCD medium
- ▶ Effects of nuclear modifications on Parton Distribution Function (PDF)?

Charmonia

- ▶ Quarkonium suppression due to color screening in QGP
- 
- ▶ Necessary prerequisite to understand cold nuclear matter effects in $p+Pb$

ATLAS detector



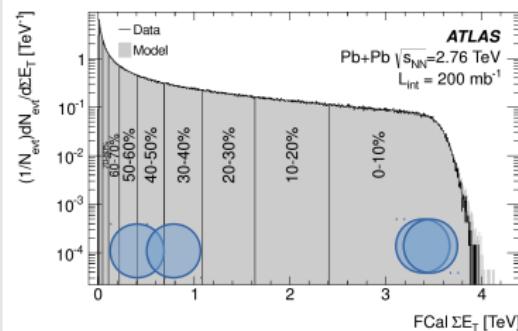
Sub-detectors

Inner Tracker	$ \eta < 2.5$
Muon Spectrometer	$ \eta < 2.7$
EM Calorimeter	$ \eta < 3.2$
Hadronic Calorimeter	$ \eta < 4.9$

Data sets

- $pp, 2.76 \text{ TeV}$
 $\int \mathcal{L} dt = 4.0 \text{ pb}^{-1}$
- $p+\text{Pb}, 5.02 \text{ TeV}$
 $\int \mathcal{L} dt = 28.1 \text{ nb}^{-1}$
- $\text{Pb}+\text{Pb}, 2.76 \text{ TeV}$
 $\int \mathcal{L} dt = 0.14 \text{ nb}^{-1}$

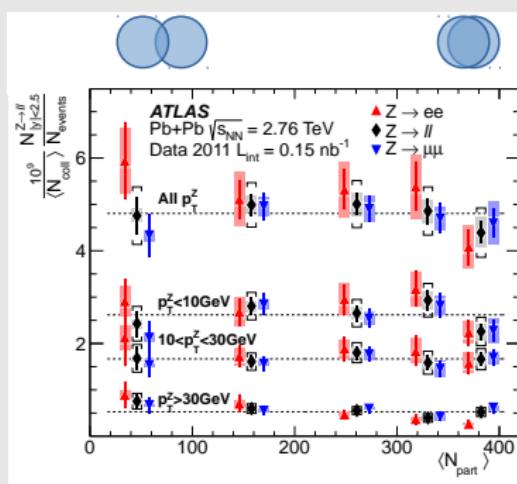
FCal $E_T \rightarrow$ Centrality



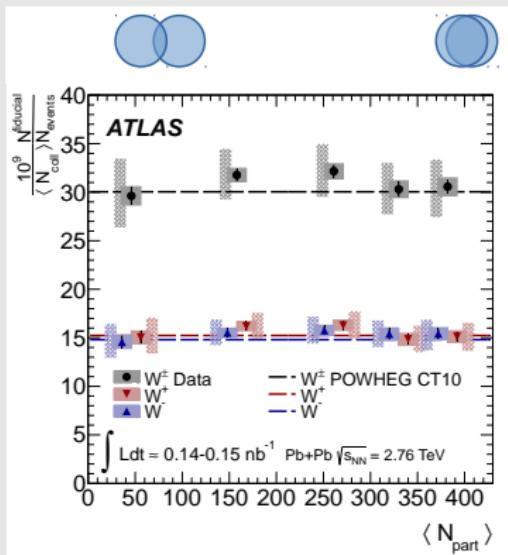
Binary nucleon-nucleon collision scaling in Pb+Pb

Phys. Rev. Lett. 110, 022301 (2013) and EPJ C (2015) 75:23

Z boson



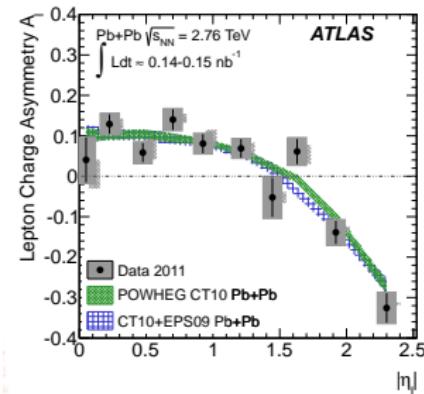
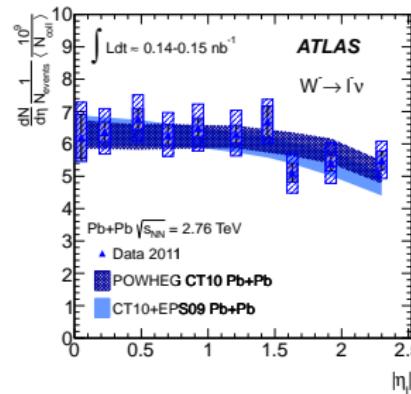
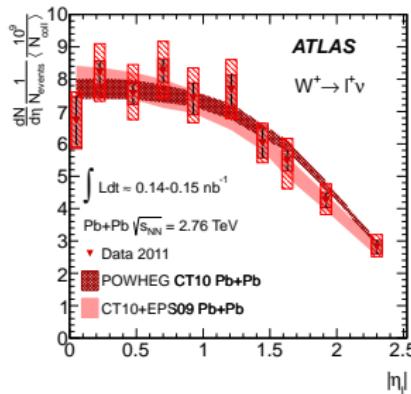
W boson



- EW boson yields consistent with a superposition of nucleon-nucleon collisions

W boson production in Pb+Pb collisions

EPJ C (2015) 75:23

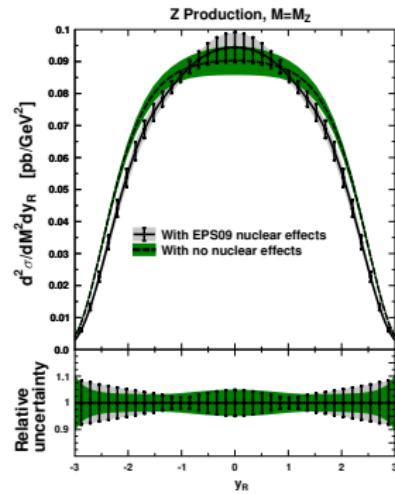


- ▶ Measurement well described by the superposition of nucleon-nucleon collisions
- ▶ Lepton charge asymmetry $A_\ell = \frac{N_{W^+} - N_{W^-}}{N_{W^+} + N_{W^-}}$
- ▶ Measurement cannot distinguish between PDFs that incorporate nuclear effects and those that do not

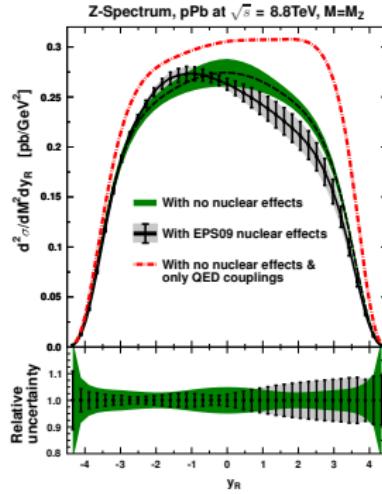
Sensitivity of PDFs to different collision systems

Paukkunen and Salgados, JHEP 1103:071,2011

Pb+Pb



p+Pb

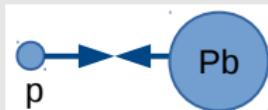


- Rapidity asymmetries in $p+Pb$ collisions advantageous over symmetric Pb+Pb collision geometry

W and Z cross section in p+Pb collisions

Phys. Rev. C 92, 044915 (2015) and ATLAS-CONF-2015-056

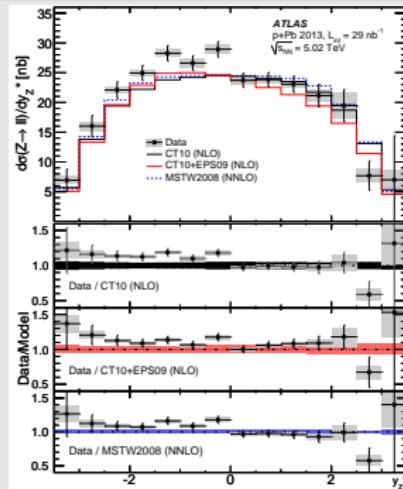
Rapidity convention



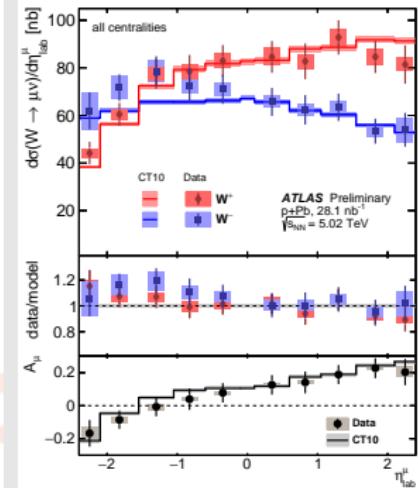
Charge Asymmetry

$$A_\ell = \frac{N_{W^+} - N_{W^-}}{N_{W^+} + N_{W^-}}$$

Z bosons



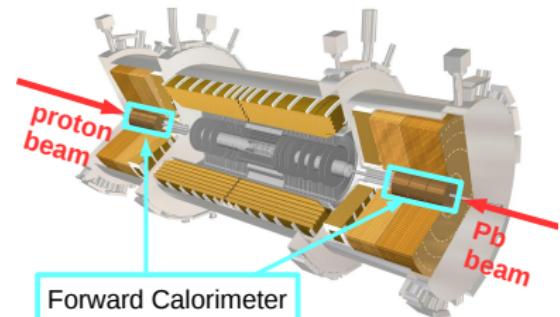
W bosons



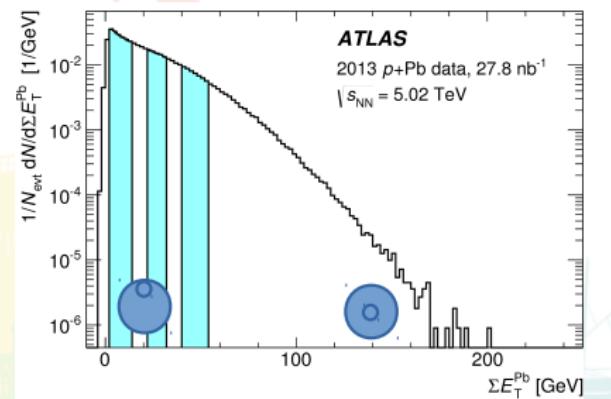
- ▶ Small excess observed in Pb-going side for Z and W^-
- ▶ Nuclear modification scenario favored by Z measurement
- ▶ Nuclear modifications do not reproduce the magnitude

Centrality in p+Pb collisions

arXiv:1508.00848 [hep-ex], accepted by EPJC



- ▶ Measurement of $\sum E_T$ in Forward Calorimeter in Pb-going direction
⇒ Centrality

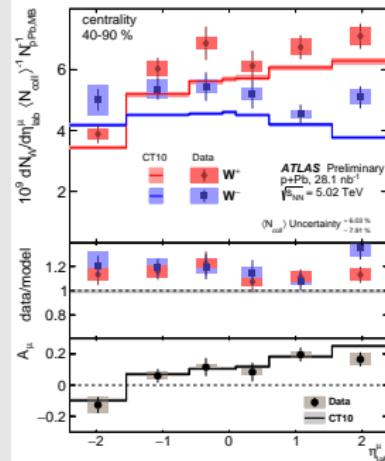


W bosons in p+Pb collisions

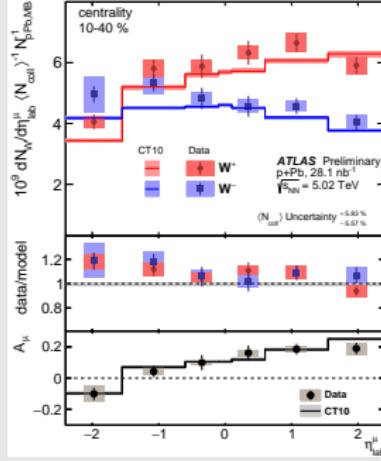
ATLAS-CONF-2015-056



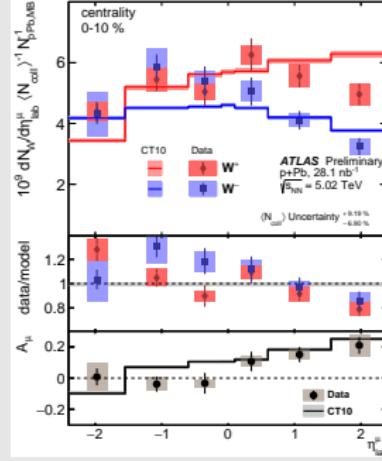
peripheral



mid-central



central

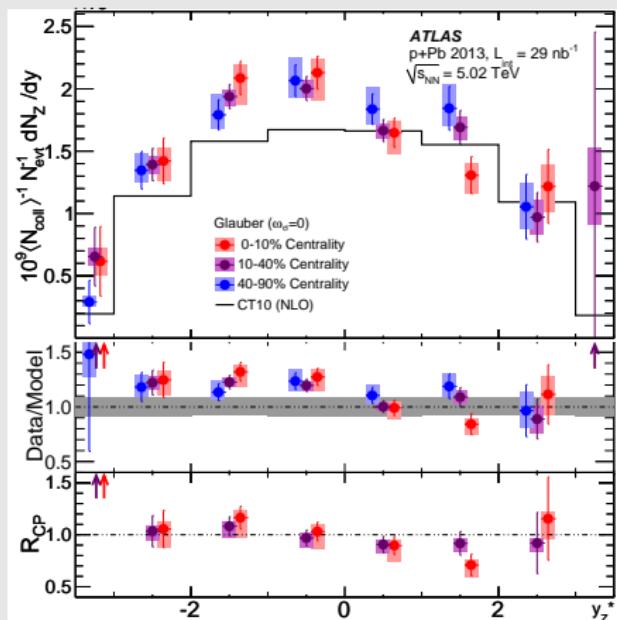


- ▶ W production vs η_{lab}^{μ} for three centrality bins normalized to number binary collisions and minimum-bias events
- ▶ Centrality dependence of nuclear modifications ?

Z bosons in p+Pb collisions



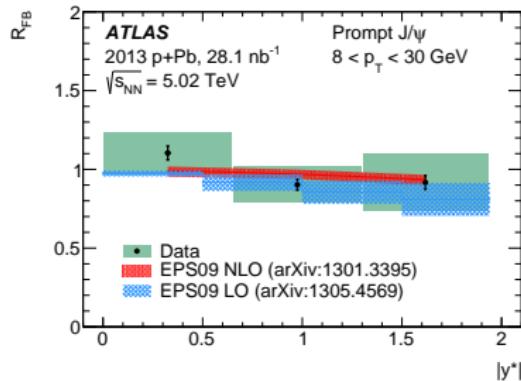
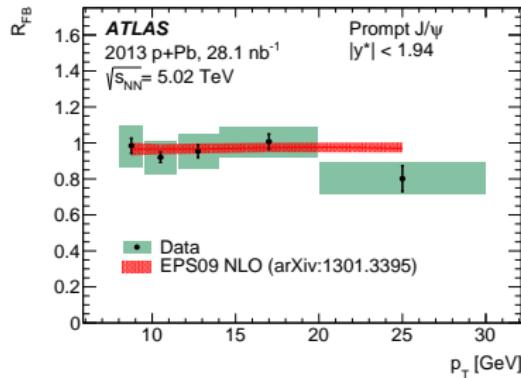
Phys. Rev. C 92, 044915 (2015)



- ▶ Z production vs y^* for three centrality bins normalized to number binary collisions and minimum-bias events
- ▶ Centrality dependence of nuclear modifications ?

J/ψ forward-backward production ratio

Phys. Rev. C 92, 034904 (2015)



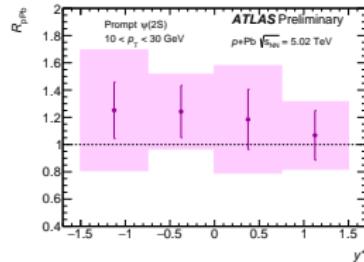
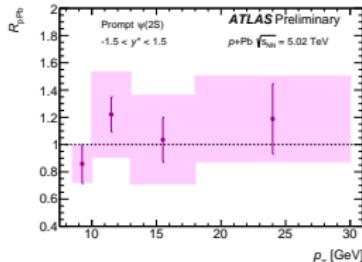
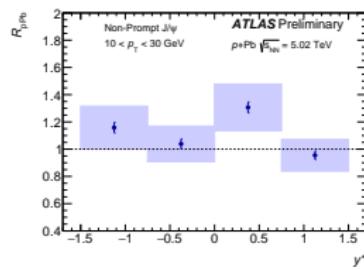
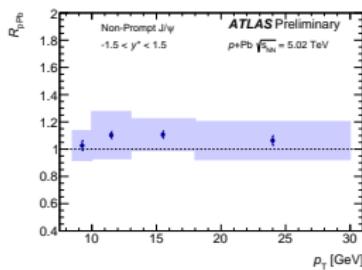
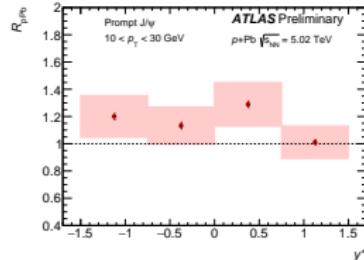
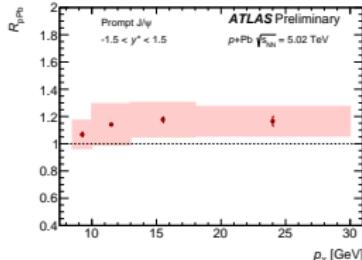
- ▶ Forward-Backward ratio R_{FB}

$$R_{FB}(p_T, y^*) = \frac{d^2\sigma(p_T, y^* > 0) / dp_T dy^*}{d^2\sigma(p_T, y^* < 0) / dp_T dy^*}$$

- ▶ In the ratio R_{FB} many systematic uncertainties cancel
- ▶ Forward-backward ratio of prompt J/ψ is compatible with both EPS09 models

Nuclear modification of (non-)prompt $\psi(nS)$

ATLAS-CONF-2015-023



- Nuclear modification factor $R_{p\text{Pb}}$

$$R_{p\text{Pb}} = \frac{N_{p\text{Pb}}}{\langle T_{p\text{Pb}} \rangle \times \sigma^{pp}}$$

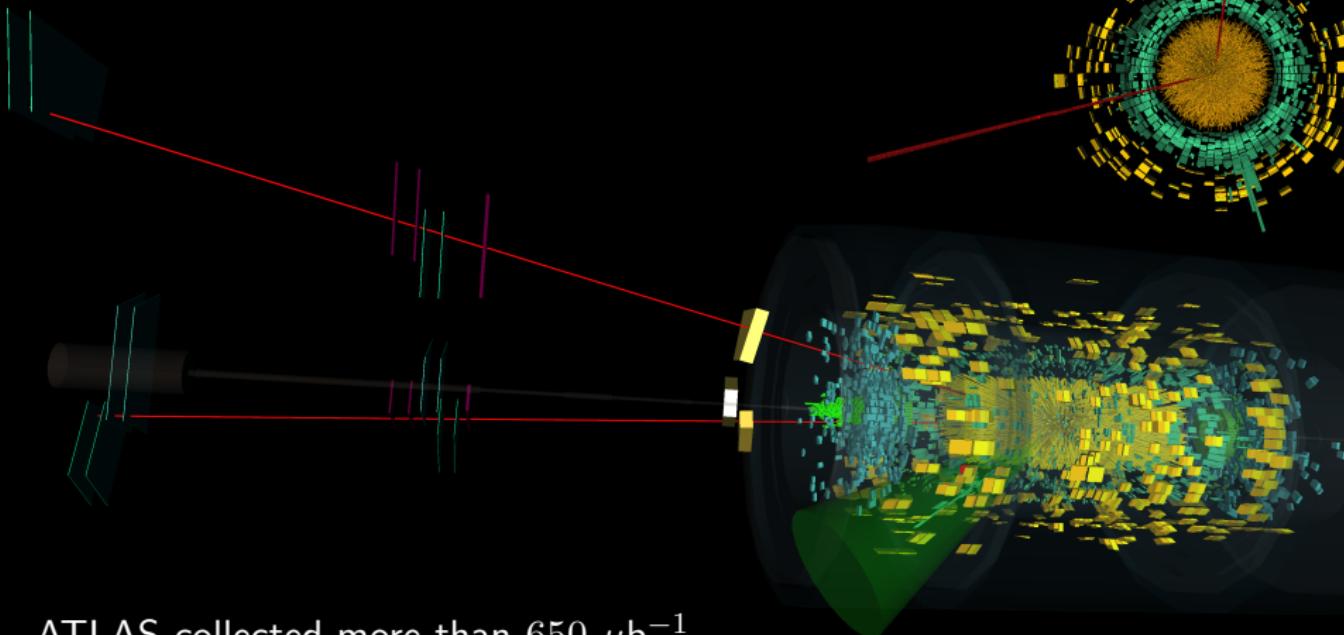
$$R_{p\text{Pb}} \begin{cases} = 1, & \text{no modification} \\ \neq 1, & \text{nuclear effects} \\ & \text{medium} \end{cases}$$

- Reference (pp) spectra constructed by interpolations
- No significant changes for $|y^*| < 1.5$ or $10 < p_T < 30 \text{ GeV}$

Outlook for Run2

HION-2015-01

Pb+Pb, $\sqrt{s_{NN}} = 5.02$ TeV
Z+jet candidate
FCal $\Sigma E_T = 2.40$ TeV



ATLAS collected more than $650 \mu b^{-1}$
of Pb+Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV in November-December 2015

Summary

- ▶ The ATLAS experiment produced a variety of results for electroweak bosons and charmonia in $p+\text{Pb}$ and $\text{Pb}+\text{Pb}$ collisions in Run1
 - ▶ Overall good description of data by models
 - ▶ In $\text{Pb}+\text{Pb}$ system, W and Z production consistent with binary nucleon-nucleon collision scaling
 - ▶ EW boson measurements in $p+\text{Pb}$ collisions can be used to differentiate between various models
 - ▶ Z measurements in $p+\text{Pb}$ collisions are best described by PDFs with nuclear modifications
 - ▶ Charmonia results in $p+\text{Pb}$ collisions are consistent with EPS09 for R_{FB} and do not show a significant change in $R_{p\text{Pb}}$ in the measured ranges of p_{T} or $|y^*|$
- ▶ Many more results can be expected for pp and $\text{Pb}+\text{Pb}$ collisions at $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}$ taken in 2015

backup



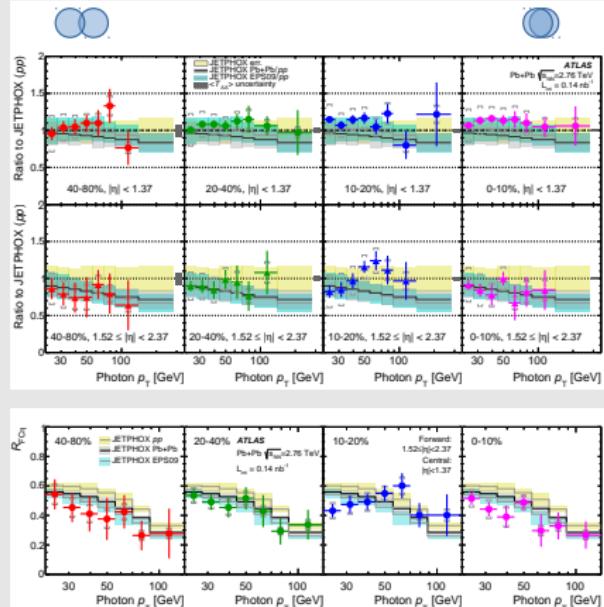
Probing (n)PDFs with photons in Pb+Pb collisions

Phys. Rev. C 93 (2016) 034914

- ▶ Data to NLO pQCD ratio
→ JETPHOX predictions with and without nuclear modifications
- ▶ Forward-central ratio
→ Significant reduction of systematic uncertainties

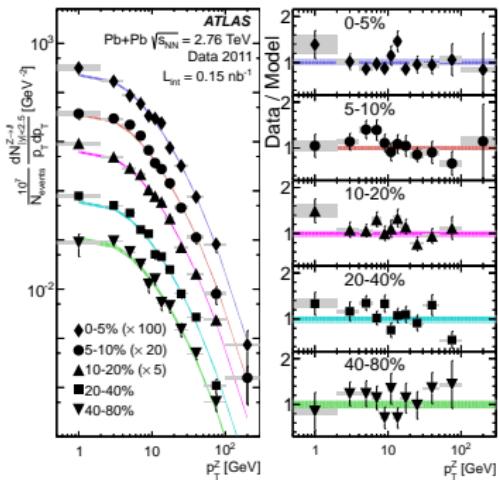
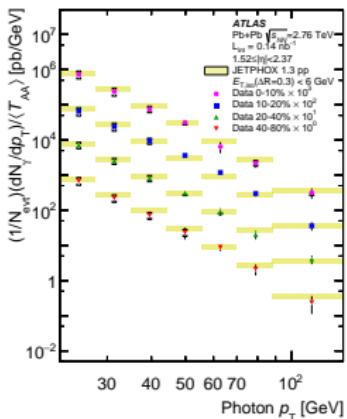
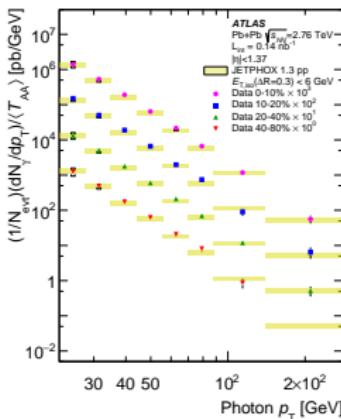
$$R_{FC\eta} = \frac{d\sigma/dp_T(1.52 < |\eta| < 2.37)}{d\sigma/dp_T(|\eta| < 1.37)}$$

Isolated prompt photons



Photon and Z spectra in Pb+Pb collisions

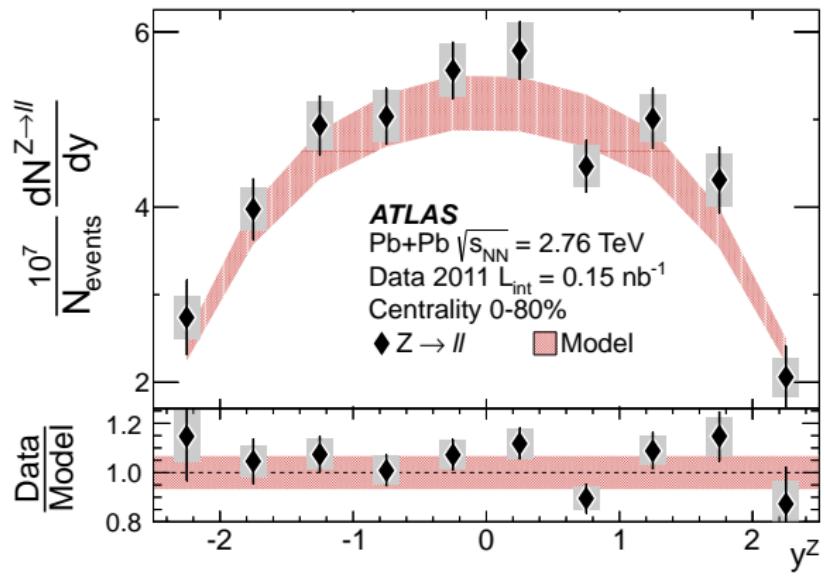
Phys. Rev. C 93 (2016) 034914 and Phys. Rev. Lett. 110,022301 (2013)



- Good agreement between models and data

Z bosons in Pb+Pb collisions

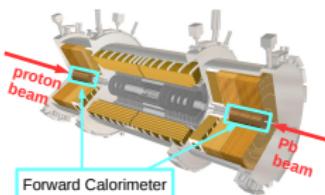
Phys. Rev. Lett. 110, 022301 (2013)



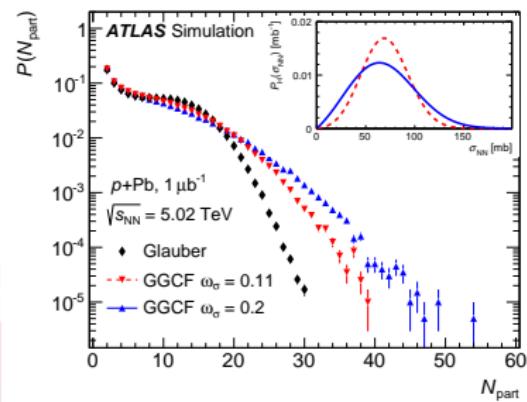
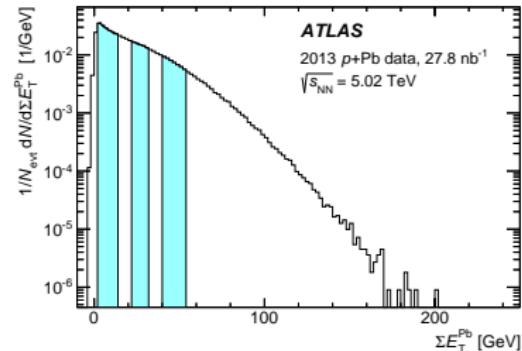
- Good agreement between models and data

Details on centrality in p+Pb collisions

arXiv:1508.00848 [hep-ex], accepted by EPJC



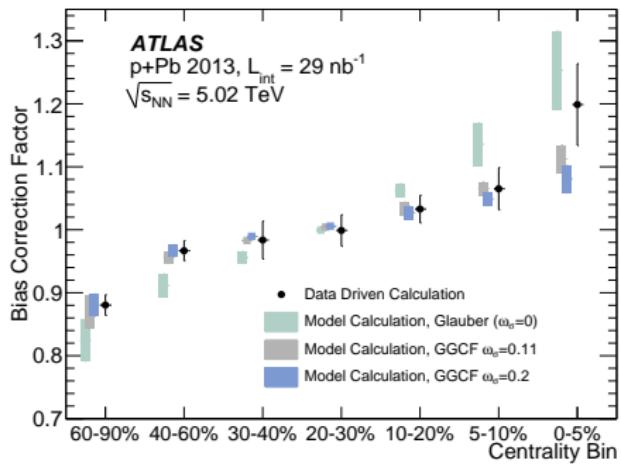
- ▶ Transverse energy deposited in FCal in Pb-going direction $\sum E_T^{\text{Pb}}$
- ▶ Use Glauber or Glauber-Gribov Color Fluctuation (GGCF) models to map measurement with geometric quantities $\langle N_{\text{part}} \rangle$ or $\langle N_{\text{coll}} \rangle$
- ▶ Magnitude of event-by-event fluctuations is given by ω_σ



Centrality bias corrections in p+Pb collisions

arXiv:1412.0976 [nucl-ex] and Phys. Rev. C 92, 044915 (2015)

- Centrality bias: Increase of Underlying event in hard scatterings



- Process independent correction factor from model calculations and data-driven measurements

Potential partonic in-medium effects

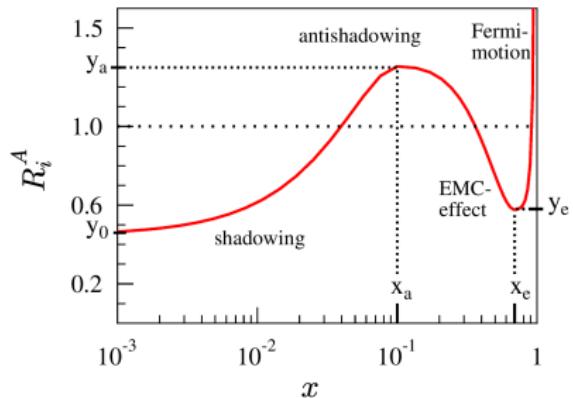
- ▶ Gluon saturation
- ▶ Gluon shadowing
- ▶ Partonic energy-loss
- ▶ Modified parton distributions
- ▶ Modified fragmentation function

Example EPS09

Eskola, Paukkunen, Salgado
JHEP 0904:065, 2009

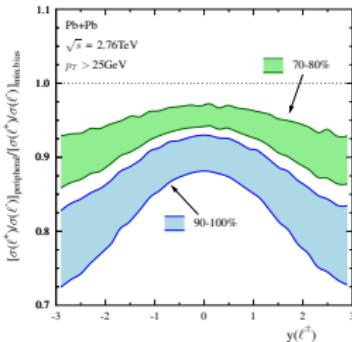
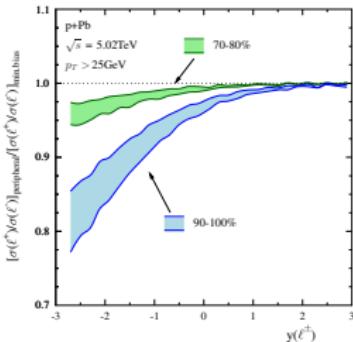
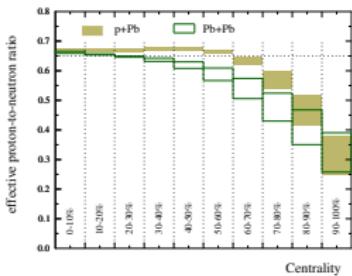
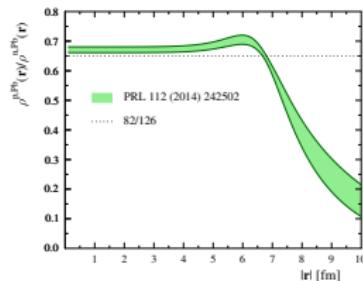
- ▶ Medium modified PDFs
- ▶ NLO, constrained by DIS on nuclei, Drell-Yan in $p+A$, incl. pion production in pp and $d+Au$

$$f_i^A(x, Q^2) \equiv R_i^A(x, Q^2) f_i^{\text{CTEQ6.1M}}(x, Q^2)$$



Potential neutron skin measurements

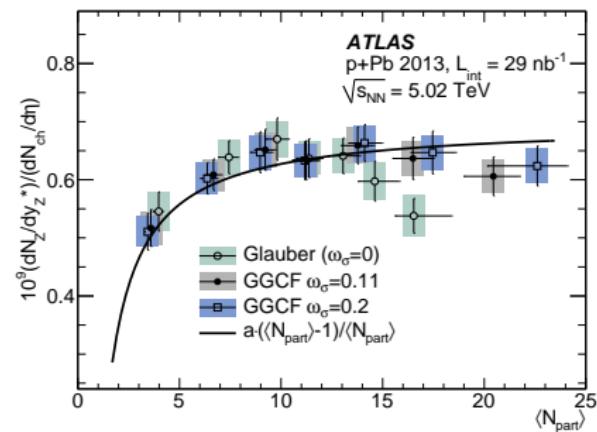
Paukkunen, Phys. Lett. B 745 (2015) 73



- ▶ W^\pm production sensitive to isospin of colliding quarks
- ▶ Neutron skin would have measurable impact on W production in peripheral collisions

Z bosons vs charged particles in p+Pb collisions

Phys. Rev. C 92, 044915 (2015)

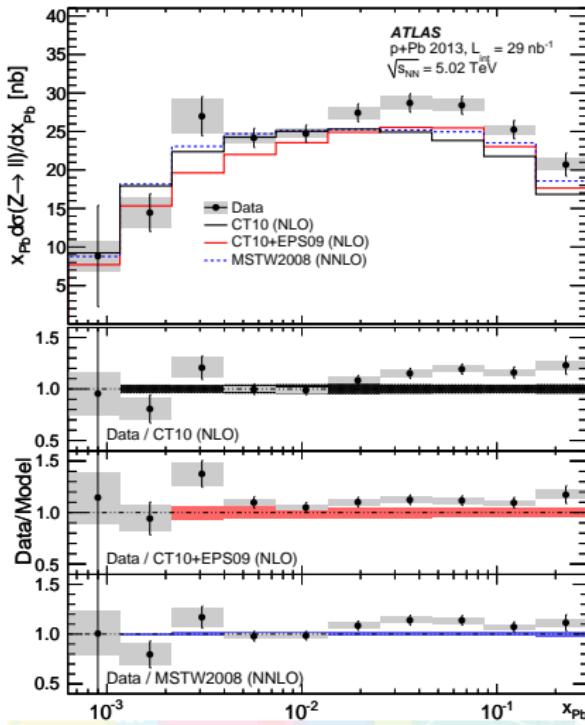


- Ratio of multiplicities of Z bosons and inclusive charged particles

Z bosons in p+Pb collisions

Phys. Rev. C 92, 044915 (2015)

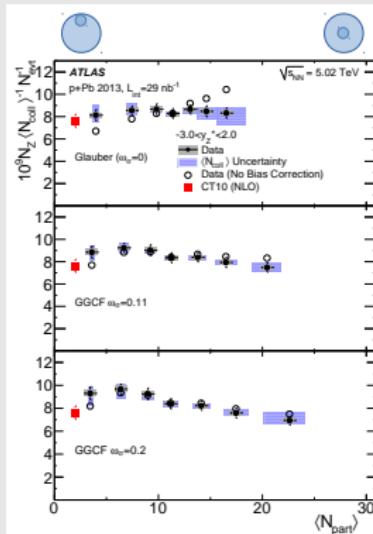
$$x_{\text{Pb}} = \frac{M_Z \exp(-y_Z^*)}{\sqrt{s_{\text{NN}}}}$$



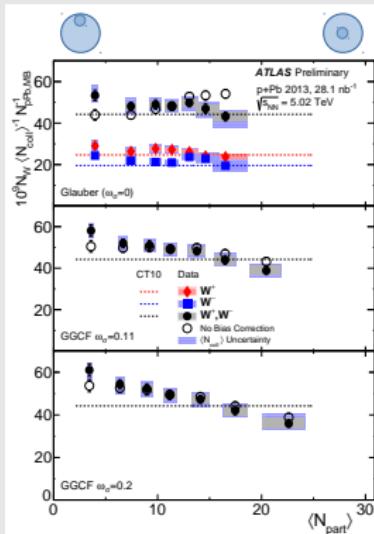
Binary collision scaling in p+Pb collisions

Phys. Rev. C 92, 044915 (2015) and ATLAS-CONF-2015-056

Z bosons



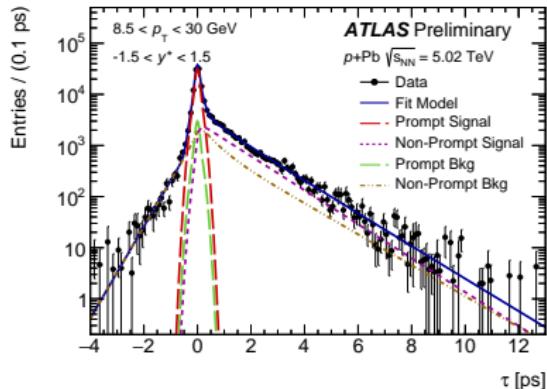
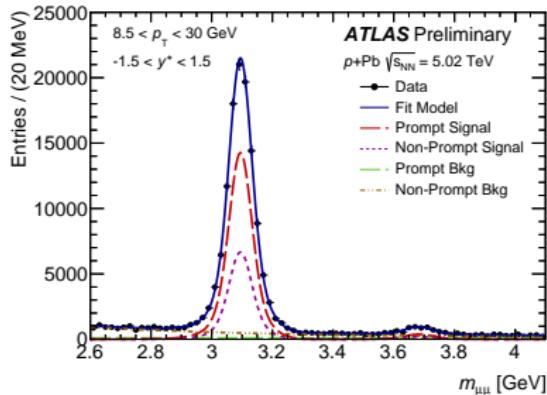
W bosons



- Weak bosons do (or do not) scale – depending on the model used for $p+Pb$ centrality calculation

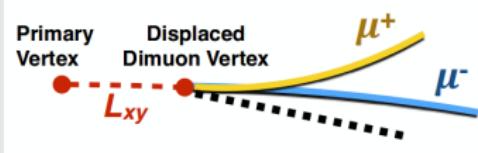
Prompt and non-prompt charmonia in p+Pb

ATLAS-CONF-2015-023



Prompt and non-prompt $\psi(nS)$

- ▶ Prompt $\psi(nS)$
 - Direct production
 - Feed-down contribution
- ▶ Non-prompt $\psi(nS)$
 - Decays from B hadrons

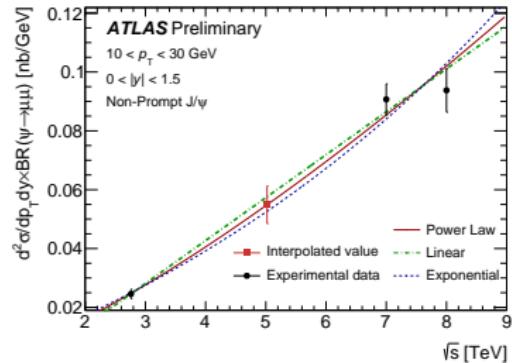
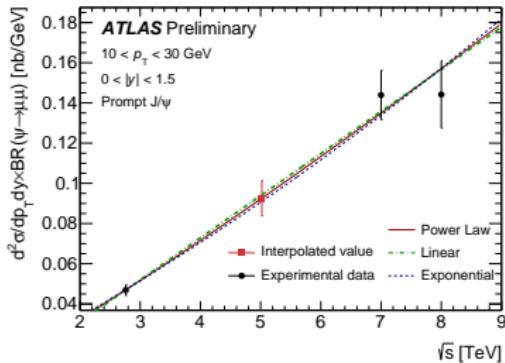


Pseudo-proper lifetime

$$\tau = \frac{L_{xy} m_{\mu\mu}}{p_T^{\mu\mu}}$$

Proton-proton reference for $\psi(nS)$ measurement

ATLAS-CONF-2015-023



$$\sigma(\sqrt{s}) = \begin{cases} p_0 + p_1 \sqrt{s}, \\ (\sqrt{s}/p_0)^{p_1}, \\ p_0 (1 - \exp(-\sqrt{s}/p_1)), \end{cases}$$

linear
power law
exponential.