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

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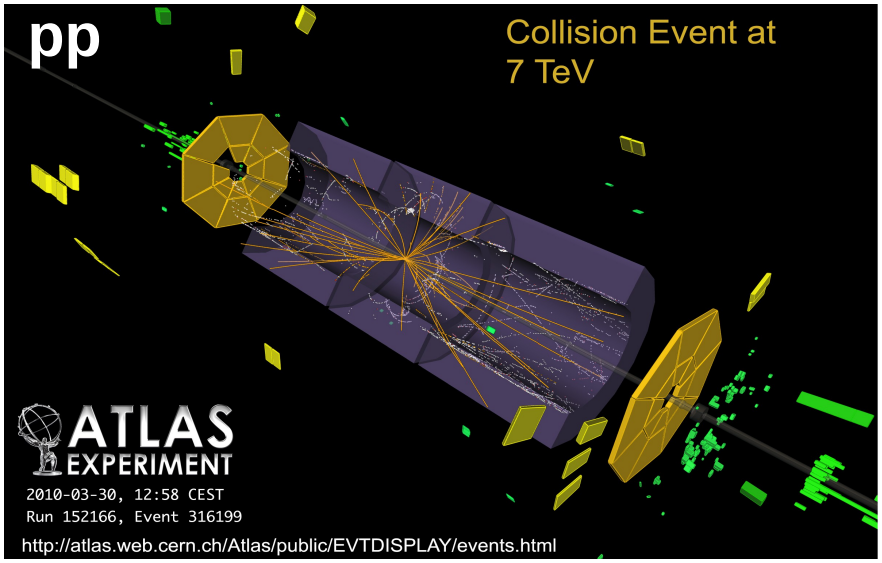
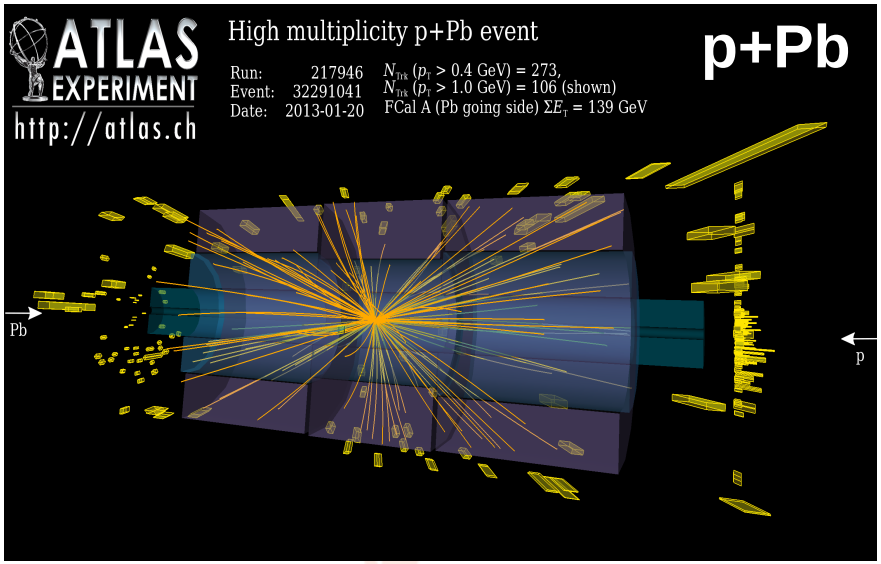
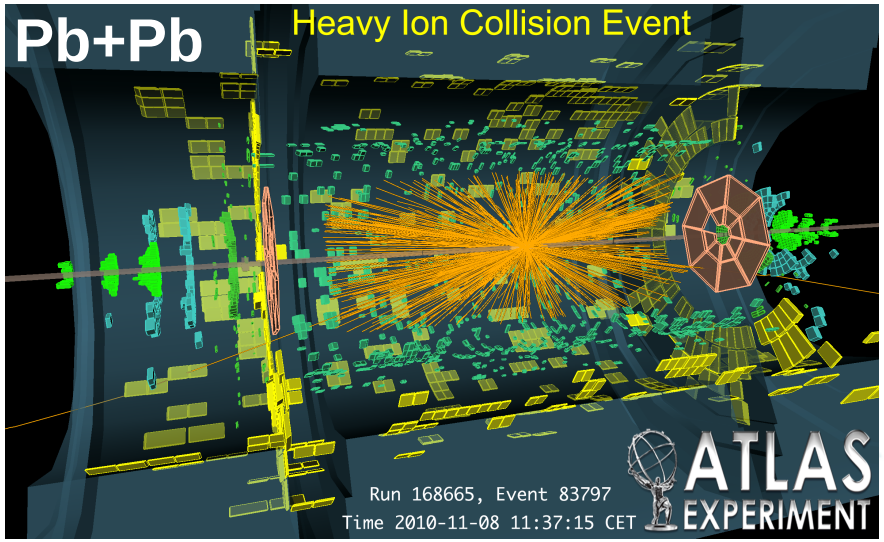
Heavy-ion collisions







Pb+Pb	Study the Quark-Gluon Plasma
p+Pb	Disentangle initial from final state effects
pp	Reference measurement

Vector bosons and Charmonia in heavy-ion collisions

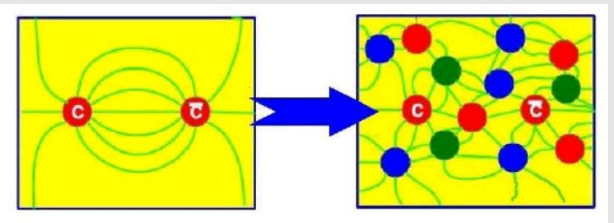
- Electroweak (EW) bosons, as well as heavy-flavor quarks, are produced in early stages of a heavy-ion collision
- Leptonic decay products do not interact strongly
  $\rightarrow$ Excellent messengers from a strongly interacting medium

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)?

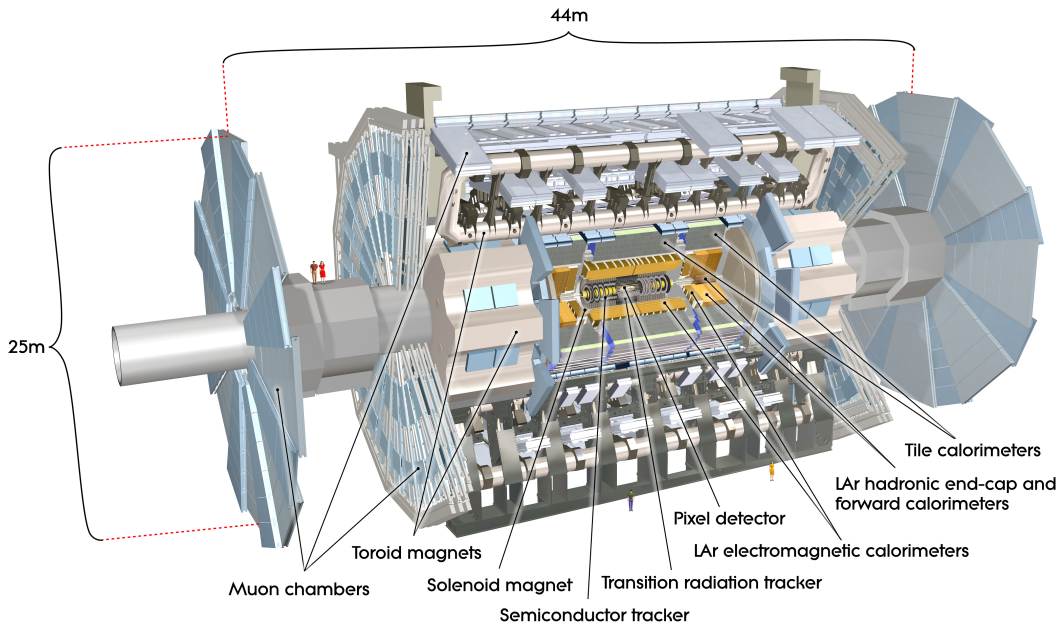
Charmonia

- Quarkonium suppression due to color screening in QGP



- Necessary prerequisite to understand cold nuclear matter effects in p+Pb

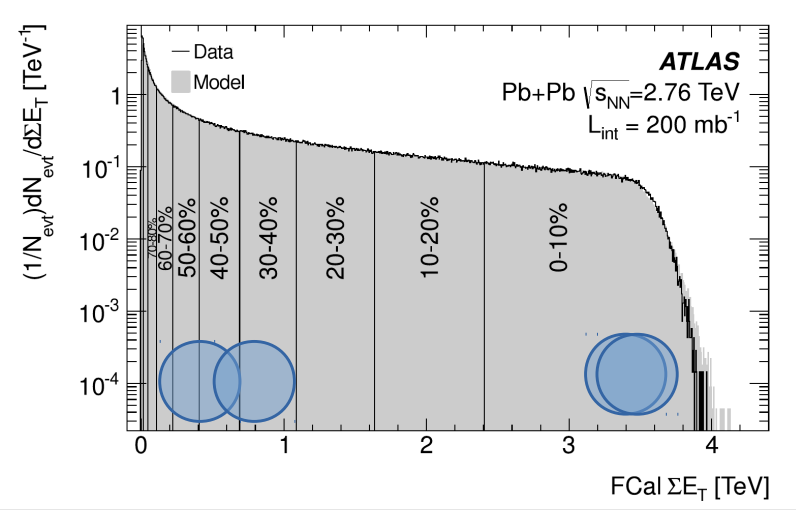
ATLAS detector



Data sets

- pp, 2.76 TeV
  $\int \mathscr{L} \mathrm{d}t = 4.0\ \mathrm{pb}^{-1}$
- p+Pb, 5.02 TeV
  $\int \mathscr{L} \mathrm{d}t = 28.1\ \mathrm{nb}^{-1}$
- Pb+Pb, 2.76 TeV
  $\int \mathscr{L} \mathrm{d}t = 0.14\ \mathrm{nb}^{-1}$

FCal $E_\mathrm{T} \rightarrow$ Centrality



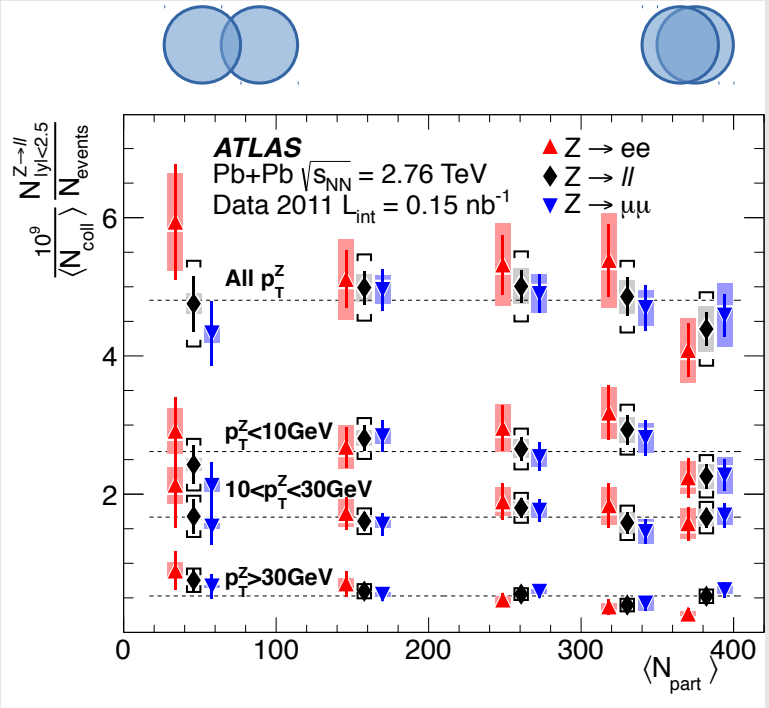
Sub-detectors

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

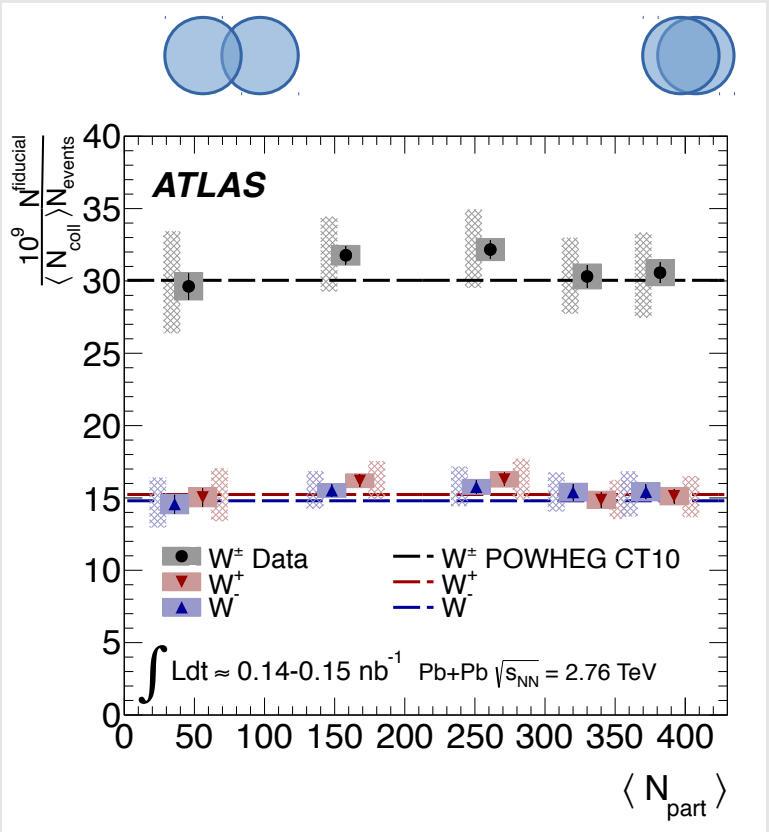
Binary nucleon-nucleon collision scaling in Pb+Pb

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

Z boson



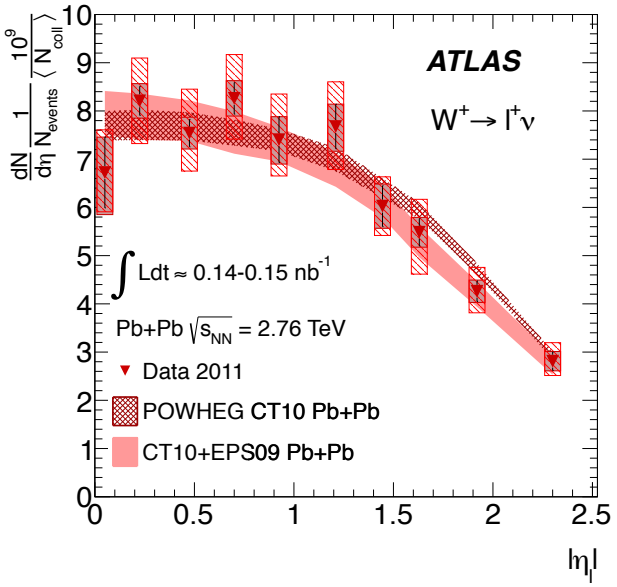
W boson

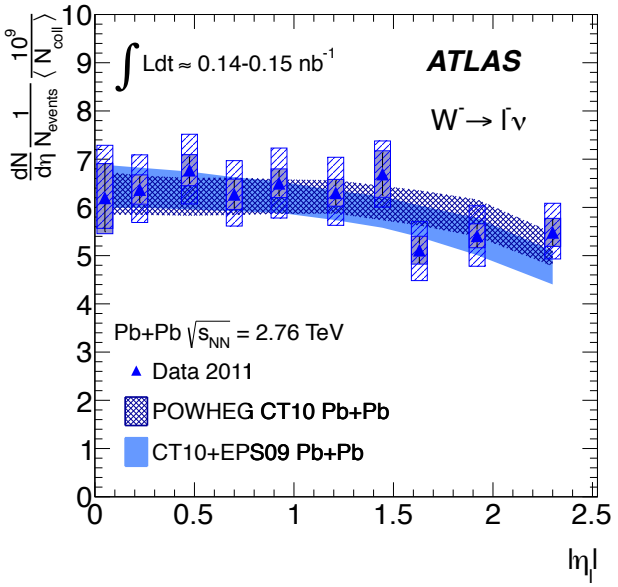


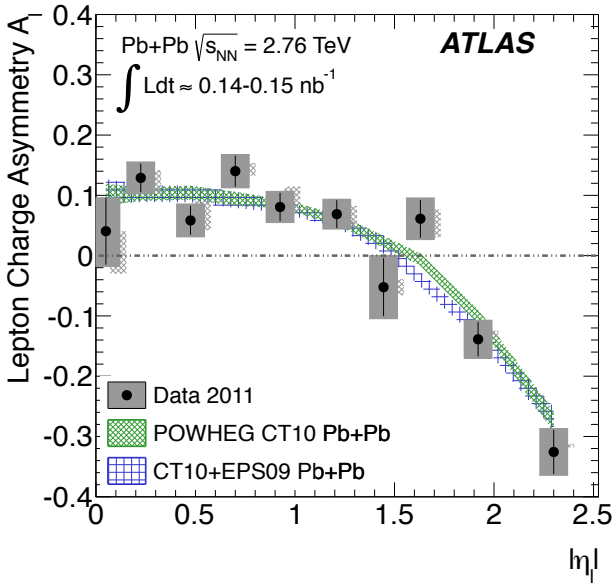
- EW boson yields consistent with a superposition of nucleon-nucleon collisions

W boson production in Pb+Pb collisions

EPJ C (2015) 75:23





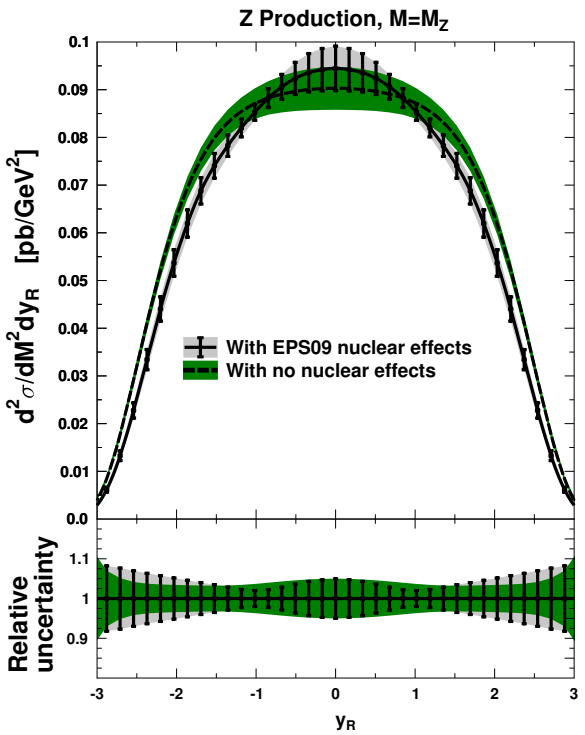


- Measurement well described by the superposition of nucleon-nucleon collisions
- Lepton charge asymmetry $A_\ell = \frac{N_{W+} - N_{W-}}{N_{W+} + N_{W-}}$
- Measurement cannot distinguish between PDFs that incorporate nuclear effects and those that do not

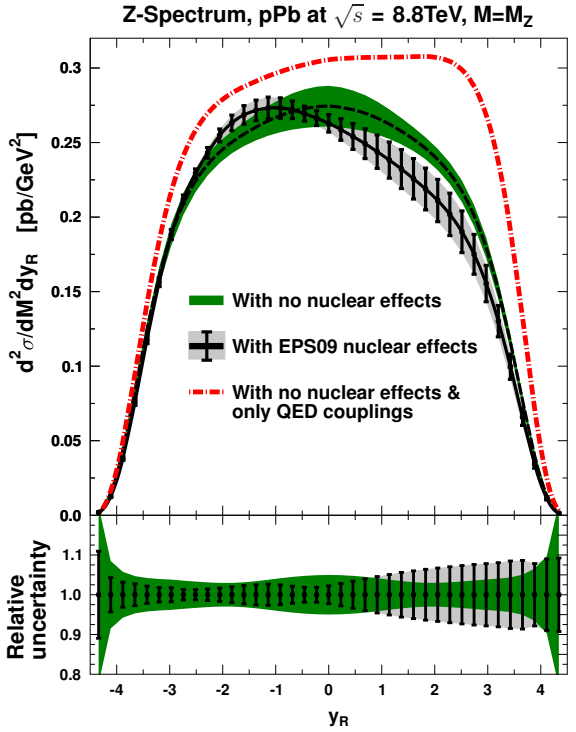
Sensitivity of PDFs to different collision systems

Paukkunen and Salgados, JHEP 1103:071,2011

Pb+Pb



p+Pb

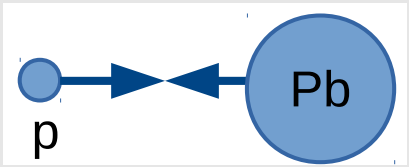


- Rapidity asymmetries in p+Pb collisions advantageous over symmetric Pb+Pb collision geometry

W and Z cross section in p+Pb collisions

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

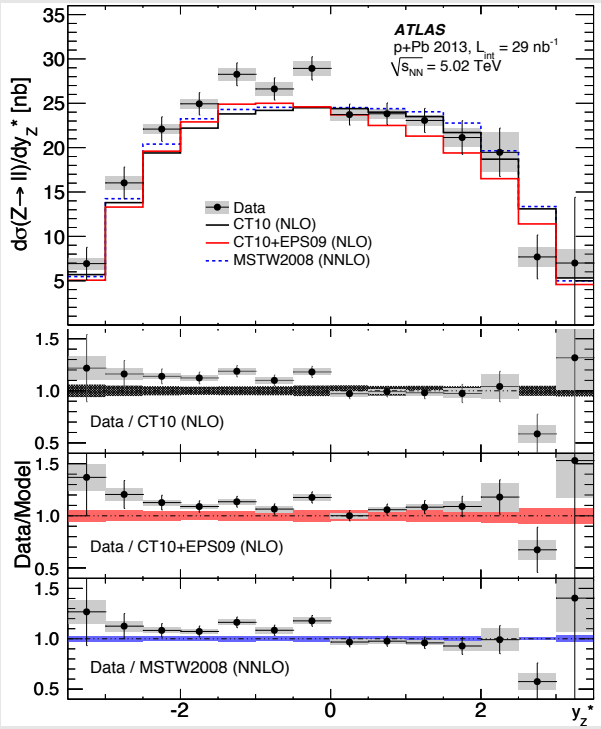
Rapidity convention



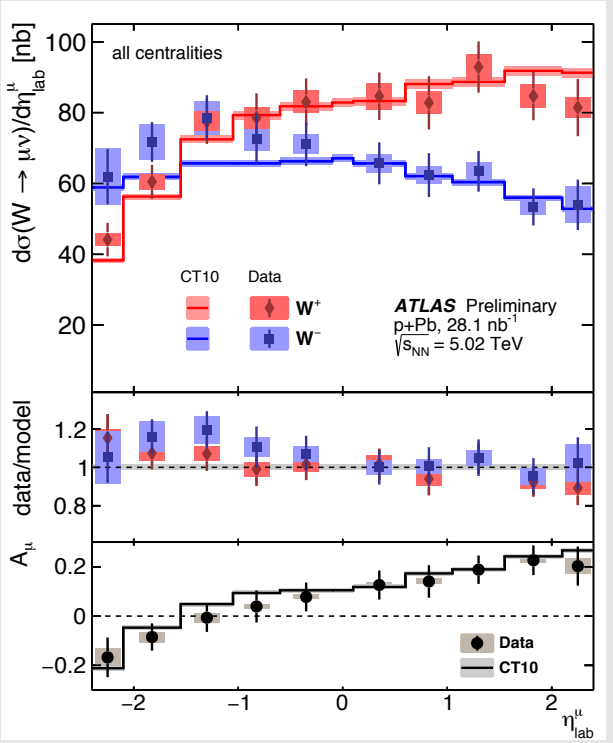
Charge Asymmetry

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

Z bosons



W bosons

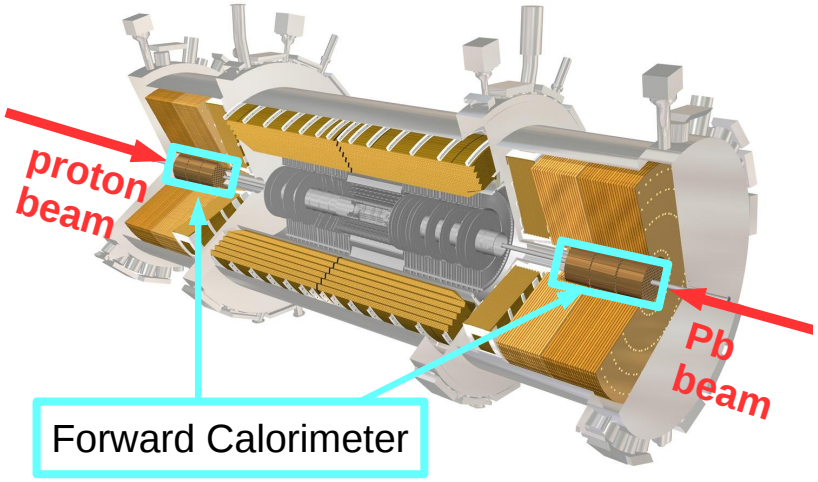


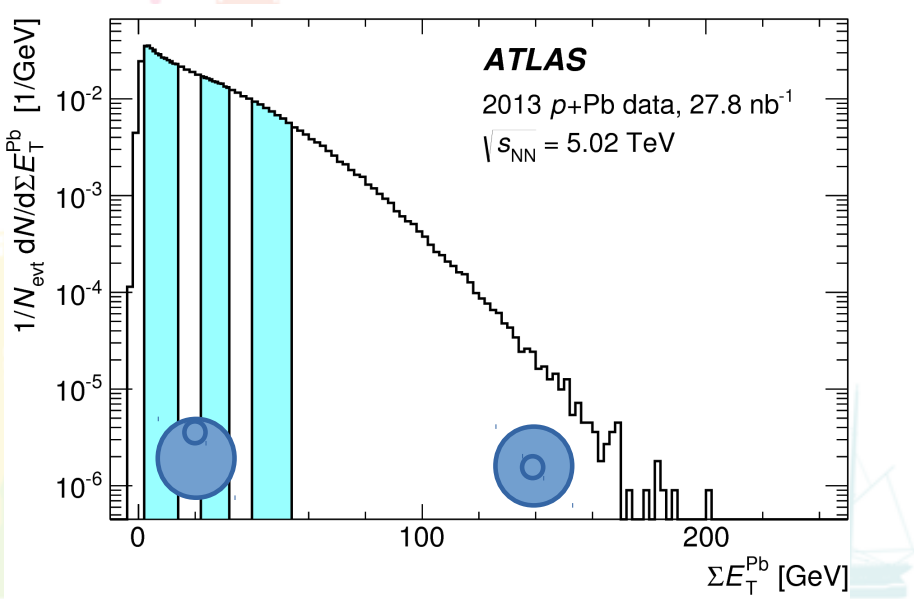
- Small excess observed in Pb-going side for Z and W^-
- Nuclear modification scenario favored by Z measurement
- Nuclear modifications do not reproduce the magnitude

Centrality in p+Pb collisions

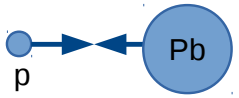
arXiv:1508.00848 [hep-ex], accepted by EPJC

- Measurement of $\sum E_{\mathrm{T}}$ in Forward Calorimeter in Pb-going direction
  $\Rightarrow$ Centrality



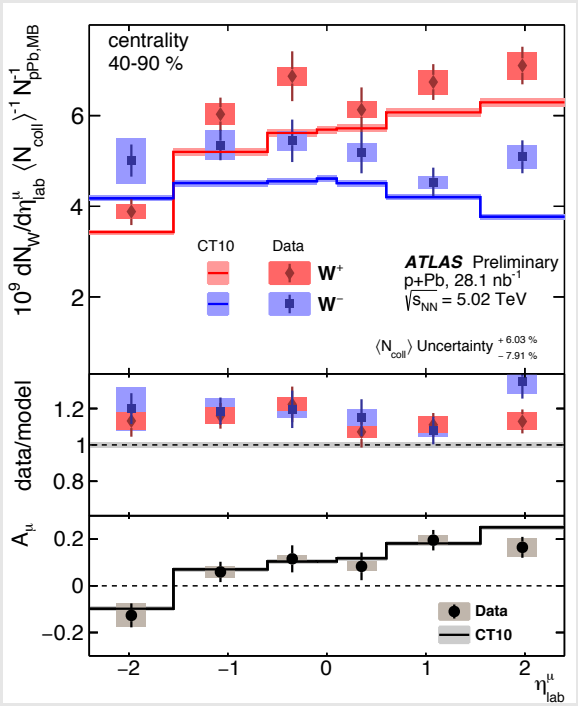


W bosons in p+Pb collisions

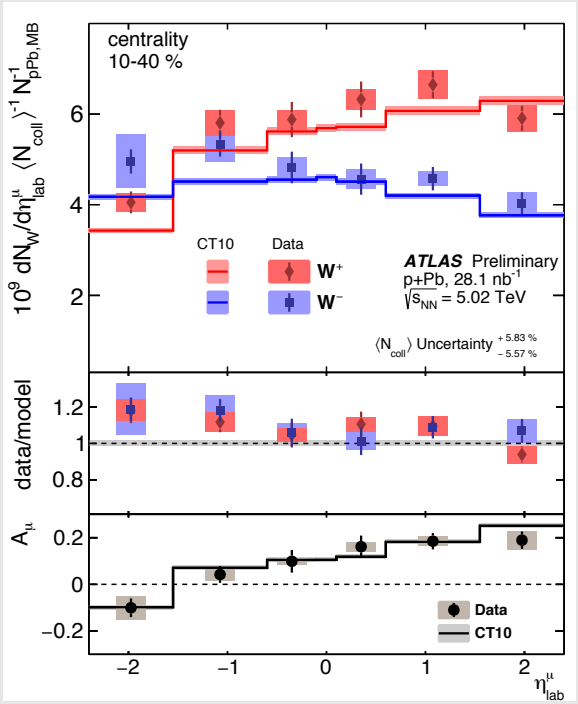


ATLAS-CONF-2015-056

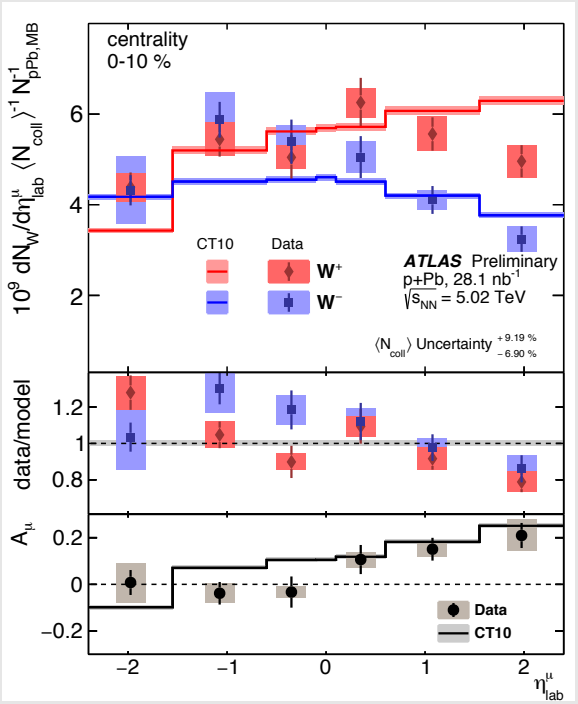
peripheral



mid-central



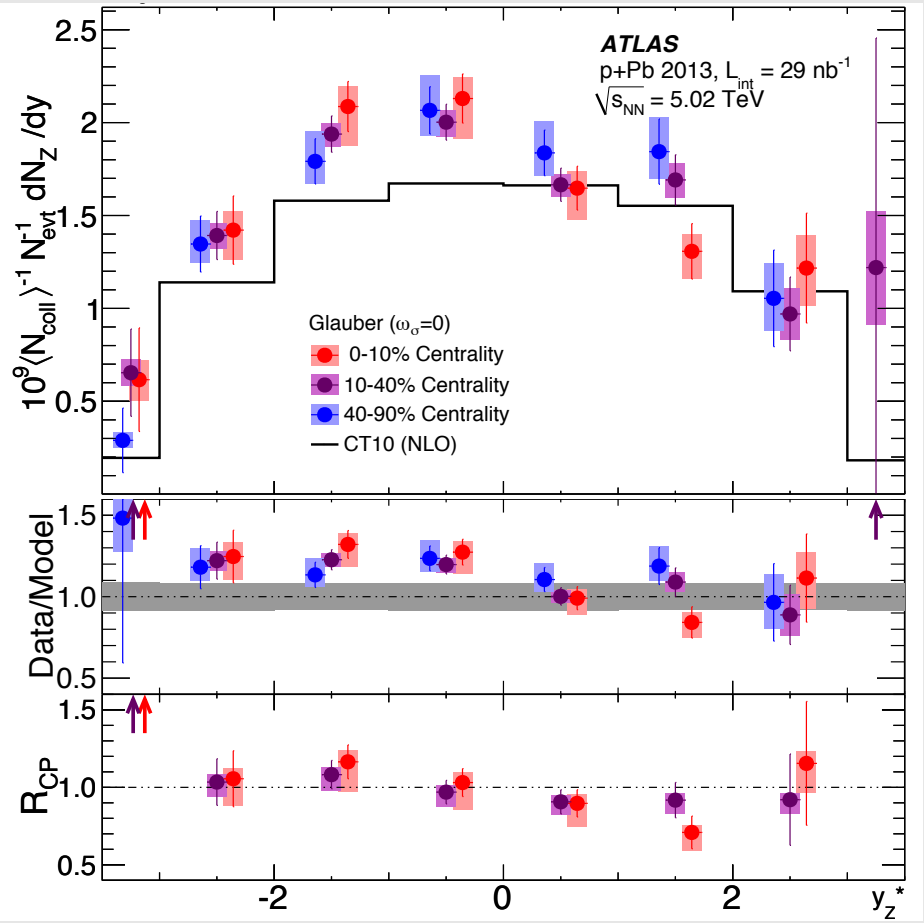
central



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

Z bosons in p+Pb collisions

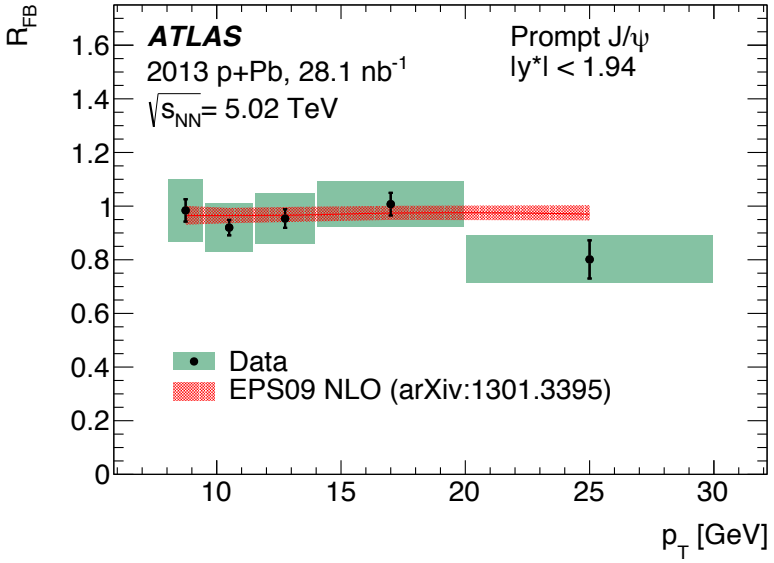
Phys. Rev. C 92, 044915 (2015)

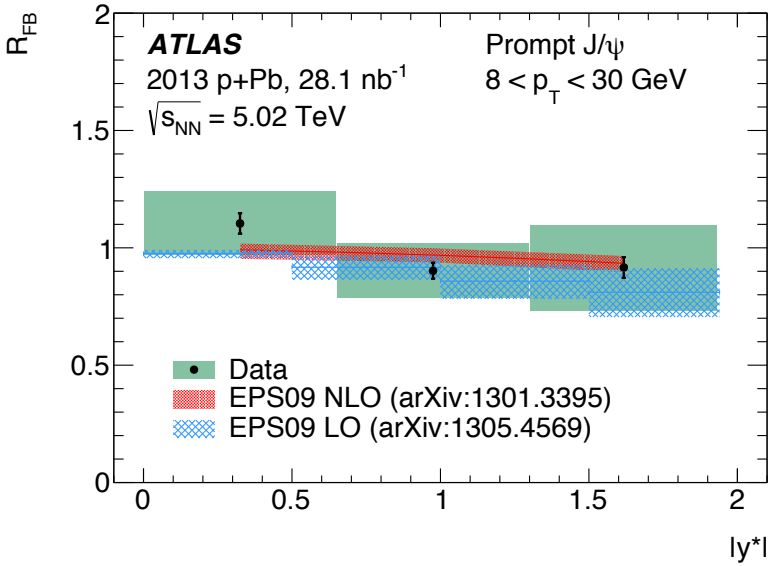


- Z production vs y^* for three centrality bins normalized to number binary collisions and minimum-bias events
- Centrality dependence of nuclear modifications ?

J/ψ forward-backward production ratio

Phys. Rev. C 92, 034904 (2015)





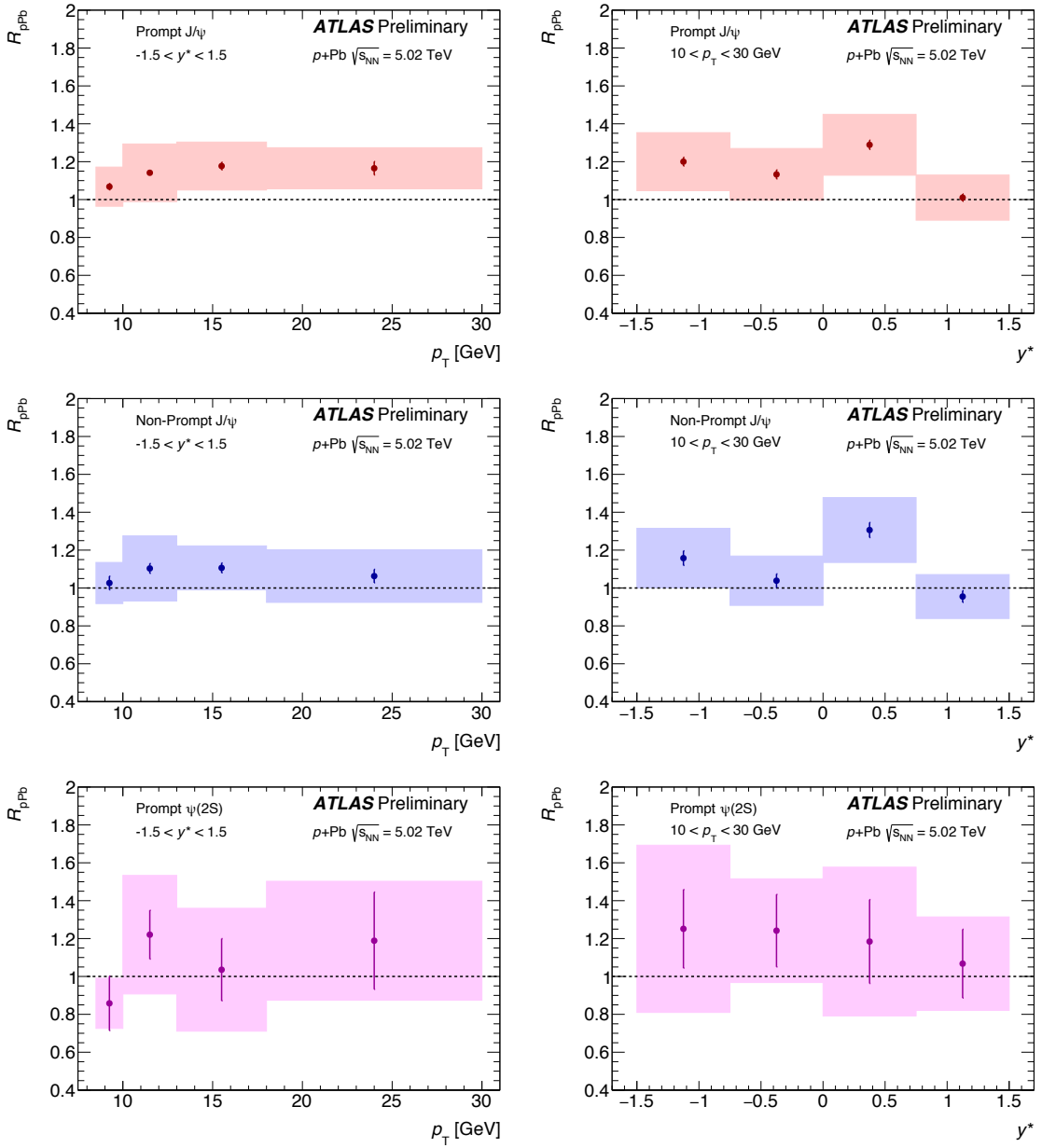
- Forward-Backward ratio R_{FB}

$$R_{\mathrm{FB}}(p_{\mathrm{T}}, y^*) = \frac{\mathrm{d}^2\sigma(p_{\mathrm{T}}, y^*>0)/\mathrm{d}p_{\mathrm{T}}\mathrm{d}y^*}{\mathrm{d}^2\sigma(p_{\mathrm{T}}, y^*<0)/\mathrm{d}p_{\mathrm{T}}\mathrm{d}y^*}$$

- 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



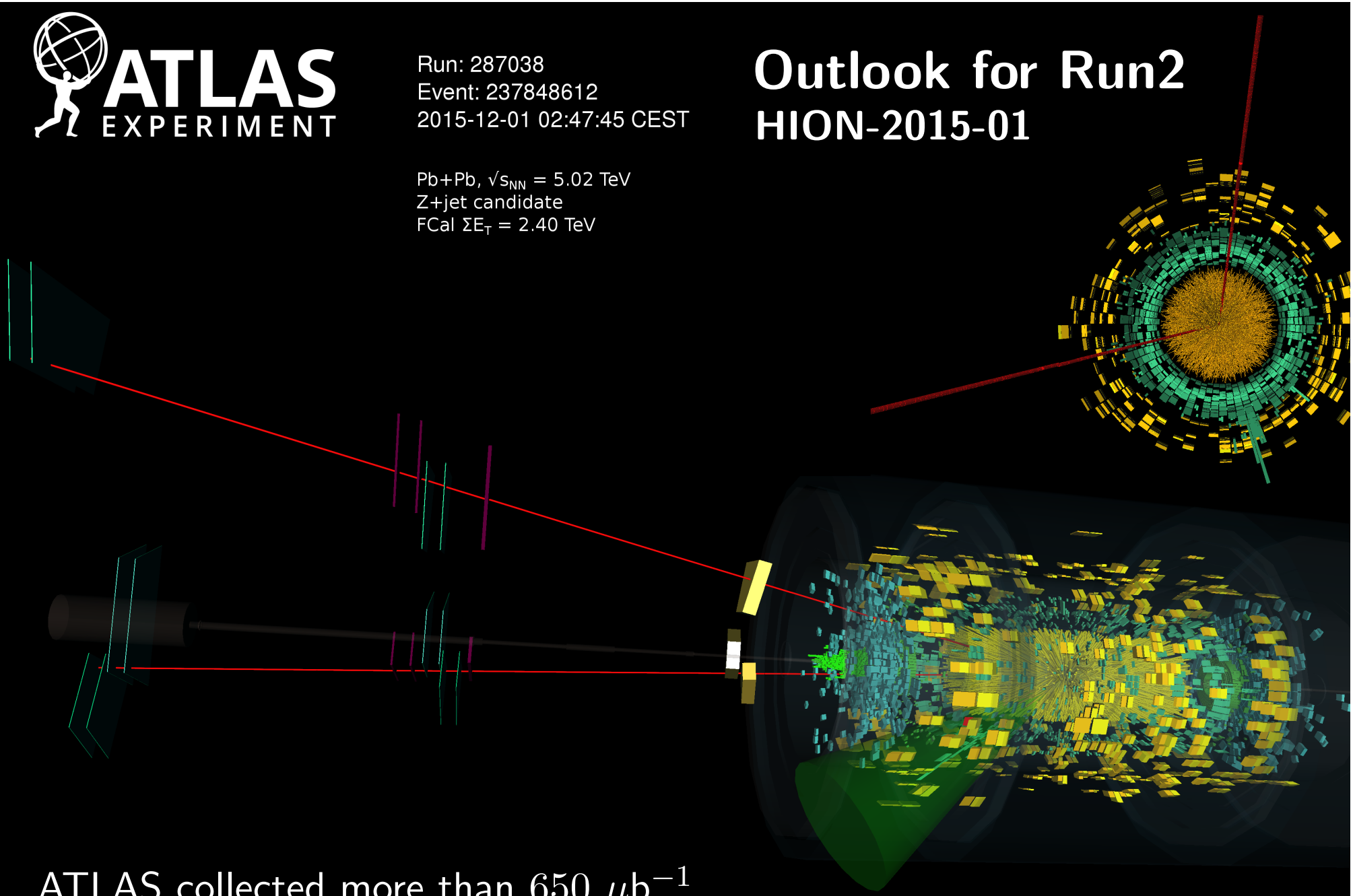
- Nuclear modification factor $R_{p\mathrm{Pb}}$

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

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

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

Outlook for Run2
HION-2015-01



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

Summary

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

backup

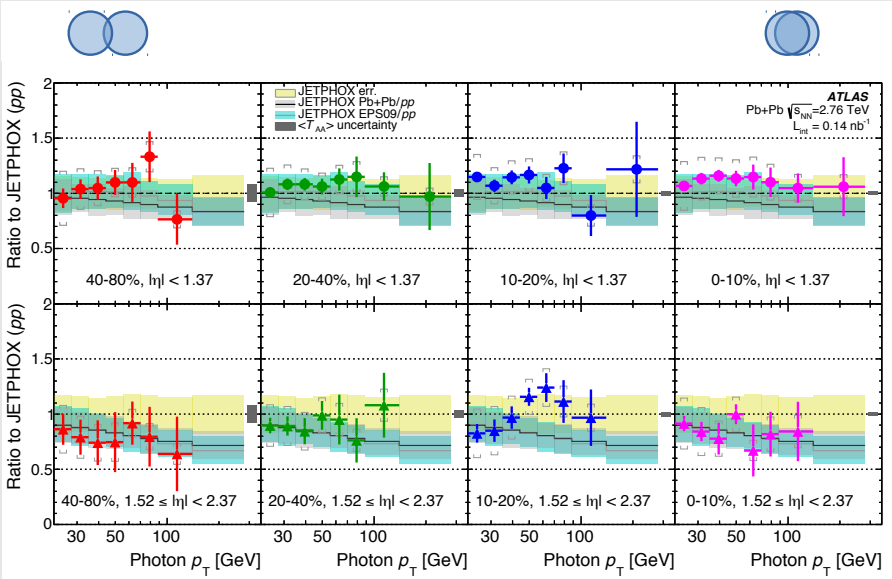
Probing (n)PDFs with photons in Pb+Pb collisions

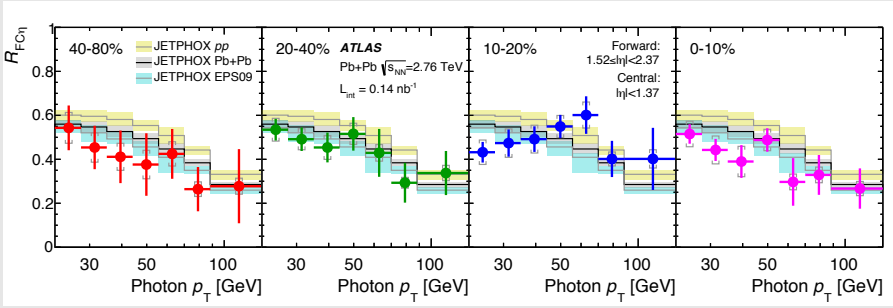
Phys. Rev. C 93 (2016) 034914

Isolated prompt photons

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

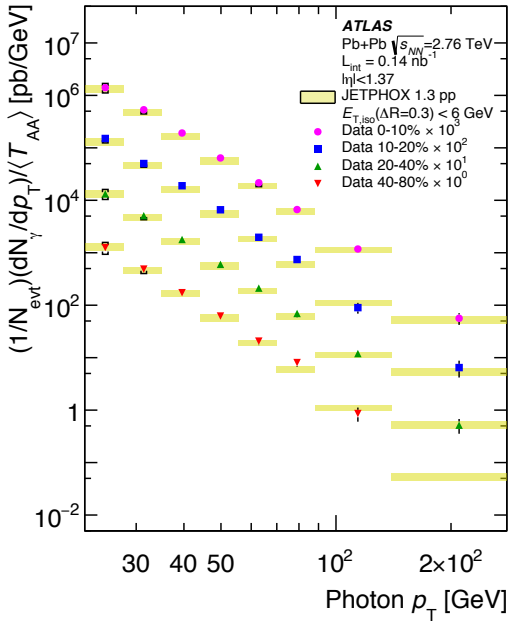
$$R_{\mathrm{FC}\eta} = \frac{\mathrm{d}\sigma/\mathrm{d}p_{\mathrm{T}}(1.52<|\eta|<2.37)}{\mathrm{d}\sigma/\mathrm{d}p_{\mathrm{T}}(|\eta|<1.37)}$$

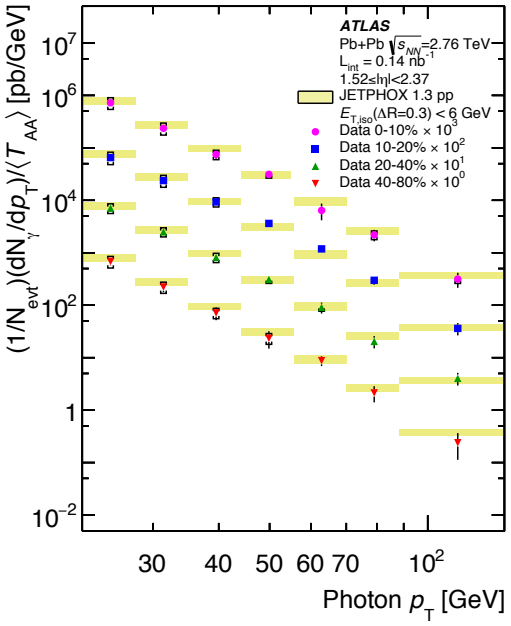


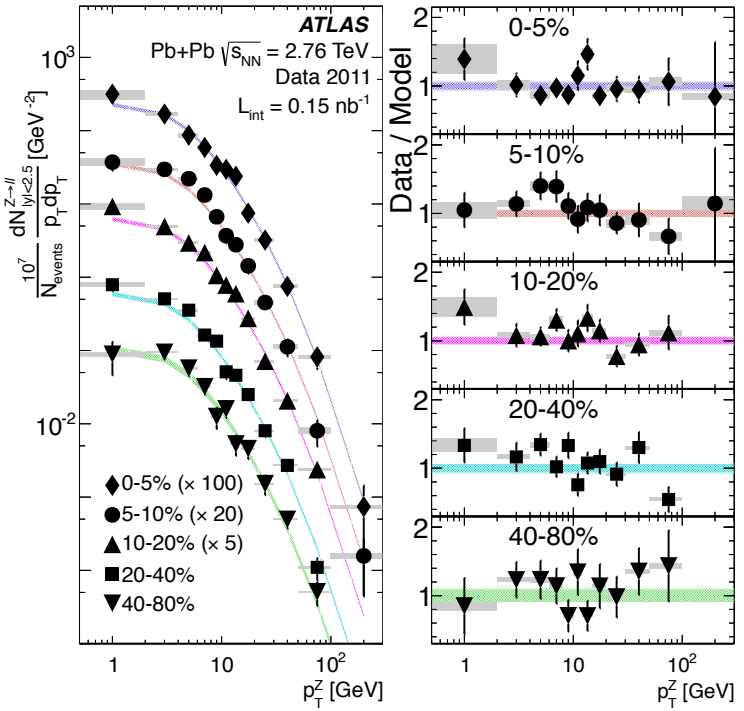


Photon and Z spectra in Pb+Pb collisions

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



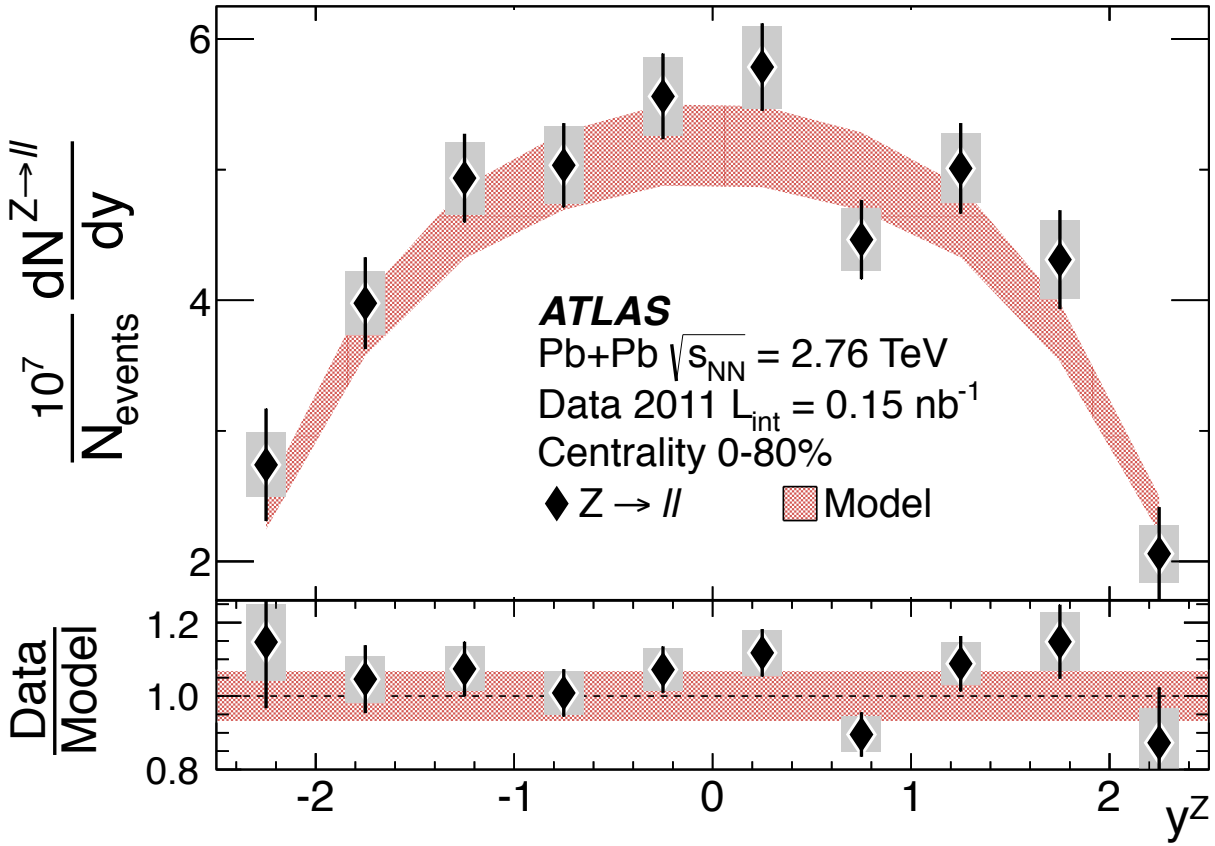




- Good agreement between models and data

Z bosons in Pb+Pb collisions

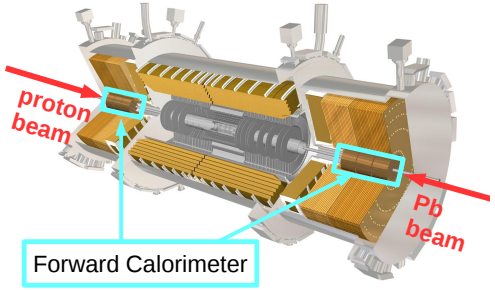
Phys. Rev. Lett. 110,022301 (2013)



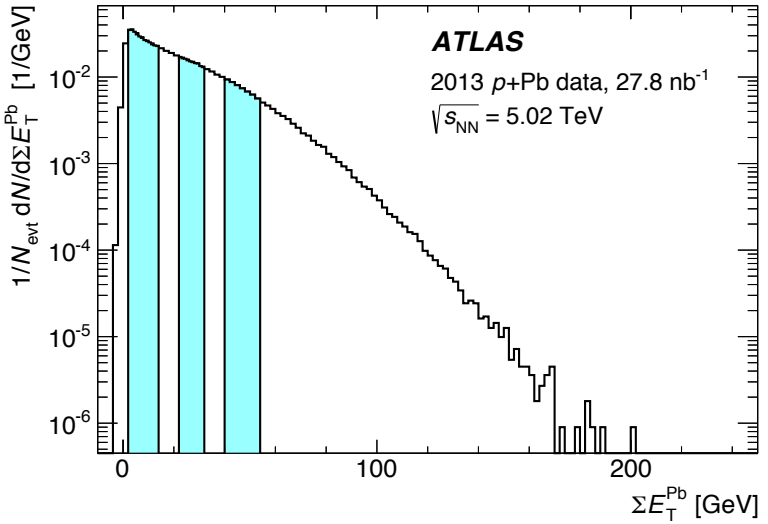
- Good agreement between models and data

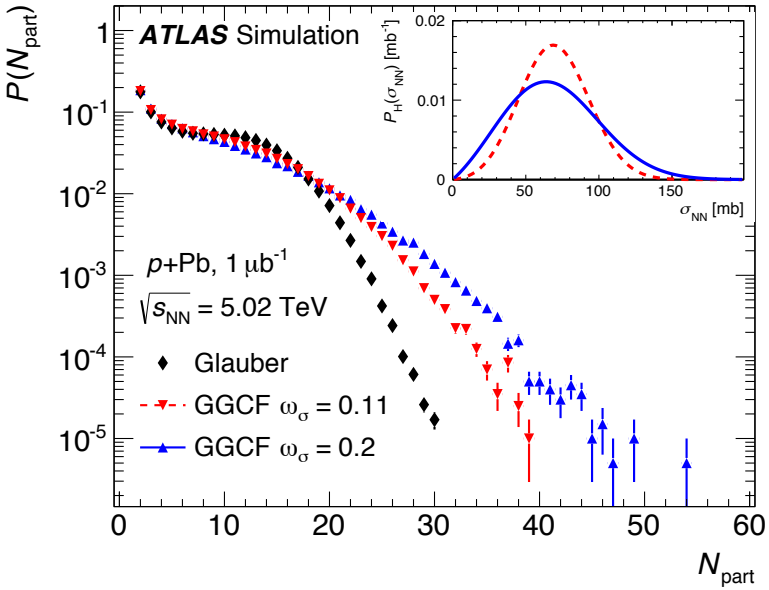
Details on centrality in p+Pb collisions

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



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

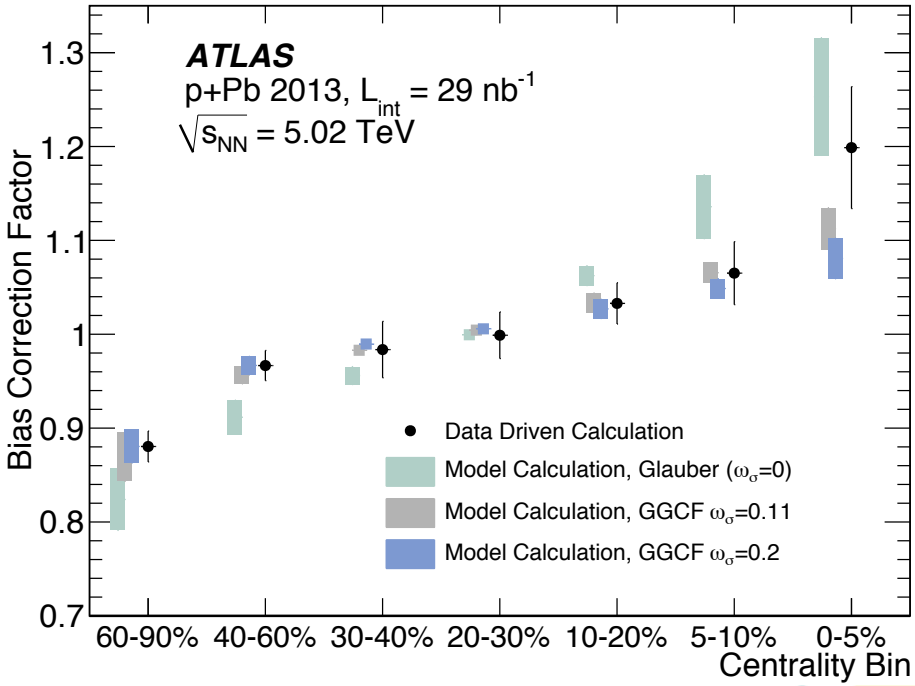




Centrality bias corrections in p+Pb collisions

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

- Centrality bias: Increase of Underlying event in hard scatterings



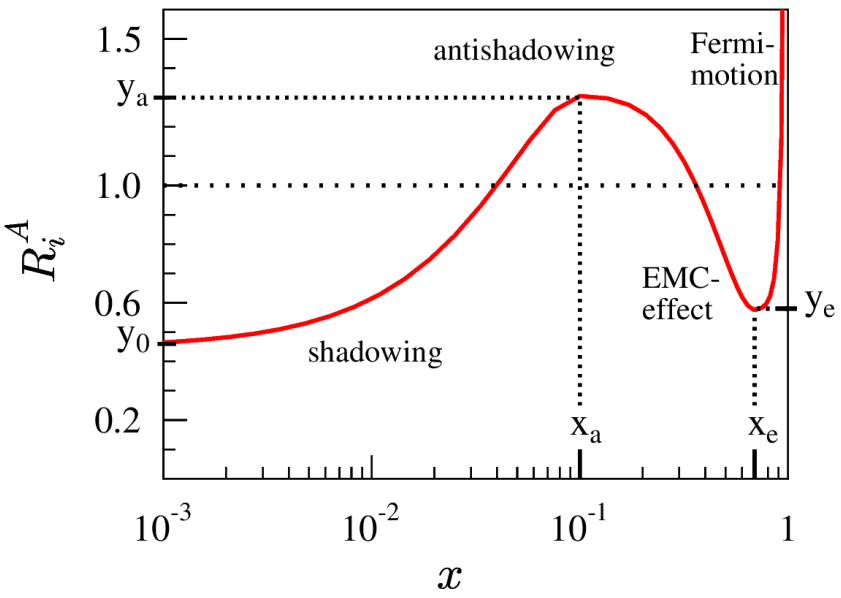
- Process independent correction factor from model calculations and data-driven measurements

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

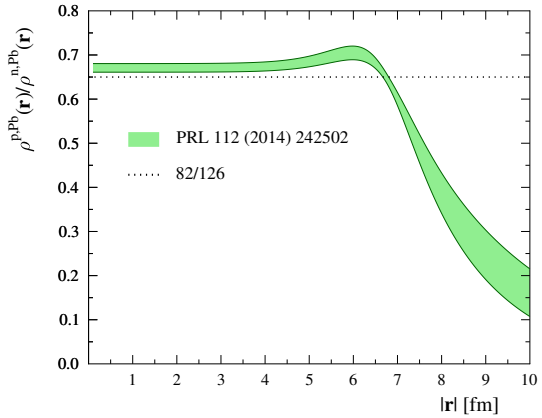
- Medium modified PDFs
- NLO, constrained by DIS on nuclei, Drell-Yan in p+A, incl. pion production in pp and d+Au

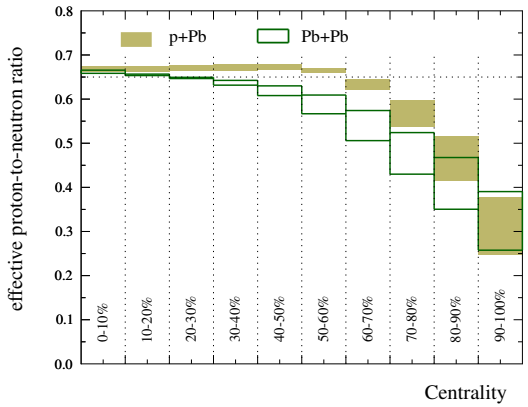


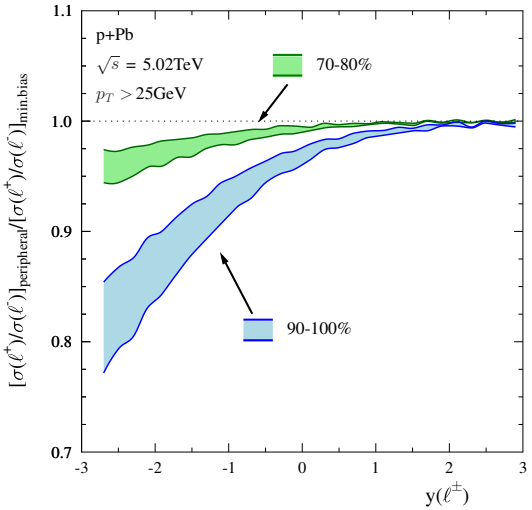
$$f_i^A(x,Q^2) \equiv R_i^A(x,Q^2) f_i^{\mathrm{CTEQ6.1M}}(x,Q^2)$$

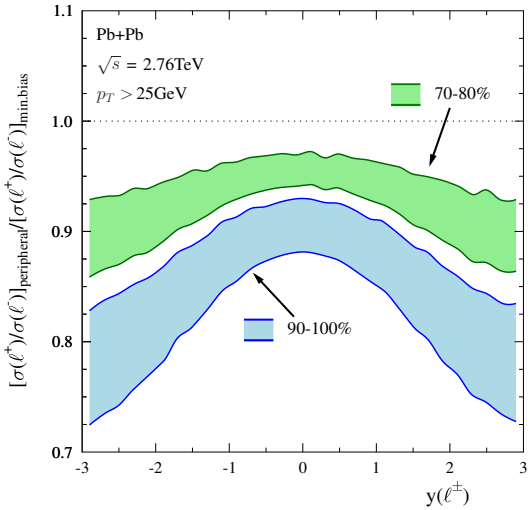
Potential neutron skin measurements

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





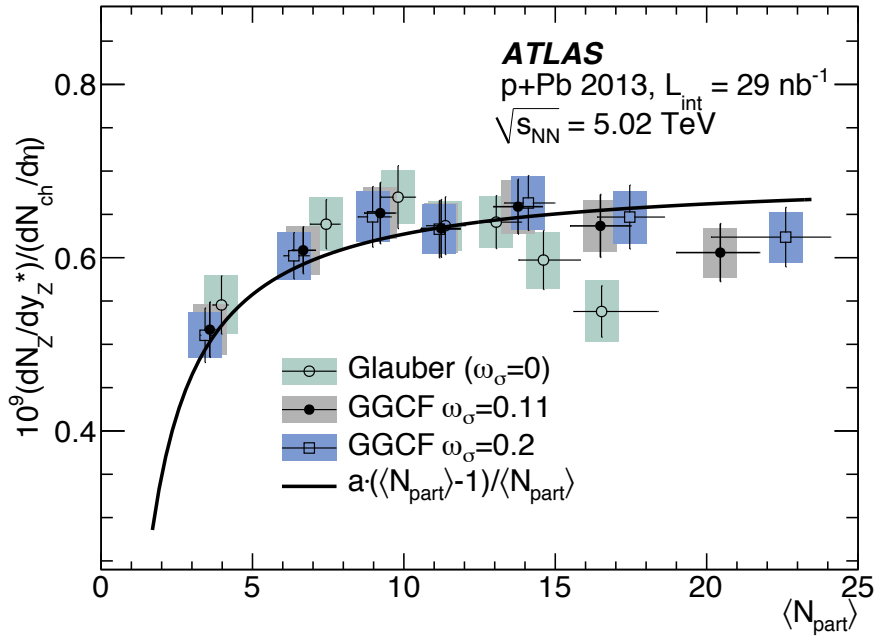




- $W^{\pm}$ production sensitive to isospin of colliding quarks
- Neutron skin would have measurable impact on W production in peripheral collisions

Z bosons vs charged particles in p+Pb collisions

Phys. Rev. C 92, 044915 (2015)

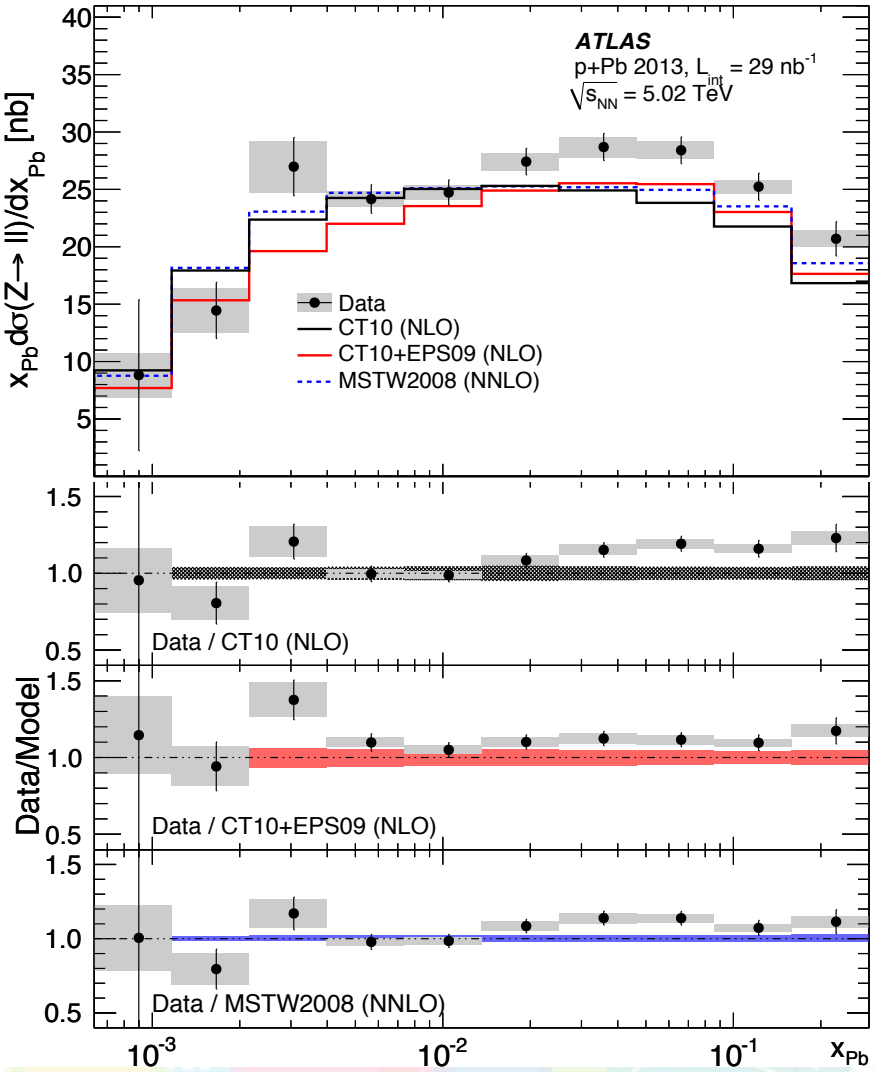


- Ratio of multiplicities of Z bosons and inclusive charged particles

Z bosons in p+Pb collisions

Phys. Rev. C 92, 044915 (2015)

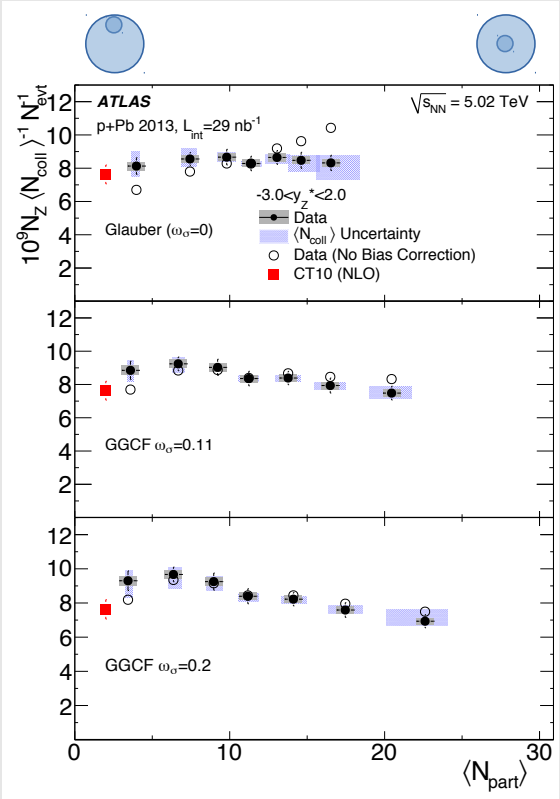
$$x_{\mathrm{Pb}} = \frac{M_Z \exp\left(-y_Z^*\right)}{\sqrt{s_{\mathrm{NN}}}}$$



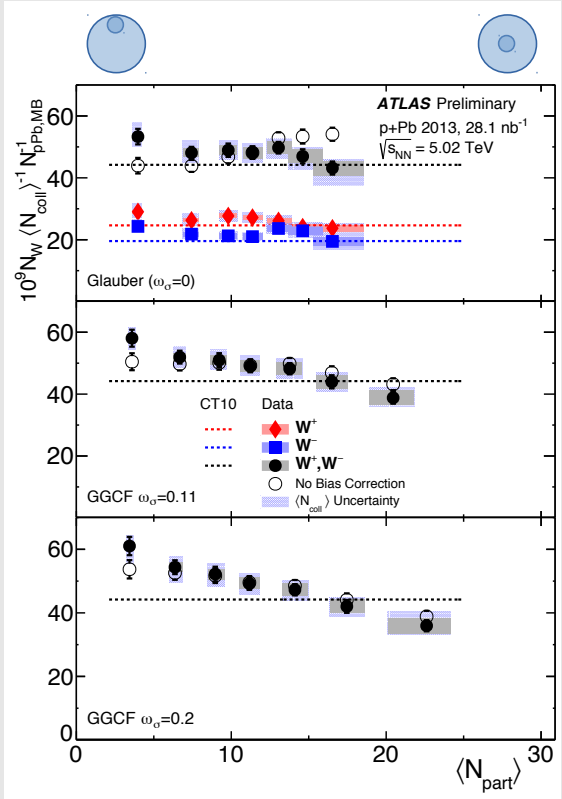
Binary collision scaling in p+Pb collisions

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

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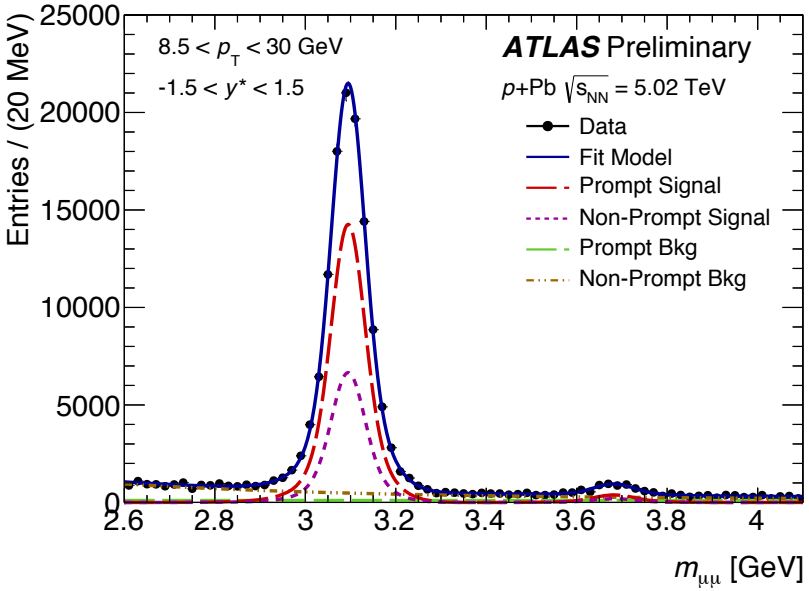
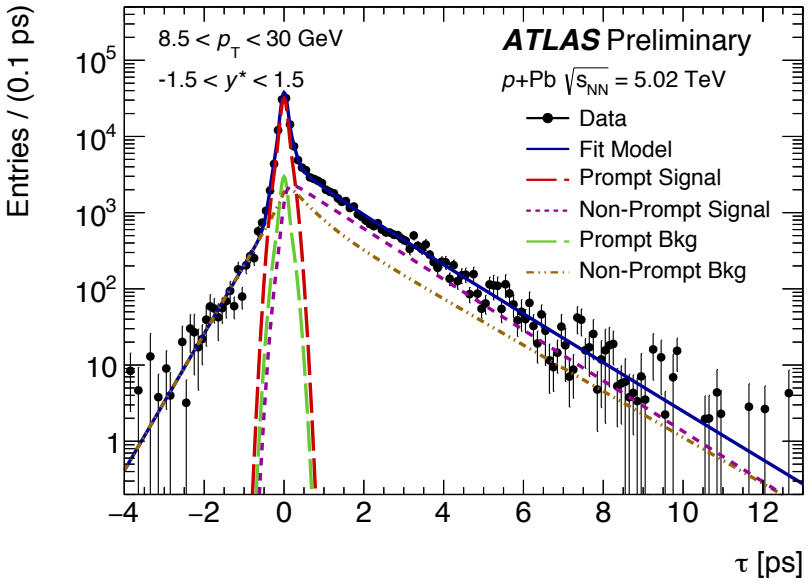
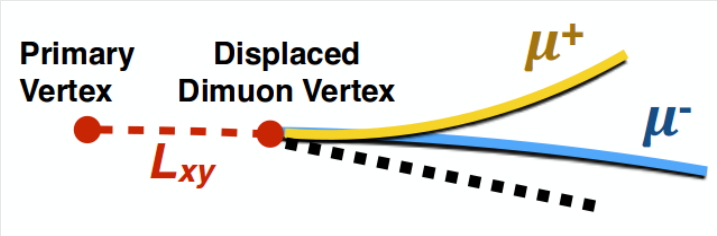




Prompt and non-prompt $\psi(nS)$

- 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

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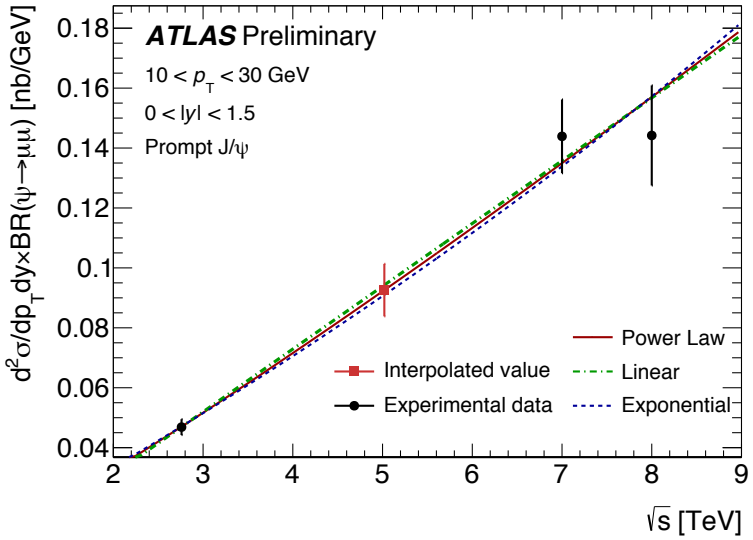

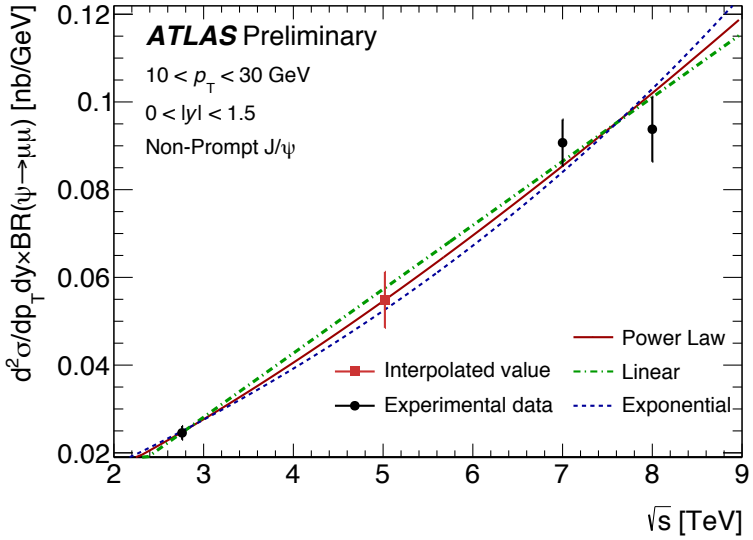

$$\sigma(\sqrt{s}) = \begin{cases} p_0 + p_1\sqrt{s}, & \text{linear} \\ (\sqrt{s}/p_0)^{p_1}, & \text{power law} \\ p_0\left(1 - \exp(-\sqrt{s}/p_1)\right), & \text{exponential.} \end{cases}$$