

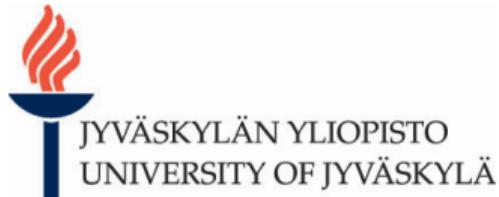
Evidence of shadowing in inelastic nucleon-nucleon cross section [from EW-boson production]

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Based on arXiv:2003.11856 with
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Motivation

Introduction

- ▶ Electroweak boson production in heavy-ion collisions¹ is a “standard candle” for testing factorization in nuclear collisions
- ▶ We consider the recent analyses² of W^\pm and Z production by ATLAS for Pb+Pb data at LHC Run II, $\sqrt{s_{nn}} = 5.02$ TeV
- ▶ The nuclear modification factor is experimentally defined as

$$R_{\text{PbPb}}^{\text{exp}}(y) = \frac{1}{\langle T_{AA} \rangle} \frac{\frac{1}{N_{\text{evt}}} dN_{\text{PbPb}}^{W^\pm, Z} / dy}{d\sigma_{\text{pp}}^{W^\pm, Z} / dy}$$

- ▶ $\langle T_{AA} \rangle = \langle N_{\text{bin}} \rangle / \sigma_{\text{nn}}^{\text{inel}}$, where $\langle N_{\text{bin}}(\sigma_{\text{nn}}^{\text{inel}}) \rangle$ is from a MC Glauber model calculation
- ▶ ATLAS and others use $\sigma_{\text{nn}}^{\text{inel}} = 70$ mb, from a fit to proton-proton data

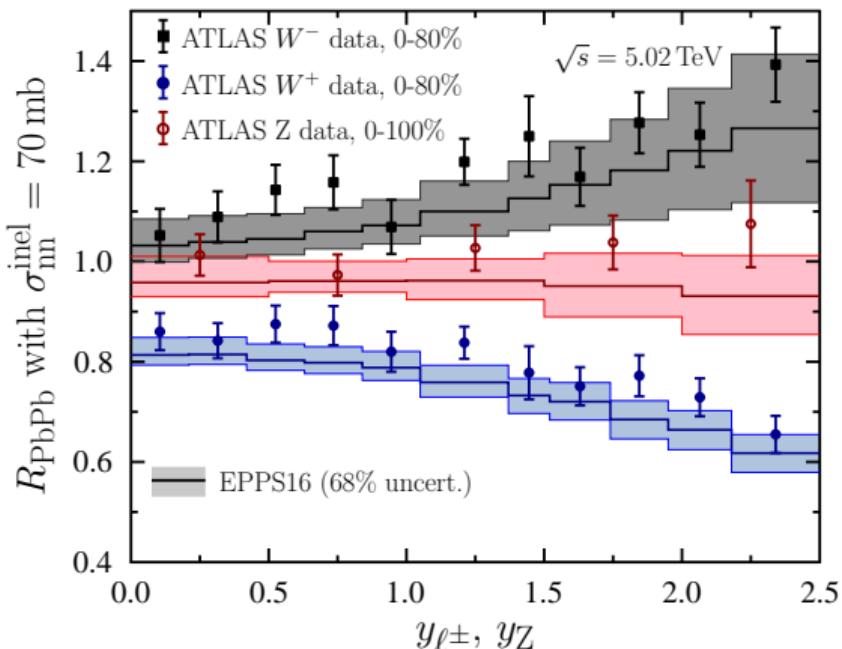
¹H. Paukkunen and C. A. Salgado, JHEP **03**, 071 (2011)

²G. Aad *et al.* (ATLAS), Eur. Phys. J. **C79**, 935 (2019)

G. Aad *et al.* (ATLAS), Phys. Lett. B **802** (2020) 135262

Motivation

R_{PbPb} from ATLAS

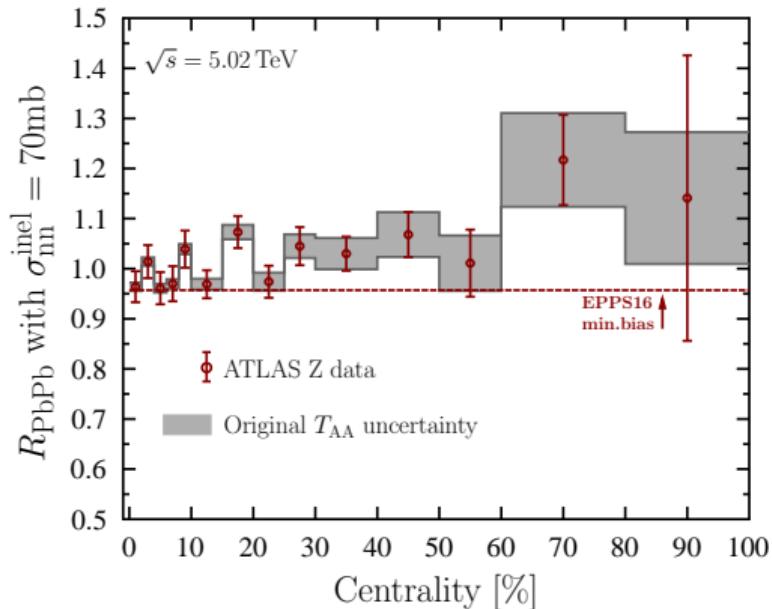
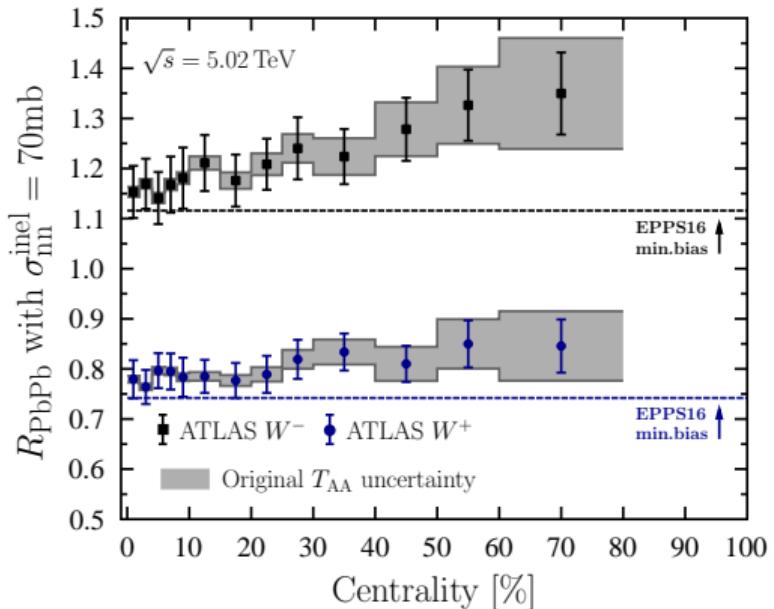


$$R_{\text{PbPb}}^{\text{theor}}(y) = \frac{1}{(208)^2} \frac{d\sigma_{\text{PbPb}}^{W^\pm, Z}/dy}{d\sigma_{\text{pp}}^{W^\pm, Z}/dy}$$

- ▶ The calculations in NNLO pQCD with NNPDF3.1 proton PDFs and EPPS16 nuclear modifications, a theory standard candle
- ▶ NNPDF3.1 PDFs match ATLAS data for W^\pm and Z in $p+p$ at $\sqrt{s} = 5.02 \text{ TeV}$ very well. On the other hand, EPPS16 matches $p+\text{Pb}$ results very well.
- ▶ $R_{\text{PbPb}}^{\text{exp}}$ lies slightly, but clearly, above the calculated result
- ▶ Our suggestion: Use these data to calibrate the Glauber model!

Motivation

R_{PbPb} from ATLAS as a function of centrality

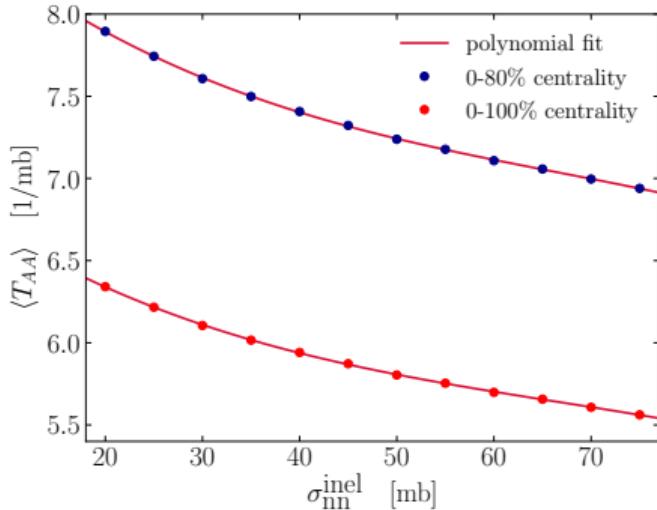


- ▶ Anomalously strong centrality dependence?

Nuclear suppression of $\sigma_{\text{nn}}^{\text{inel}}$

What is the normalization preferred by the data?

- MC Glauber model maps $\sigma_{\text{nn}}^{\text{inel}}$ to $\langle T_{AA} \rangle$ for each centrality class
- We find the best fit for $\sigma_{\text{nn}}^{\text{inel}}$ by requiring re-normalized $R_{\text{PbPb}}^{\text{exp}}$ to match $R_{\text{PbPb}}^{\text{theor}}$



$$R_{\text{PbPb}}^{\text{exp}} = \frac{1}{\langle T_{AA}(\sigma_{\text{pp}}^{\text{inel}}) \rangle} \frac{\frac{1}{N_{\text{evt}}} dN_{\text{PbPb}}^{W^\pm, Z} / dy}{d\sigma_{\text{pp}}^{W^\pm, Z} / dy}$$

$$R_{\text{PbPb}}^{\text{theor}} = \frac{1}{(208)^2} \frac{d\sigma_{\text{PbPb}}^{W^\pm, Z} / dy}{d\sigma_{\text{pp}}^{W^\pm, Z} / dy}$$

$$\chi^2 = \sum_i \left[\frac{R_i^{\text{exp}} \times \frac{\langle T_{AA}(\sigma_{\text{pp}}^{\text{inel}}) \rangle}{\langle T_{AA}(\sigma_{\text{nn}}^{\text{inel}}) \rangle} - R_i^{\text{theor}} + \sum_k f_k \beta_i^k}{\delta_i^{\text{exp}} \times \frac{\langle T_{AA}(\sigma_{\text{pp}}^{\text{inel}}) \rangle}{\langle T_{AA}(\sigma_{\text{nn}}^{\text{inel}}) \rangle}} \right]^2 + T \sum_k f_k^2,$$

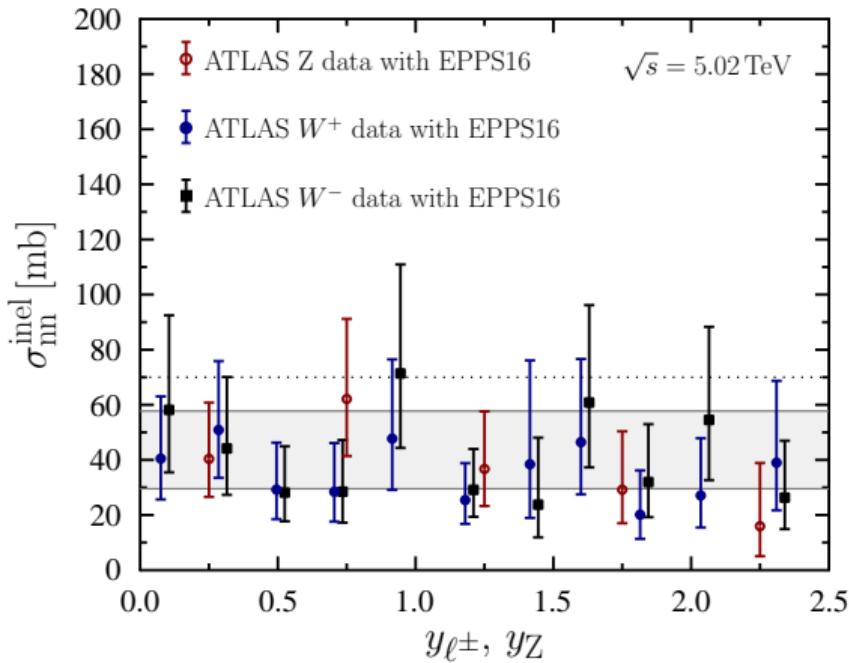
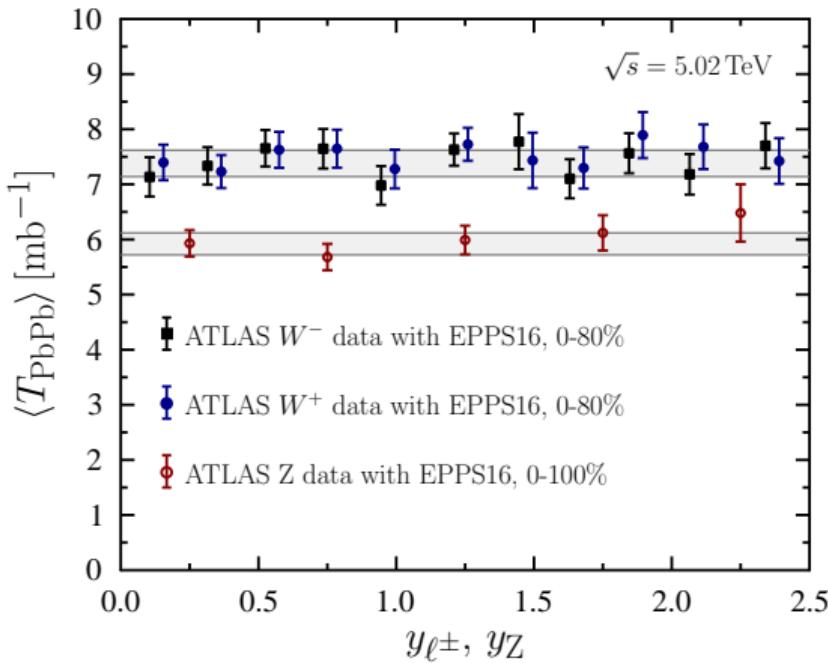
$$\beta_i^k \equiv \frac{1}{2} \left[R_i^{\text{theor}}(S_k^+) - R_i^{\text{theor}}(S_k^-) \right]$$

TGlauberMC v 2.4
[SoftwareX 1-2 (2015) 13-18]

Results

arXiv:2003.11856

Fitted normalization

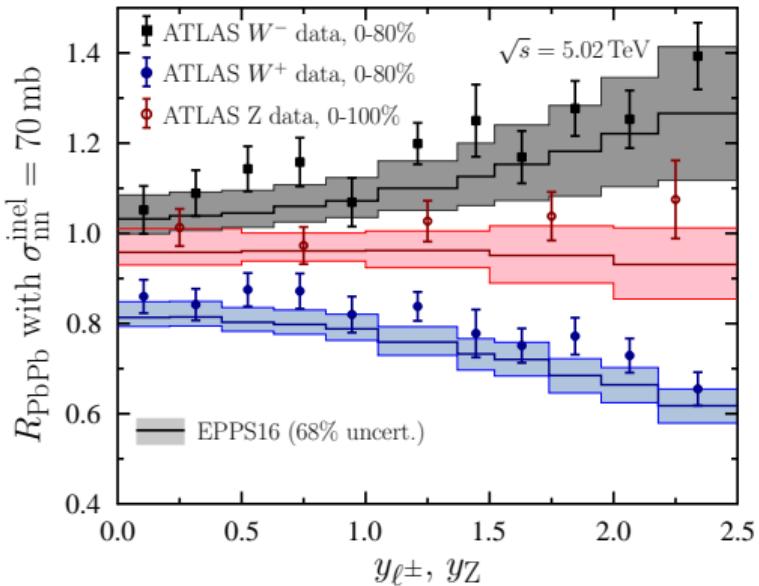


- ▶ Data points here obtained by equating $R_{\text{PbPb}}^{\text{exp}}$ and $R_{\text{PbPb}}^{\text{theor}}$, and solving for $\langle T_{AA} \rangle$
- ▶ $\sigma_{\text{nn}}^{\text{inel}} = 70 \pm 5 \text{ mb} \rightarrow 41.5^{+16.2}_{-12.0} \text{ mb}$

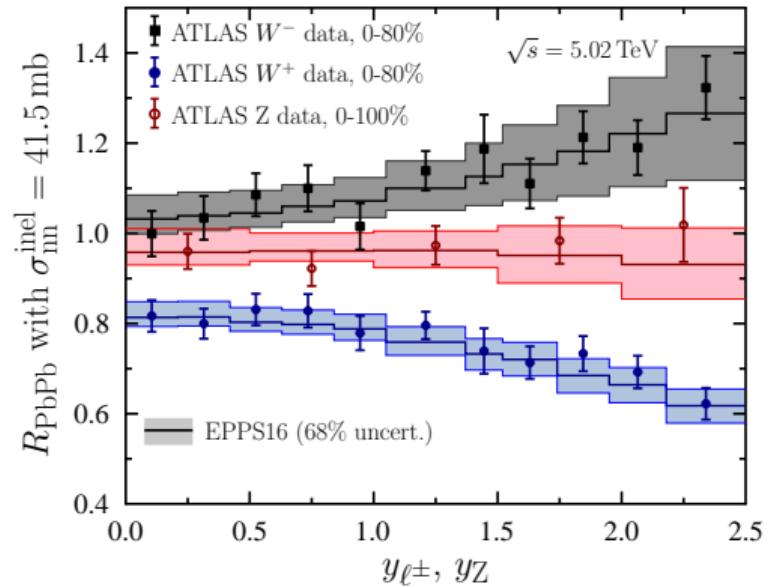
Results

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Re-normalized R_{PbPb}



The original ATLAS data with
 $\sigma_{\text{nn}}^{\text{inel}} = 70 \text{ mb}$

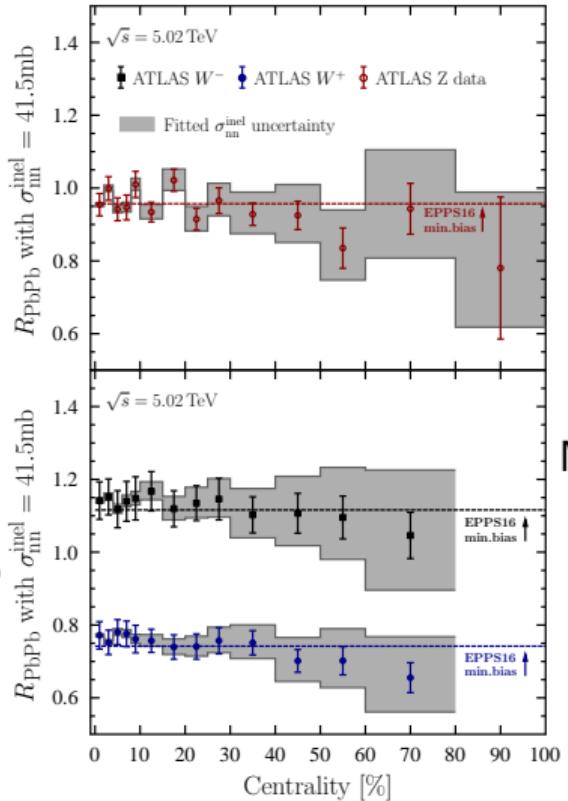
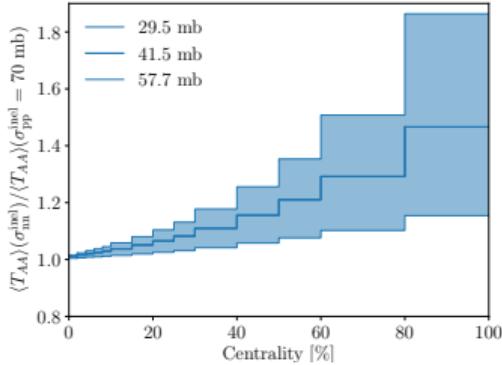
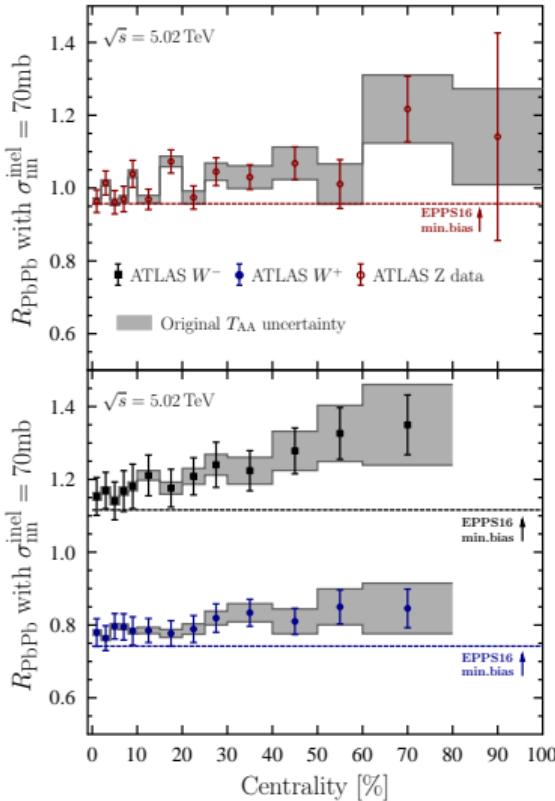


Data re-normalized using the central fit
value of $\sigma_{\text{nn}}^{\text{inel}} = 41.5 \text{ mb}$

Results

arXiv:2003.11856

Re-normalized R_{PbPb} as a function of centrality



Nuclear suppression of $\sigma_{\text{nn}}^{\text{inel}}$ from eikonal minijet model

- ▶ Can the large suppression of $\sigma_{\text{nn}}^{\text{inel}}$ be explained?
- ▶ In an eikonal minijet model, $\sigma_{\text{nn}}^{\text{inel}}$ in AA can be calculated using nuclear PDFs (no soft component here):

$$\sigma_{\text{nn}}^{\text{inel}}(s; p_0, \lambda, [Q]) = \pi \int_0^\infty \left(1 - e^{-\sigma_{\text{jet}}(s, p_0, [Q]) T_{\text{pp}}(b, \lambda)}\right) db^2,$$

$$\sigma_{\text{jet}}(s; p_0, [Q]) = \int_{p_0} \sum_{ijkl} f_i(Q) \otimes f_j(Q) \otimes \hat{\sigma}_{ij \rightarrow kl}(Q),$$

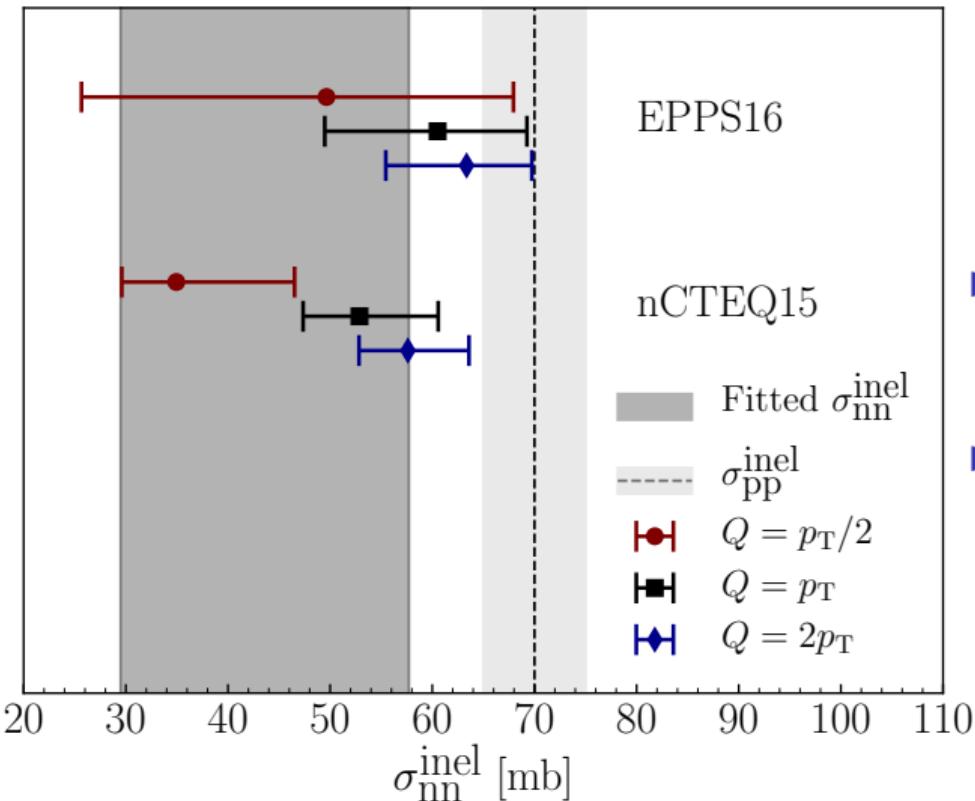
$$T_{\text{pp}}(b, \lambda) = \frac{1}{4\pi\lambda^2} e^{-\frac{b^2}{4\lambda^2}}$$

- ▶ Fix p_0, λ from proton-proton data using $\sigma_{\text{pp}}^{\text{inel}}$ and $\sigma_{\text{pp}}^{\text{tot}}$
- ▶ Compute $\sigma_{\text{nn}}^{\text{inel}}(s; p_0, \lambda, [Q])$ for AA with nPDFs from EPPS16 and nCTEQ15 analyses

Results

arXiv:2003.11856

Nuclear suppression of $\sigma_{\text{nn}}^{\text{inel}}$ from eikonal minijet model



- ▶ The error bands represent the 68% confidence limit uncertainties of nPDF sets
- ▶ Both nPDF sets are in line with the suppression obtained from the fits with ATLAS data

Summary

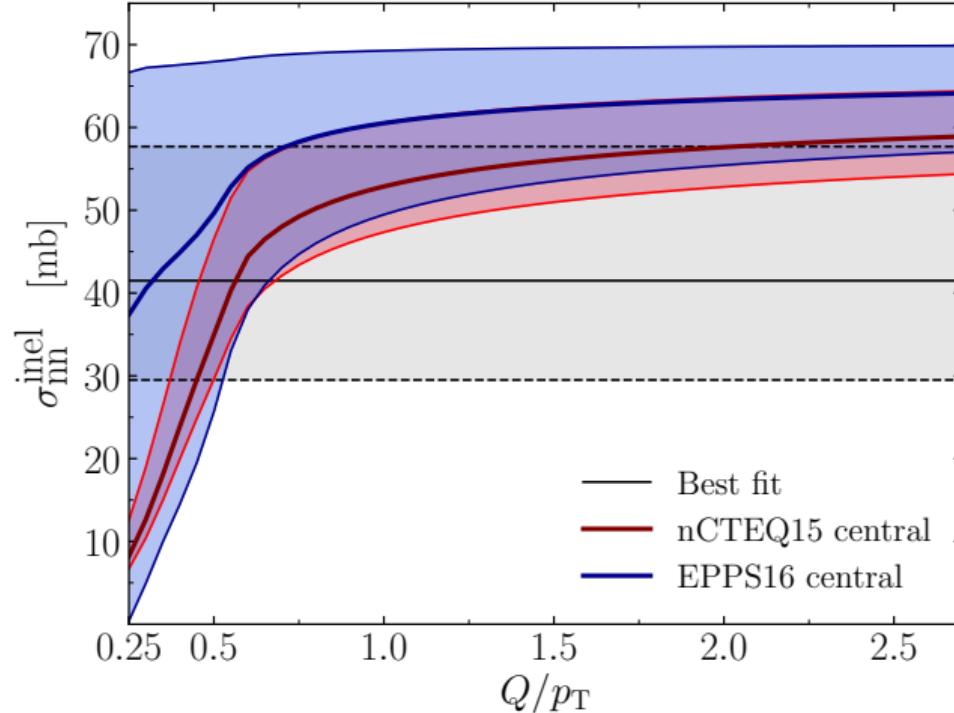
- ▶ We have compared the state-of-the art calculation to the measured W^\pm and Z boson $R_{\text{PbPb}}^{W^\pm, Z}$ to obtain the nuclear-suppressed value for $\sigma_{\text{nn}}^{\text{inel}}$ at $\sqrt{s_{\text{nn}}} = 5.02 \text{ TeV}$
- ▶ The recent high-precision ATLAS EW data from LHC run II prefer a significantly suppressed $\sigma_{\text{nn}}^{\text{inel}}$

$$\sigma_{\text{nn}}^{\text{inel}} = 70 \pm 5 \text{ mb} \rightarrow 41.5_{-12.0}^{+16.2} \text{ mb}, \quad \langle T_{\text{AA}}^{0-100\%} \rangle = 5.61 \pm 0.06 \frac{1}{\text{mb}} \rightarrow 5.923_{-0.197}^{+0.195} \frac{1}{\text{mb}}$$

- ▶ This change in $\sigma_{\text{nn}}^{\text{inel}}$ would affect all the extractions and analyses of R_{AA} by the change in $\langle T_{\text{AA}} \rangle$
- ▶ The amount of suppression in $\sigma_{\text{nn}}^{\text{inel}}$ is consistent with nuclear shadowing of PDFs in the eikonal minijet model calculation

EXTRAS

Nuclear suppression of $\sigma_{\text{nn}}^{\text{inel}}$ from eikonal minijet model



Eikonal minijet model

$$\sigma_{\text{el}} = \pi \int_0^{\infty} \left(1 - e^{-\chi(b,s)}\right)^2 db^2$$

$$\sigma_{\text{in}} = \pi \int_0^{\infty} \left(1 - e^{-2\chi(b,s)}\right) db^2$$

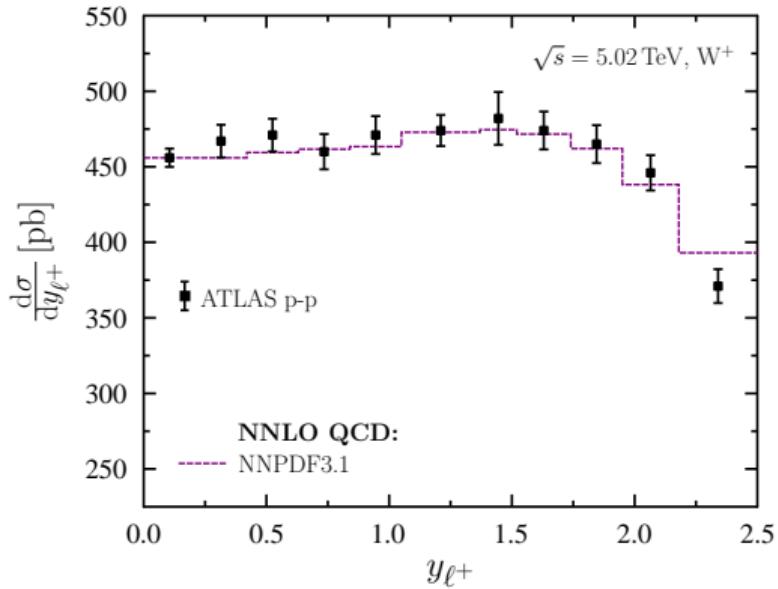
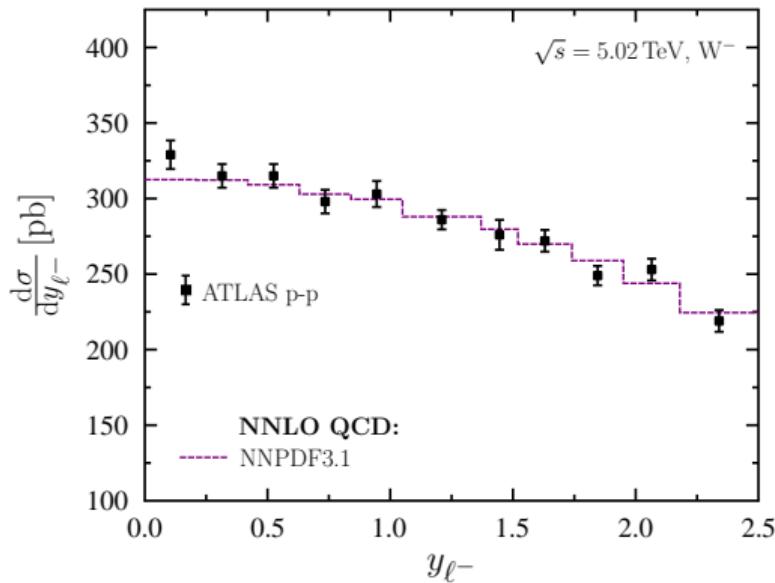
$$\sigma_{\text{tot}} = 2\pi \int_0^{\infty} \left(1 - e^{-\chi(b,s)}\right) db^2$$

$$\chi(b, s) \equiv \frac{1}{2k} \int_{-\infty}^{\infty} U(b, z) dz$$

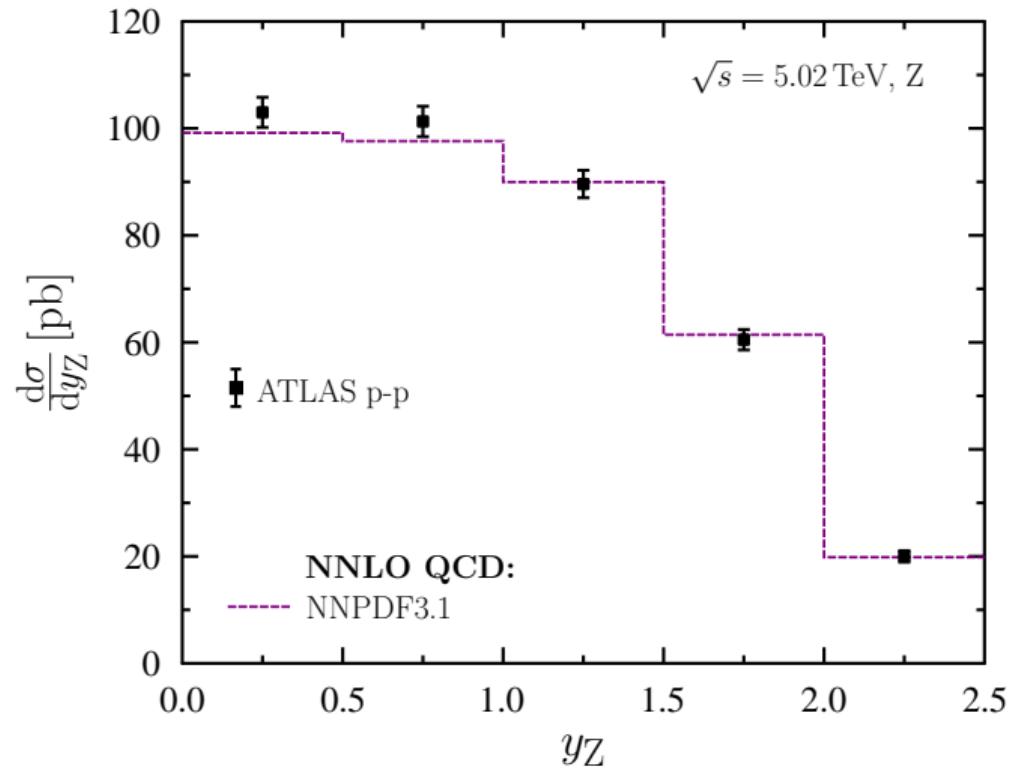
$$2\chi(b, s) = \sigma_{\text{jet}}(s, k_0) T_{\text{pp}}(b)$$

$$T_{\text{pp}}(b) = \frac{1}{4\pi\sigma^2} e^{-\frac{b^2}{4\sigma^2}},$$

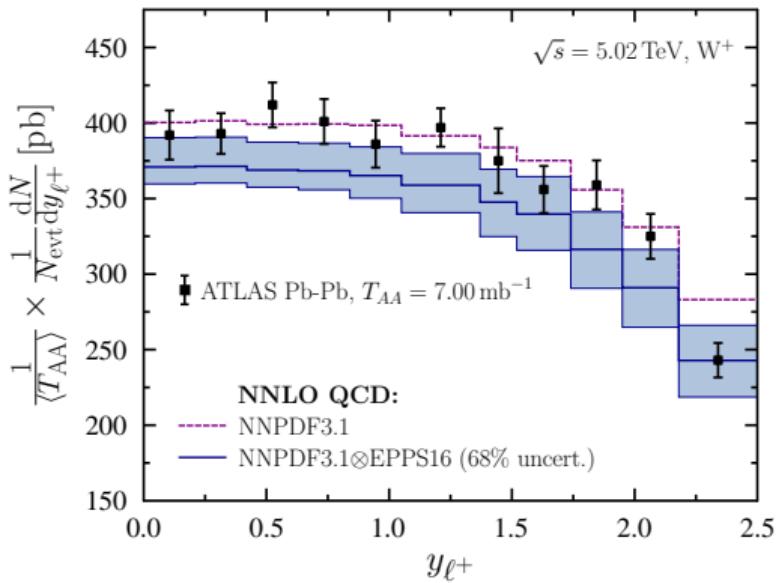
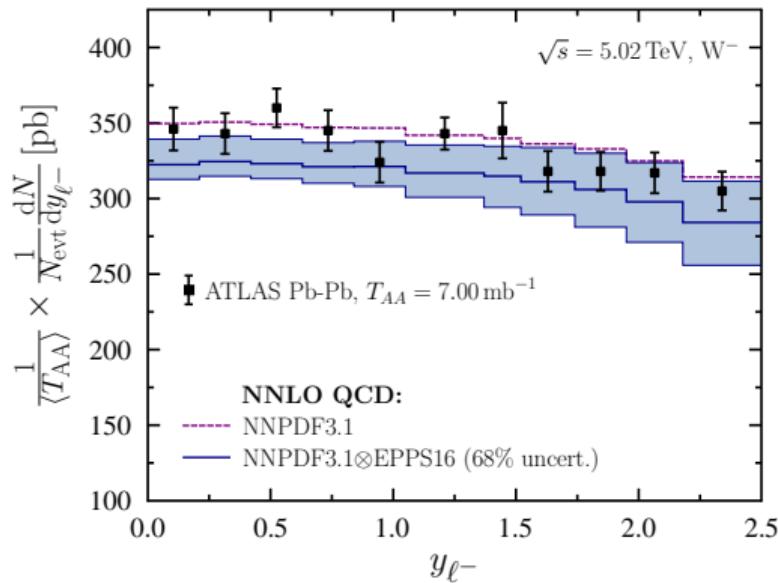
W in pp



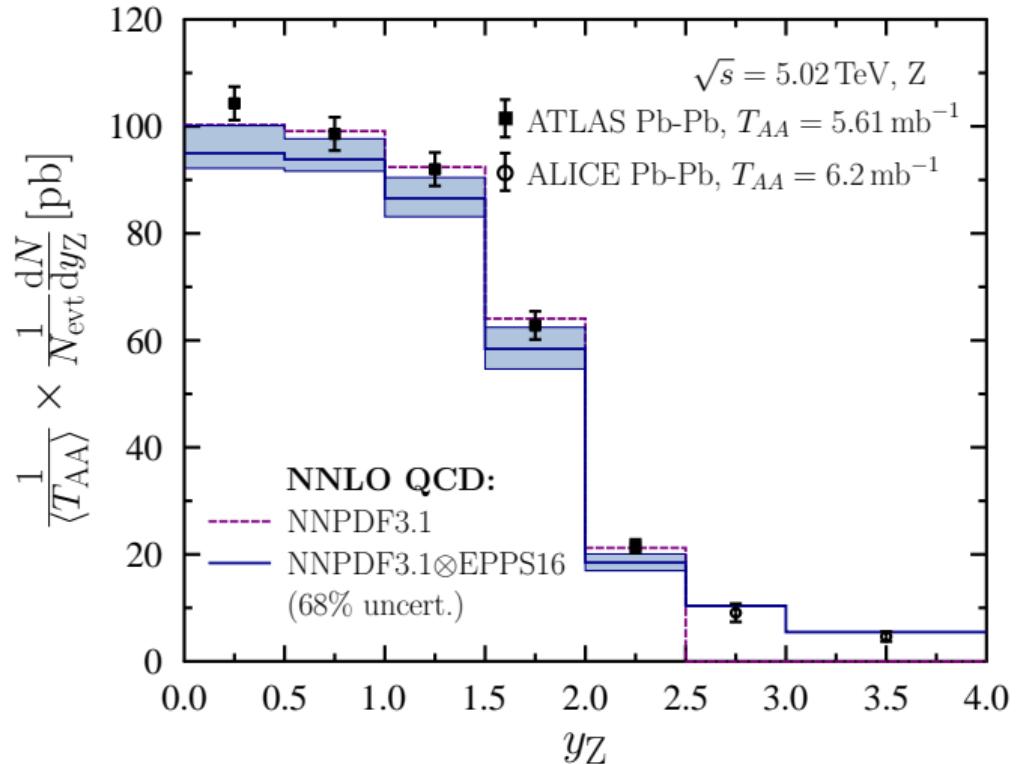
Z in pp



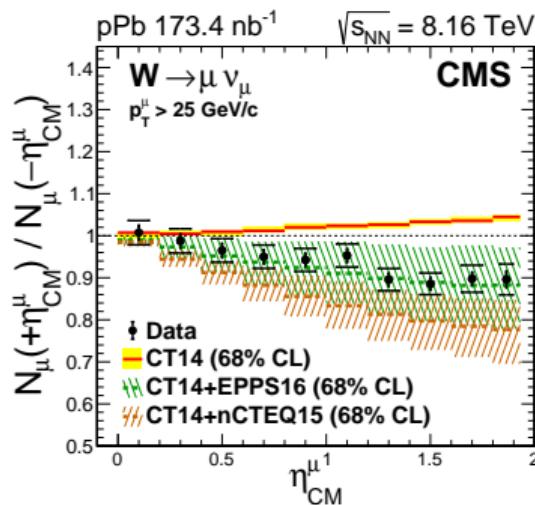
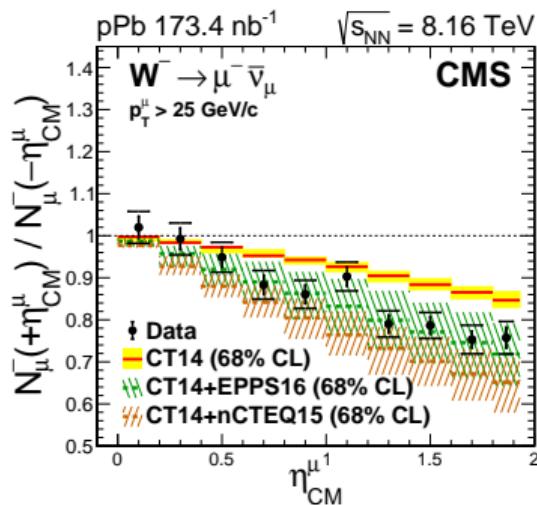
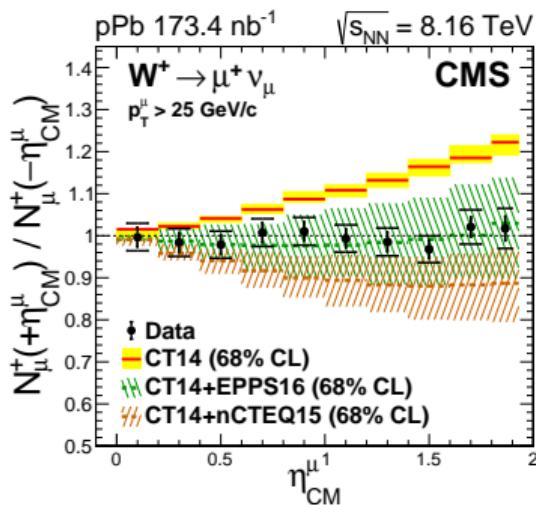
W in PbPb without corrections



Z in PbPb without corrections



Forward-backward ratios in muons at $\sqrt{s} = 8.16$ TeV



CMS collaboration, Phys.Lett.B 800 (2020) 135048