Electroweak-boson production from small to large collision systems with ALICE at the LHC

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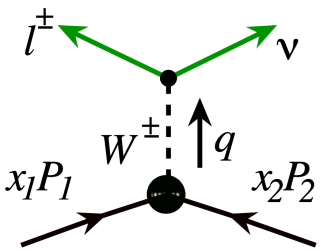
Physics motivation

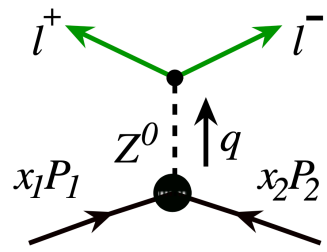
Z and W bosons:

- Production in Drell-Yan process:
  - Heavy mass, produced in the hard processes, during the initial stages of the collision.
  - Weakly interacting particles.
  - QCD factorization:

$$\sigma_{AB} \propto \sum_q \frac{4\pi e_q^2 \alpha^2}{9\hat{s}} f_q(x_1, Q^2) f_{\bar{q}}(x_2, Q^2)$$

- Leptonic decay: insensitive to the strongly-interacting medium.



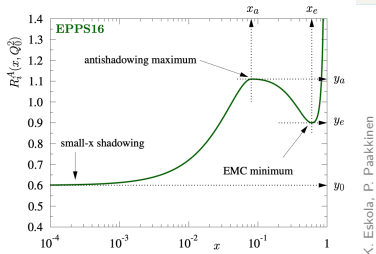


J. C. Peng and J. W. Qiu
The Universe 4 (2016) 3, 34-44

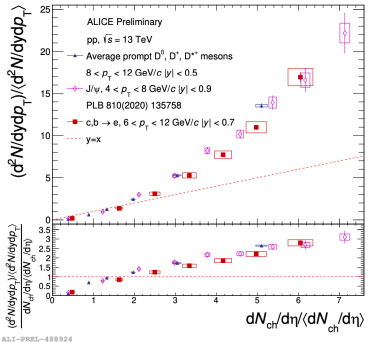
Physics motivation

Measurements in p–Pb and Pb–Pb collisions:

- Parton Distribution Function (PDF) is modified by nuclear effects.
  - Robust understanding of nuclear PDF (nPDF) is crucial to all the heavy-ion measurements.



K. Eskola, P. Paakkinen
H. Paukkuuen, C. Salgado
EPJC (2017) 77:163

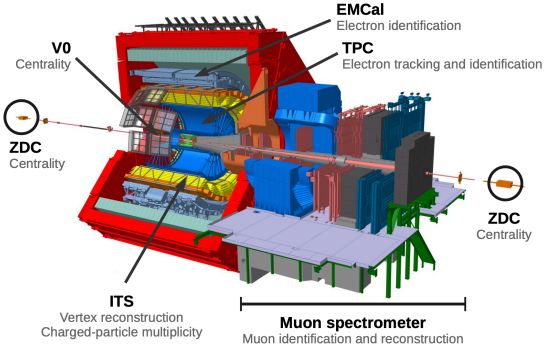


Measurements in pp collisions:

- Probe of particle production mechanism in pp collisions.
  - Observed heavy-flavour production faster than linear w.r.t. charge particle multiplicity. Studying the W production w.r.t. multiplicity helps to investigate the origin of the increasing trend.

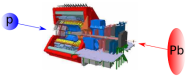
S. G.Weber,A. Dubla, A.Andronic, and A. Morsch
EPJC (2019) 79:36

The ALICE detector



pp: Electrons reconstructed in the central barrel ($|\eta| < 0.6$).
p–Pb and Pb–Pb: Muons reconstructed in the forward spectrometer ($-4 < \eta < -2.5$). Probing of the low ($\sim 10^{-4}$ to $\sim 10^{-3}$) and high ($\sim 10^{-1}$ to almost unity) Bjorken-x regions.

p–Pb, p-going:

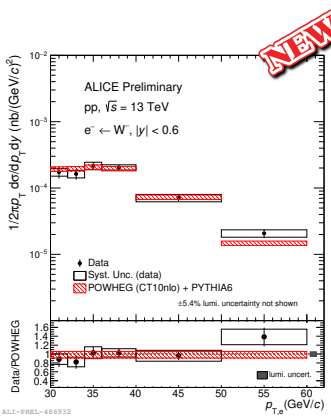


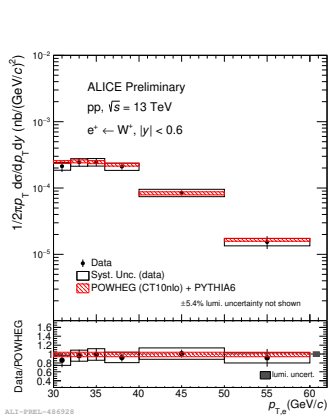
$2.03 < y_{\mathrm{cms}} < 3.53$

p–Pb, Pb-going:

$-4.46 < y_{\mathrm{cms}} < -2.96$

$W^{\pm}$ in pp at 13 TeV





$e^- \leftarrow W^-$ $e^+ \leftarrow W^+$

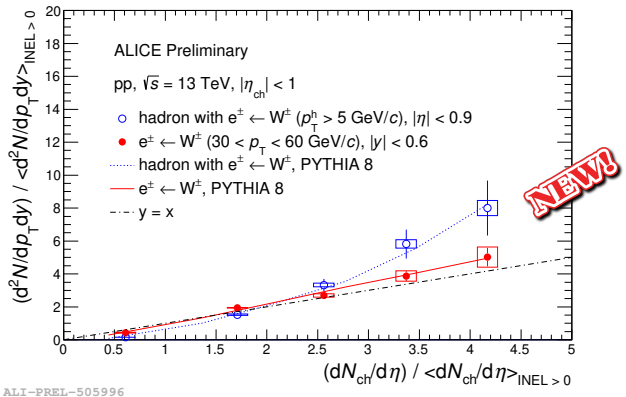
p_T-differential cross sections

- Isolated electron:
  - $|y| < 0.6$
  - $30 < p_T < 60\,\mathrm{GeV}/c$
  - $E_{\mathrm{iso}} = E_{R=0.3}/E_e < 0.05\,\mathrm{GeV}/c^2$
- Consistent with pQCD (POWHEG + CT10nlo) prediction.

POWHEG: JHEP 06(2010)043

CT10: PRD 82(2010)074024

$W^{\pm}$ in pp at 13 TeV

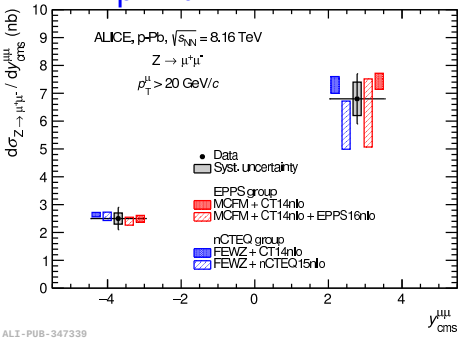


Multiplicity dependent yield

- W boson yield is linear w.r.t. multiplicity while W with associated hadron yield increases faster than linear.
  - W: Large Q^2, single track in final state, colorless: no strong autocorrelation.
- Well reproduced with PYTHIA 8 with multiple particle interaction and color reconnection.

Z production in p–Pb and Pb–Pb

p–Pb



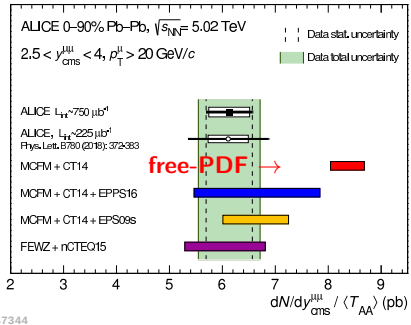
ALI-PUB-347339

Cross sections, compatible with predictions with and without nuclear modifications.

CT14: Phys. Rev. D 93, 033006 (2016)
EPS09: JHEP 07(2012)073
EPPS16: EPJC(2017) 77:163
nCTEQ15: Phys. Rev. D 93, 085037 (2016)
MCFM: EPJC 77(2017)7
FEWZ: Comp. Phys. Comm. 182(2011)2388-2403

Pb–Pb

JHEP 09(2020)076



ALI-PUB-347344

$\langle T_{AA} \rangle$-scaled yield

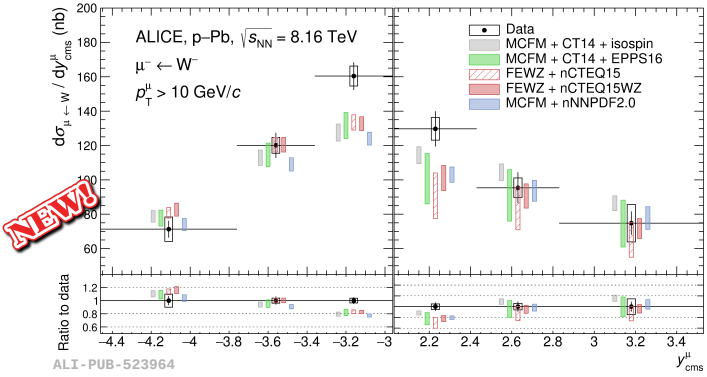
- Compatible with calculations including nPDFs using three different models,
- 3.4σ deviation from free-PDF prediction with CT14.

$W^{\pm}$ in p–Pb at 8.16 TeV

Differential cross sections as a function of rapidity, compared to theoretical predictions.

- All models underestimate data for bins closest at midrapidity
  - Both at forward and backward (1.4 and 2σ from EPPS16 predictions).
  - Powerful to constrain Bjorken-x dependent PDFs and nPDFs.

W^- Pb-going W^- p-going

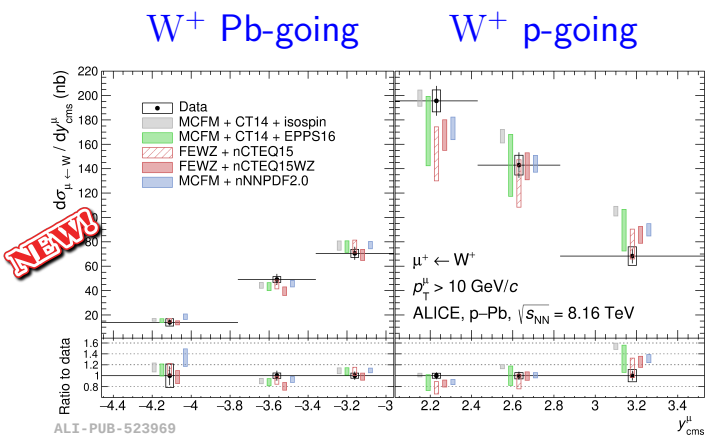


arXiv:2204.10640[nucl-ex]
nCTEQ15WZ: EPJC 80(2020)968
nNNPDF2.0: JHEP 09(2020)183

$W^{\pm}$ in p–Pb at 8.16 TeV

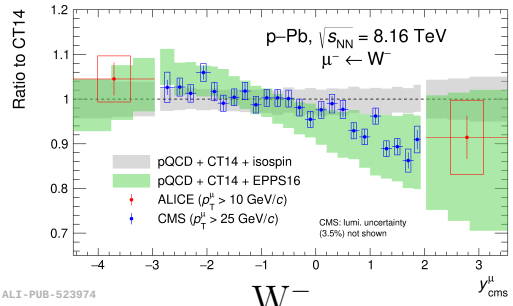
Differential cross sections as a function of rapidity, compared to theoretical predictions.

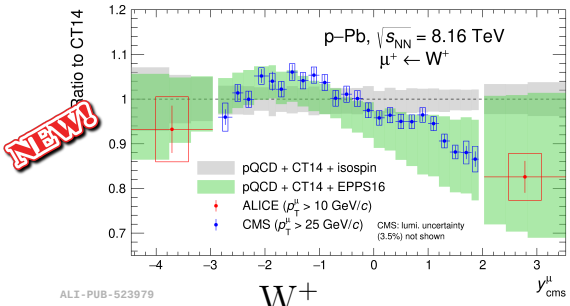
- 3.5σ deviation from free-PDF calculation for W^+ at forward rapidity for the bin at largest rapidity



$W^{\pm}$ in p–Pb at 8.16 TeV

Comparison with CMS results at midrapidity (PLB 800(2020)135048). arXiv:2204.10640[nucl-ex]

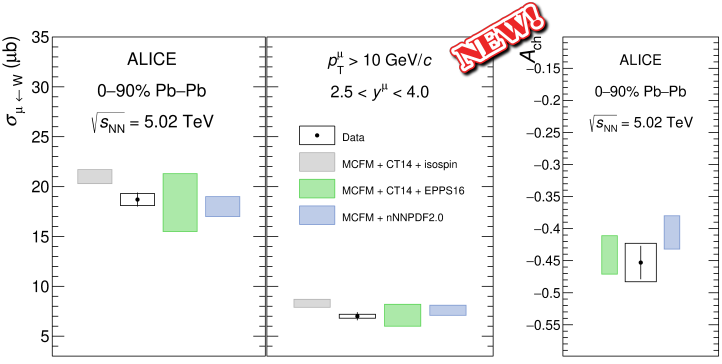




- Cross section ratio to CT14 eliminates the effects of different p_T cuts between ALICE and CMS. The ratio encodes the effects of the nuclear modifications.
- ALICE results in agreement with the trend at the edges of the CMS acceptance. In agreement with the trend predicted by EPPS16.

$W^{\pm}$ in Pb–Pb at 5.02 TeV

Cross section and **charge asymmetry**



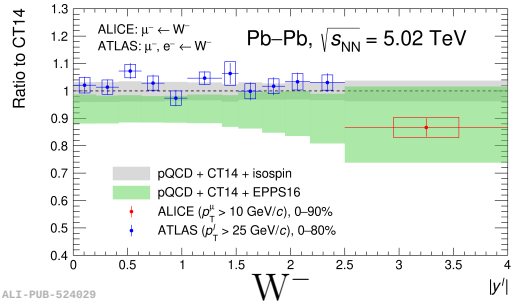
arXiv:2204.10640[nucl-ex]

- Models with free-PDF overestimate the cross section while models including nuclear effects agree with the measurement very well.
  - Suggests visible nuclear effects.

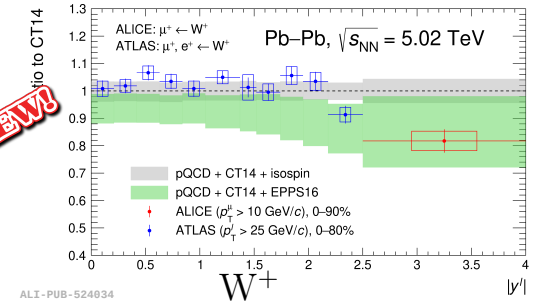
$$A_{\mathrm{ch}} = \frac{N_{\mu^+ \leftarrow W^+} - N_{\mu^- \leftarrow W^-}}{N_{\mu^+ \leftarrow W^+} + N_{\mu^- \leftarrow W^-}}$$

$W^{\pm}$ in Pb–Pb at 5.02 TeV

Comparision with ATLAS results at midrapidity (EPJC 79(2019)935). arXiv:2204.10640[nucl-ex]



NEW!

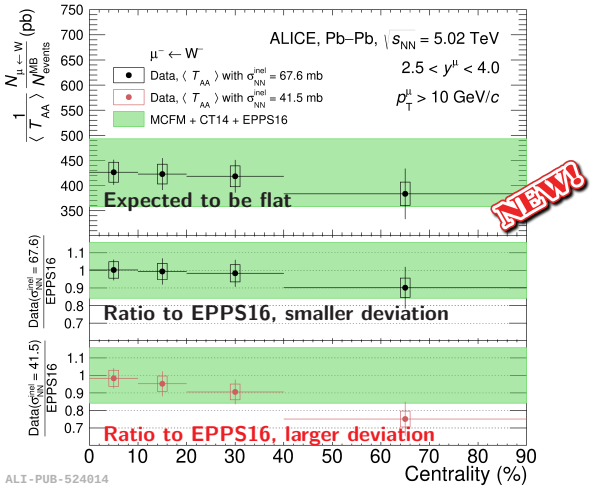


- EPPS16 provides good predictions of ALICE data, while it underestimates the ATLAS measurement.
- Interesting to do the η-differential study in forward rapidity.

$W^{\pm}$ in Pb–Pb at 5.02 TeV

Centrality-dependent $\langle T_{AA} \rangle$-scaled yield

arXiv:2204.10640[nucl-ex]



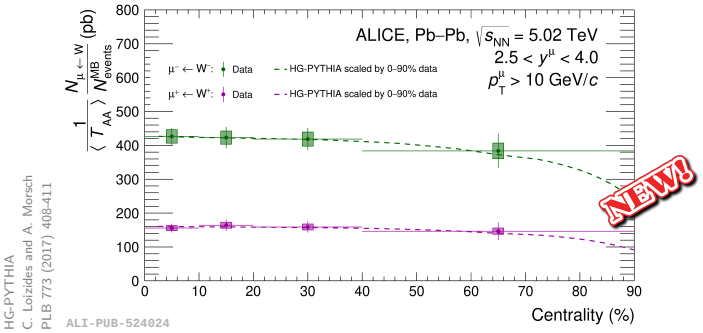
- Biased by determination of nuclear overlapping function T_{AA}.
- If the measurement is rescaled with alternative T_{AA} value:
  - Alternative T_{AA} forcing the ATLAS W/Z measurements to agree with the EPPS16 calculation.
  - Measurement with this alternative T_{AA} is less agreement with EPPS16.

Eskola et al. (PRL 125(2020)212301)

$W^{\pm}$ in Pb–Pb at 5.02 TeV

Centrality-dependent $\langle T_{AA} \rangle$-scaled yield

arXiv:2204.10640[nucl-ex]



- HG-PYTHIA: includes biases from event selection and geometry that cause suppression in peripheral collisions.
- Neutron-skin effect affects the production of W^+ and W^- in different directions.

Conclusions and perspectives

In pp:

- Auto-correlation plays an important role in the particle produciton w.r.t. multiplicity.
- PYTHIA 8 with MPI and CR well predicts the measurements.

In p–Pb and Pb–Pb:

- Production measurements of W and Z bosons provide important inputs to nPDF global fits. Deviation on nPDF prediction is visible in p–Pb collisions in closest at midrapidity region (W^-).
- Measurement with Run3 and Run4 sample: more statistics, p_T,y,multiplicity-differential with more bins.

Thank you for your attention!

Back-up