PROCEEDINGS OF SCIENCE

Electroweak-boson production in pp, p–Pb and Pb–Pb collisions with ALICE

Nicolò Valle, on behalf of the ALICE collaboration

University and INFN Pavia, Italy

E-mail: nicolo.valle@cern.ch

Electroweak-boson production in hadronic processes can be used for the investigation of the parton distribution functions (PDFs). This is particularly true in heavy-ion collisions at the LHC, where the initial state is still poorly constrained by measurements and is important for the interpretation of the evolution of the system. The ALICE experiment can measure W and Z bosons via their leptonic decays in the electron channel at midrapidity ($|y_{\rm lab}| < 0.6$) and in the muon channel at forward rapidity ($-4 < y_{\rm lab} < -2.5$). The observations at large $y_{\rm lab}$ are especially important for investigating a phase space region that is largely unconstrained by other heavy-ion experiments.

This work presents the recent ALICE results on electroweak boson measurements in p–Pb collisions at $\sqrt{s_{\rm NN}} = 8.16$ TeV and Pb–Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV. They include production cross sections and nuclear modification factors as a function of rapidity and collision centrality. The results are compared to pQCD calculations; those showing clear evidence of nuclear modification of the PDFs will be highlighted. In addition, preliminary results on W boson production in pp collisions at $\sqrt{s} = 13$ TeV are presented.

Particles and Nuclei International Conference - PANIC2021
5 - 10 September, 2021
Online

https://pos.sissa.it/

PoS(PANIC2021)223

1. Introduction

At the LHC, W and Z bosons are mainly produced via Drell-Yan processes, whose underlying theory is very well known. The hardness of such processes makes electroweak bosons very effective probes to measure the hadronic parton distribution functions (PDFs).

The role of W and Z bosons as standard candles for perturbative QCD (pQCD) calculations holds also in heavy-ion collisions. At the LHC, they can be used to investigate the initial state of the collision. In particular, the measurement of W and Z leptonic decay products is unaffected by the formation of the hot strongly interacting medium and provides direct information on the so-called cold nuclear effects, such as the nuclear modification of the PDFs.

Nuclear PDFs (nPDFs) parameterizations still suffer from large uncertainties, mainly because of the lack of experimental data. W and Z measurements by the LHC experiments can constrain nPDFs in a kinematic region at large momentum transfer ($Q^2 \simeq M^2_{\mathrm{Z,W}}$) and in different Bjorken-x regions, depending on the boson rapidity. So far, the ALICE Collaboration has measured W and Z bosons in proton-lead and lead-lead collisions at large rapidity (probing kinematic domains with very low and very high Bjorken-x within the nucleus), as well as W bosons in pp collisions at midrapidity. Table 1 provides information on the datasets collected in the different collision systems used for these measurements. A selection of the most recent results will be presented in the following.

Table 1: Summary of ALICE results on Z and W boson production at different nucleon-nucleon collision energy $\sqrt{s_{\mathrm{NN}}}$.

Observables	System	$\sqrt{s_{\mathrm{NN}}}$	$\mathcal{L}_{\mathrm{int}}$	Results
$\mathrm{Z} \to \mu\mu$, $\mathrm{W} \to \mu\nu$ $(-4 < y_{\mathrm{lab}} < -2.5)$	p–Pb	5.02 TeV	$\sim 10.8\ \mathrm{nb}^{-1}$	[1]
	p–Pb	8.16 TeV	$\sim 21.2\ \mathrm{nb}^{-1}$	[2], *new*
	Pb–Pb	5.02 TeV	$\sim 750\ \mu\mathrm{b}^{-1}$	[2, 3], *new*
$\mathrm{W} \to \mathrm{e}\nu$ $(\lvert y_{\mathrm{lab}}\rvert < 0.6)$	pp	13 TeV	$\sim 6.6\ \mathrm{pb}^{-1}$	*new*

2. Electroweak-boson reconstruction

At forward rapidity, in p–Pb and Pb–Pb collisions, the $\mathrm{W}^{\pm}$ and Z signals are measured in the single-muon and muon-pair channels, respectively. Muons are reconstructed in a spectrometer covering the rapidity interval $-4 < y < -2.5$ and protected by a set of absorbers which ensure a high purity of muons in the collected sample. A detailed description of the ALICE detectors can be found in [4]. The W-boson signal is extracted by fitting the inclusive single-muon p_{T} distribution in the range $p_{\mathrm{T}} > 10$ GeV/c with a template including the decay of heavy-flavour states and the muonic decay of Z bosons. In particular, the single-lepton contribution from heavy-quark states is computed with FONLL [5] pQCD calculations while the ratio between W and Z yields is fixed according to POWHEG [6]. The Z-boson signal is extracted by counting the number of opposite-sign muon pairs reconstructed with invariant mass between 60 and 120 GeV/c^2. Only muons with $p_{\mathrm{T}} > 20$ GeV/c are used to reject those coming from quarkonium decays; the background contamination in the remaining sample amounts to 1.5% or even less, depending on the collision system.

Finally, for both W and Z, an efficiency correction is added by means of simulations embedded in real data to better reproduce the occupancy of the detector. The details of the analyses are described in [1] and [2].

The W^-, W^+ signals at midrapidity in pp collisions are extracted using single electrons or positrons measured at midrapidity with the Time Projection Chamber and ElectroMagnetic Calorimeter. The rapidity coverage $|y| < 0.6$ is chosen to fit the calorimeter fiducial region. Electrons are selected by requiring an energy-to-momentum ratio close to unity, $p_T > 40$ GeV/c, and isolation criteria based on the energy and number of particles around the candidate. In particular, the isolation energy cut allows for a data-driven subtraction of heavy-quark states decay, while the contamination from Z decay is estimated with POWHEG simulations.

3. Selected highlights

3.1. p-Pb and Pb–Pb. In p–Pb collisions the nucleon-nucleon centre of mass system (cms) is boosted in the direction of the proton beam. This results in a shift of the rapidity coverage of the muon spectrometer with respect to the cms frame ($\Delta y = \pm 0.456$). When the lead beam moves towards the spectrometer (Pb-going configuration), the forward Drell-Yan production requires a high-x quark in the lead nucleus. When the lead beam moves in the opposite direction (p-going), the spectrometer acceptance is sensitive to highly virtual low-x quarks in the lead nucleus. In Pb–Pb symmetric collisions, high-x and low-x quarks are involved simultaneously in the forward production, so that the different nuclear effects to the PDFs of the two quarks cannot be disentangled.

In the following, the $W^+ \to \mu^+\nu_\mu$, $W^- \to \mu^-\bar{\nu}_\mu$ and $Z \to \mu^+\mu^-$ production yields and cross sections will be presented as a function of the boson rapidity and collision centrality. In order to investigate the presence of nuclear shadowing or the enhancement of the PDFs, the results will be compared to MCFM [7] pQCD calculations based on PDF parameterizations with and without nuclear modification. CT14 free-nucleon PDFs [8] are considered in the first case, while EPPS16 [9] is used as nPDF set.

The rapidity spectra and charge asymmetries for W production in p-Pb collisions at $\sqrt{s_{NN}}$ = 8.16 TeV are reported in Figure 1. The W^+ $y-$differential cross section measured in the p-going configuration is compared to theory in the left panel. The measurement is in better agreement with predictions including nuclear shadowing; the tension with free-nucleon PDFs goes up to 3.7σ in the most forward rapidity interval, where the Bjorken-x of the lead parton is of the order of 10^{-4}. It should be noticed how the data uncertainties are smaller than the EPPS16 ones, suggesting that such measurements are able to provide constraints for the future generation of nPDF models. The production of $W^{\pm}$ depends on the light-quark content in the hadron, so that the lepton-charge asymmetry can probe the up-to-down nPDFs ratio in the nucleus. Such asymmetry is compared to pQCD calculations in the right panel of Figure 1.

In Figure 2, two results obtained from Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV are shown. In both panels the production yield of W or Z bosons is normalized by the nuclear overlap function T_{AA} and by the production cross section in pp at the same energy. Since T_{AA} is proportional to the number of binary nucleon-nucleon collisions N_{coll}, the resulting observable (R_{AA}) probes the N_{coll}-scaling hypothesis when measured in different centrality classes of the collision. Within uncertainties, the scaling is confirmed by the W measurement displayed in the left panel. Here, the difference between

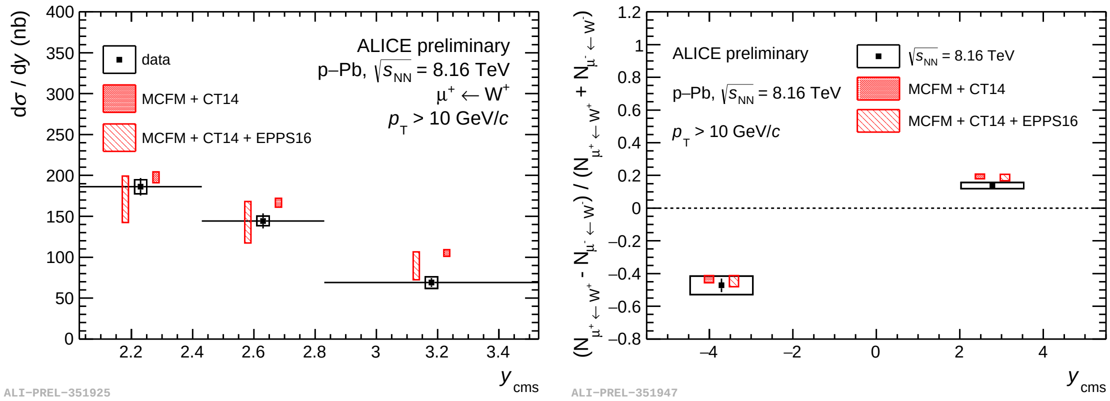

Figure 1: Results in p–Pb collisions at $\sqrt{s_{\rm NN}}$ = 8.16 TeV. *Left*: comparison between differential cross section of $W^+ \to \mu^+\nu_\mu$ and NLO pQCD calculations based on PDFs (CT14 [8]) or nPDFs (EPPS16 [9]). *Right*: Lepton-charge asymmetry for W^+, W^- production compared to the same pQCD calculations. Positive and negative $y_{\rm cms}$ values are used for the p-going and Pb-going configurations, respectively. Vertical bars and boxes on data represent statistical and systematic uncertainties, respectively.

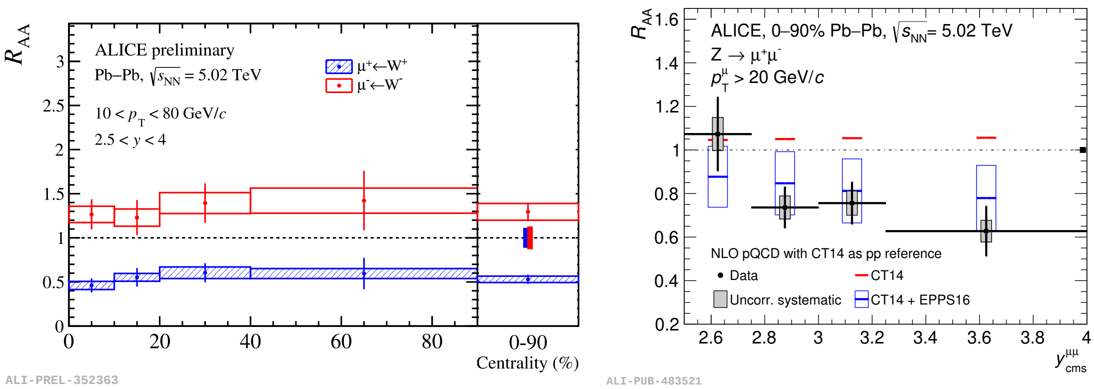

Figure 2: Results in Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV. *Left*: $R_{\rm AA}$ of W^+ and W^- productions as a function of the centrality of the collision. *Right*: $R_{\rm AA}$ of Z production as a function of dimuon rapidity compared to pQCD calculations based on free-nucleon (CT14 [8]) and nuclear (EPPS16 [9]) PDFs. The pp cross section is from pQCD calculations. Vertical bars and boxes on data represent statistical and systematic uncertainties, respectively. The $R_{\rm AA}$ correlated systematic uncertainty is displayed as a box on the unity line.

W^+ and W^- production rates is an effect of the Pb isospin. On the right, the Z-boson $R_{\rm AA}$ [2] is shown as a function of rapidity and compared to theory predictions. The results clearly favour the presence of nuclear modification, especially at large rapidity. The overall significance of nuclear shadowing in this sample computed with respect to CT14 free-nucleon calculations amounts to 3.4σ.

3.2. proton-proton. The results on W production in pp collisions at $\sqrt{s}$ = 13 TeV at midrapidity are shown in Figure 3. The production cross sections of W^- (left) and W^+ (right) are measured as a function of $p_{\rm T}$ and they are consistent with NLO calculations based on POWHEG [6]. The proton isospin tends to make the W^+ production rate greater than that for W^-.

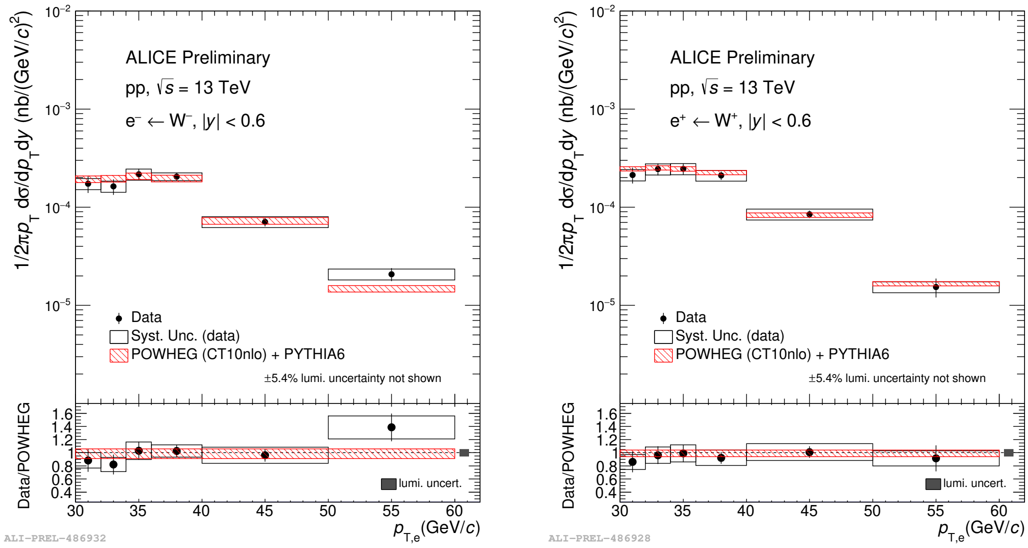

Figure 3: Results in pp collisions at $\sqrt{s}$ = 13 TeV. Cross section production of e^- (*left*) and e^+ (*right*) from W^- and W^+ decay, respectively. Results are compared to simulations based on POWHEG. Vertical bars and boxes on data represent statistical and systematic uncertainties, respectively.

4. Conclusions

ALICE measured W and Z production in all the heavy-ion collision systems collected during LHC Run 2, as well as W production in pp collisions at 13 TeV. Results in p–Pb and Pb–Pb collisions are provided at large rapidities, corresponding to a kinematic region of the annihilating quarks at high and low Bjorken-x, where the nuclear PDFs are less constrained by data. The results are better described by pQCD calculations accounting for nuclear modification of the PDFs. The precision of the results make these ALICE measurements eminently suitable for inclusion in future nPDF global fits.

References

[1] Adam J. *et al.* [ALICE coll.] *J. High Energy Phys.* **02** (2017) 077.

[2] Acharya A. *et al.* [ALICE coll.], *J. High Energy Phys.* **09** (2020) 076.

[3] Acharya A. *et al.* [ALICE coll.] *Phys. Lett.* **B780** (2018) 372-383.

[4] Aamodt K. *et al.* [ALICE coll.] *J. Instrum.* **3** (2008) S08002.

[5] Cacciari M. *et al. J. High Energy Phys.* **10** (2012) 137.

[6] Aioli S. *et al. J. High Energy Phys.* **07** (2008) 060.

[7] Boughezal R. *et al. Eur. Phys. J.* **C77** no. 1 (2017) 7.

[8] Dulat S. *et al. Phys. Rev.* **D93** (2016) 033006.

[9] Eskola K. J. *et al. Eur. Phys. J.* **C77** (2017) 163.