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Electroweak boson production in p–Pb and Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV with ALICE

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Abstract

W and Z bosons are massive weakly-interacting particles, insensitive to the strong interaction. They provide therefore a medium-blind probe of the initial state of the heavy-ion collisions. The final results for the W and Z-boson production in p–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV are presented. The production cross-section is well described by perturbative calculations but the data cannot further constrain the nuclear modification of the parton distribution functions. The W-boson production is also studied as a function of the collision centrality, and found to be constant within uncertainties.

The Z-boson production was also measured in Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV with ALICE. This is the first measurement at forward rapidity at such energies. The preliminary results for the invariant yields divided by the nuclear overlap functions are described by perturbative calculations including nuclear modifications of the PDFs.

Keywords: Heavy ions, W boson, Z boson, p–Pb collisions, Pb–Pb collisions, muons, forward rapidities

1. Introduction

The study of the W and Z-boson production has become accessible for the first time in p–Pb and Pb–Pb collisions at the LHC [1–8]. W and Z bosons are insensitive to the strong interaction, and provide therefore a medium-blind reference for the study of the initial-state effects of the collision, such as the nuclear modification of the Parton Distribution Functions (PDFs). The measurements performed over a large range of rapidity by the LHC experiments give access to a region of high virtuality ($Q^2 \sim M^2_{\rm W,Z}$) and Bjorken-x values (from about 10^{-4} to almost unity) in which the nuclear PDFs (nPDFs) are poorly constrained from previous experiments [9]. Furthermore, the W and Z-boson production depends on the quark-flavour composition of the nucleus and it is therefore sensitive to the flavour modification of the quark densities inside the nucleus [9].

The ALICE experiment measured the W and Z-boson production in p–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV. The final results [1] are presented in section 2. The Z-boson production was also recently measured in Pb–Pb collisions at the same energy. The preliminary results are described in section 3. Finally, a summary of the measurements is provided in section 4.

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2. p–Pb collisions

The ALICE experiment studied the W and Z-boson production in the muonic decay channel in p–Pb collisions at $\sqrt{s_{\rm NN}}$= 5.02 TeV [1]. Muons are detected with the ALICE muon spectrometer [10] in the pseudo-rapidity interval $-4 < \eta^{\mu} < -2.5$ in the laboratory frame. Data were collected in two configurations for the beams: one with the proton traveling clockwise in the accelerator, thus moving toward the muon spectrometer (p-going direction), and the other where the direction of the proton and lead beams were inverted (Pb-going direction). The different energies of the proton ($E_{\rm p}$ = 4 TeV) and of the lead beams ($E_{\rm Pb} = 1.58 \cdot A_{\rm Pb}$ TeV, where $A_{\rm Pb}$ is the atomic mass of the lead ion), result in a rapidity shift of the nucleon-nucleon center of mass of $\Delta y = 0.465$ in the proton direction with respect to the laboratory frame. With the conventional assumption that the proton travels towards positive rapidity, the rapidity intervals explored in the muon measurements are $-4.46 < y_{\rm cms} < -2.96$ in the Pb-going direction and $2.03 < y_{\rm cms} < 3.53$ in the p-going direction. The data samples correspond to a luminosity of 5.81 ± 0.20 nb^{-1} and 5.03 ± 0.18 nb^{-1}, respectively.

The analysis strategy is described in detail in [1]. The W-boson candidates are extracted from a Monte Carlo (MC) template fit of the transverse momentum distribution of single muons. For what concerns the Z bosons, the selection of events (muon pseudorapidity $-4 < \eta^{\mu} < -2.5$ and transverse momentum $p_{\rm T}^{\mu} >$ 20 GeV/c) defines a nearly background-free sample, and the signal is therefore extracted by counting the entries in the invariant-mass distribution of opposite-sign muon pairs in the region $60 < m_{\mu\mu} < 120$ GeV/c^2 [1].

The cross-section for Z-boson production in the dimuon decay channel with $p_{\rm T}^{\mu} > 20$ GeV/c measured in p–Pb collisions is shown in the left panel of Fig. 1. The middle and right panels show the cross-section for muons with $p_{\rm T}^{\mu} > 10$ GeV/c from W$^-$ and W$^+$ boson production, respectively. The results are compared with NLO and NNLO theoretical calculations both with and without including the nuclear modification of the PDFs. The NLO calculations [9] with the CT10 [11] PDF set (blue hatched boxes) and the NNLO [12] calculations with the MSTW2008 [13] PDF set (blue filled boxes) both describe data within uncertainties. The results are also compared with the corresponding calculations including the EPS09 NLO [14] parameterisation of the nuclear modification of the PDFs, shown as hatched and filled red boxes, respectively. The inclusion of the nuclear effects results in a slight reduction of the cross-section. However, the effect is small and all calculations describe the data within uncertainties.

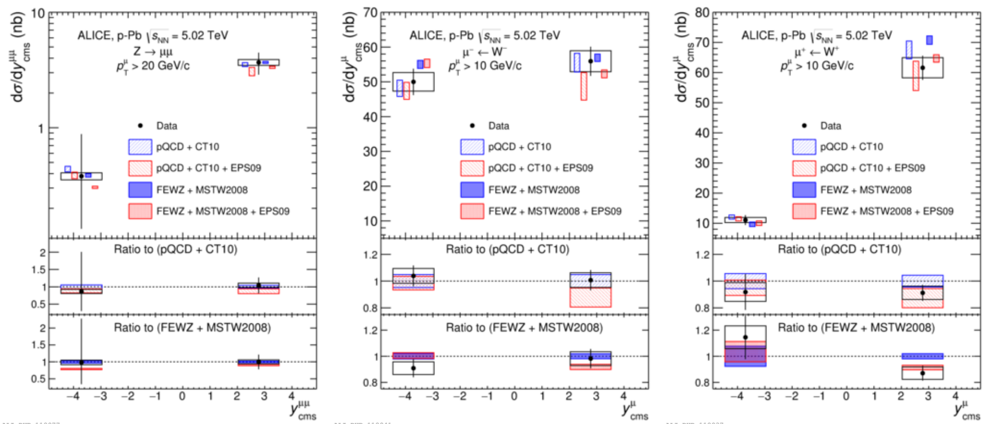

Fig. 1. Rapidity-differential cross section of Z (left panel), W$^-$ (middle panel) and W$^+$ (right panel) boson production in p–Pb collisions at $\sqrt{s_{\rm NN}}$= 5.02 TeV. The vertical bars (boxes) are the statistical (systematic) uncertainties. Results are compared with NLO [9] and NNLO calculations [12] with and without including the nuclear modification of the PDFs. In the top panel, the calculations are shifted in rapidity for a better visibility. The vertical middle (bottom) panel shows the ratio of data and NLO (NNLO) calculations divided by the NLO (NNLO) calculations without the nuclear modification of the PDFs.

The W-boson production is also studied as a function of the collision centrality, estimated from the energy deposited in the neutron zero degree calorimeter [15]. Such a production is expected to scale with the number of binary nucleon-nucleon collisions, provided that the centrality determination is not biased [15]. The cross sections divided by the average number of nucleon-nucleon collisions measured in the backward and forward rapidity regions are shown in the left and right panel of Fig. 2. The production cross section as a function of collision centrality is compatible with a constant within uncertainties.

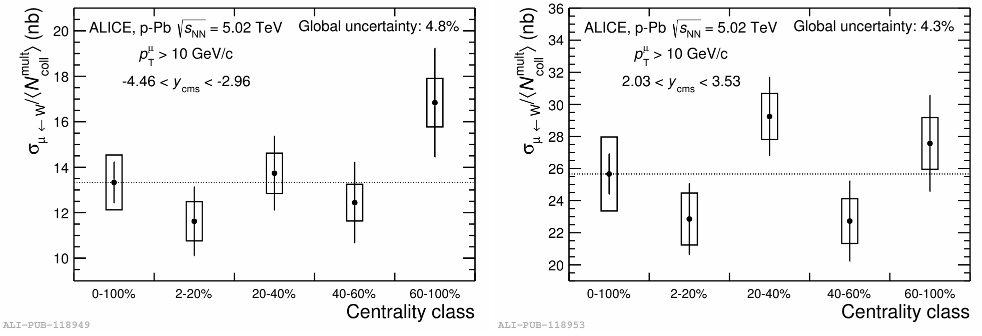

Fig. 2. Cross-section of muons from W-boson decays normalised to the average number of binary collisions as a function of the collision centrality measured in the backward (left panel) and forward (right panel) rapidity regions. The vertical bars (open boxes) are the statistical (systematic) uncertainties. The dotted line is the centrality integrated value and it is only shown as a reference.

3. Pb–Pb collisions

The Z-boson production is measured at forward rapidities in Pb–Pb collisions at $\sqrt{s_{\rm NN}}$= 5.02 TeV. The analysed data correspond to an integrated luminosity of about 225 μb^{-1}. The centrality of the collision is estimated via a Glauber model fit of the signal amplitude of the V0 scintillator arrays, as described in [16]. The analysis strategy is similar to the one used in p–Pb collisions [1].

The Z-boson yields normalised to the average nuclear overlap function $T_{\rm AA}$ are shown in Fig. 3 as a function of the number of participants weighted by the number of binary collisions ($\langle N_{\rm part}\rangle_{N_{\rm coll}}$). The results

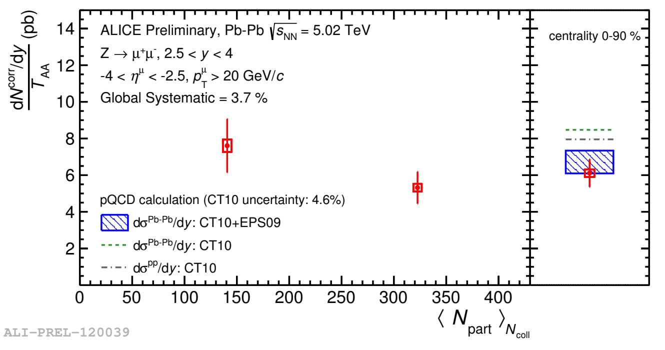

Fig. 3. Z-boson yields normalised to the average nuclear overlap function $T_{\rm AA}$ as a function of the number of participant weighted by the number of collisions ($\langle N_{\rm part}\rangle_{N_{\rm coll}}$). The vertical bars (open boxes) are the statistical (systematic) uncertainties. The centrality-integrated result is shown in the right panel and it is compared to theoretical expectations for pp collisions (dashed-dotted grey line), and for Pb–Pb collisions with (hashed blue box) and without (dashed green line) accounting for nuclear modifications of the PDFs.

are compatible with a constant within uncertainties. The centrality-integrated result is shown in the right panel of Fig. 3 and it is compared with theoretical calculations [9]. The Z-boson production is expected to be dependent on the flavour composition of the nucleus. In particular, the Z-boson yields in Pb–Pb collisions without accounting for nuclear effects (dashed green line), scaled by T_{AA}, are expected to be larger than the ones in pp collisions (dashed-dotted grey line). On the other hand, the inclusion of the nuclear effects leads to a reduction of the Z-boson yields (hashed blue box), which are found to be smaller than for pp collisions. The data are better described by the calculations that include the nuclear modification of the PDFs.

4. Conclusions

The ALICE experiment studied the W and Z-boson production at backward and forward rapidity in p–Pb collisions at $\sqrt{s_{NN}}$= 5.02 TeV [1]. The measured cross sections are compared with NLO and NNLO calculations with and without including the nuclear modifications of the PDFs. The results are described by all calculations. The nuclear modification of the PDFs cannot be constrained with the current uncertainties. The W-boson production was also studied as a function of the collision centrality: the measured cross sections normalised to the number of binary nucleon-nucleon collisions are found to be constant within uncertainties.

The Z-boson production was also studied at forward rapidities in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV. The Z-boson yields normalised by the nuclear overlap function do not depend on centrality within uncertainties. The centrality-integrated result shows a clear preference towards calculations including the nuclear modification of the PDFs.

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