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Z and W boson production in pPb collisions with CMS

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Z and W boson production in pPb collisions with CMS

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Abstract

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Keywords: CMS, pPb collisions, electroweak bosons

1. Introduction

Thanks to its high center-of-mass energy and high luminosity, the LHC allows the study of Z and W boson production in heavy-ion collisions for the first time. Their leptonic decays are of particular interest, since the leptons do not suffer from final state interactions with the medium produced in these collisions. Both Z and W bosons were measured by the ATLAS [1, 2] and the CMS [3, 4, 5] experiments using PbPb collision data taken in 2010 and 2011 at $\sqrt{s_{NN}} = 2.76$ TeV, confirming with a precision of about 10%, that the production cross section scales with the number of elementary nucleon-nucleon collisions. However, in heavy-ion collisions, electroweak boson production can be affected by initial state conditions [6, 7].

The parton distribution functions (PDFs) can be modified in nuclei, which together with the fact that the nucleus contains neutrons besides protons, can modify the observed cross sections compared to pp collisions. The pPb collision data taken in 2013 is currently the best sample to constrain nuclear PDFs (nPDFs) in a previously unexplored region of phase space. This paper presents the first results on Z and W boson production in pPb collisions measured by the CMS experiment [8, 9].

2. Analysis procedure

The analysis is performed on the pPb collision data sample corresponding to an integrated luminosity of $L_{\text{int}} = (34.6 \pm 1.2) \text{ nb}^{-1}$, that has an uncertainty of 3.5% from the calibration [10] shown separately for the results. The beam energies were 4 TeV for protons and 1.58 TeV per nucleon for lead nuclei, resulting in a center-of-mass energy per nucleon pair of $\sqrt{s_{NN}} = 5.02$ TeV. Due to the energy difference between the colliding beams, the nucleon-nucleon

¹ A list of members of the CMS Collaboration and acknowledgements can be found at the end of this issue.

Figure 1. *Left*: Invariant mass of selected muon pairs from pPb data compared to PYTHIA+HIJING simulation. *Right*: Missing transverse energy distribution for $W^+ \rightarrow e^+\nu$ events within the $-0.5 < \eta_{\text{lab}} < 0.0$ range fitted with a sum of $W^+ \rightarrow e^+\nu$ (yellow), $Z \rightarrow ll$ (white), $W^+ \rightarrow \tau^+\nu$ (red) shapes from simulations and a modeled QCD multi-jet (blue) contribution.

center-of-mass frame is not at rest with respect to the laboratory frame. Massless particles emitted at $\eta_{\text{cm}} = 0$ will be detected at $\eta_{\text{lab}} = 0.465$ in the laboratory frame. The results are presented with the proton-going side defining the region of positive (pseudo)rapidity values.

The Z and W bosons are identified through their decays to muons or electrons with high transverse momentum (p_T). The muon analysis is based on a sample triggered by requiring a single muon with p_T above 12 GeV/c, while the electron analysis makes use of a photon-triggered sample with an energy threshold of 15 GeV. Both leptons are reconstructed with the algorithms used in pp collisions and standard selection criteria are applied [11, 12].

The Z boson candidates are defined as an opposite-charge muon pair in the 60–120 GeV/ c^2 mass range where both muons have $p_T > 20$ GeV/c and are within the $|\eta_{\text{lab}}| < 2.4$ muon detector coverage. The invariant mass of muon pairs is shown in the left-hand side of Figure 1 and compared to Monte Carlo (MC) simulation. The number of Z candidates found in the pPb data sample is 2183. Backgrounds are subtracted by a data-driven method counting the opposite-charge electron-muon pairs in the Z boson mass range and correcting for the differences in the lepton efficiencies. It accounts for the main electroweak backgrounds, $t\bar{t}$ and part of QCD background producing opposite-charge leptons. Remaining backgrounds are estimated by counting the same-charge muon pairs and subtracted.

The W boson candidate events are selected by requiring a $p_T > 25$ GeV/c lepton, that is isolated to reduce contamination from jet fragmentation. Opposite-charge dilepton events corresponding to Z boson, Drell-Yan or quarkonium decays are rejected. The number of leptons coming from W boson decays is extracted by fitting the missing transverse energy (E_T) distribution of the selected events. The shapes of E_T for the $W \rightarrow l\nu$ signal, the $W \rightarrow \tau\nu$ and $Z \rightarrow ll$ (with a missing lepton) backgrounds are provided by simulations and the shape of the QCD multi-jet background is modeled by a functional form which is shown to reproduce the E_T shape of events containing non-isolated leptons. One example fit is shown in Figure 1, which is performed separately in bins of η_{lab} and for the different lepton charges.

In order to correct for the trigger, reconstruction and selection efficiency, the electroweak processes are simulated using the PYTHIA 6 event generator [13] with a mixture of pp and pn interactions corresponding to pPb collisions. Each signal event is embedded into a minimum bias heavy-ion background event produced by the HIJING event generator [14]. The embedded events are processed through the trigger emulation and the same event-reconstruction and analysis procedure as the collision data. To correct for possible differences between data and simulation, a data-driven method similar to the one described in [11] is used to determine correction factors to the baseline lepton efficiencies from simulation. The Z boson measurement is additionally corrected for acceptance that is calculated using the POWHEG generator [15] with CT10NLO free proton PDF set [16] and interfaced with PYTHIA parton shower.

Figure 2. Rapidity differential cross section (*left*) and forward-backward ratio (*right*) of Z boson production in pPb collisions compared to predictions from MCFM with MSTW2008NLO PDF with and without the nuclear modification from EPS09 or DSSZ nPDFs. The error bars represent the statistical, and the boxes the systematic uncertainties.

3. Results

The Z boson production cross section is calculated by counting the number of Z candidates in data, subtracting the background, correcting for acceptance and efficiency and dividing by the integrated luminosity. The measured inclusive Z boson production cross section in a restricted rapidity range is $\sigma_{pPb \rightarrow Z \rightarrow \mu^+ \mu^-}(-2.5 < y_{c.m.} < 1.5) = 94.1 \pm 2.1(\text{stat.}) \pm 2.4(\text{syst.}) \pm 3.3(\text{lumi.})$ nb. For the same rapidity range, the POWHEG+PYTHIA pp simulation predicts 94.0 ± 4.7 nb after scaling with the number of nucleons in the Pb nucleus ($A = 208$), which agrees with the measured value. The left hand-side of Figure 2 shows the differential cross section of Z boson production as a function of rapidity in the center-of-mass frame compared to predictions from MCFM generator [17]. The MCFM predictions are calculated with MSTW2008NLO [18] free proton PDF set with and without the nuclear modification from EPS09 [19] or DSSZ [20] nPDF sets and scaled by A . The measured differential cross section is consistent with the theory predictions within uncertainties that are dominated by the statistical uncertainties. The forward-backward ratio, defined as $d\sigma(+y)/d\sigma(-y)$, is expected to be more sensitive to nuclear effects [6], because normalization uncertainties cancel both in theory and in experiment. The right hand-side of Figure 2 shows the measured forward-backward ratio as a function of $|y_{c.m.}|$ compared to the MCFM predictions. Due to the large statistical uncertainties, this measurement is not able to distinguish between different nPDF sets but it can constrain their uncertainties by adding new data points to the global fits in a previously unexplored region of the $Q^2 - x$ phase space.

The W boson production cross section as a function of pseudorapidity in the laboratory frame is calculated from the fitted signal yields, correcting for the lepton efficiencies and dividing by the integrated luminosity. The measured cross sections in the muon and electron channels are found to be in good agreement, hence their combination is performed. Since the cross section alone lacks discriminating power between different PDF sets [9], various asymmetries are determined to reduce both the experimental and theoretical uncertainties. The left hand-side of Figure 3 shows the lepton charge asymmetry, $(d\sigma^+ - d\sigma^-)/(d\sigma^+ + d\sigma^-)$, as a function of η_{lab} compared to theoretical predictions. The predictions use the CT10 PDF set for the nucleons with or without the modification from EPS09 nPDF set as described in [6]. The W charge asymmetry is a sensitive probe of the down to up quark PDF ratio. In the proton fragmentation region ($\eta_{lab} > 0.465$), the data agrees well with the predictions, but in the Pb fragmentation region (especially in $\eta_{lab} < -1$) both predictions stand above the measurements. These results could be explained by assuming different nuclear modification of the down and up quarks in the Pb nucleus, which is assumed to respect isospin symmetry in most nPDF fits, such as EPS09. The forward-backward asymmetries for the different charges show a similar hint of possible difference between the down and up quark nPDFs. The right hand-side of Figure 3 shows the forward-backward asymmetry of the charge-summed W bosons, $d\sigma(+\eta_{lab})/d\sigma(-\eta_{lab})$, which achieves maximum sensitivity to nuclear modification of PDFs. It probes the small- x modification of the nPDF (shadowing) over the large- x modification (anti-shadowing). The measurement favors the EPS09 modified PDF as compared to the un-modified CT10.

Figure 3. Charge (left) and forward-backward (right) asymmetry of W boson production in pPb collisions.

4. Conclusions

First measurements of Z and W boson production in pPb collisions with the CMS experiment were reported. At first order, the production cross section scales with number of binary nucleon-nucleon collisions. The results were compared to NLO theory predictions with and without nuclear modification, that show hints of nuclear effects but more luminosity is needed to distinguish between different nPDF sets. These measurements set significant constraints for the global fits of nPDFs in a previously unexplored region of phase space.

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