Study of Z boson production in pp, pPb and PbPb collisions in CMS

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Abstract. The Z boson production is studied in PbPb and pp collisions at $\sqrt{s_{NN}} = 2.76$ TeV and in pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV using data collected by the CMS experiment at the LHC. The Z boson production is observed to be proportional to the number of elementary nucleon-nucleon collisions in both PbPb and pPb collisions. The measured differential cross sections as a function of transverse momentum and rapidity are in agreement with NLO pQCD calculations using different parton distribution functions with and without nuclear effects. Using the PbPb and pp data, the nuclear modification factor is presented as well as the forward-backward ratio measured in pPb collisions.

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. Electroweak bosons are essentially unmodified by the hot and dense medium created in nucleus-nucleus collisions, and their leptonic decays are of particular interest since the leptons pass through the medium without interacting strongly. However, in heavy ion collisions, the production of electroweak bosons can be affected by initial-state effects. 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.

Based on the first PbPb collisions at the LHC in 2010, the CMS collaboration has reported results on Z and W boson production [1, 2]. In this paper, the study of Z boson production at the center-of-mass energy per nucleon pair $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV is presented using PbPb collision data collected in 2011 corresponding to an integrated luminosity of 150 μb^{-1} and using pp collision data recorded in 2013 with an integrated luminosity of 5.4 pb^{-1} [3]. These data samples allow for more precise measurement of the Z boson nuclear modification factor (R_{AA}) and its dependence on transverse momentum (p_{T}), rapidity (y) and collision centrality. 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. The results on Z boson production cross section in pPb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV corresponding to an integrated luminosity of 34.6 nb^{-1} are also presented [4].

2. Z bosons in PbPb and pp collisions at $\sqrt{s_{NN}} = 2.76$ TeV

The Z bosons are identified through their leptonic decays to muon or electron pairs. Signal candidates are selected by requiring an opposite charge lepton pair in the 60–120 GeV/c^2

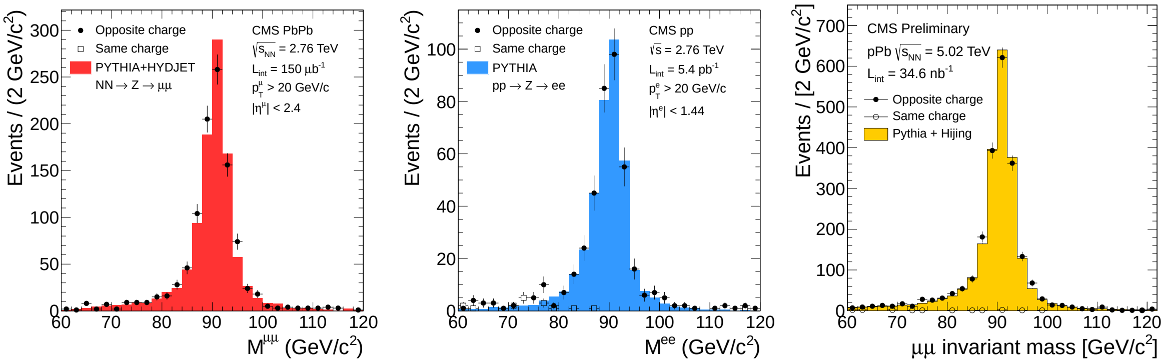

Figure 1. Invariant mass of the selected lepton pairs from PbPb (*left*), pp (*middle*) and pPb (*right*) collisions compared to the corresponding simulations.

invariant mass range with both leptons having $p_{\mathrm{T}} > 20$ GeV/c and found to be in $|\eta^{\mu}| < 2.4$ for muons or $|\eta^{\mathrm{e}}| < 1.44$ for electrons. The dimuon rapidity is limited to $|y| < 2$, while the dielectron rapidity is kept in the $|y| < 1.44$ range. Figure 1 shows examples of the invariant mass distribution of Z boson candidates in PbPb and pp collisions. Overlaid histograms are from PYTHIA+HYDJET [5] and PYTHIA [6] simulations that are used to determine the acceptance and efficiency corrections for the PbPb and pp sample, respectively.

The corrected Z boson yield is normalized by the number of minimum bias (MB) events or by the integrated luminosity in the two datasets. The results from the muon and electron decay channels are in agreement within the statistical uncertainties and a combination is performed in the common kinematic region $|y| < 1.44$. Figure 2 shows the normalized Z boson yield in PbPb collisions for the combined dilepton channel as a function of centrality, rapidity and transverse momentum. The results are in agreement with predictions from the POWHEG [7] generator in case of p_{T} dependence or with predictions from [8] in case of y dependence using CT10 PDF set [9] with and without the nuclear effects from EPS09 nPDF set [10].

The R_{AA} is calculated by dividing the corrected yield from PbPb collisions by the cross section measured in pp collisions and scaled by the nuclear overlap function (T_{AA}), which is proportional

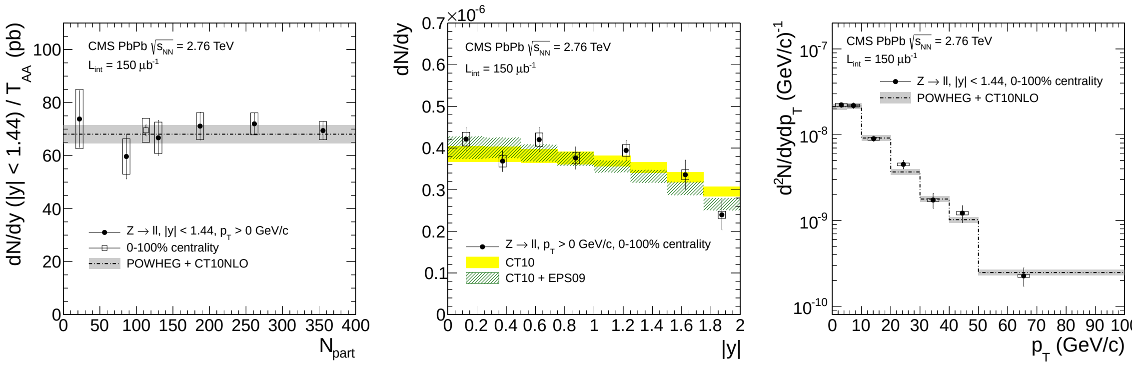

Figure 2. The Z boson yield per MB event measured in PbPb collisions shown for the combined dilepton channel as a function of event centrality (*left*), Z boson y (*middle*) and p_{T} (*right*). The yields are compared to predictions with (green) and without (yellow) nuclear modification effects vs. y, and to POWHEG (gray) vs. centrality and p_{T}.

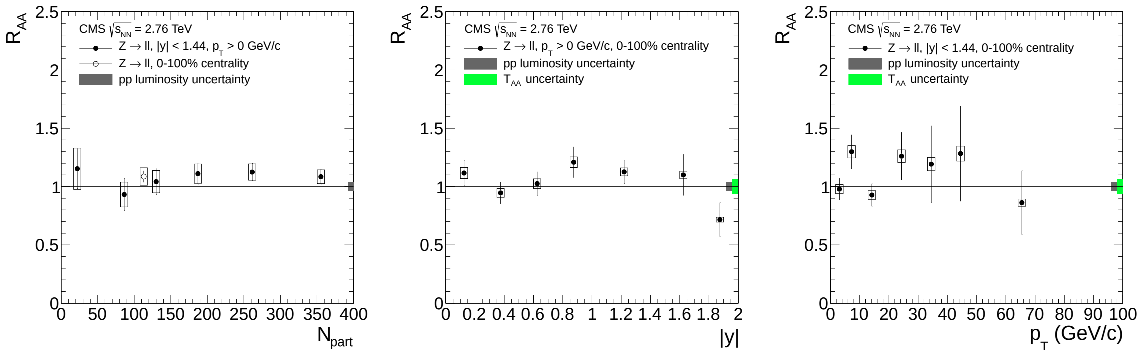

Figure 3. Nuclear modification factor of Z boson production for the combined dilepton channel as a function of N_{part} (*left*), y (*middle*) and p_{T} (*right*). Gray (green) box at $R_{\mathrm{AA}} = 1$ corresponds to the pp luminosity (T_{AA}) uncertainty.

to the average number of binary nucleon-nucleon collisions (N_{coll}). Figure 3 shows the R_{AA} of Z boson production as a function of centrality, rapidity and transverse momentum. In every event class, it is compatible with unity and the integrated values are 1.06 ± 0.05 (stat.) $\pm\, 0.08$ (syst.) in the dimuon and 1.02 ± 0.08 (stat.) $\pm\, 0.15$ (syst.) in the dielectron channel. From the centrality dependence, one can confirm that the Z boson production in PbPb collisions scales with N_{coll}. The results as a function of y and p_{T} are compatible with unity within uncertainties and no initial state nuclear effects are visible with the current amount of data.

3. Z bosons in pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

Due to the LHC magnet system, the p and Pb beam energies were different that resulted in a $\Delta y = 0.465$ shift of the nucleon-nucleon center-of-mass frame compared to the laboratory frame. The results are presented in the center-of-mass frame with positive rapidity values corresponding to the proton fragmentation region. The Z boson candidates are selected as an opposite-charge muon pair in the 60–120 GeV/c^2 mass range where both muons have $p_{\mathrm{T}} > 20$ GeV/c and are within the $|\eta_{\mathrm{lab}}| < 2.4$ muon detector coverage. The invariant mass of muon pairs is shown in the right-hand side of Figure 1 and compared to PYTHIA+HIJING [11] simulation that is used to determine the efficiency correction factors. The acceptance correction is calculated from POWHEG simulation with CT10 PDF set interfaced with PYTHIA parton shower.

The measured inclusive Z boson production cross section in pPb collisions is $\sigma_{\mathrm{pPb}\to\mathrm{Z}\to\mu\mu}(-2.5 < y_{\mathrm{c.m.}} < 1.5) = 94.1 \pm 2.1$ (stat.) $\pm\, 2.4$ (syst.) $\pm\, 3.3$ (lumi.) nb using the calibrated integrated luminosity. For the same restricted rapidity range, the POWHEG simulation predicts 94.0 ± 4.7 nb after multiplying by the number of nucleons in the Pb nucleus ($A = 208$), which corresponds to the hypothesis of binary collision scaling in pPb. The inclusive result is in a good agreement with the NLO pQCD prediction.

The measured differential cross section as a function of rapidity in the center-of-mass frame is compared to predictions from MCFM generator [12] in the left-hand side of Figure 4. The MCFM predictions are calculated with MSTW2008NLO free proton PDF set [13] with and without the nuclear modification from EPS09 or DSSZ nPDF sets [10, 14] and multiplied 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 [8], because normalization uncertainties cancel both in theory and in experiment. The right-hand side of Figure 4 shows the measured forward-backward ratio as a function

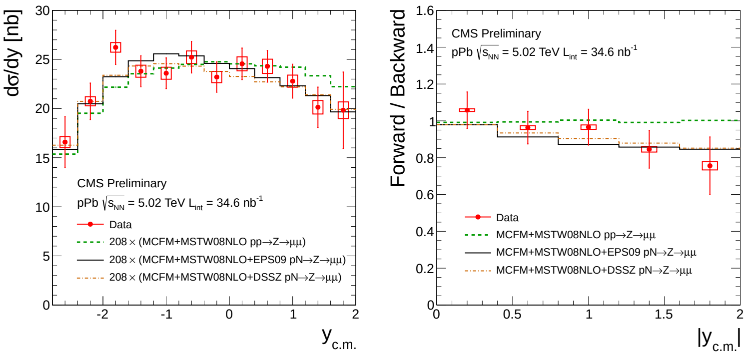

Figure 4. Rapidity differential cross section (*left*) and forward-backward ratio (*right*) of Z boson production in pPb collisions compared to predictions from MCFM with MSTW2008NLO PDF with and without the nuclear modification from EPS09 or DSSZ nPDFs.

of $|y_{\text{c.m.}}|$ 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.

4. Conclusions

CMS showed that Z boson production is unmodified by the hot and dense QCD medium produced in heavy ion collisions, and its yield scales with the number of binary nucleon-nucleon collisions. The nuclear modification factor does not exhibit large deviations from unity showing that nuclear effects are small with respect to the uncertainties of the PbPb measurements. The measurement of Z bosons in pPb collisions demonstrate that at first order, the 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 constraints for the global fits of nPDFs in a previously unexplored region of phase space.

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