W and Z boson production in 5.02 TeV pp and p+Pb collisions with the ATLAS detector

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Abstract

This proceeding reports the ATLAS results of measuring vector boson production in pp and p+Pb collisions at the center-of-mass energy of 5.02 TeV per nucleon. Z bosons are reconstructed via leptonic decays and results are presented as a function of Z-boson rapidity. W bosons are identified by measuring leptons coming from W decays and the results are presented as a function of lepton pseudorapidity. In pp collisions Z boson cross section in $|y_Z| < 2.5$ is $590 \pm 9$ (stat.) $\pm 12$ (syst.) $\pm 32$ (lumi.) pb. In p+Pb system kinematic distributions of W and Z bosons are compared to models based on NLO and NNLO QCD calculations using different PDF sets. Using PDF modification shows better agreement of the model and the data. Measurements done in different centrality intervals show that the PDF modification in p+Pb may have centrality dependence.

Keywords: ATLAS, heavy ion, W boson, Z boson, nPDF, centrality

Experimental study of electroweak (EW) bosons in relativistic heavy ion (HI) collisions is an integral part of the physics program carried out by all four detectors taking data at the Large Hadron Collider (LHC). The results of these programs have demonstrated several important phenomena. Since EW bosons and their leptonic decay products do not interact strongly with the hot and dense matter created in the HI collision, their production rates are expected to be sensitive to the effective overlap area of colliding nuclear matter. This has been confirmed in measurements performed by the ATLAS and CMS experiments with Z and W bosons decaying leptonically or semileptonically where it has been shown that the production rate of non-strongly interacting particles in Pb+Pb collisions scales with the nuclear thickness function $dN_{\text{ch}}/dy$. EW bosons are also used as an outstanding tool to study nuclear modifications to parton distribution functions (PDF). These effects include nuclear shadowing, anti-shadowing and the EMC effect. In particular, rapidity distributions of Z and W bosons determined by the Bjorken $x$ of the interacting partons are sensitive to the presence of nuclear modification. The existing Pb+Pb measurements due to their limited precision cannot exclude the presence of the nuclear modification $dN_{\text{ch}}/dy$.

Study of asymmetric collisions systems, such as proton-lead (p+Pb) can be used to differentiate between initial and final state effects in HI collisions. The results using 2013 p+Pb data at the center-of-mass energy, $\sqrt{s_{\text{NN}}} = 5.02$ TeV on EW boson production have been published by all LHC experiments [6, 7, 8, 9, 10]. Using preliminary result [11] on Z boson production in pp collisions at the same center-of-mass energy as in p+Pb it becomes possible to study modifications observed in that system with respect to a physics measurement rather than to calculated prediction.

The p+Pb data obtained by the ATLAS experiment at $\sqrt{s_{\text{NN}}} = 5.02$ TeV corresponding to integrated luminosity of 29 nb$^{-1}$ has been used to measure Z boson production in muon and electron decay channels [6]. Events for analysis in the electron channel were selected by high-level trigger requiring an electron with at least 15 GeV transverse momentum that also passes loose identifica-
tion criteria. Similarly, events in the muon channel were selected with the high-level trigger requiring a muon with transverse momentum of at least 8 GeV. In total 1647 (2032) Z boson candidates were reconstructed in electron (muon) decay channel. In particular, electrons within the range $2.5 < |y| < 4.9$ are reconstructed based on the energy deposited in the forward calorimeter that allows for the reconstruction of Z boson candidates up to $|y| < 3.5$. This yields additional 264 Z boson candidates. Total measured Z boson fiducial cross section of $139.8 \pm 4.8$ (stat.) $\pm 6.2$ (syst.) $\pm 3.8$ (lumi.) nb is found to be slightly higher compared to model predictions based on perturbative QCD (pQCD) calculations. The data is compared to the simulated MC generated with the CT10 PDF at NLO, scaled to the integrated cross section calculated with DYNNLO at NNLO using the CT14 PDF set [12].

Preliminary measurement of the Z boson cross section has been obtained from the $pp$ data sample corresponding to the integrated luminosity of 24.7 $\pm$ 1.3 pb$^{-1}$ at $\sqrt{s} = 5.02$ TeV. Events for the analysis have been selected with the high-level trigger requiring a muon with transverse momentum of at least 14 GeV. In total 7293 Z boson candidates passed all the analysis selection. The Z boson fiducial cross section is measured to be $590 \pm 9$ (stat.) $\pm 12$ (syst.) $\pm 32$ (lumi.) pb. Model with CT10 PDF set predicts a significantly lower cross section of 537 pb. The NNLO prediction using the CT14 PDF set [13] and calculated using a version of DYNNOLO 1.5 [14, 15] yields a cross section of 573.7 $\pm$ 13.9 $\pm$ 9.4 $\pm$ 32.5 pb which agrees well with the measurement within its uncertainties.

The rapidity differential cross section measured in $p+Pb$ data is presented in Figure 2 and compared to model calculations. The data shows a strong asymmetry about $y^Z = 0$ compared to the model prediction with CT10 PDF set and is better described by the models containing nuclear modification such as EPS09.

In the same $p+Pb$ dataset the $W \rightarrow \mu\nu$ production and the dependence of the cross section on the pseudorapidity of the muons has also been studied [16]. Prediction based on pQCD calculations reproduce the data well, except for the $W^-$ boson in the lead-going direction where there is an excess above the model, which is consistent with the similar observation in the Z boson measurement. In order to study the difference in production of $W^+$ and $W^-$ bosons, the observable called lepton
The lead-going side. Upper panel of Figure 3 shows deviation from the CT10 prediction on observed in different nuclear modifications present inside the lead nucleus and efficiency. This difference can be explained by nuclear PDF modification present inside the lead nucleus and effects observed in p+Pb measurements as discussed above.

Figure 3: The upper panel shows the cross section of the W+ and W− production measured in p+Pb data as a function of the lepton pseudorapidity compared to the model prediction based on CT10 PDF set. The middle panel shows the data-to-model ratios for and the lower panel shows the lepton charge asymmetry compared to the model.

Measurements suggest that the nuclear modification factor has dependence on collision centrality [6, 16]. Figure 5 shows the W+ and W− boson differential yields in lepton pseudorapidity (upper panel) together with ratio to the model prediction (middle panel) and lepton charge asymmetry (bottom panel) for events in the 0-10% centrality class. There appears to be a dependence of the shape of the pseudorapidity distributions of both positively and negatively charged muons from W bosons on centrality. The data shown in the middle panel suggests the presence of a slope in most central collisions. The asymmetry shown in the lower panel also shows deviation from the prediction. This is similar to the trend observed in the Z boson measurement as discussed in [6].

Nuclear modification factor as a function of yZ was measured for three different centrality classes of p+Pb events. Results suggest that the asymmetry observed in the rapidity distribution of the RpPb, is more pronounced for more central collisions as shown in Figure 5. To quantify the change in asymmetry in different centrality classes, each RpPb distribution is fitted to a linear function. The resultant slopes for 40-90%, 10-40% and 0-10% centrality bins are 0.02 ± 0.04, −0.05 ± 0.03 and −0.14 ± 0.04, respectively. The uncertainties come from the fitting and are dominated by the uncertainties of the p+Pb data.

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Figure 5: The upper panel shows the cross section of the $W^+$ and $W^-$ production as a function of the lepton pseudorapidity compared to model prediction based on CT10 PDF set measured in 0-10% centrality interval of the $p+Pb$ data. The middle panel shows the data-to-model ratios for and the lower panel shows the lepton charge asymmetry compared to the same model [10].

Figure 6: The nuclear modification factor in most peripheral (40-90%) and most central events (0-10%). The uncertainties on each point include statistical and systematic uncertainties from $p+Pb$ and $pp$ measurements. The band around unity represents the uncertainty of $(T_{pb})$ and luminosity [11].

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