Conference Paper

Measurement of W and Z boson production in 5 TeV pp, p+Pb and Pb+Pb collisions with the ATLAS detector

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Abstract

W and Z bosons are short lived and do not interact strongly. Thus their production yields measured via lepton decay channels in lead-lead with respect to proton-proton collisions provide direct tests of both binary collision scaling and possible modification of parton distribution functions (nPDF) due to nuclear effects. Further, the proton-lead collisions provide an excellent opportunity to study nPDFs in detail. The ATLAS detector has a broad acceptance in the muon and electron channels, with excellent performance even in the high occupancy environment of central heavy-ion collisions. ATLAS has recorded 0.49 nb^{-1} of lead-lead data at the new center-of-mass energy of 5.02 TeV. Sizes of weak boson production samples are expected to increase by a factor of eight relative to the available Run 1 data at 2.76 TeV. In addition the data can be compared directly to the 29 nb^{-1} of proton-lead data collected in Run 1 at the same energy. In this report, W and Z boson production yields, and lepton charge asymmetries from W decays are presented differentially in rapidity and transverse momentum as a function of centrality in lead-lead and proton-lead collisions.

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1. Introduction

The Relativistic Heavy Ion Colider (RHIC) showed that strongly interacting matter produced in collision of two heavy nuclei takes the form of quark gluon plasma (QGP) [1]. In such medium produced color particles are expected to lose energy which leads to a phenomenon known as jet quenching. Suppression of charge hadron yields in heavy-ion collisions was already reported by experiments at RHIC and the LHC [2–4].

A direct way to study the initial stage of proton-proton (pp), proton-nucleus and nucleus-nucleus collisions is to measure production of colorless electroweak (EW) bosons, namely high-energy photons, $W^{\pm}$ and Z. These bosons are created at the very early stage of the collision in the hard parton-parton interaction. Leptonic decays of $W^{\pm}$ and Z are expected to not interact substantially with the QGP, making them useful probes of the QGP. This unique feature makes them sensitive to the initial geometry of the nuclei and nuclear modifications to parton distribution functions (nPDF) can be studied. A measurement of direct photon production [5] by the PHENIX experiment at RHIC showed that their rates scale with the nuclear thickness function. Very similar conclusions came from the first measurements of electroweak vector bosons in lead-lead (Pb+Pb) collisions performed by the ATLAS and CMS experiments [6-10]. In principle their production rates were found to be independent of the presence of QGP. Furthermore, the weak boson production in proton-lead (*p*+Pb) and Pb+Pb collisions may differ from the *pp* system. There are two main sources of these differences. The first one is related to the presence of neutrons in the nucleus which have different quark composition compared to protons. Secondly, EW boson productions can be affected by effects arising from partons being bound in the nucleus where the PDF of the free nucleon might be modified leading to parton depletion or enhancement [11].

This report covers the most recent measurements on *W* and *Z* boson production in the *pp*, *p*+Pb and Pb+Pb systems at $\sqrt{s_{NN}} = 5.02$ TeV by the ATLAS Collaboration. They are based on data collected in 2013 and 2015. A detailed description of the ATLAS detector is provided in Ref. [12].

2. Z boson production

The Z boson production has been measured in pp, p+Pb and Pb+Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV using data corresponding to an integrated luminosity of 29 nb^{-1} and 0.49 nb^{-1} [13, 14], respectively. Figure 1 presents Z boson yields scaled by the average nuclear thickness function (T_{AA}) as a function y_Z for three selected centrality intervals compared to the measurement in the pp system. The Z bosons are reconstructed via the di-muon decay channel. Good agreement with the model predictions and measured pp data points is observed. Only slight excess is observed in the most peripheral class of events. The nuclear modification factor R_{AA} is also shown in the lower panel. Good agreement with unity indicates small impact of nuclear effects.

Figure 2 presents the differential cross section as a function of *Z* boson rapidity measured in *p*+Pb at $\sqrt{s_{NN}}= 5.02$ TeV. Model estimations based on the CT10 PDF [15] set with and without EPS09 [16] nuclear corrections and MSTW2008 are also shown. The strong asymmetry around y^*_Z comes from the asymmetry of the collision. A χ^2 test of compatibility between data and the model shapes (irrespective of normalization) shows that the CT10+EPS09 shape of the *Z* boson rapidity disitrbution gives a highest p-value of 0.79 [14].

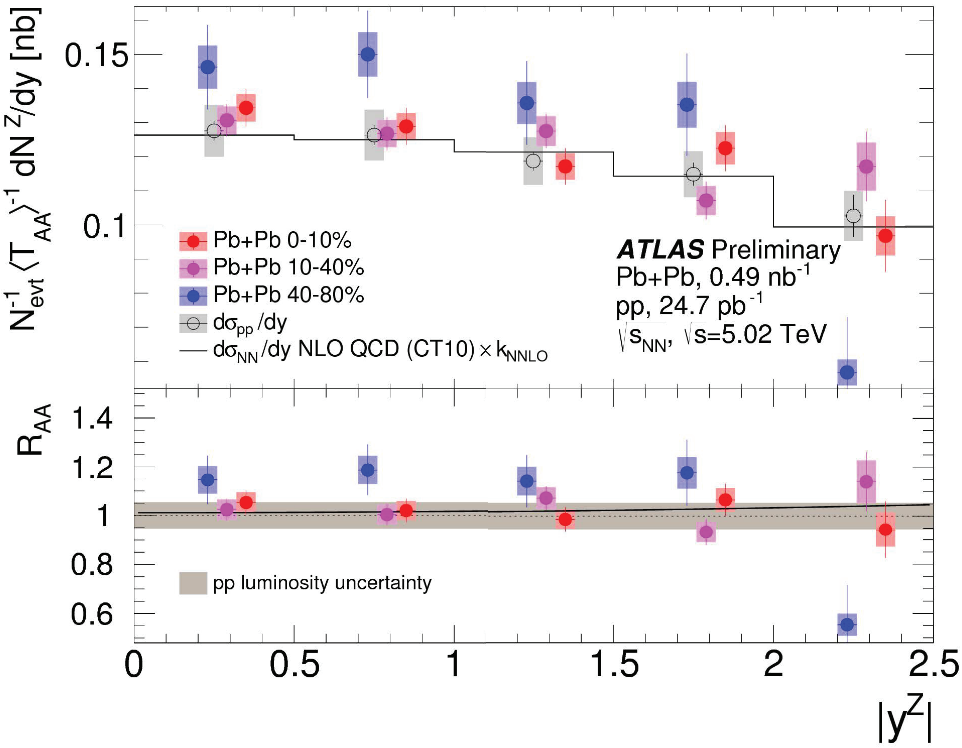

Figure 1: Upper panel presents *Z*-boson yields per event in three centrality intervals divided by T_{AA} (filled circles) in the Pb+Pb collisions and differential cross section measured in *pp* collisions (open circles) as a function of y_Z. A ratio of Pb+Pb results to the *pp* result in three centrality intervals is shown in the bottom panel. The *pp* luminosity uncertainty (5.4%) is indicated as a band around unity. The statistical and systematic uncertainties are presented by error bars and shaded boxes, respectively. Results of the Powheg-based model using CT10 PDF are also shown as a solid line [13].

3. W boson production

W boson production in the muon decay mode has been measured in Pb+Pb collisions at $\sqrt{s_{NN}}$=5.02 TeV using data corresponding to integrated luminosity of 0.49 nb^{-1} [17]. The production yields are calculated within the fiducial region defined by muon pseudorapidity, $0.1 < |\eta| < 2.4$, muon transverse momentum, $p_T > 25$ GeV, missing transverse energy, $E_T^{miss} > 25$ GeV and transverse mass of the muon and missing transverse momentum, $m_T > 40$ GeV. The total numbers of background subtracted and efficiency corrected events for *W* production are 34500 ± 290 $(stat.)^{+2100}_{-2600}$ (syst.) and 31300 ± 270 $(stat.)^{+1900}_{-2500}$ (syst.) for W^+ and W^- respectively. Figure 3 presents the difference in production yields between positive and negative *W* bosons called as charge asymmetry and defined by:

$$A_\mu(\eta) = \frac{dN_{W^+}/d\eta - dN_{W^-}/d\eta}{dN_{W^+}/d\eta + dN_{W^-}/d\eta}$$

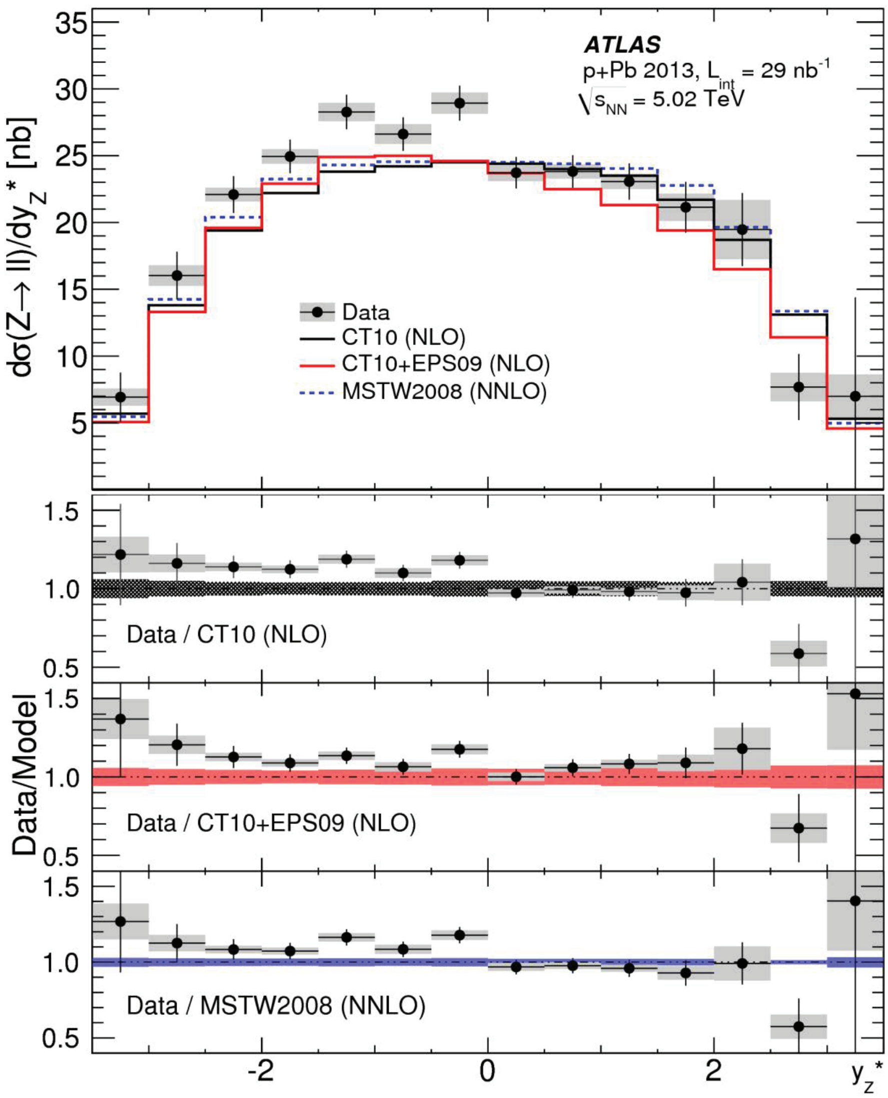

Figure 2: Differential cross section as a function of the Z boson rapidity compared with several model calculations in the upper panel. The statistical and systematic uncertainties are presented by error bars and shaded boxes, respectively. The uncertainties on models are not shown. Bottom panels present ratios of data to models. The uncertainties of the model calculations (scale and PDF uncertainties added in quadrature) are shown as bands around unity in each panel [14].

where $dN_{W^+}(dN_{W^-})$ is a corrected number of W^+ (W^-) bosons. Charge asymmetry is extracted from the 0-80% centrality interval as a function of the muon absolute pseudorapidity. This observable is sensitive to PDFs and may also be sensitive to the nuclear modifications. The data are compared to Powheg scaled by k_{NNLO} using CT10 free nucleon PDF and MCFM using the most recent nuclear modifications to PDF, namely EPPS16 [18] and nCTEQ15 [19]. Sensitivity to nuclear modifications is not observed as all three predictions agree well. The muon charge asymmetry is roughly constant for $|\eta_\mu| < 1.5$ and the data are described well by the predictions. For higher η_μ data points deviate from the expectations by no more than 3 σ.

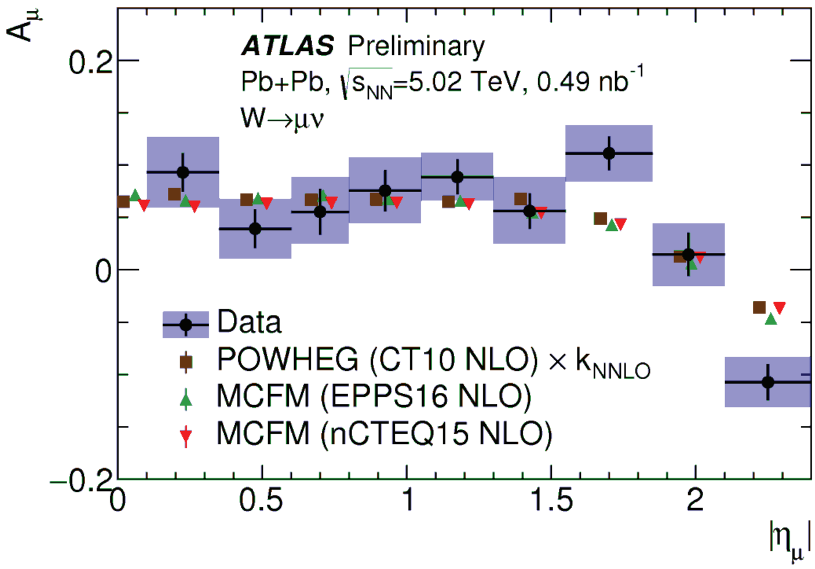

Figure 3: Charge asymmetry as a function of the muon pseudorapidity compared with several model calculations. The error bars correspond to the statistical uncertainties, error boxes correspond to the total systematic uncertainties. The uncertainties on the model are only statistical [17].

4. Conclusions

Measurements of *Z* and *W* boson production have been reported based on *pp*, *p*+Pb and Pb+Pb data collected at $\sqrt{s_{NN}} = 5.02$ TeV by the ATLAS experiment at the LHC. Predictions based on perturbative QCD calculations describe the data well. Differences between the data and predictions are observed for the Pb-going side, in case of *p*+Pb collisions, where there appears to be an excess above the model. The muon charge asymmetry for Pb+Pb collisions is in good agreement with all three predictions, except for the forward direction where there are discrepancies between the data and predictions at the level up to 3σ.

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