PROCEEDINGS OF SCIENCE

Z-boson production in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV

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The measurement of Z-boson production in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV is reported. It is performed in the dimuon decay channel, through the detection of muons with pseudorapidity $-4 < \eta_{\mu} < -2.5$ and transverse momentum $p_{\mathrm{T}}^{\mu} > 20$ GeV/c. The invariant yield is measured for opposite-sign dimuons with invariant mass $60 < m_{\mu\mu} < 120$ GeV/c^2 and rapidity $2.5 < y^{\mu\mu} < 4$. The yield is also presented as a function of rapidity and centrality. The results are compared with theoretical calculations, both with and without nuclear modifications to the Parton Distribution Functions (PDFs). A 3.4σ deviation is seen in the integrated yield between the data and calculations based on the free-nucleon PDFs, while good agreement is found once nuclear modifications are considered.

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1. Introduction

Electroweak bosons are useful tools to study the initial state in heavy-ion collisions. Because of their heavy masses, their production cross section can be calculated within electroweak theory along with corrections due to gluon radiation. This has been done up to next-to-next-to leading order (NNLO) [1]. Furthermore, neither the electroweak bosons nor their decay products carry color charge, which prevents them from interacting with the strong quantum chromodynamic medium formed in heavy-ion collisions. Lastly, there are hints that electromagnetic interactions may occur for the decay products, but the effect this has on their transverse momentum (p_T) is negligible compared to their momenta [2].

Electroweak bosons are mainly produced through quark-antiquark annihilation (also known as Drell-Yan processes) and are therefore sensitive to the distribution of quarks and gluons within the nucleons. These distributions are described by so-called parton distribution functions (PDFs). They give the probability of finding a quark or gluon with momentum fraction x and energy scale Q^2 for a given process. The PDFs are obtained by global fits to data, mostly from Deep Inelastic Scattering experiments.

It has been observed that once proton PDFs are known, PDFs for (heavy) nuclei cannot be obtained through simple scaling of the number of protons and neutrons. Instead, separate nuclear PDFs (nPDFs) are needed, which are obtained through global fits to data from proton–nucleus or nucleus–nucleus collisions. The aforementioned lack of electromagnetic final state interactions makes the electroweak bosons a useful probe of the initial state in heavy-ion collisions, in particular of the nPDFs. This contribution describes the production of Z bosons in Pb–Pb collisions at the LHC using data collected with the muon spectrometer of the ALICE detector.

2. Analysis method

The analysis was performed on a data sample of Pb–Pb collisions at a center-of-mass energy per nucleon pair of $\sqrt{s_{NN}}$ = 5.02 TeV collected in 2015 and 2018. The events were triggered by requiring the presence of a dimuon pair with opposite charge in addition to the minimum bias requirement. The latter is the coincidence of a signal in both the V0A and V0C subdetectors. A centrality selection on the events was done, requiring a centrality between 0 and 90%. The estimation of centrality was done using the sum of the V0A and V0C signals. The selected tracks were required to have a pseudorapidity of $-4 < \eta < -2.5$ and polar angle at the front absorber $2° < \theta_{abs} < 10°$ to match the acceptance of the muon spectrometer. To remove tracks not pointing to the interaction vertex, a selection was applied on the product of the track momentum and its distance of closest approach to the vertex. Furthermore, tracks were required to have a matching entry in the trigger stations. Lastly, the tracks were required to have a transverse momentum of $p_T > 20$ GeV/c.

An invariant mass spectrum was computed by constructing every pair of opposite-sign dimuons per event. An additional selection on the rapidity of the dimuon was done, requiring $2.5 < y < 4.0$. The invariant mass spectrum is shown in the left plot of Fig. 1. The number of Z-boson candidates was then obtained by counting the number of bin entries in the interval 60-120 GeV/c^2 (roughly symmetric around the PDG mass of 91.2 GeV/c^2 [3]). To estimate the background contributions, the number of same-sign pairs was also computed. Only one such pair was found and this entry was subtracted from the number of Z-boson candidates. The remaining number of candidates was corrected by the reconstruction efficiency of the detector, which was obtained through simulations.

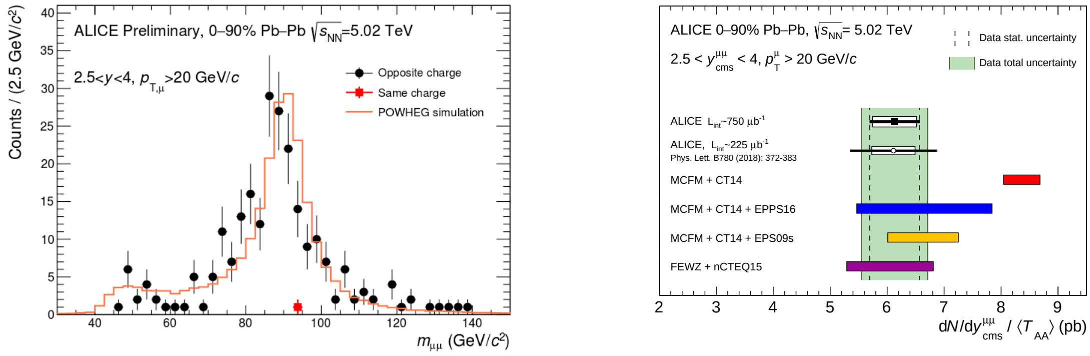

Figure 1: Left: Invariant mass spectrum of opposite-sign dimuons. The spectrum as computed with a MC simulation using POWHEG as event generator is also shown, and is in good agreement with the data. Right: Integrated invariant yield compared with several theoretical calculations [4–7]. Figures taken from [8].

3. Results

The normalized invariant yield is calculated as

$$\frac{{\rm d}N/{\rm d}y}{T_{\rm AA}} = \frac{N_{\rm Z}}{A\epsilon \times N_{\rm MB} \times \Delta y \times T_{\rm AA}}, \tag{1}$$

where $A\epsilon$ is the aforementioned reconstruction efficiency within the fiducial acceptance, $N_{\rm MB}$ the number of minimum bias events corresponding to the number of triggered events analyzed, Δy the rapidity interval considered and $T_{\rm AA}$ the nuclear overlap function. The latter normalizes the Pb–Pb yield to the yield per nucleon–nucleon collision. The integrated yield is shown in the right plot of Fig. 1. A comparison is made with an earlier ALICE measurement which was performed over a subsample of the current dataset. As expected, the increase in data size leads to a reduction of the statistical uncertainty. Comparisons are also made with theoretical models, that either do or do not include nuclear modifications of the PDFs. The free-nucleon PDFs (without nuclear modifications) displayed are CT14NLO [4], while the nPDFs are EPS09s, EPPS16 and nCTEQ15 [5–7]. A 3.4σ deviation is found with the free-nucleon PDFs. All three nPDFs agree within uncertainties with the measured data point.

Differential yields versus rapidity and versus centrality were obtained as well. These can be seen in Fig. 2. On the left plot, the rapidity dependence is shown. At larger rapidity, the differences between the data and free-nucleon PDFs tend to increase. Although the shape is in general described by both free-nucleon PDFs as well as nPDFs, the former tends to overpredict the data. On the right plot, the differential yield is plotted as a function of centrality. Within uncertainties it seems that there is no strong centrality dependence. The EPS09s nPDF set contains an impact parameter dependence, so that the distributions depend on collision centrality. However, no strong centrality dependence of the Z-boson production is predicted, in agreement with the data.

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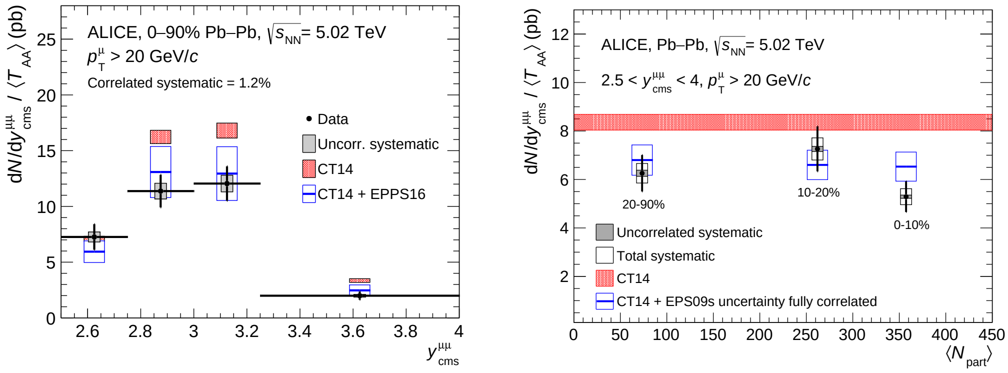

Figure 2: Differential invariant yield. The left plot shows the yield as a function of rapidity while the right plot shots it as a function of centrality. Figures taken from [8].

4. Conclusion

The production of Z bosons in Pb–Pb collisions at a center-of-mass energy per nucleon pair of $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV has been reported. The results are compared with various theoretical models that either do or do not include nuclear modifications of the proton PDFs. A 3.4σ deviation is found in the integrated yield between the data and free-nucleon PDF predictions. In contrast, the integrated yields computed using different nPDFs all agree with the data within uncertainties. Differential yields versus centrality and rapidity have been obtained as well. No strong centrality dependence is observed. The rapidity dependence is quantitatively described by nPDFs while it is only qualitatively described by free-nucleon PDFs.

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