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Understanding the initial state effects by the measurement of the Drell-Yan process in pPb collisions with CMS

Hyunchul Kim[1,*] on behalf of the CMS Collaboration

[1]Chonnam National University

Abstract. The Drell-Yan process is considered as an essential probe to understand initial-state protons, usually described by the parton distribution functions (PDFs) for stand-alone protons and by the nuclear PDFs (nPDFs) for protons confined in the nucleus. In the LHC era, Z and W boson production in pPb and PbPb collisions have been used to investigate the initial-state effects. In this presentation, we report results for the Drell-Yan process in pPb collisions at a center-of-mass energy of 8.16 TeV with the CMS detector. Differential cross sections are presented as functions of dimuon p_T, rapidity and ϕ^* in a wider dimuon mass region which includes not only the Z boson mass range but also the lower mass region down to 15 GeV. In addition, the forward-backward asymmetries are shown in both mass regions, and the uncertainties are found to be smaller than in the model calculations. The results in the Z mass region are the most precise to date, while the measurements in the lower mass region allow access to a new phase space of nPDF studies at a lower longitudinal momentum fraction x and lower energy scale Q^2. The results are compared to the EPPS16 and nCTEQ15WZ nPDFs, and the free-proton PDF CT14. An improved understanding of the nuclear PDF and the modeling of pPb collisions is achieved.

1 Introduction

The parton distribution function (PDF) is defined as the probability density for finding partons i.e. quarks and gluons inside the proton as a function of the momentum fraction x of the parton at energy scale Q^2 [1]. The nuclear PDF (nPDF) can be modified because the nucleons exist in the nucleus, compared to that in a free proton [2]. These (n)PDFs are extracted from global fits to experimental data [3, 4].

Drell-Yan (DY) process, proposed by Sidney Drell and Tung-Mow Yan in 1970 to explain the production of lepton-antilepton pairs in high energy collisions [5], is an important probe for nPDF studies as they are created in the initial stages of the collisions and are free from final state interactions.

In the DY process, quark and antiquark pairs from colliding nucleons are annihilated and decayed into lepton pairs with opposite charges by exchanging a virtual γ or a Z boson. A Z boson has been used as the clean signal to test nPDFs because of the higher mass and small backgrounds. In addition, the measurement through a virtual γ allows access to a wider x range.

*e-mail: hyunchul.kim@cern.ch

In this contribution, the study of DY dimuon production from proton-lead (pPb) collisions at $\sqrt{s_{\rm NN}}$ = 8.16 TeV with the CMS detector is reported. The detailed information about the analysis can be found in [6].

2 Event Selection

The differential cross section of the DY process via dimuon decay channel is measured within the dimuon invariant mass range $15 < m_{\mu\mu} < 600$ GeV. The transverse momentum ($p_{\rm T}$), the absolute value of the rapidity in the nucleon-nucleon center-of-mass frame ($y_{\rm CM}$), and the ϕ^* dependence are measured in two dimuon mass ranges for $15 < m_{\mu\mu} < 60$ GeV and $60 < m_{\mu\mu} < 120$ GeV, targeting to lower mass range and Z boson mass, respectively. The variable ϕ^* is defined as $\tan\left(\frac{\pi-\Delta\phi}{2}\right)\sin(\theta^*_\eta)$, where $\Delta\phi$ is the opening angle between decaying muons [7–9]. The θ^*_η is related to the pseudorapidities of the muons by the relation $\cos(\theta^*_\eta) = \tanh(\Delta\eta/2)$, where $\Delta\eta$ is the difference in pseudorapidity between the two muons. The ϕ^* value are measured by the angular variables with better precision than $p_{\rm T}$, especially at lower $p_{\rm T}$ values. The forward-backward ratios ($R_{\rm FB}$) are defined as the ratio of the cross sections in the positive rapidity range to that in the negative rapidity range and measured in the same dimuon mass ranges.

For the analysis, the proton-lead ion collision data at a nucleon-nucleon center-of-mass energy of $\sqrt{s_{\rm NN}}$ = 8.16 TeV, with a total integrated luminosity of 173.4 ± 6.1 nb^{-1} are used. At least two muons in the pseudorapidity in a laboratory frame with opposite charges are required. The main event and dimuon candidate selection conditions are that the requiring $p_{\rm T}$ of the leading muon and another muon is larger than 15 and 10 GeV, respectively. The other detailed selection conditions can be found in [6].

3 Results

At the beginning of the analysis, various backgrounds are estimated by their source. The backgrounds involving two isolated muons, such as $Z/\gamma^* \rightarrow \tau^+\tau^-$, $t\bar{t}$, tW, or dibosons are estimated from the "eμ method" with simulated samples. The contribution from heavy-flavor meson decays is only a small fraction and corrected from same-sign eμ events. The contributions with one or more muons in jets are subtracted by the "misidentification rate method" [10, 11] After subtracting the sum of background contributions from data, the domination of the DY signal is measured, and the agreement between data and the expectation is shown. Following the background estimation, detector resolution and final state radiation are corrected for. The acceptance and efficiency correction is considered to the corrected differential cross section. The differential fiducial cross sections without acceptance correction are also measured.

Figure 1 shows the fiducial cross sections as the function of dimuon rapidity in the $15 < m_{\mu\mu} < 60$ GeV and $60 < m_{\mu\mu} < 120$ GeV ranges. The experimental data are compared with the expectations from POWHEG, using the CT14 only proton PDF [12] and CT14+EPPS16 nPDF sets [3]. The measurement in the lower mass range $15 < m_{\mu\mu} < 60$ GeV is allowed to access the lower x region. In the Z boson mass range $60 < m_{\mu\mu} < 120$ GeV, EPPS16 nPDF shows better agreement with data than CT14 PDF alone. But the concrete conclusions in favor of nPDF expectation are prevented by imperfect modeling in POWHEG, from $p_{\rm T}$ or ϕ^* differential results in the same mass region.

The $R_{\rm FB}$ results in the $15 < m_{\mu\mu} < 60$ GeV and $60 < m_{\mu\mu} < 120$ GeV are shown in Fig. 2. The results from the data are compared with CT14 proton PDF and EPPS16 and nCTEQ15WZ nPDF predictions [4] based on CT14. In the Z boson mass region, $R_{\rm FB}$ is

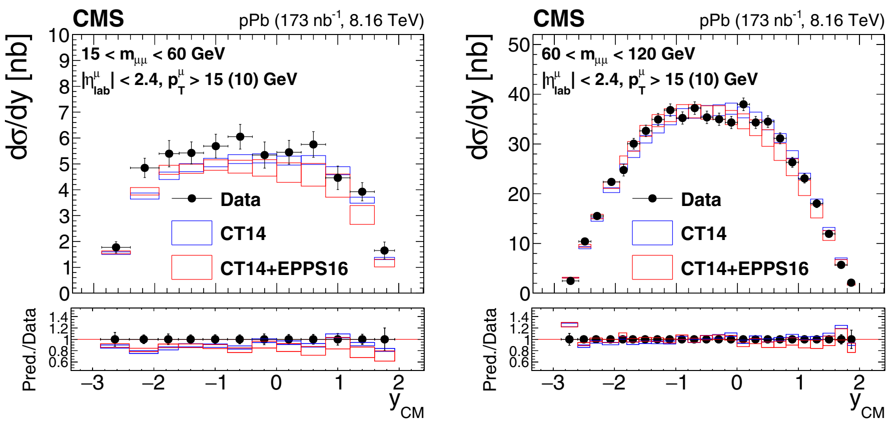

Figure 1. Differential fiducial cross section for the DY process measured in the dimuon channel, as a function of the rapidity in the center-of-mass frame for $15 < m_{\mu\mu} < 60$ GeV (left) and $60 < m_{\mu\mu} < 120$ GeV (right). The vertical error bars on the data represent the quadratic sum of the statistical and systematic uncertainties. Model predictions from CT14 [12] protn PDF (blue) or CT14+EPPS16 [3] (red) nPDF sets are shown. The boxes show the 68% confidence level (n)PDF uncertainty on these predictions. The ratios of predictions over data are shown in the lower panels, where the data and (n)PDF uncertainties are shown separately, as error bars around one and as colored boxes, respectively.

smaller than unity as shown in the experimental data and the expectations from nPDFs in contrast to proton PDF only. The data points that have smaller uncertainties compared to expectation can also contribute to further improving the models.

Results are consistent with previous W boson in pPb measurements at the same collision energy [13] and Z boson measurements in pPb measurements at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV [14]. Recently the DY measurement contributed to the update of nPDF models such as nNNPDF3.0 [15]. In addition, more contributions to further nPDF developments by the constraints are expected.

4 Summary

Measurements of cross sections and forward-backward ratios for the Drell-Yan process are reported for the first time in proton-ion collisions with the CMS detector. The results are presented in two mass regions, in the range below the Z boson mass, and around the Z boson mass. The measurements in the lower mass range allow access to a new phase space for (n)PDF studies. These novel results provide strong constraints to theoretical calculations and are expected to become more essential for the predictions and analysis of future LHC Run3 data.

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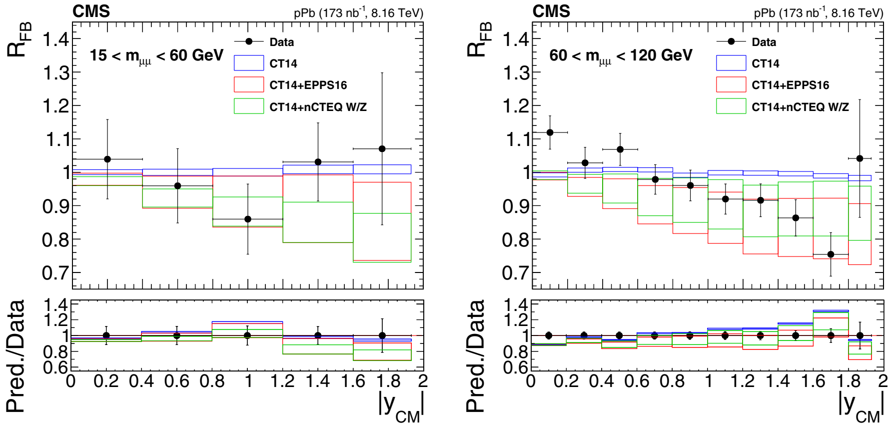

Figure 2. Forward-backward ratios for 15 – 60 GeV (left) and 60 – 120 GeV (right). The vertical error bars on the data points represent the quadratic sum of the statistical and systematic uncertainties. The theory predictions from the CT14 [12] proton PDF (blue), CT14+EPPS16 [3] (red), or CT14+nCTEQ15WZ [4] (green) nPDF sets. The boxes show the 68% confidence level (n)PDF uncertainty in these predictions. The ratios of predictions over data are shown in the lower panels, where the data and the (n)PDF uncertainties are shown separately, as error bars around one and as coloured boxes, respectively.

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