PROCEEDINGS OF SCIENCE

Z boson production in proton-lead collisions accounting for transverse momenta of initial partons

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We report on a recent calculation of inclusive Z boson production in proton-lead collisions at the LHC taking into account the transverse momenta of the initial partons [1]. In the calculation the framework of k_T-factorization has been used. The appropriate TMDs for lead nuclei have been constructed using the parton branching method. The results are compared with data from CMS taken at $\sqrt{s} = 5.02$ TeV.

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PoS(DIS2019)126

1. Introduction

The production of Z bosons in hadron-hadron collisions is described as the annihilation of a pair $q\bar{q} \to Z$. To describe this process we are going to use k_T-factorization. In this approach, [2, 3], the parton densities depend on longitudinal momentum fraction of hadrons' momentum as carried by partons as well as on partons' transverse momenta and also hard scale. Such transverse momenta come from the intrinsic motion of the partons inside the hadrons but also from the perturbative evolution of the partons from a small scale to the hard scale of the process. The hard process is in general calculated with off-shell initial partons. In the past years, significant progress has been made by the calculations of hard processes not only for initial gluons but also for initial quarks [4]. The transverse momentum dependent parton densities (TMDs) for protons were recently obtained from precision fits to deep-inelastic cross section measurements within the parton-branching (PB) approach [5, 6, 7]. Here we are in particular interested in exploring the transverse momentum structure of the partonic content of lead nucleus at relatively large values of its longitudinal momentum. To achieve this we extend the PB approach to the case of heavy nuclei, in particular to lead nucleus, and apply the newly constructed nuclear TMDs (nTMDs) together with off-shell matrix elements to calculations of Z boson production in pPb collisions at the LHC.[1]The interest is motivated by experiments at CERN where proton-lead and lead-lead collisions are studied. The precise knowledge of the partonic structure of the lead nucleus and the factorization used will allow to increase the precision of the theoretical description of the initial state of proton-lead and lead-lead collisions. In order to demonstrate the usefulness of the newly obtained nTMDs for lead nucleus, we calculate the cross section for the rapidity and p_T spectrum of Drell-Yan pairs with an intermediate Z/γ^* boson state. Furthermore, such a final state, being a colorless particle, gives the opportunity for particularly interesting investigations complementary to results obtained in studies of jet final states in [8, 9].

2. Nuclear TMDs

In the PB approach, the parton density is evolved with the DGLAP evolution equation from a small scale (where the initial parton density is parametrized) to the scale of the hard process using an iterative procedure. In this way, every single splitting process during the evolution is calculated, and kinematic constraints in each parton splitting step are treated. Once a physical meaning is given to the evolution scale, the transverse momentum of the partons involved in each splitting can be calculated, and a transverse momentum dependent (TMD) parton density can be obtained. The details of the method can be found in [7]. The nuclear TMD is obtained by a convolution of the starting distribution with the evolution kernel as described in Ref. [7]. The starting distribution $f_{0,b}^{\mathrm{Pb}}(x,\mu_0^2)$ for lead nucleus is taken to be one of the available collinear nuclear PDFs (nPDFs), e.g. the nCTEQ15 [10]. In [1] three different collinear nPDFs were used to produce the corresponding nTMDs. In particular the two most commonly used nPDFs nCTEQ15 [10] and EPPS16 [13]. Additionally we did comparisons with distributions obtained in Ref. [14] which allow for more reliable description of the low-x region. The nTMDs based on these nPDFs (PB-gluon_D_c_ncteq1568CL_Pb) turned out to be rather similar to the results obtained based on

[1]Whenever we refer to Z boson production we mean a production of a lepton pair via both Z and γ^* exchange.

PoS(DIS2019)126

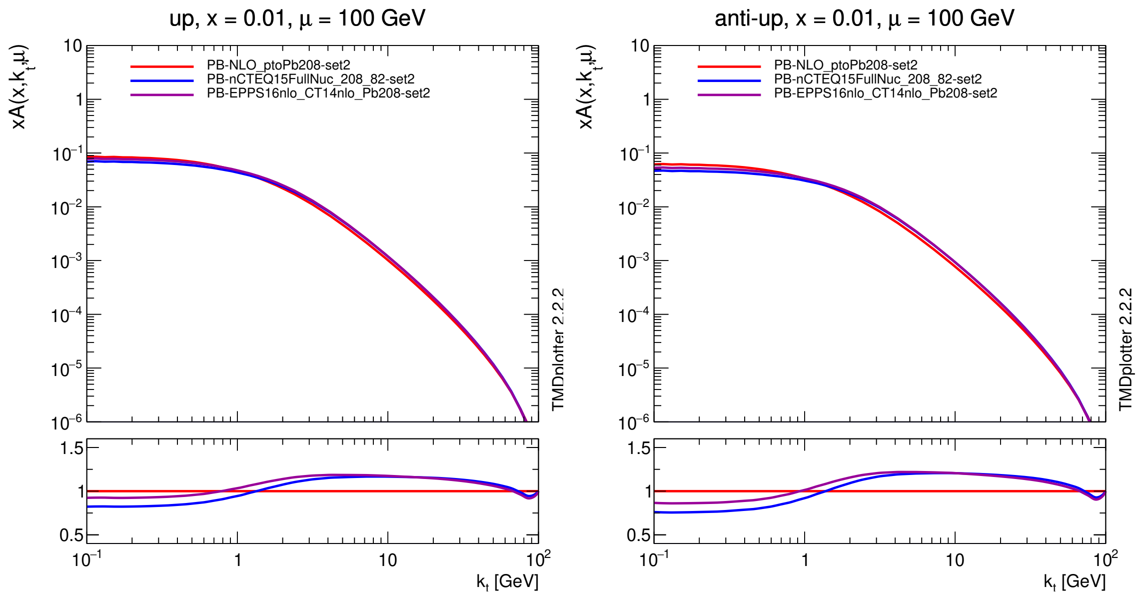

Figure 1: Comparison of different nuclear transverse momentum dependent parton densities for u and $\bar{u}$ quarks at $x = 0.01$ at the scale $\mu = 100$ GeV. Depicted are the `Set2` distributions that are used in the calculations in Sec. 3.

the nCTEQ15 nPDFs In Fig. 1 we compare different nuclear TMDs with PB-NLO_ptoPb208 at $x = 0.01$ and $\mu = 100$ GeV. We can see that both nuclear TMDs (PB-nCTEQ15FullNuc_208_82 and PB-EPPS16nlo_CT14nl_Pb208) are quite similar and differ from the PB-NLO_ptoPb208 distributions.

3. Results

We present now our predictions for the inclusive Z boson production in pPb collisions at the LHC

$$p\text{Pb} \to (Z/\gamma^*) \to \ell\bar{\ell} \tag{3.1}$$

at $\sqrt{s} = 5.02$ TeV and compare them with CMS data [15]. The intermediate vector boson is decaying into a pair of electrons or muons and these two channels are combined and we compare with this combined data. The measurement is done in the fiducial region defined by: $p_T^\ell > 20$ GeV, $|\eta_{\text{lab}}^\ell| < 2.4$ and $60 < m_{\ell\ell} < 120$ GeV. In our calculations we use leading order (LO) off-shell matrix elements as calculated by the KaTie Monte Carlo generator [4] and the TMDs (and PDFs) discussed in Sec. 2. The factorization and renormalization scales are set to be equal to the Z boson mass, $\mu = m_Z$. In Fig. 2 we first present a comparison of predictions obtained using different PB TMDs for lead and proton [5]. We can see a very good description of the data provided by the k_T-factorization framework. This is true for all the nuclear TMDs. We observe only minor differences between predictions obtained with different nTMDs which suggest that the details of the nuclear corrections are here secondary compared to the framework itself. On the other hand, we can see that neglecting the nuclear correction entirely (using lead composed out of free-proton

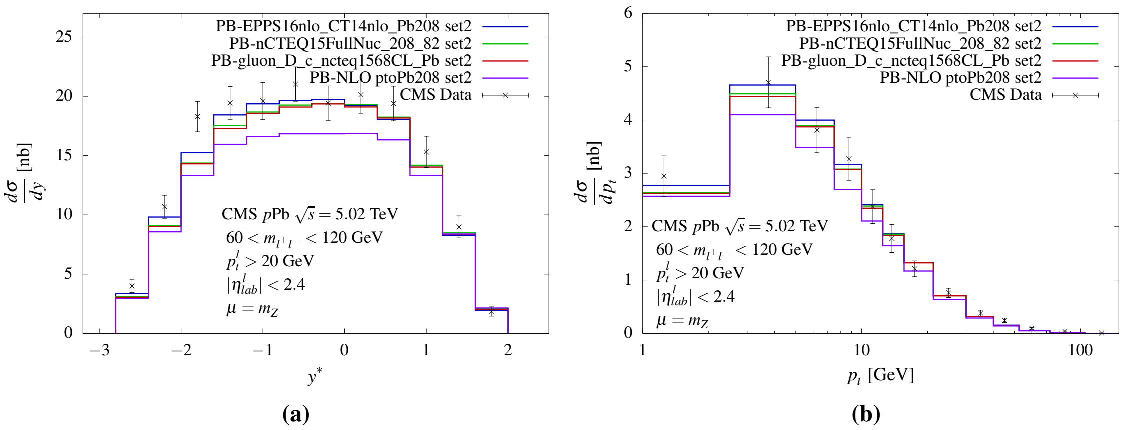

Figure 2: Comparison of predictions for: (a) Z boson (center of mass) rapidity y^*, and (b) Z boson transverse momentum, p_T, distributions obtained within k_T-factorization using different PB nTMDs/TMDs with the CMS data [15].

TMDs – PB-NLO_ptoPb208) undershoots the measured cross sections as a function of the rapidity and the transverse momentum. One should highlight that these are absolute distributions meaning that the LO framework we are using predicts not only the shape of the distributions but also their normalization (the uncertainty of the prediction is discussed at the end of this section).

The results are very similar for all the nuclear TMDs and therefore we concentrate only on the ones obtained with the PB-nCTEQ15FullNuc_208_82 distributions. We have constructed the first sets of nuclear TMDs for gluons as well as all the quarks. It was done using the parton branching method employing different choices of α_S arguments. We have used the constructed nTMDs in the k_T-factorization framework to calculate predictions for Z boson production at pPb collisions at the LHC. The obtained results show very good description of the CMS data [15] for both rapidity and p_T distributions. One should highlight here that predictions are not only for the shape of the distributions but also for their normalization.

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PoS(DIS2019)126