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ORIGINAL ARTICLE

Study of Z-boson production in di-lepton channel on pPb collisions at $\sqrt{S_{NN}} = 5.02$ TeV

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Abstract

There is a growing interest in the analysis of the most recent results of the ALICE, ATLAS, and CMS detectors in asymmetric systems (pPb) due to the possibility of establishing some theoretical prescriptions for PbPb collisions and gaining insight this way into the behavior of the medium itself. The analysis of data in both cases can allow the understanding of the parton distribution functions (PDFs) under different regimes. For the study of the initial state in proton-led collisions at 5.02 TeV, in this contribution, the Drell-Yan process was chosen once the inclusive lepton production represents a *clean* process, independent of the color degree of freedoms. For this study, an extension of the Glauber model was considered for the cross section. Under this approach, we can examine the initial vertex of the hard process described by the proton–proton (*pp*) signal cross section σ_{pp} and apply the *usual standard* calculations through the factorization theorem. We focused on the analysis of the p_T (transverse momentum) distribution and compared the role of different factorization schema in the behavior of the distribution at low p_T.

KEYWORDS

Glauber model, Drell-Yan, collision, lead, PDF, TMD

1 | INTRODUCTION

There is a growing interest in the examination and analysis of the results in ALICE, ATLAS, and CMS detectors in the case of pPb collisions at the Large Hadron Collider energies. Such interest in asymmetric systems is due to the possibilities, on the one hand, of establishing some references for lead–lead collisions and, on the other hand, to gain insight into the behavior of the medium itself.

One should also remember that, in particular, the parton distribution functions (PDFs) of a free proton, in comparison to the PDFs corresponding to the bound nucleons, the so-called nuclear PDFs (nPDFs), should behave differently. In this regard, the analysis of the data can allow the understanding of the PDFs under different regimes. Besides, the presence of the initial and final state effects in proton–nucleus collisions is well recognized (Cronin et al. 1975). For example, in the case of ion–lead collisions, the interaction with the quark-gluon plasma (QGP) can lead to jet quenching or the dissolution of the quarkonia.

In this last case, there are two possibilities: it is a manifestation of the nature of the final interaction or a final-state effect of events hidden or absorbed in the QGP. In the case of a proton–nucleus collision, one is in the presence of a "cold system" known as cold nuclear matter, and therefore, it is possible to disentangle the initial and final state effects.

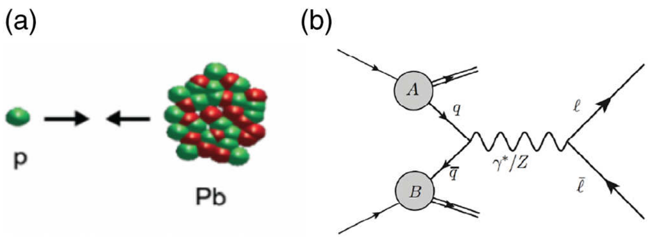

FIGURE 1 (a) pPb collision and (b) leading-order (LO) diagrams of Drell-Yan process

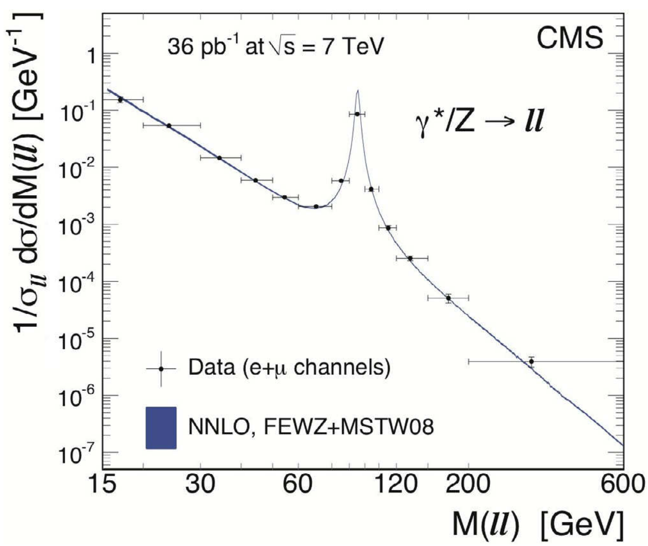

FIGURE 2 Di-lepton mass cross section in a pp collision at $\sqrt{s_{NN}} = 7$ TeV

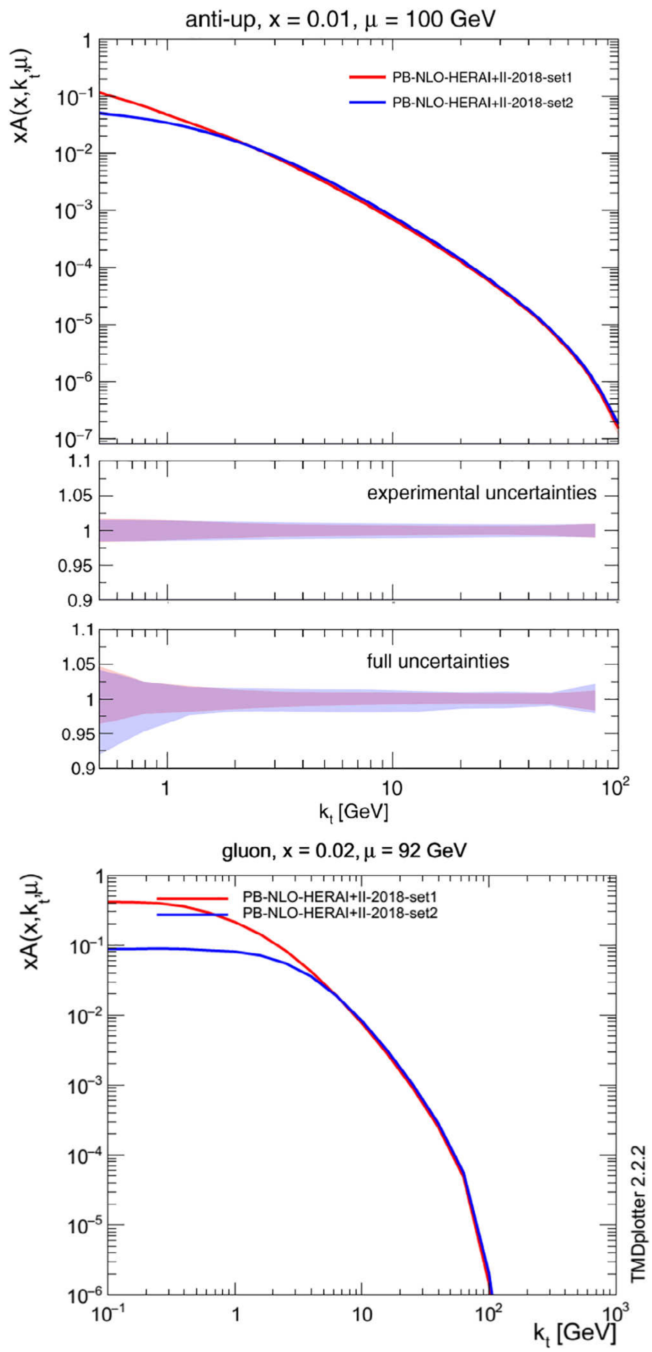

FIGURE 3 k_T distribution of $\bar{d}$ and gluon for a typical x value of 0.02 at a scale of the Z-mass

The motivation for this research was the study of the initial state in proton–lead collisions at 5.02 TeV using the Drell-Yan process (Drell & Yan 1970), whose leading-order (LO) diagram is shown in Figure 1b. We chose this process because inclusive lepton production is a clean process, independent of the color degree of freedoms and, therefore, of the strong interaction.

We consider an extension of the Glauber model (D'Enterria 2003; Glauber & Matthiae 1970) to express the cross section as $\sigma_{pA} = A\sigma_{pp}^{DY}$, where A is the number of nucleons of the colliding ion. In this approach, σ_{pA} simply scales with A in relation to σ_{pp}^{DY}.

As mentioned above, we can examine the initial vertex of the hard process described by σ_{pp} and apply the *usual standard* calculations through the factorization theorem. We particularly focused on the analysis of the p_T (transversal momentum) distribution and compared the role of transverse momentum-dependent (TMD) factorizations for hadron–hadron collisions (Collins et al. 1989; Maltoni et al. 2007; Sasaki & Uematsu 2001) in the behavior of the distribution at low p_T.

2 | CALCULATIONS

The di-leptonic decays of Z boson have a mass spectrum, as shown in Figure 2,[1] for the electronic and muonic channels.

The LO calculations were made using the *Pythia8* generator. The simulations of the pp collision were

[1] CMS collaboration.

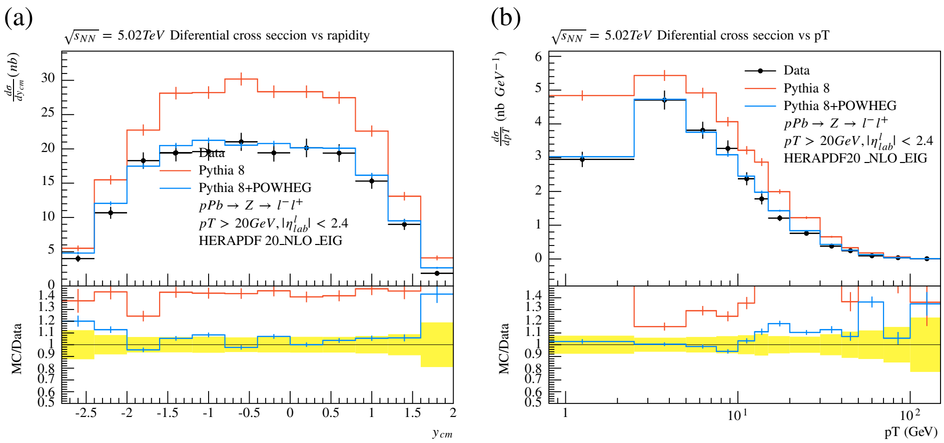

FIGURE 4 Cross section dependency with (a) rapidity and (b) transversal momentum. leading-order (LO) and next-to-leading order (NLO) *Pythia* plus *POWHEG*

all performed with only one subprocess switch-off: corresponding to the Z-boson production on the annihilation. To implement the next-to-leading order (NLO) calculations, we adopted the *POWHEG-BOX* framework. We worked mainly with two parameters inside this package: *pTsqmin* and *hdamp*. Both are parameters involved in the cross section calculations. The *pTsqmin* leads to the minimum p_T value for the generation of radiation. The *hdamp* parameter effectively regulates the high p_T radiation. To implement the cross-section calculations using transversal momentum-dependent PDFs (TMD *PDF*s), we used the generator *CASCADE*.

Figure 3 (Bermudez Martinez et al. 2019) shows transverse momentum-dependent parton densities (PB-NLO-2018-set 1 and PB-NLO-2018-set 2) as a function of k_T. The most important point is that, at the low k_T region, there is a significant difference between one set and another. Because of this, the *pTsqmin*-parameters of *POWHEG-BOX* (Alioli et al. 2010; Frixione et al. 2007; Mück 2015; Nason 2004) is adopted to constrains where TMD is working when *CASCADE* (Jung et al. 2010) is used. The idea is to use the TMD that has a better physical explanation for the initial state of the parton to reproduce what Pythia has demonstrated using the parton shower.

3 | RESULTS

3.1 | *Pythia8* plus *POWHEG*: LO and NLO calculations

The integration between *Pythia8 plus POWHEG* means that the simulation was made by *Pythia8* using the NLO cross-section calculation performed by *PPWHEG*.

Once all calculations have been performed, we constructed the rapidity and transverse momentum plots. To achieve the correct match on the rapidity distribution, it is necessary to take into account the difference between what

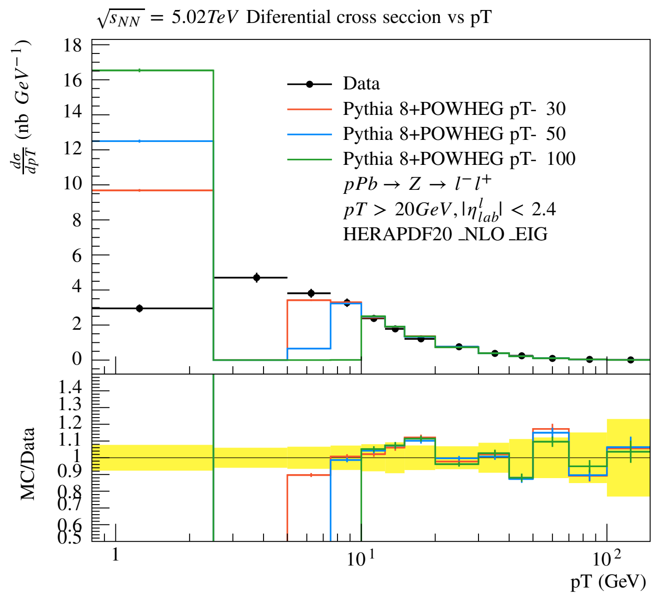

FIGURE 5 p_T distribution with different values of this "p_T-cut" with parton shower OFF

the event generator *does* and what happens in a real collision to obtain the experimental data. The collision studied is between protons and lead ions; meanwhile, *Pythia8* "collides" two proton beams. In addition to the scale of the cross sections, this also has an impact on the angular distribution. Then, it is necessary to be careful about the asymmetry of the colliding beams. For standard calculations, we used a shift on rapidity, $\Delta y = 0.465$, reported by Khachatryan et al. (2016).

There exists a different way to obtain the same result, that is, differentiating the corresponding beams energies, and the result is the same for the rapidity distribution without significant change on the p_T cross section.

The standard *PDF* was used for the LO calculation in the *Pythia8* (see the red line in Figure 4). Accordingly, there is a wide mismatch between the experimental data and the simulation. This mismatch in the high p_T bins

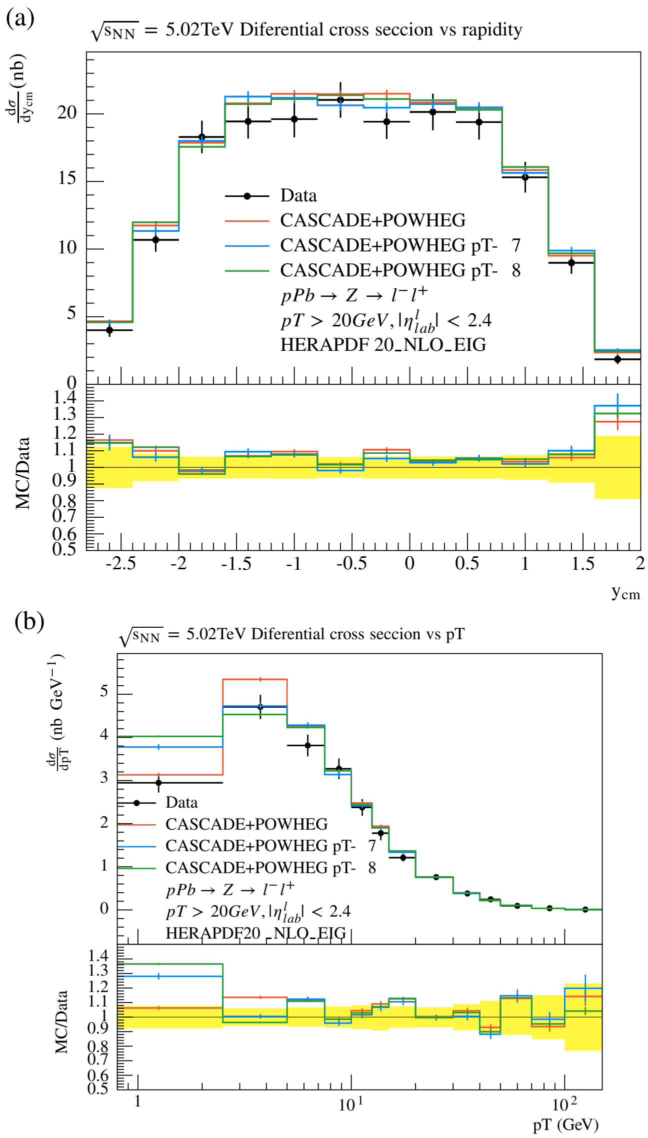

FIGURE 6 Cross-section dependency with (a) rapidity and (b) transversal momentum. *CASCADE* plus *POWHEG* next-to-leading order (NLO) calculation. Dependency with p_T-cut

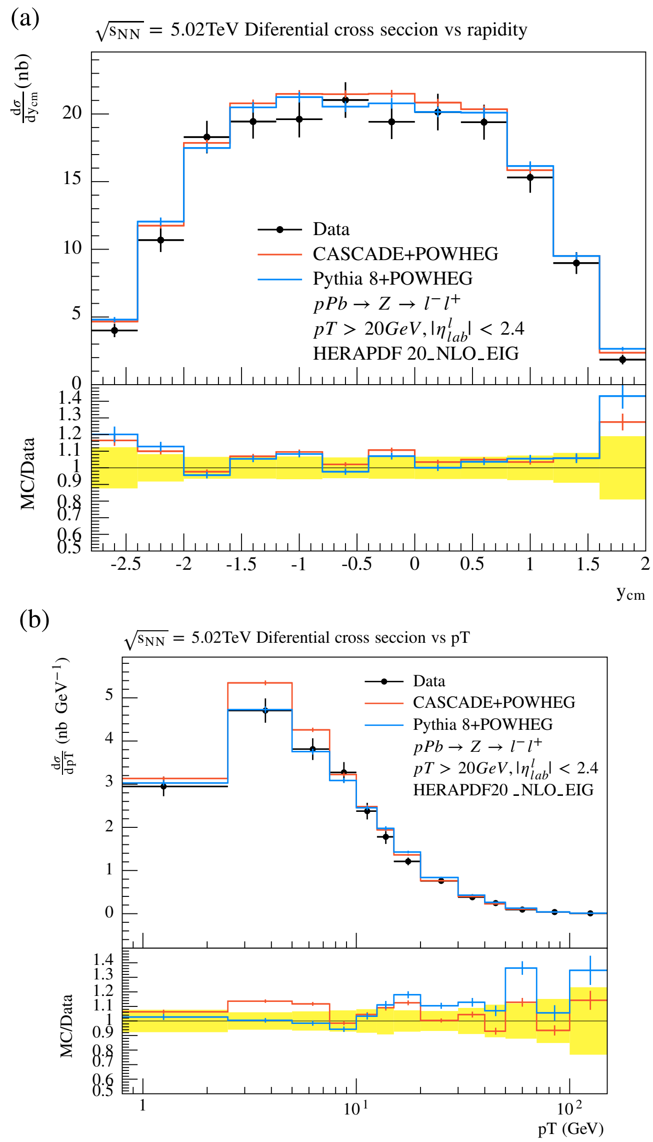

FIGURE 7 Cross-section dependency with (a) rapidity and (b) transversal momentum. *CASCADE* plus *POWHEG* (standard) next-to-leading order (NLO) calculation

is obtained, even scaling the cross section by the nucleon number of the Pb-nucleus. After this, it is necessary to include NLO calculations that were performed using the *POWHEG-BOX*.

In the first place, all calculations of the matrix elements were constructed using the default values of *POWHEG-BOX*. In the case of *POWHEG*, the *PDF* used was a different one, shown in all NLO calculation plots: *HERAPDF20_NLO_EIG*.

The parameters that we are interested in exploring are the *ptsqmin* and *hdamp*. Because *hdamp* did not showed significant influence on the behavior of the p_T-distribution at the low p_T-region, our calculations focused on the *ptsqmin* parameter. It is interesting to demonstrate what this p_T-cut does. To observe how *pTsqmin* works, we constructed a plot, as shown in Figure 5, for different values of the p_T-cut and the behavior of the p_T-distribution calculated with *Pythia8* without the parton shower. The deepness at the low p_T region before the p_T-cut is supposed to be filled by the parton shower from *Pythia*.

In Figure 6, it is easy to see how sensible the p_T spectrum is with *pTsqmin* variation.

3.2 | *CASCADE*: Including TMD *PDFs*

Figure 7 shows the behavior of cross section for the rapidity and the transverse momentum for *Pythia8* matching *CASCADE*. For the default values of the *POWHEG* package, there is only a small difference at the low p_T region. It is

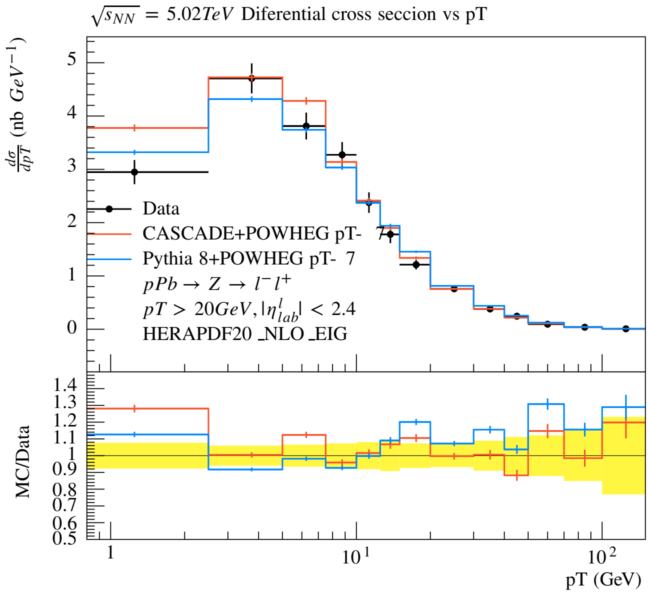

FIGURE 8 Comparison between *Pythia8* plus *POWHEG* and *CASCADE* plus *POWHEG* at p_T-cut = 7 GeV

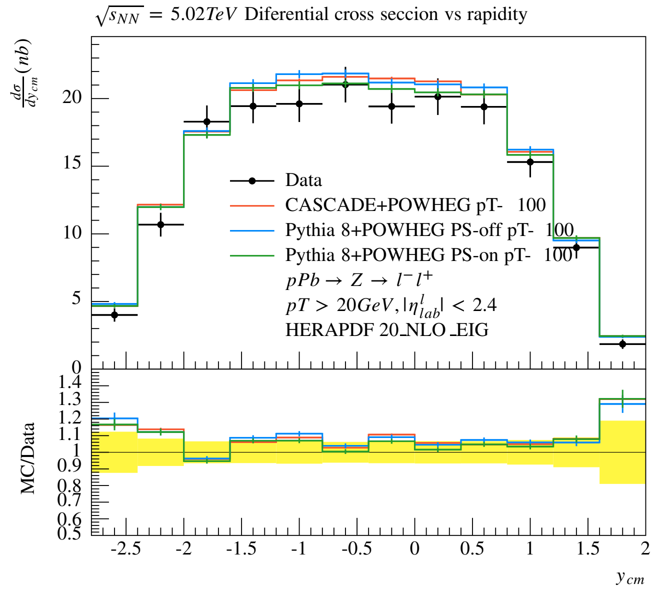

FIGURE 9 Comparison between *Pythia8* plus *POWHEG* and *CASCADE* plus *POWHEG* at p_T-cut = 100 GeV

possible to conclude that TMD can reproduce what has been conducted for the parton shower from *Pythia*. There is a hidden detail, and the importance of the TMD works depends on the scale factor that is now considered a p_T-cut. Then, for the next comparison we will used the default value of *pTsqmin*.

3.3 | *CASCADE* versus *Pythia*

Figures 8 and 9 show a comparison between plots corresponding to *Pythia8* and *CASCADE* in p_T cross-section distribution. In the first one, practically all *CASCADE* output comes from *POWHEG* calculation due to the low values of p_T-cut.

Although it is evident that a better tune is needed to reach a correct behavior at the low p_T-region, it is importance to note that *TMDs* play an essential role when the p_T-cut obtains high-enough values. Then, all the unfilled regions by parton shower from *Pythia* were performed by *CASCADE*.

4 | CONCLUSION

A rivet plugin to analyze the Drell-Yan process in pPb collisions was written and is ready to use. Predictions were generated by matching and merging NLO calculations with *CASCADE* using a Monte Carlo generator that utilizes TMD PDFs and *PYTHIA 8*. In both cases, two parameters corresponding to the NLO calculation of the matrix elements with *POWHEG* were used to combine the NLO accuracy with PS resummation.

Our main conclusion is that the low p_T-region can be filled with a better physical interpretation by the TMD *PDFs* using *CASCADE*. Moreover, it is possible to improve the results refining the tune with other parameters and setting the scale of the TMD in Z boson mass order instead of the *pTsqmin* value, which is carried out using the update of *CASCADE*.

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