Studies on pp and pPb Drell Yan production

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Abstract: The validation of a rivet plugin for Drell Yan production from proton-lead collisions was made. Distributions of $d\sigma/dp_T$ obtained from simulation with POWHEG and the shower Monte Carlo programs CASCADE and PYTHIA 6 were computed and compared to the available data. Other calculations of POWHEG+shower were made using different parameters, and their results compared and analyzed. For proton-proton collisions the Next-to-Leding-Order (NLO) $d\sigma/dp_T$ was compared to POWHEG's, with different parameters. The results of POWHEG + CASCADE simulation was compared to the data and to the results from a different NLO software.

Contents

1 Introduction

The Drell Yan process consists of the interaction of two quarks in the initial state, resulting on a lepton pair in the final state, through the formation of a virtual Z boson (Figure 1).

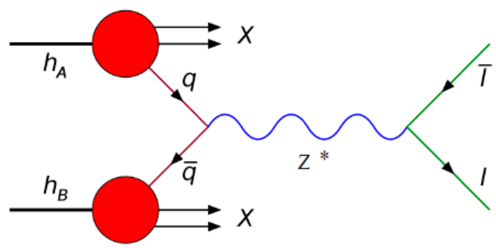

Figure 1: The Drell Yan process.

It is of our interest to study the Drell Yan process coming from proton-proton (pp) and proton-lead (pPb) collisions. The Glauber multiple collision model [1], states that the inelastic pPb cross section can be derived form the nucleon-nucleon cross section σ_{NN} as in:

$$\sigma_{pA} = \int d^2b[1 - e^{-\sigma_{NN}(s)T_A(b)}] \tag{1}$$

In (1), b is the impact parameter, s is the square of the center mass of energy, and T_A is the Nuclear thickness function, which represents the number of nucleons in the nucleus A per unit area along the z direction, separated from the center of the nucleus by b. From its definition is derived:

$$T_A(b) = \int dz\rho_A(b, z) \tag{2}$$

On a first approximation, relation (1) can be reduced to leading relations (3) and (4). This means that for pPb interaction the cross section can be reduced to the NN cross section times the number of nucleons in Pb.

$$\sigma_{pA} \approx \int d^2b \sigma_{NN}(s) T_A(b) \tag{3}$$

$$\sigma_{pA} \approx \sigma_{NN}(s) A \tag{4}$$

To make our simulation we are using POWHEG box, which is a Next-to-Leading-Order (NLO) calculation of the matrix elements that translate from the initial state to the final state. The diagrams that are included in these calculations are shown in Figure 2.

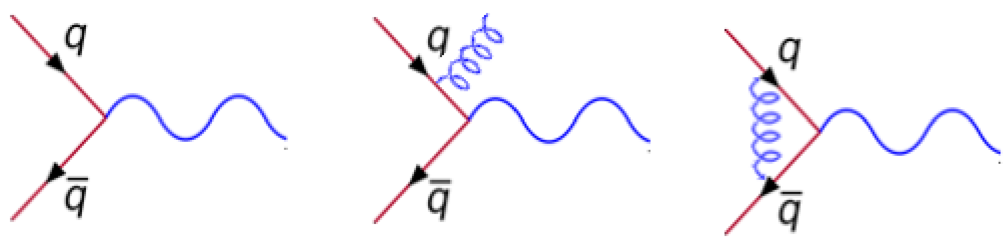

Figure 2: Feynman Diagrams of the process included in the NLO calculations.

Inside POWHEG one has to fix certain parameters, among them $p_{T\,min}$, *pdfset* and h_{damp}. $p_{T\,min}$ establishes a cut in the transverse momentum. The matrix elements calculated with POWHEG will fill the cross section above the $p_{T\,min}$ chosen. The *pdfset* is referring to the collinear pdf and h_{damp} is a parameter that suppress divergences that exists on the NLO cross section at low transverse momentum (p_T).

The output of POWHEG can be introduced to any shower Monte Carlo program, like PYTHIA or CASCADE, with the advantage that the latter includes the TMDs in its calculation. The shower would fill the cross section below $p_{T\,min}$.

The task is then to validate a rivet plugin for pPb Drell Yan production, to obtain NLO + TMD calculations and compare the results to other NLO calculations.

2 Results

To write a rivet plugin for pPb Drell Yan production, we scaled the cross section to the number of nucleons in ^{208}Pb according to the Glauber multiple collision model [1]. To make the simulation we used the parameters $h_{damp} = 0.5$, $p_{T\,min} = 50$, $\sqrt{s_{NN}} = 5.02 TeV$. The collision simulated was Z $\rightarrow e^{-}e^{+}$ and the pdf set introduced in POWHEG was the PB set 2 to use later with CASCADE and CT10 when using later PYTHIA 6. Consequently, the TMD set 2 was introduced in CASCADE for the transverse momentum. The obtained plots were compared to the data from a CMS article [2] and they are shown in Figure 3.

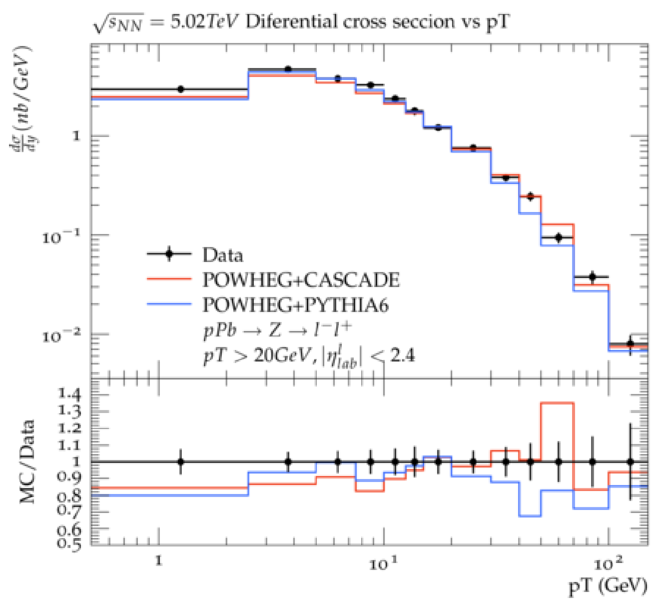

Figure 3: Differential cross section with p_T

In Figure 3 it is possible to observe that both curves obtained have similar behavior. They have an acceptable ratio compared to the data with the exception of an observable bump on the POWHEG+CASCADE curve near the 50 GeV. This behavior might be associated with the matching of the TMDs and the NLO, but the binning does not allow to see it clearly.

Then we proceeded to analyze the response to p-p collisions to, simplify the problem.

The next plots show the comparison of the POWHEG $d\sigma/dp_T$ using different $p_{T\ min}$ with the NLO $d\sigma/dp_T$ for a $\sqrt{s_{NN}} = 8TeV$.

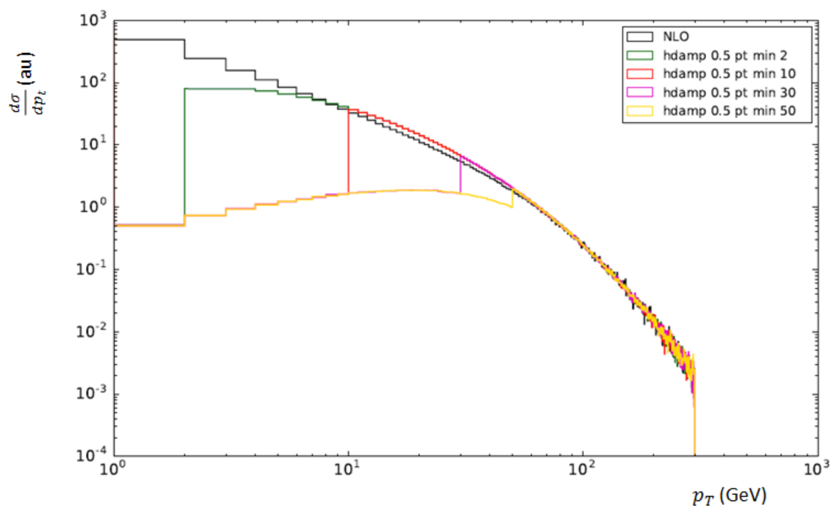

Figure 4: Comparing POWHEG and NLO differential cross section with p_T

In Figure 4 it can be seen that the POWHEG curves present a sharp cut at the position where $p_{T\ min}$ was chosen. Nevertheless, all curves are the same, just with a different cut. As expected, at high p_T the POWHEG curves show the same behavior as the NLO cross section.

Next, we compared the simulation using POWHEG ($h_{damp} = 0.5$ and $p_{T\ min} = 30$ and $50GeV$) + CASCADE to the data from a pp ATLAS analysis [3] that uses a finer bining (Figure 5). On the same plots we also compared POWHEG+TMD to the resulting curves from a similar simulation made with MC@NLO, another NLO calculation.

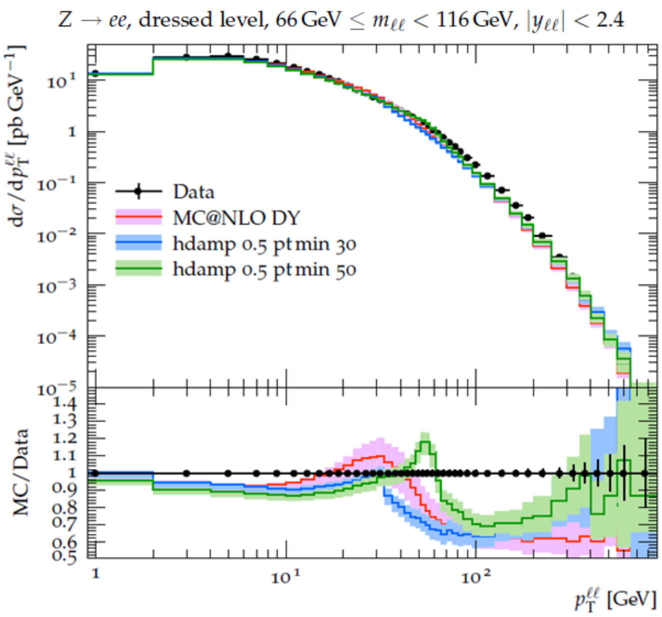

Figure 5: Comparing POWHEG+CASCADE with data and MC@NLO

We can observe that at low p_T the three curves are close to the data and having the same behavior. This result proves that the TMDs are giving a reliable result filling the histograms. Increasing the transverse momentum there is a bigger dependency on the calculation that is being used to make the simulation and the value of $p_{T\,min}$ that was chosen. We can see again a bump near 30 GeV on the blue curve and near 50 GeV on the red curve, corresponding to its $p_{T\,min}$ cut. Once again, this might be caused by the matching the TMDs and the matrix elements from POWHEG. Also, choosing this cut can make the bump more or less pronounced. At higher p_T the scale of the process (μ^2) has a significant impact. MC@NLO employs a higher scale, and the coupling constant of the strong interaction (α_s) decreases with the increment of μ^2. Since the cross section depends directly on α_s, we can see that the MC@NLO curve is lower than the POWHEG result.

Going back to pPb collisions, we will now compare the results of using different pdf/TMD sets in POWHEG+CASCADE to the available data. The results for pdf/TMD set 1 and 2 are shown on Figure 6, for $h_{damp} = 0.5$ and $p_{T\,min} = 30$ and $50GeV$.

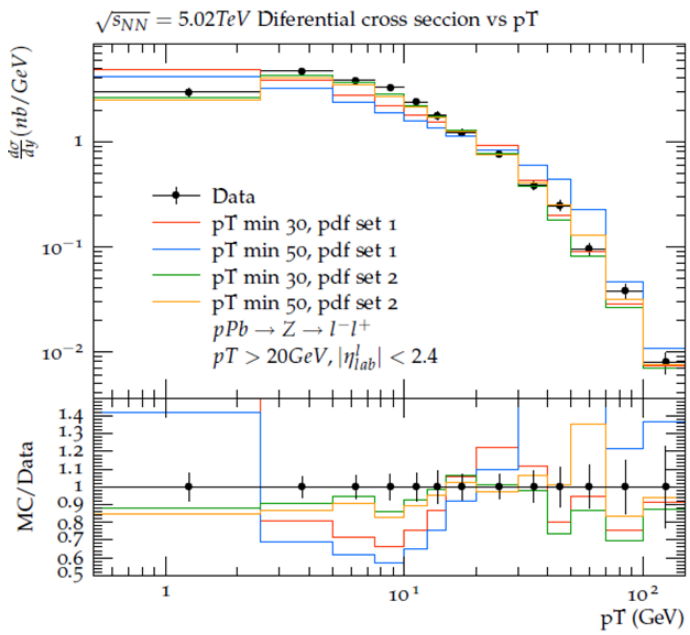

Figure 6: Comparing POWHEG+CASCADE using sets 1 and 2 to data from CMS analysis

The plots employing PB set 2 show results closer to the data and their curves are smoother. The bump mentioned before can be seen, mostly for $p_{T\ min} = 50$. This effect is again less visible because of the binning that is being used.

The differences among the TMD set 1 and 2 can be seen in Figure 7, where the two curves were plotted with [4].

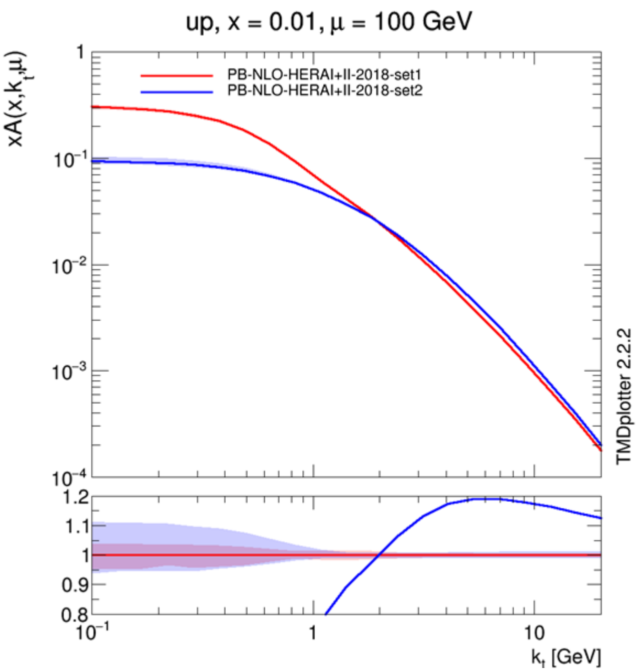

Figure 7: Comparing TMD sets 1 and 2 with p_T

Next, we compared the results using pdf/TMD set 2 for POWHEG+CASCADE and set CT10 for POWHEG+PYTHIA 6 (Figure 8). The values used were again $h_{damp} = 0.5$ and $p_{T\ min} = 30$ and $50GeV$.

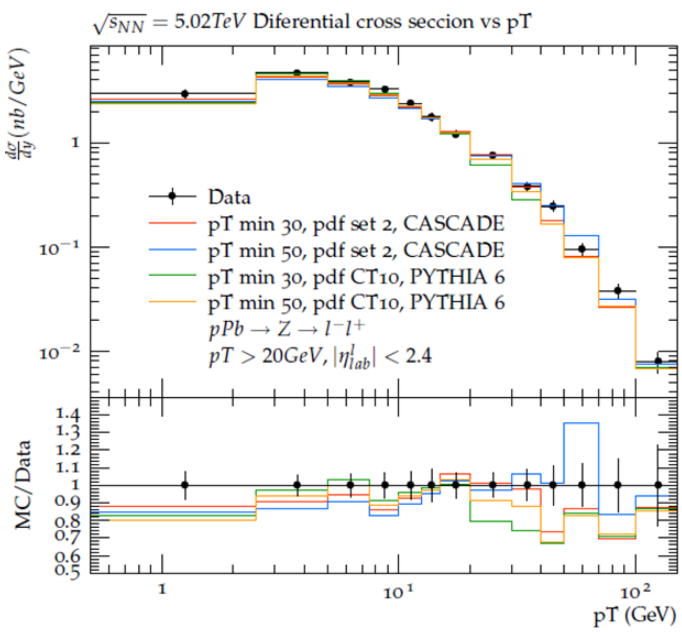

Figure 8: Comparing POWHEG+CASCADE using pdf/TMD set 2 and POWHEG+PYTHIA 6 using pdf set CT10 to data from CMS analysis

The results show that both curves have the same behavior at low p_T. For p_T from 20 to $50GeV$ the results using CASCADE are better, and again we can see the bump near $50GeV$ for the CASCADE curve.

3 Conclusions

During the Summer Program we have been able to write a rivet plugin for pPb Drell Yan production.

We have shown that using POWHEG+TMD gives a good description of the Drell Yan spectra, since it is appropriate for both pp and pPb collisions, it works for different $\sqrt{s_{NN}}$ and gives a description similar to other NLO calculations.

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[3] ATLAS measurement, (2016). Eur.Phys.J. C76 no.5, 291

[4] http://tmdplotter.desy.de/