The impact of the LHC nuclear program on nPDFs

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Abstract.
The proton-lead and lead-lead runs at the LHC are providing an enormous amount of data sensitive to the nuclear modifications of the initial state. The measurements explore a region of phase space not probed by previous experiments opening a possibility to test and, hopefully, also improve the current knowledge of nuclear parton densities. In this talk, we discuss to what extent the present quantitative results for the charge asymmetry in electroweak boson production show sensitivity to the nuclear parton distributions.

1. Introduction

A detailed description of the partonic structure of nucleons prior to a hard scattering is a key ingredient in precise description of high-energy collider data. As such structure cannot yet be determined from the first principles of QCD, sets of parton density functions (PDFs) are traditionally extracted from experimental data by means of global fits in the framework of perturbative QCD. The accuracy reached in the determination of free-proton parton distributions is astonishing, with sets available up to $\mathcal{O}(\alpha_s^2)$ (NNLO) [1, 2, 3, 4]. The situation is quite different when the free proton is substituted by a nucleus: as the amount of data is far more limited and the kinematical coverage rather restricted in comparison to the free-proton case, the nuclear PDFs (nPDFs) are still far less precise [5, 6, 7, 8]. Most of the available nuclear data come from deep-inelastic scattering (DIS) which is a process dominated by the valence and the sea quark distributions leaving especially the gluon densities unconstrained. To improve this state of affairs, results from the LHC proton-lead and lead-lead runs should provide with a completely novel information.

In this talk, we consider the electroweak boson production in both proton-lead and lead-lead collisions measured by ATLAS [9] and CMS [10] comparing these data with the theoretical predictions using nPDFs. All the data used here are preliminary and only limited conclusions can be drawn.

2. The LHC constraining potential

The kinematical range probed by the pre-LHC nuclear experiments is very limited, the momentum fraction x not reaching much below 10^{-2} at perturbative scales $Q \gtrsim 1\,\text{GeV}$. This entails that predictions sensitive to lower values of x may depend strongly on the original

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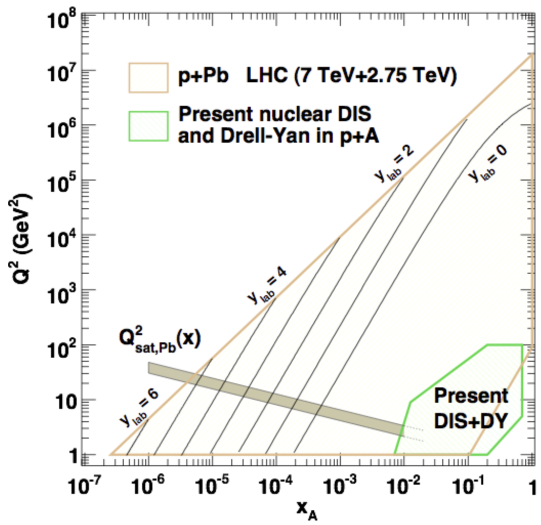

Figure 1. Kinematical coverage of the LHC proton-lead run compared with the one from earlier DIS and Drell-Yan (DY) experiments.

parameterization used in the individual nPDF fits. Especially the gluon distributions appear rather problematic: for example, in DSSZ [8] the gluon is fixed by hand to follow a certain shape while the gluon distribution of EPS09 [6] presents a much different behaviour with almost 100% uncertainty at $Q \approx 1.3\,\mathrm{GeV}$. It is then clear that more data, both from other type of experiments and in new kinematical regions, are required in order to improve the nPDFs. In that aspect the LHC can be extremely useful, as it can reach down to $x \approx 10^{-6}$ — a four-order-of-magnitude extension to the currently explored region. As can be sen from Figure 1, also the Q^2 range achievable is quite wider. Therefore, the recently recorded data from the proton-lead and lead-lead runs at the LHC look a very promising source of new information which should be carefully analyzed and eventually also included into the future extractions of nPDFs.

3. Data and theory: $\mathrm{W}^{\pm}$ charge asymmetries

From the wide variety of LHC data we shall focus on the charged electroweak boson ($\mathrm{W}^{\pm}$) production in both proton-lead and lead-lead. These particular measurements are directly sensitive to the sea and valence quark distributions and should thereby be helpful e.g. to disentangle the strange-quark contribution from the other light flavors. However, due to the large mass of $\mathrm{W}^{\pm}$, indirect constraints of gluon distributions emerging via the parton evolution may be obtainable.

Let us begin with the $\mathrm{W}^{\pm}$ production measured by CMS in proton-lead collisions at $\sqrt{s} = 5.02$ TeV [10], available as a function of the pseudorapidity η of the charged lepton originating from the $\mathrm{W}^{\pm}$ decay. The theoretical calculations have been performed to NLO accuracy using the CT10NLO [2] free-proton PDFs corrected for the nuclear effects with EPS09 [6]. The comparisons to the absolute cross-sections are presented in leftmost panels of Figure 2. The band enclosed by the blue lines is the errorband derived from the EPS09 error sets. In both cases the behaviour of the data is qualitatively similar as that of the theory predictions, but the correspondence is not perfect. We note that the uncertainties in the cross-section measurements are dominated by the systematics which can be suppressed by taking suitable ratios. The most common one is the charge asymmetry which is shown in the rightmost panel of Figure 2. Indeed, the "scatter" of the data gets attenuated in comparison to the individual absolute distributions and especially in the forward rapidities (the proton-going direction) the agreement

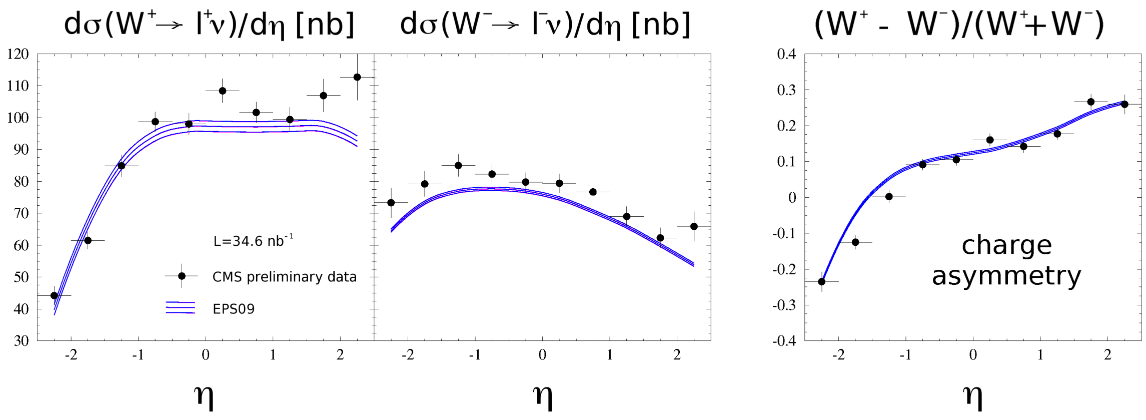

Figure 2. Left: W^+ differential cross-section as a function of η in p-Pb collisions measured by CMS [10] compared to the EPS09 [6] prediction (blue curve). **Center**: The same for W^-. **Right**: The charge asymmetry $(W^+ - W^-)/(W^+ + W^-)$. The proton PDF uncertainty has not been included.

with the NLO calculation seems almost perfect. In the backward region (the lead-going direction) there is a clear discrepancy in two rapidity bins[1]. At this stage it is impossible to draw strict conclusions concerning the observed discrepancy before the measurements by the ALICE and ATLAS collaborations become public.

Let us now turn to $W^\pm$ production in lead-lead collisions at $\sqrt{s} = 2.76$ TeV, measured by the ATLAS collaboration [9]. The charge asymmetry is shown in Figure 3 and compared with the predictions including EPS09 nuclear corrections (red) and with CT10NLO proton PDFs only (green). Both predictions are more or less compatible with these preliminary data. As the nuclear corrections induced by EPS09 are almost identical for W^+ anf W^- production, they tend to cancel when forming the charge asymmetry (as was discussed in Ref. [11]).

4. Summary

New data from the LHC has a potential to constrain nPDFs in ways that no other experiment has been able to do. In this short contribution we discussed how the measured charge asymmetries in $W^\pm$ production compare to the NLO pQCD predictions. In the case of lead-lead collisions we explicitly demonstrated that this particular observable appears not to undergo a very large nuclear modification and the predictions with and without nuclear corrections are compatible with the ATLAS data. The preliminary CMS data for the charge asymmetry in proton-lead collisions displays a certain discrepancy in comparison to the NLO predictions. Whether there is true physics behind this discrepancy remains to be confirmed by the other LHC experiments. However, we admit that our comparison here involved only a one particular set of nPDFs and the bias caused by this should be checked in a more systematic manner.

Acknowledgments

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[1] Even adding the uncertainty from the CT10NLO error sets does not seem to cure the observed difference [10]

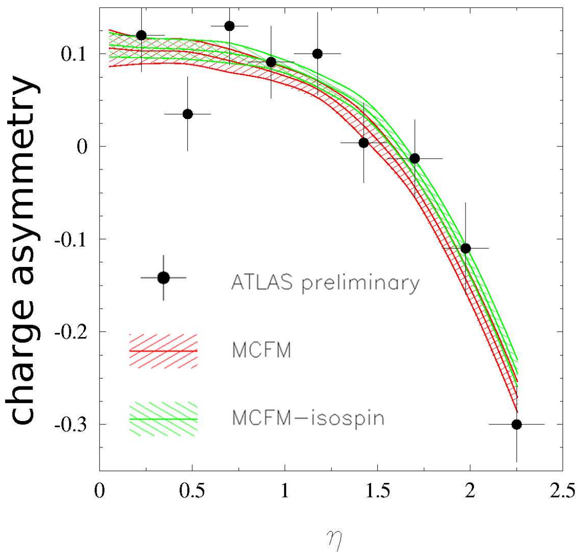

Figure 3. Charge asymmetry for $W^{\pm}$ production in Pb-Pb collisions measured by ATLAS [9]. The green band is the prediction assuming no nuclear effect other than different number of protons and neutrons in the lead nucleus (isospin effect). The red band, corresponds to the EPS09-corrected result with the CT10NLO and EPS09 uncertainties added in quadrature.

References

[1] S. Forte and G. Watt, Ann. Rev. Nucl. Part. Sci. **63** (2013) 291 [arXiv:1301.6754 [hep-ph]].
[2] H. -L. Lai, M. Guzzi, J. Huston, Z. Li, P. M. Nadolsky, J. Pumplin, C. -P. Yuan and , Phys. Rev. D **82** (2010) 074024 [arXiv:1007.2241 [hep-ph]].
[3] A. D. Martin, W. J. Stirling, R. S. Thorne and G. Watt, Eur. Phys. J. C **63** (2009) 189 [arXiv:0901.0002 [hep-ph]].
[4] R. D. Ball, V. Bertone, S. Carrazza, C. S. Deans, L. Del Debbio, S. Forte, A. Guffanti and N. P. Hartland *et al.*, Nucl. Phys. B **867** (2013) 244 [arXiv:1207.1303 [hep-ph]].
[5] M. Hirai, S. Kumano and T.-H. Nagai, Phys. Rev. C **76** (2007) 065207 [arXiv:0709.3038 [hep-ph]].
[6] K. J. Eskola, H. Paukkunen and C. A. Salgado, JHEP **0904** (2009) 065 [arXiv:0902.4154 [hep-ph]].
[7] I. Schienbein, J. Y. Yu, C. Keppel, J. G. Morfin, F. Olness and J. F. Owens, Phys. Rev. D **77** (2008) 054013 [arXiv:0710.4897 [hep-ph]].
[8] D. de Florian, R. Sassot, P. Zurita and M. Stratmann, Phys. Rev. D **85** (2012) 074028 [arXiv:1112.6324 [hep-ph]].
[9] G. Aad *et al.* [ATLAS Collaboration], arXiv:1408.4674 [hep-ex].
[10] CMS Collaboration [CMS Collaboration], CMS-PAS-HIN-13-007.
[11] H. Paukkunen and C. A. Salgado, JHEP **1103** (2011) 071 [arXiv:1010.5392 [hep-ph]].