Constraining the low-x structure of nuclei with LHCb

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Abstract. The LHCb detector's forward geometry provides unprecedented access to the very low regions of Bjorken x inside the nucleon. With full particle ID and a fast DAQ, LHCb is able to fully reconstruct plentiful charged particles and neutral mesons, as well as relatively rare probes such as heavy quarks, providing a unique set of constraints on nucleon structure functions. This contribution will discuss recent LHCb measurements sensitive to the low-x structure of nucleons, and discuss the impact of recent LHCb measurements that dramatically reduce nPDF uncertainties.

1 Introduction

Within protons and neutrons, quarks and gluons constantly radiate low-energy gluons. These gluons carry a small fraction x of the proton's momentum. The density of low-x gluons is expected to be large enough for gluon recombination to compete with radiation, leading to gluon saturation [1]. The gluon density is further enhanced in heavy nuclei, leading to an enhancement of saturation effects in heavy-ion collisions. Parton densities in nuclei are parameterized using nuclear parton distribution functions (nPDFs) [2–4]. Until recently, the gluon nPDF has been almost entirely unconstrained for $x < 10^{-4}$. Constraining nPDFs at low x will not only provide a more precise description of the partonic structure of nuclei, but could also reveal the effects of gluon saturation.

The LHCb detector is a forward spectrometer at the Large Hadron Collider (LHC) [5]. The detector's forward geometry, along with the high energies produced by LHC collisions, provides sensitivity to partons with the lowest x accessible at any collider detector in the world. The LHCb detector has collected proton-lead (pPb) data at $\sqrt{s_{\mathrm{NN}}} = 5.02$ and 8.16 TeV in both the proton-going (forward, denoted with positive rapidity) and lead-going (backward, denoted with negative rapidity) configurations. The proton-going configuration provides sensitivity to nuclear gluons with $x < 10^{-5}$.

2 Open charm production

The LHCb collaboration measuremed the nuclear modification factor $R_{p\mathrm{Pb}}$ of D^0 production at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV [6]. This measurement is now the primary constraint on the gluon nPDF for $x < 10^{-3}$. As a result of this measurement, the gluon nPDF is now precisely known for x as low as 10^{-5}. Further measurements can overconstrain the gluon density and reveal evidence of saturation. The LHCb collaboration recently published a measurement of D^0 production

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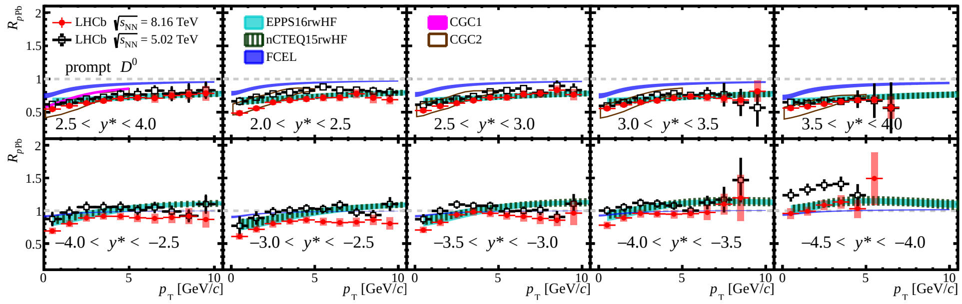

Figure 1. $R_{p\mathrm{Pb}}$ of D^0 mesons as a function of p_T and center-of-mass rapidity y^* in the (top) forward and (bottom) backward regions. The error bars and boxes show statistical and systematic uncertainties, respectively. From [7].

at $\sqrt{s_\mathrm{NN}} = 8.16$ TeV [7]. The data set used in this measurement is more than an order of magnitude larger than that used in the $\sqrt{s_\mathrm{NN}} = 5.02$ TeV measurement. Furthermore, the $\sqrt{s_\mathrm{NN}} = 8.16$ TeV measurement probes lower x because of the larger $\sqrt{s_\mathrm{NN}}$. The measured nuclear modification factors are shown in Fig. 1. The forward results agree well with previous LHCb open charm measurements, as well as nPDF predictions. These results also agree with calculations performed using the color-glass condensate (CGC) effective field theory, which account for gluon saturation effects [1]. The backward results show some tension with nPDF predictions, possibly indicating contributions from additional nuclear effects.

The LHCb collaboration also measured $R_{p\mathrm{Pb}}$ of $D^\pm$ and $D_s^\pm$ production at $\sqrt{s_\mathrm{NN}} = 8.16$ TeV [8]. The nuclear modification factors are shown in Fig. 2. These measurements show a similar pattern to the D^0 measurement at the same $\sqrt{s_\mathrm{NN}}$. The forward results agree with both nPDF and CGC predictions, while the backward results deviate from nPDF predictions. These results also show evidence of multiplicity-dependent $D_s^\pm$ enhancement.

3 Light hadron production

Because of the relatively large mass of charm hadrons, studies of charm production cannot probe $Q^2 \lesssim 4$ GeV^2. To study lower Q^2, lighter probes, such as light-flavor hadrons, are needed. The LHCb collaboration measured $R_{p\mathrm{Pb}}$ of charged hadrons, which have an average mass of about 250 MeV, at $\sqrt{s_\mathrm{NN}} = 5.02$ TeV [9]. Results are shown in Fig. 3. The forward results agree with nPDF predictions, as well as recent CGC predictions [10]. The backward results show a large nuclear enhancement that cannot be described by nPDF predictions.

Possible nuclear effects on charged-particle production can be disentangled by studying the production of identified light hadrons. The LHCb collaboration measured $R_{p\mathrm{Pb}}$ of π^0, η, and η' mesons at $\sqrt{s_\mathrm{NN}} = 8.16$ TeV [11, 12]. The resulting nuclear modification factors are shown in Fig. 4. The forward results all agree with the forward charged-particle results, and the forward π^0 results agree with nPDF predictions. The backward π^0 results show a smaller enhancement than that observed in the charged-particle measurement, while the η and η' results show no evidence of a mass-dependent enhancement.

4 Conclusion

The LHCb collaboration has constrained the low-x partonic structure of nuclei using a wide range of observables. Studies of the production of charm mesons, charged particles, and

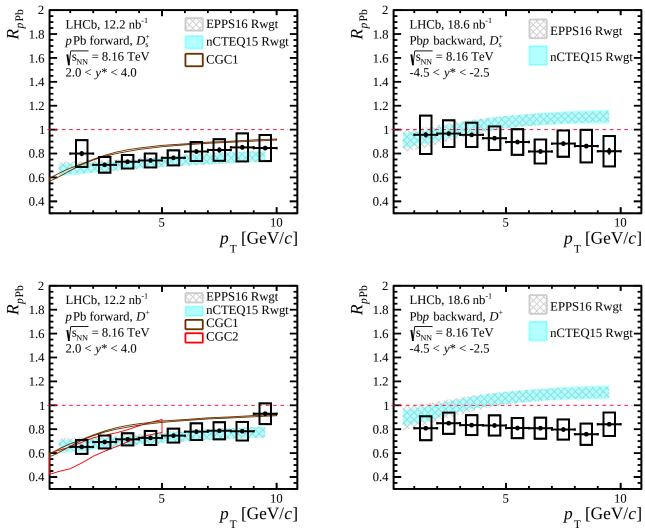

Figure 2. $R_{p\mathrm{Pb}}$ of (top) $D_s^{\pm}$ and (bottom) $D^{\pm}$ mesons in the (left) forward and (right) backward regions at $\sqrt{s_{\mathrm{NN}}} = 8.16$ TeV. The error bars and boxes show the statistical and systematic uncertainties, respectively. From [8].

identified light mesons all provide consistent descriptions of the nuclear gluon density at low x. Measurements in the lead fragmentation region indicate the presence of additional nuclear effects. The origin of these effects can be further disentangled by studying the production of identified charged particles and strange particles with the LHCb detector. In addition, the LHC is scheduled to produce proton-oxygen collisions in 2025. Constraining the oxygen nPDFs with LHCb data will help reveal the A-dependence and origin of low-x nuclear effects.

Acknowledgments

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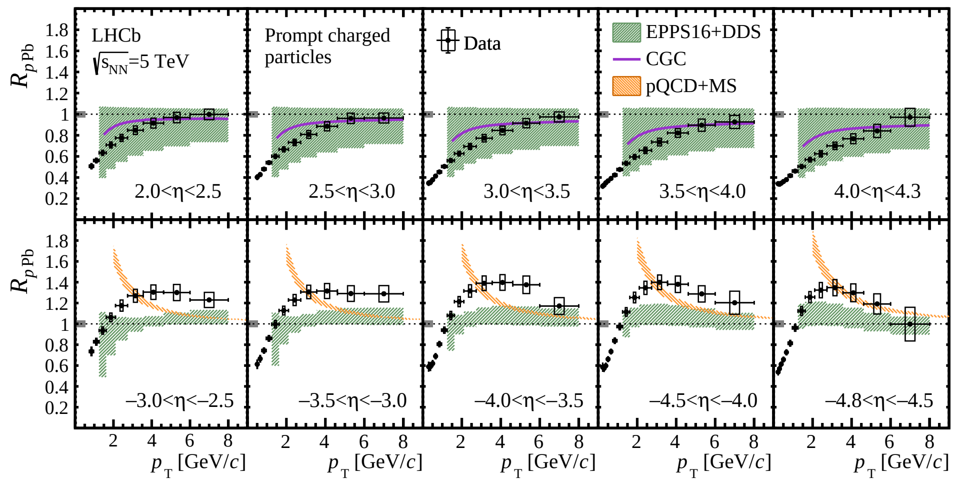

Figure 3. $R_{p\text{Pb}}$ of charged particles at $\sqrt{s_{\text{NN}}}$ = 5.02 TeV as a function of p_{T} and center-of-mass pseudorapidity η in the (top) forward and (bottom) backward regions. The error bars and boxes show statistical and systematic uncertainties, respectively. From [9].

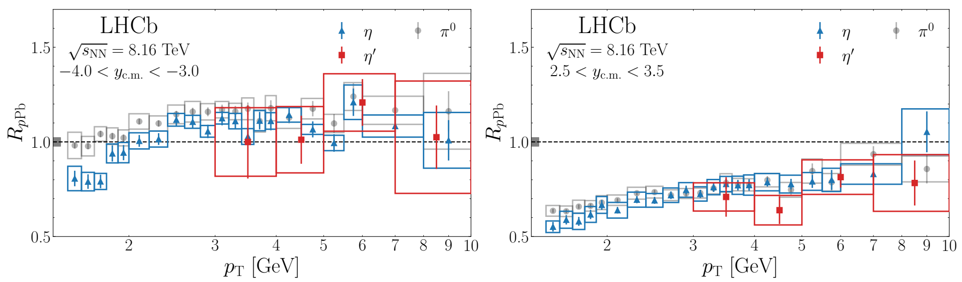

Figure 4. $R_{p\text{Pb}}$ of π^0, η, and η' mesons at $\sqrt{s_{\text{NN}}}$ = 8.16 TeV in the (top) backward and (bottom) forward regions. The error bars and boxes show the statistical and systematic uncertainties, respectively. From [12].

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