Studies of low-x phenomena with the LHCb detector

Thomas Boettcher[1],* on behalf of the LHCb collaboration

[1]University of Cincinnati

Abstract. With a unique geometry covering the forward rapidity region, the LHCb detector provides unprecedented kinematic coverage at low Bjorken-x down to $x \sim 10^{-5}$ or lower. The excellent momentum resolution, vertex reconstruction and particle identification allow precision measurements down to very low hadron transverse momentum. In this contribution we present the latest studies of the relatively unknown low-x region using the LHCb detector, including recent measurements of charged and neutral hadron production, as well as direct photon and hadron correlations in proton-proton and proton-lead collisions. Comparisons to various theoretical model calculations are also discussed.

The LHCb detector is a general purpose detector fully instrumented at forward rapidity at the LHC [1]. The LHCb detector's forward acceptance allows it to study kinematic regions inaccessible to other LHC experiments. LHCb is sensitive to iteractions between low- and high-Bjorken-x partons. In proton-lead collisions, LHCb is sensitive to nuclear partons with x as small as 10^{-6}, and LHCb data provides some of the strongest available constraints on nuclear parton distribution functions (nPDFs) for $x < 10^{-3}$ [2, 3]. As a result, LHCb data could be sensitive to novel phenomena such as parton saturation, which is expected to be significant at low x and momentum transfer squared Q^2.

LHCb's sub-detectors include a high-precision Vertex Locator (VELO), which provides a vertex position resolution of $10 - 50$ μm transverse to the beamline [4]. In addition, ring imaging cherenkov detectors allow for charged hadron identification, and the forward spectrometer configuration provides excellent charged-particle momentum resolution. These subdetectors were originally designed to study heavy flavor hadron decays in pp collisions, but they have also allowed LHCb to produce precise measurements of heavy flavor hadron production in pPb collisions. The LHCb experiment recently measured prompt D^0 production at $\sqrt{s_{\rm NN}} = 8.16$ TeV [5]. The prompt D^0 nuclear modification factor $R_{p\rm Pb}$ was measured over a wide rapidity range for $0 < p_{\rm T} < 10$ GeV. The measured $R_{p\rm Pb}$ is shown in Fig. 1. At forward rapidities, the measured $R_{p\rm Pb}$ agrees well with nPDF predictions [6–8], as well as with color glass condensate (CGC) predictions, which account for parton saturation effects [9–11]. At backward rapidities, the LHCb measurement shows some tension with nPDF predictions. This tension is particularly clear in the forward-backward ratio ($R_{\rm FB}$), which is shown in Fig. 2. In addition, modifications due to fully coherent eneryg loss (FCEL) in the nucleus alone are unable to describe the data.

The LHCb experiment's measurements of heavy flavor production are currently being used in state-of-the-art nPDF fits and provide strong constraints in the low-x region [2, 3]. However, the high mass of heavy-flavor hadrons limits the sensitivity of these measurements

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*e-mail: boettcts@ucmail.uc.edu

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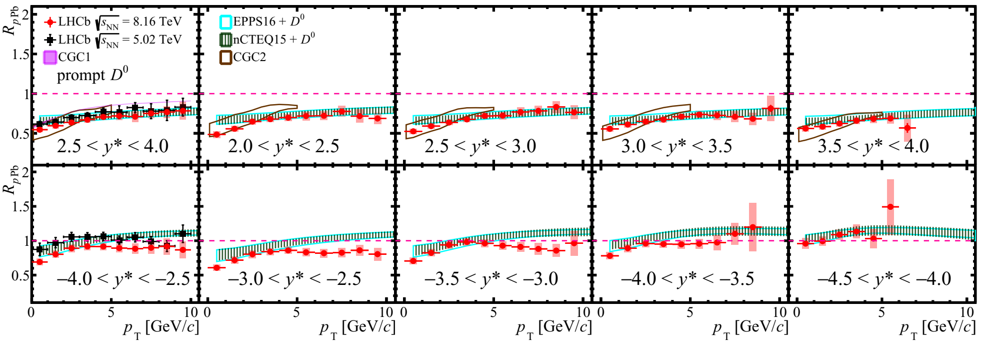

Figure 1. LHCb measurement of the D^0 nuclear modification factor in pPb collisions at $\sqrt{s_{NN}}$ = 8.16 TeV [5].

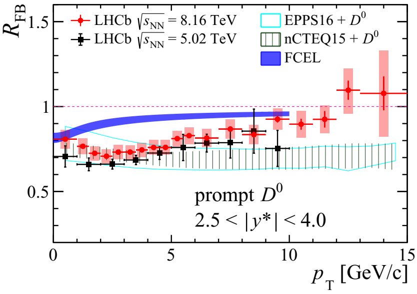

Figure 2. LHCb measurement of the D^0 forward-backward ratio in pPb collisions at $\sqrt{s_{NN}}$ = 8.16 TeV [5].

to $Q^2 \gtrsim 4\text{GeV}^2$. Measurements of light hadron production can probe lower Q^2, potentially providing greater sensitivity to parton saturation effects. The LHCb experiment has measured inclusive charged-particle production in pPb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV [12]. The charged-particle $R_{p\text{Pb}}$ was measured as a function of both p_T and rapidity. Results are shown in Fig. 3. The forward rapidity data are compared to nPDF and CGC predictions [7, 13]. The measurement agrees well with the nPDF predictions, although the nPDF uncertainties are large. The forward data disagree with the CGC prediction, although subsequent next-to-leading order CGC calculations better describe the data [14]. The backward $R_{p\text{Pb}}$ data show a much larger excess than the nPDF predictions. The backward data also disagrees with a perturbative quantum chromodynamics (pQCD) calculation that include FCEL [15], which successfully describes a similar enhancement observed by the PHENIX collaboration [16]. The failure of available models to describe the LHCb data suggests that other nuclear effects contribute to the enhancement, such as radial flow or final-state recombination [17, 18].

Measurements of $R_{p\text{Pb}}$ of identified particles are necessary to determine the origin of the LHCb charged-particle enhancement. Because charged particles produced in LHC collisions are mostly pions, measurements of π^0 production probe similar kinematics and production mechanisms as inclusive charged-particle measurements. Additionally, π^0s are reconstructed from photon pairs, so the systematic uncertainties in charged-particle and π^0 production measurements are mostly independent. LHCb has measured the π^0 $R_{p\text{Pb}}$ at forward and backward

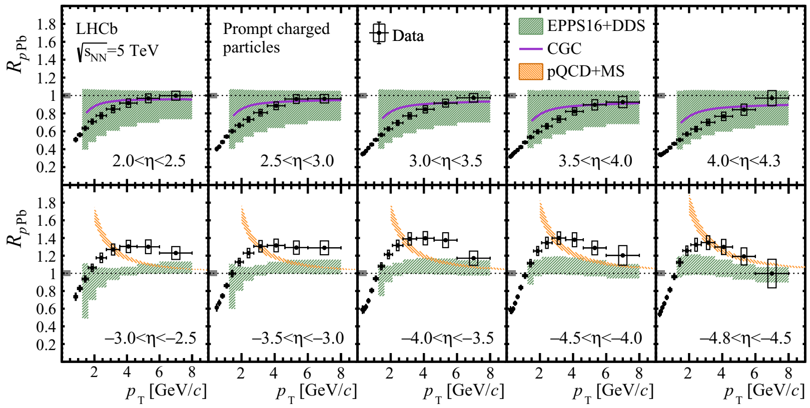

Figure 3. LHCb measurement of the charged-particle nuclear modification factor in pPb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV [12].

rapidity at $\sqrt{s_{NN}}$ = 8.16 TeV [19]. The π^0 candidates were reconstructed from photon pairs. To avoid the effects of overlapping clusters in the electromagnetic calorimeter, one of the photons is required to convert in the detector material. A proton-proton reference sample is constructed by interpolating between measurements at $\sqrt{s}$ = 5.02 and 13 TeV. The resulting $R_{p\mathrm{Pb}}$ measurements are shown in Fig. 4. The measurements are compared to pQCD predictions computed using nPDFs that include LHCb measurements of D^0 production at $\sqrt{s_{NN}}$ = 5.02 TeV [20–22]. The forward measurement agrees well with the nPDF prediction, as well as with the LHCb charged-particle $R_{p\mathrm{Pb}}$ measurement. The backward measurement shows a slightly larger enhancement than the nPDF prediction, but smaller than that observed in the LHCb charged-particle data. This suggests that the charged-particle excess could be due to a mass-dependent effect such as radial flow, or due to a baryon-enhancing effect like final state recombination. Additional studies of identified particles such as p, η, and η' could help untangle the contributions from these effects.

Since the LHCb experiment began recording pPb collisions in 2013, it has provided the strongest available constraints on nPDFs at low x. As a result, the low-x gluon nPDF in particular has quickly gone from almost entirely unconstrained to well known in just the last few years [2, 3]. The study of low-x nPDFs has suddenly become a high-precision field. With recent LHCb measurements, low-x nPDFs will soon be overconstrained, and emerging discrepancies between measurements and predictions could point to novel QCD phenomena.

Acknowledgements

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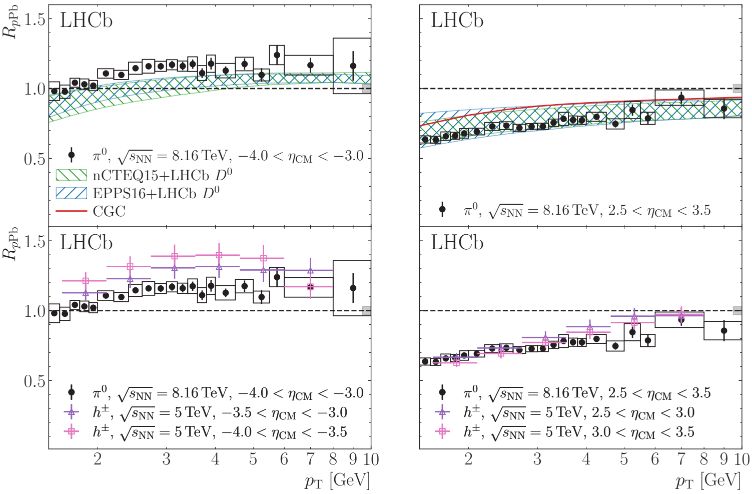

Figure 4. LHCb measurement of the π^0 nuclear modification factor in pPb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 8.16 TeV [19].

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