PROBING LOW-x PHENOMENA AT THE LHCb*

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The LHCb experiment is able to probe kinematic coverage at low Bjorken-x down to 10^{-5} or lower due to its forward rapidity coverage. In this contribution, studies of vector boson and hadron production in proton–lead collisions are presented. The Z boson events are used to probe the proton structure, while a relatively unknown low-x region is studied with charged and neutral hadron production. Comparisons to theoretical model calculations are also discussed.

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1. Introduction

The LHCb experiment at CERN has been originally designed for heavy-flavour physics studies in collisions between protons as a single-arm spectrometer instrumenting the pseudorapidity region $2.0 < \eta < 5.0$. In addition to flavour physics programme, the LHCb experiment is capable of performing electroweak and quantum chromodynamics measurements in proton–proton, proton–lead, and lead–lead collisions, enabling the exploration of previously unmeasured kinematic regions.

In these proceedings, three recent LHCb results are briefly summarised [1–3]. Studies of vector boson and hadron production in proton–lead collisions are reviewed. Such measurements probe parton distribution functions in a relatively unknown low-x region.

2. Prompt charged particle production

Charged particle production in proton–lead collisions is sensitive to the properties of the strong interaction from small to large momentum exchanges between the interacting partons of the hadrons. Modifications of the charged

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particle production rate in proton–lead collisions relative to proton–proton collisions can be modelled assuming a variety of nuclear matter effects. In particular, low values of Bjorken-x can be probed with high-energy collisions at the most forward rapidities.

The nuclear modification factor $R_{p\mathrm{Pb}} \equiv \sigma_{p\mathrm{Pb}}/(A\sigma_{pp})$ for prompt charged particles is measured for the first time in the forward and backward regions at the LHC in pp and pPb collisions at $\sqrt{s_{NN}} = 5$ TeV [1]. The charged particles are reconstructed with $p > 2$ GeV/c and $0.2 < p_{\mathrm{T}} < 8.0$ GeV/c. The observed number of tracks is corrected due to reconstruction and selection inefficiencies and fake tracks background.

The measured differential cross section of inclusive production of prompt long-lived charged particles is shown in Fig. 1. The total uncertainty is around 3% for most kinematic intervals both in pp and pPb collisions. As a result, the data place stringent constraints on non-perturbative QCD models in high-energy nuclear collisions.

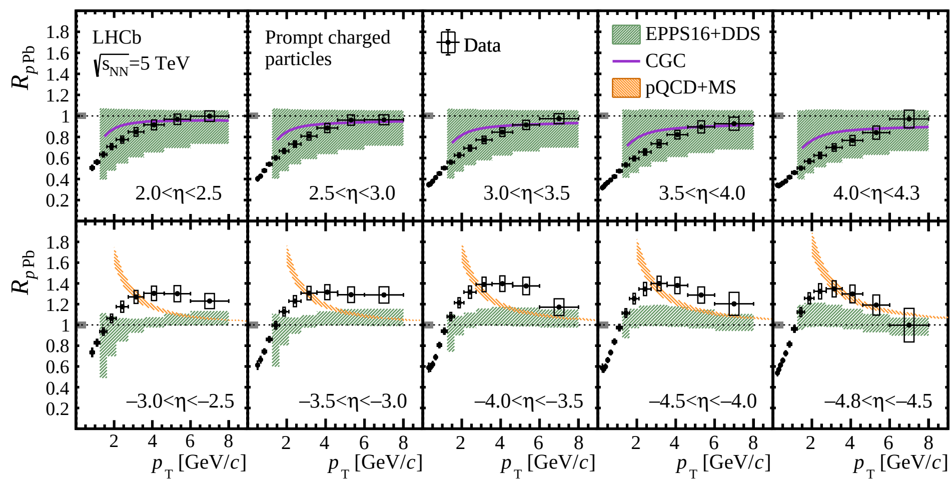

Fig. 1. Nuclear modification factor as a function of p_{T} in different η intervals for the (top) forward and (bottom) backward regions, compared with the predictions from Refs. [4–7]. Vertical error bars correspond to statistical uncertainties, open boxes to uncorrelated systematic uncertainty and the filled boxes at $R_{p\mathrm{Pb}} = 1$ to the correlated uncertainty from the luminosity.

3. Nuclear modification factor of neutral pions

Neutral pion production is an important probe of nuclear effects in proton–lead collisions, particularly to cold nuclear matter effects on the initial state of the bound nucleons in the colliding nucleus. The cold nuclear matter effects are encoded into nuclear parton distribution functions which are determined using fits to data and are currently poorly constrained for partons with momentum fraction Bjorken-x smaller than about 10^{-4}. The nuclear modification factor of neutral pions is measured in proton–lead collisions collected at a center-of-mass energy per nucleon of 8.16 TeV. The π_0 production cross section is measured differentially in transverse momentum (p_{T}) for $1.5 < p_{\mathrm{T}} < 10.0$ GeV and in center-of-mass pseudorapidity (η_{CM}) regions $2.5 < \eta_{\mathrm{CM}} < 3.5$ (forward) and $-4.0 < \eta_{\mathrm{CM}} < -3.0$ (backward) defined relative to the proton beam direction.

The measured nuclear modification factor is shown in Fig. 2. A total uncertainty of less than 6% is found in most p_{T} intervals which will provide strong constraints on models of nuclear structure and particle production in heavy-ion collisions. The forward measurement is sensitive to nPDFs for Bjorken-x as low as 10^{-6}, while the backward measurement shows the first evidence of enhanced π_0 production in proton–ion collisions at the LHC.

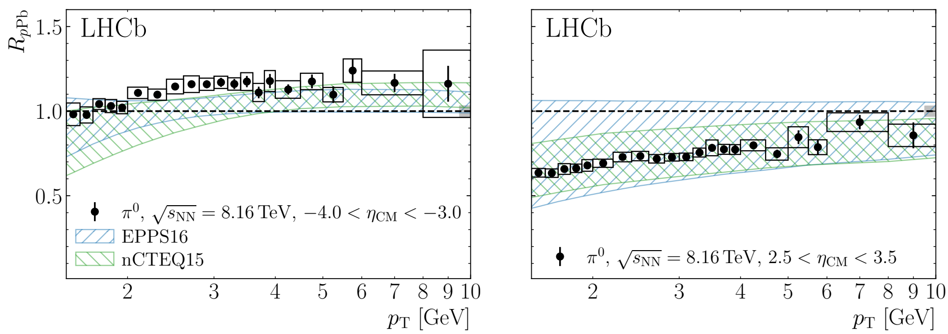

Fig. 2. Measured π^0 nuclear modification factor in the (left) backward and (right) forward η_{CM} regions. The error bars show the statistical uncertainties, while the open boxes show the systematic uncertainties. The solid black boxes show the overall normalization uncertainties from the luminosity estimate and efficiency correction factors. The measurements are compared to next-to-leading order perturbative quantum chromodynamics calculations [4] using the EPPS16 [8] and CTEQ15 [9] nPDF sets and the DSS14 π^0 fragmentation functions [10].

4. Measurement of the Z-boson production

Inclusive Z-boson production in proton–lead collisions is an important process to probe quantum chromodynamics. Due to the value of the Z-boson mass, the cross-section calculation can be factorised as a product of the hard scattering and the initial state of the collision. Since the Z bosons and their leptonic decay final states have nearly no interaction with the nuclear medium, the Z-boson production together with hadronic probes production can differentiate between effects of the initial and final state.

The first measurement of the differential Z-boson production cross section in the forward region in proton–lead collisions is performed at a nucleon–nucleon centre-of-mass energy of $\sqrt{s_{NN}} = 8.16$ TeV [3]. The forward–backward ratio and the nuclear modification factors are measured in addition to the differential cross section as functions of the Z-boson rapidity in the centre-of-mass frame, the transverse momentum of the Z boson, and a geometric variable ϕ^* [3]. The results are in good agreement with the nuclear parton density function predictions and they can be used to constrain some of those [3]. As an example, the $R_{\rm FB}$ is measured differentially as a function of y^*_Z which shows a general suppression below unity for all three intervals.

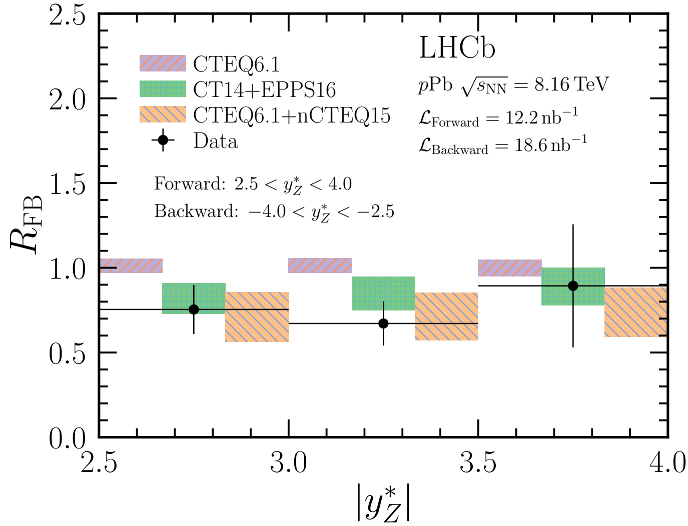

Fig. 3. The measured forward–backward ratio ($R_{\rm FB}$) as a function of y^*_Z compared with the Powheg predictions using CTEQ6.1, EPPS16 and nCTEQ15 [8, 9, 11–16].

5. Conclusions

In this conference contribution, we presented three measurements using proton–lead collision data which demonstrate the unique capabilities of the LHCb experiment to study nuclear effects and nuclear parton distribution functions. Other measurements related to these topics can be found in [17]. An increase in the data sample sizes of proton–lead and lead–lead collision is expected which will improve the precision of presented measurements.

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