Studies of nucleon structure at 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 identification and a fast DAQ, LHCb can fully reconstruct charged particles and neutral mesons. The new measurements presented in this contribution provide unique constraints on nuclear parton distribution functions and saturation models.

1 Introduction

Decades of studies have revealed that nucleons are more complex than a system of three quarks bound by gluons. Instead, it consists of a dynamic interplay of valence quarks, sea quarks, and gluons (known as partons) interacting through the principles of QCD. In high-energy collisions, the partonic structure can be described through parton distribution functions (PDFs). The two degrees of freedom of PDFs are the exchanged momentum between partons, $Q^2 \sim m^2 + p_T^2$, and the momentum fraction of the parton with respect to the nucleon, $x \sim \frac{Q}{\sqrt{s_{NN}}} e^{-\eta}$. As can be observed in Fig.1, the LHCb experiment can access the low-x, $10^{-6} < x < 10^{-4}$, and high-x, $10^{-3} < x < 10^{-1}$, regions, which are complementary to the other experiments. For nuclei, the partonic structure can be described by analogous distributions called nuclear PDF (nPDF), also parametrised as a function of the number of nucleons.

2 The LHCb experiment

The LHCb experiment is a fully instrumented detector in the forward region, $2.0 < \eta < 5.0$, as shown in Fig.1 [1]. It has a momentum resolution of $\Delta p/p \in [0.5, 1]\%$ and a primary vertex resolution of $[10, 35]$ μm. Thanks to the complete particle identification capabilities, the LHCb experiment can detect $p, \pi, K, e, \mu,$ and γ. Due to its asymmetric geometry, in proton-lead collisions, pPb, the Bjorken-x region covered by the experiment differs depending on whether the proton is moving toward the detector (forward configuration) or the nuclei are moving toward the detector (backward configuration).

3 Recent LHCb measurements

3.1 $\Psi(2S)$ production in pPb collisions at $\sqrt{s_{NN}} = 8.16$ TeV

The production of $\Psi(2S)$ mesons in pPb collisions at a centre-of-mass energy per nucleon pair of $\sqrt{s_{NN}} = 8.16$ TeV has been measured using the data sample with an integrated lumi-

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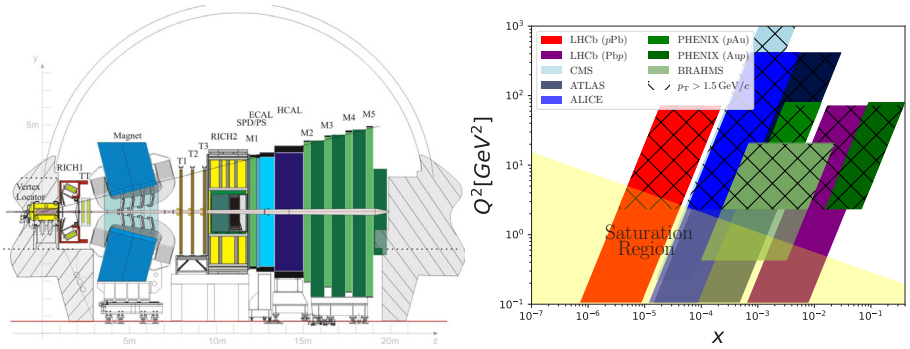

Figure 1. (left) LHCb display during Run2 from [1]. (right) (Q^2, x) diagram for LHC and RHIC experiments.

nosity of 34 nb^{-1} [2]. The prompt and non-prompt components are separated by a pseudo-proper time, t_z, fit as seen in Fig.2. Results are provided as functions of the meson's transverse momentum and rapidity in the nucleon–nucleon centre-of-mass frame. Additionally, forward-to-backward production ratios and nuclear modification factors are determined. The results show that prompt $\Psi(2S)$ production is suppressed in pPb collisions by 25% compared to prompt J/Ψ production as shown in Fig.2. This indicates a factorisation breaking with respect to the final state. The Comover model [3] reproduces the data as well as CGC+ICEM [4]. The suppression levels for non-prompt $\Psi(2S)$ and J/Ψ mesons are comparable.

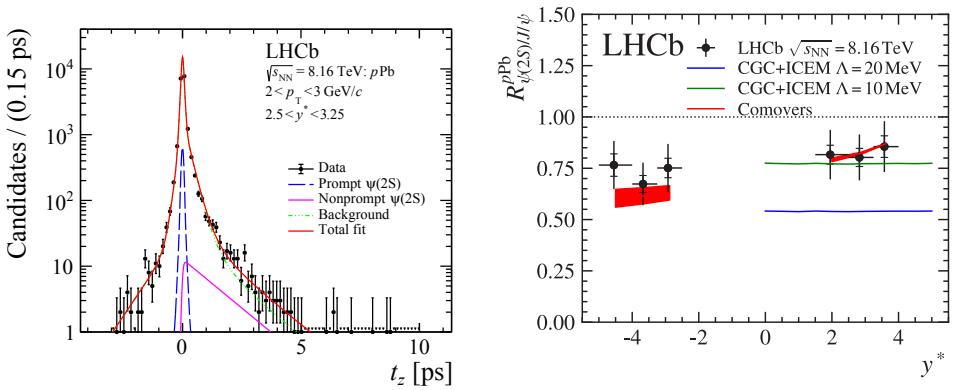

Figure 1. (left) Pseudo proper-time fit distribution of $\Psi(2S)$ candidates overlaid with a fit to separate prompt and non-prompt contributions. (right) Nuclear modification factor, R_{pPb}, ratio as a function of rapidity compared with the CGC and Comovers model.

3.2 D_s^+ and D^+ production in pPb collisions at $\sqrt{s_{NN}}$ = 8.16 TeV

The LHCb experiment measured the production of prompt D^+ and D_s^+ mesons in pPb collisions at $\sqrt{s_{NN}}$ = 8.16 TeV, in both the forward ($1.5 < y^* < 4.0$) and backward ($-5.0 < y^* < -2.5$) rapidity regions [5]. The nuclear modification factors for both meson

species are determined as functions of transverse momentum and rapidity. The D^+ and D_s^+ nuclear modification factors are compatible with each other and with the D^0 result in the forward region. Moreover, the nCTEQ15 and EPPS16, and CGC predictions are compatible with the data. However, in the backward region, the D_s^+ result is higher than the other D mesons. Additionally, the nPDFs slightly overestimate the D^+ data while being compatible with the D_s^+.

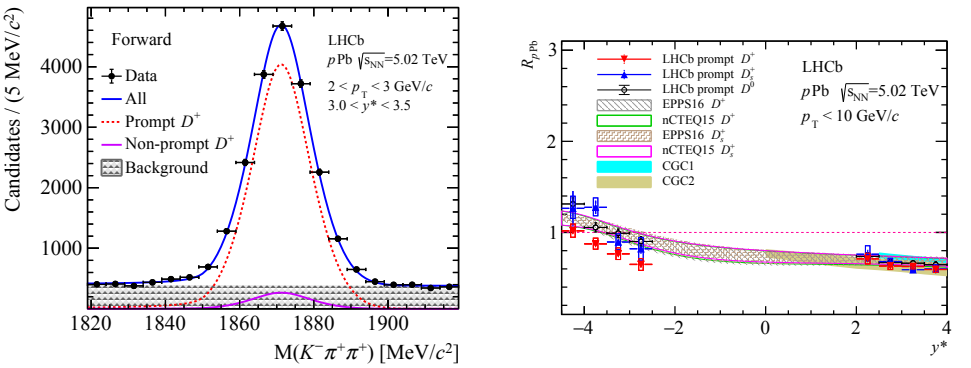

Figure 3. (left) Invariant mass spectra of the $K^-\pi^+\pi^+$ final state. (right) Nuclear modification factor for D^0, D^+ and D_s^+ as a function of rapidity compared with CGC and nPDFs models.

3.3 η/η' production in pp and pPb collisions at $\sqrt{s_{NN}}$ = 8.16 TeV

The production of η and η' mesons is measured in proton-proton, pp, and pPb collisions at $\sqrt{s_{NN}}$ = 8.16 TeV. Measurements are performed in the centre-of-mass rapidity intervals $2.5 < y^* < 3.5$ and $-4.0 < y^* < -3.0$, defined relative to the proton beam direction. Production cross-sections are measured as functions of transverse momentum, in the ranges $1.5 < p_T < 10$ GeV for η mesons and $3 < p_T < 10$ GeV for η' mesons. These cross-sections are used to derive nuclear modification factors, which are found to be consistent for both mesons at forward and backward rapidities 4. These results indicate no significant mass dependence of light meson production. Additionally, η and η' nuclear modification factors are compared with that for the π^0 showing agreement within uncertainties.

3.4 Exclusive J/Ψ and $\Psi(2S)$ production in pp collisions at $\sqrt{s}$ = 13 TeV

Measurements of the cross-sections for J/Ψ and $\Psi(2S)$ central exclusive production in pp collisions at $\sqrt{s}$ = 13 TeV are presented [6]. Additionally, the ratio of the $\Psi(2S)$ to J/Ψ cross-sections is measured at an average photon–proton centre-of-mass energy of 1 TeV. These processes probe the gluonic PDF at the scale of the charm quark mass. The contribution from elastic production is separated from the inelastic contribution by fitting the $p_T^2(\mu^+,\mu^-)$ distribution. For the first time in proton–proton collisions, the dependence of the J/Ψ and $\Psi(2S)$ cross-sections on the total momentum transfer, $p_T^2 \sim \Delta t$, is measured and found to be consistent with observations in electron–proton collisions as presented in Fig.5.

References

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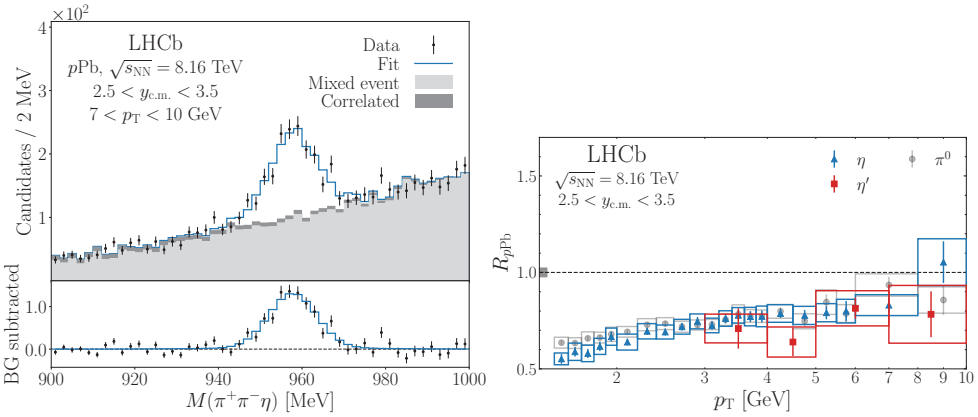

Figure 4. (left) Invariant mass fit to extract the η' signal. (right) Nuclear modification factor, R_{pPb}, of η, η' and π^O mesons in the forward region.

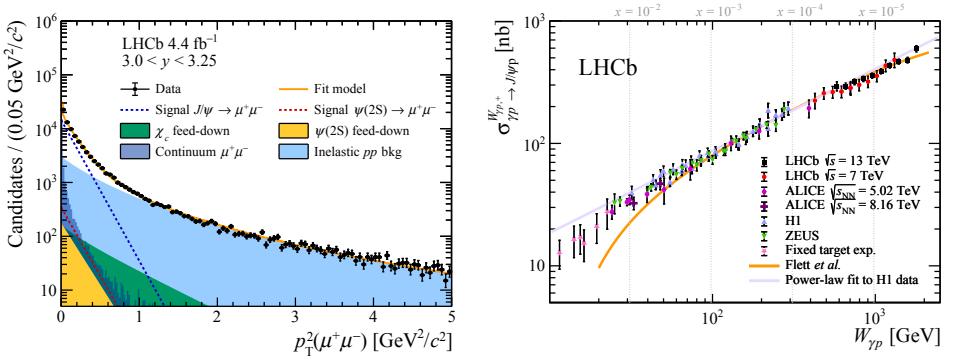

Figure 5. (left) Di-muon transverse momentum distribution overlaid with a fit to extract the elastic component. (right) Cross-section as a function of the photon-proton centre-of-mass energy, $W_{\gamma p}$.

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