PROCEEDINGS OF SCIENCE

Polarization and strangeness production at LHCb

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Strange hadron production is an important probe of hadronization in hadron collisions. Thanks to its forward geometry, precise vertex reconstruction and particle identification capabilities, the LHCb detector is ideally suited to study strangeness production in an unexplored kinematic regime. In addition, the SMOG system allows the study of strangeness production and polarization in the highest energy fixed-target collisions ever produced in a laboratory. This is even more relevant now since recent studies have linked the polarization of hyperons to the process of hadronization, and the origin of hyperon polarization from unpolarized proton-proton and proton-nucleus collisions is not yet fully understood. We present recent LHCb measurements of hyperon polarization in fixed-target pNe collisions, as well as of strangeness enhancement in charm hadron production in pPb beam-beam collisions. We also discuss their implications for Transverse Momentum Dependent parton-distributions and fragmentation functions as well as hadronization modification in small collision systems.

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1. Introduction

The LHCb detector is a single-arm forward spectrometer with a unique coverage in pseudorapidity, $2 < \eta < 5$, with respect to other LHC experiments [1, 2]. The detector includes a high-precision tracking system providing optimal vertex and momentum resolution, two ring-imaging Cherenkov detectors for charged particle identification, a calorimeter system to identify photons, electrons and hadrons, and a muon system. The LHCb fixed-target system, called SMOG (System for Measuring the Overlap with Gas), allows injection of noble gas into the primary LHC vacuum, and study of beam-gas collisions at different nucleon-nucleon center-of-mass (c.m.) energies, namely $\sqrt{s_{NN}} = 68$ and 110 GeV, higher compared to previous fixed-target experiments.

2. Λ transverse polarization in pNe collisions at $\sqrt{s_{\mathrm{NN}}} = 68.4$ GeV

The spontaneous transverse polarization of Λ hyperons was first observed in 1976 in unpolarized collisions of protons with an energy of 300 GeV on a beryllium target [3]. A polarizing fragmentation function, denoted by $D_{1T}^{\perp}$, has been proposed to account for the polarized production of Λ hyperons [4]. The mechanism involving the $D_{1T}^{\perp}$ function is the same as that used in the framework of the transverse-momentum-dependent (TMD) unpolarized fragmentation functions to describe the fragmentation of an unpolarized quark into a transversely polarized hadron. TMDs account for spin and momentum correlations at the soft level, potentially explaining the observed asymmetries [5]. Since one possible approach is to determine these functions from experimental data, several attempts were made to describe Λ polarization, both on the theoretical and experimental sides, at different accelerators and center-of-mass energies. LHCb performed a measurement of transverse Λ and $\bar{\Lambda}$ polarization using its fixed-target configuration [6]. The polarization is determined using proton-neon (pNe) data collected in 2017 from collisions at a nucleon-nucleon center-of-mass energy of $\sqrt{s_{\mathrm{NN}}} = 68.4$ GeV, generated by a 2.5 TeV proton beam incident on neon nuclei at rest. The hyperons are reconstructed through the decays $\Lambda \to p\pi^-$ and $\bar{\Lambda} \to \bar{p}\pi^+$. These decays exhibit significant parity violation, resulting in large asymmetries in the angular distribution of their decay products. In particular, the angular distribution of the proton in the Λ rest frame is given by

$$\frac{dN}{d\cos\theta} = \frac{dN_0}{d\cos\theta}(1 + \alpha P_\Lambda \cos\theta), \tag{1}$$

where θ is the angle between the proton momentum and the normal to the production plane spanned by the beam and the Λ momentum directions, $\frac{dN_0}{d\cos\theta}$ is the decay distribution for unpolarized Λ hyperons, P_Λ is the magnitude of the Λ polarization, and α is the value of the parity-violating decay asymmetry for the Λ hyperon. The magnitude of the polarization is determined from a fit to the angular distribution of the proton. The final polarization measurements are: $P_\Lambda = 0.029 \pm 0.019\,(\mathrm{stat}) \pm 0.012\,(\mathrm{syst})$ and $P_{\bar{\Lambda}} = 0.003 \pm 0.023\,(\mathrm{stat}) \pm 0.014\,(\mathrm{syst})$. The polarization measurements have also been performed in bins of the Λ transverse momentum p_T, pseudorapidity η, rapidity y and x-Feynman variable x_{F}. The results are shown in Fig. 1. In Fig. 2 the LHCb results of Λ polarization as a function of x_{F} are compared with the results from other experiments albeit at different energies and collision systems. The polarization values obtained in this analysis are compatible with previous measurements, in particular with the HERA-B [7] results which cover a similar x_F interval. The agreement is noteworthy considering the differences between the two experiments and the colliding systems.

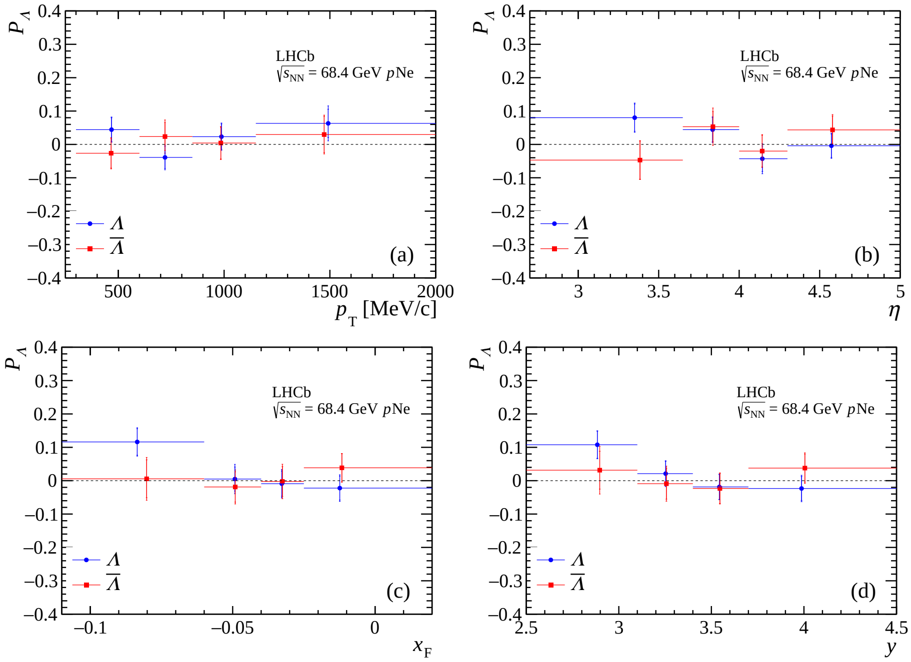

Figure 1: Polarization as a function of (a) p_T, (b) η, (c) x_F and (d) y. Blue (red) symbols are for Λ ($\bar{\Lambda}$). In each plot the data is integrated over the $0.3 < p_T < 3$ GeV and/or $2 < \eta < 5$ kinematic range.

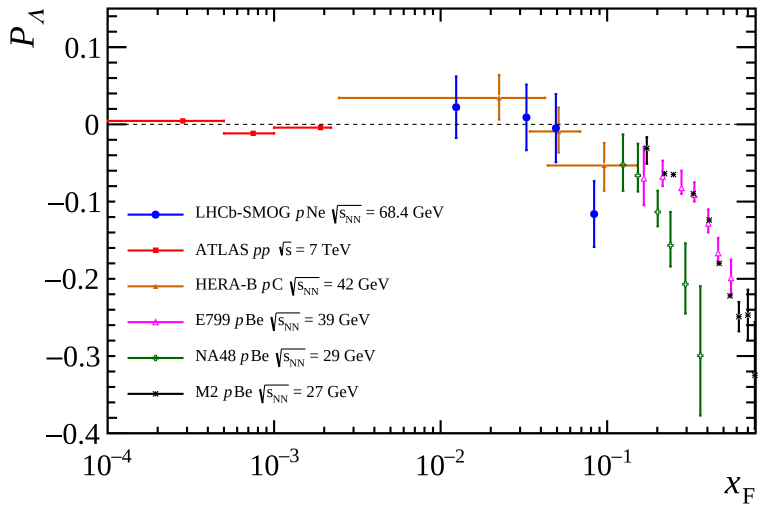

Figure 2: Comparison of Λ hyperons polarization as a function of x_F obtained in experiments with different energies and with different colliding systems.

3. Strangeness production

Strangeness enhancement is considered a signature for Quark-Gluon-Plasma formation in heavy-ion collisions. In order to precisely evaluate it, it is essential to estimate effects which can mimic it, such as cold nuclear matter (CNM) effects. The pPb collisions collected by LHCb represent an optimal environment for both studying CNM effects and testing theories which predict QGP droplets in small systems.

3.1 Prompt Ξ_c^+ production in pPb collisions at $\sqrt{s_{\rm NN}} = 8.16$ TeV

The production of the charm-strange baryon, Ξ_c^+, was measured in heavy-ion collisions for the first time at LHCb [8]. The measurements are performed using the pPb and Pbp collisions covering the rapidity region $1.5 < y^* < 4.0$ and $-5.0 < y^* < -2.5$ respectively (where y^* denotes the rapidity in the c.m. frame) at a center-of-mass energy of $\sqrt{s_{\rm NN}} = 8.16$ TeV. The Ξ_c^+ candidates are reconstructed via the hadronic decay to the $p\,K\,\pi^+$ final state. The double-differential cross-sections of prompt Ξ_c^+ production as a function of transverse momentum p_T and rapidity y^* are shown in Fig 3, compared with theoretical predictions from the HELAC-Onia [9] simulations with 3 factorization scales. With the same sample, the differential ratio of Ξ_c^+ to Λ_c^+ baryons is measured

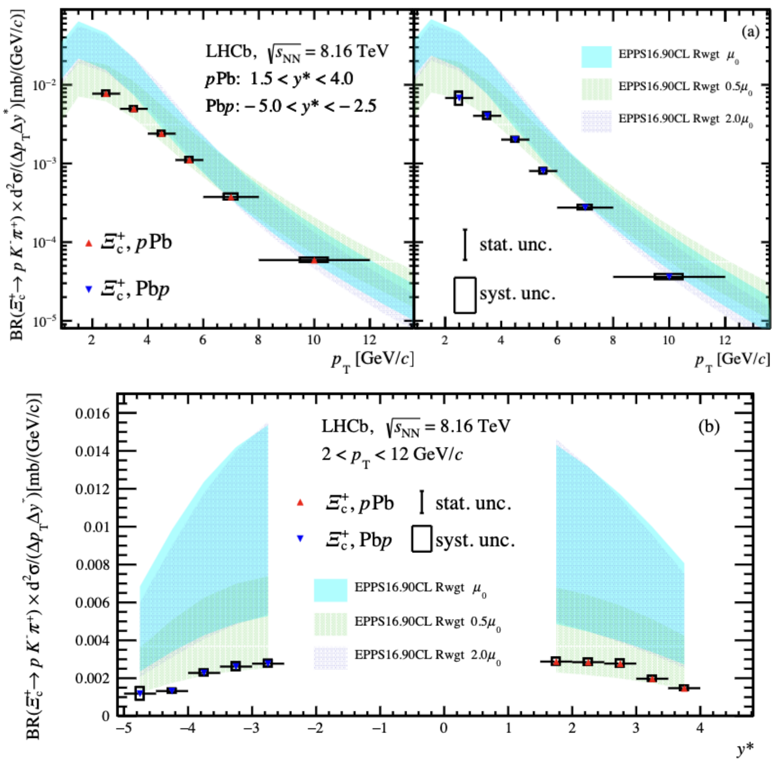

Figure 3: Double-differential cross-section of the prompt Ξ_c^+ baryon production times $\mathcal{B}(\Xi_c^+ \to pK^-\pi^+)$ as a function of (top) p_T and (bottom) y^* in pPb (red triangles) and Pbp (blue triangles) collisions.

for the first time at forward rapidity and it is shown in Fig. 4 as a function of p_T. The ratio shows a flat distribution, with no clear sign of strangeness enhancement.

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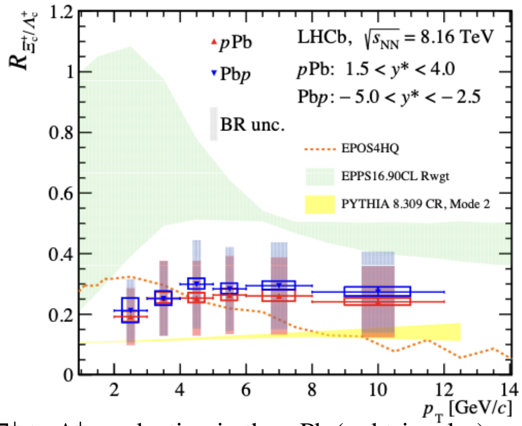

Figure 4: Ratio of prompt Ξ_c^+ to Λ_c^+ production in the pPb (red triangles) and Pbp (blue triangles) samples as a function of p_T.

3.2 Prompt D^+, D_s^+ production in pPb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV

The production of the D^+ and D_s^+ mesons was studied in pPb and Pbp collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV for the first time at forward rapidity [10]. The Nuclear Modification factor $R_{p{\rm Pb}} = \frac{1}{A}\frac{\sigma_{p{\rm Pb}}}{\sigma_{pp}}$ for both mesons as a function of the transverse momentum is shown in Fig. 5, compared with previous LHCb D^0 measurements [11] and theoretical curves, showing good agreement with nPDFs calculations. Fig. 6 illustrates the production ratio between D^+, D_s^+ and D^0[11] mesons,

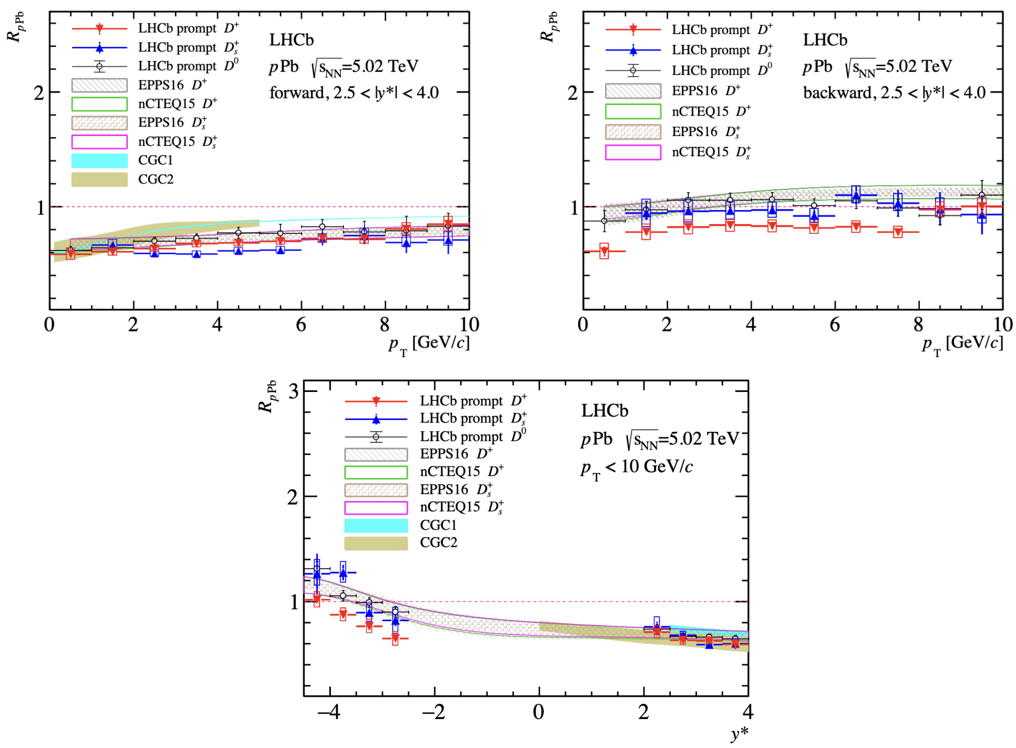

Figure 5: Nuclear modification factor $R_{p{\rm Pb}}$ as a function of p_T (for forward y^* top left, and backward y^* top right) and as function of y^* (bottom), for D^+ and D_s^+ meson production.

showing agreement with the LHC*b* and ALICE *pp* results, but no particular enhancement in either forward or backward region.

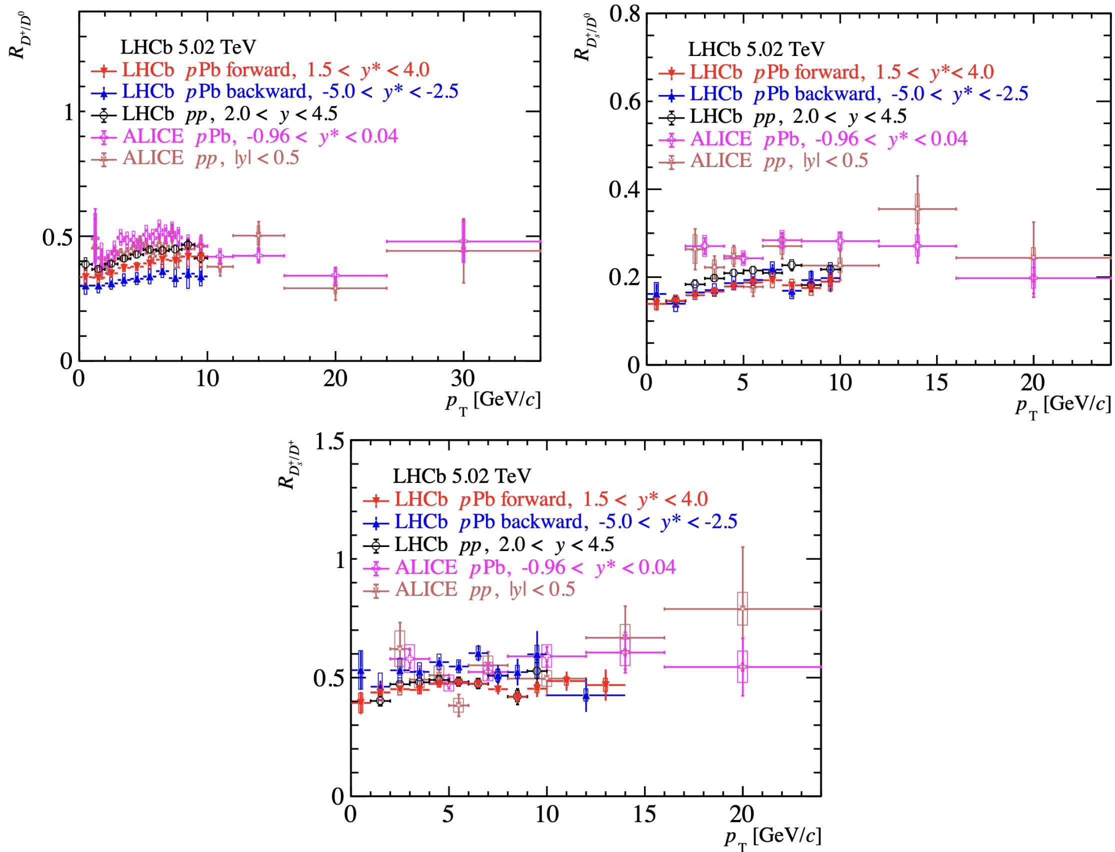

Figure 6: Production ratios as a function of p_T in pPb and Pbp collisions.

4. Conclusion

The first measurement of Λ hyperon polarization measured in pNe fixed-target collisions at $\sqrt{s_{NN}}$ = 68.4 GeV is presented, and the results obtained are in very good agreement with all the previous measurements albeit performed in different colliding systems and center-of-mass energies. Two results focused on strangeness enhancement evidence are also shown, precisely the production cross-section of the Ξ_c^+ strange meson compared with Λ_c^+ and the production ratios of strange mesons such as D^+, D_s^+ and D^0, both in proton-lead collisions collected by LHC*b*. All the measurements are in agreement with theoretical calculations and previous measurements and will be crucial to constrain the theoretical framework especially concerning heavy quark hadronization.

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