Recent results from LHCb

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Abstract. The LHCb experiment is a fully instrumented detector in the forward region at the Large Hadron Collider. LHCb's forward acceptance and unique detector capabilities enable a broad heavy-ion physics program. LHCb has studied colliding systems from pp to PbPb, as well as fixed-target collisions with a wide variety of target species. This contribution presents recent results from the LHCb experiment.

1 Introduction

The LHCb detector is a forward spectrometer at the Large Hadron Collider [1]. The LHCb detector is fully instrumented, consisting of tracking, calorimetry, and particle identification systems. In particular, the LHCb tracking system includes a Vertex Locator (VELO), a silicon strip detector close to the beamline that provides transverse vertex resolution of $10 - 50\ \mu$m. In addition, LHCb also includes two Ring Imaging Cherenkov (RICH) detectors, which allow for charged hadron identification. As a result, the LHCb detector can reconstruct and identify charged hadrons, photons, leptons, and light nuclei produced in high-energy hadron collisions. These capabilities, along with the detector's forward acceptance, allow LHCb to perform unique studies of heavy-ion collisions in unexplored kinematic regions.

In addition to operating as a collider detector, LHCb can also operate as a fixed-target experiment by injecting gas into the VELO region using the System for Measuring the Overlap with Gas (SMOG) [2]. Consequently, LHCb is the highest energy fixed-target experiment ever conducted. With SMOG, LHCb has performed studies of both proton-gas and lead-gas collisions using a wide variety of noble gas targets.

2 Open heavy-flavor production and hadronization

LHCb's excellent vertex resolution and particle identification capabilities make it an ideal detector for studying heavy-flavor production. The LHCb experiment has used these capabilities to study bottom quark hadronization in high-multiplicity pp collisions [3]. LHCb measured the Λ_b^0/B^0 production ratio as a function of multiplicity in pp collisions at $\sqrt{s} = 13$ TeV. This measurement uses the similar $\Lambda_b^0 \to J/\psi p K^-$ and $B^0 \to J/\psi \pi^- K^+$ final states to maximize the cancellation of systematic uncertainties in the baryon-to-meson ratio. As a result, this measurement requires precise identification of both charged hadrons and leptons. The resulting baryon-to-meson ratio is shown as a function of multiplicity in Fig. 1. This ratio agrees with results from e^+e^- collisions at low multiplicity [4], but grows as multiplicity increases.

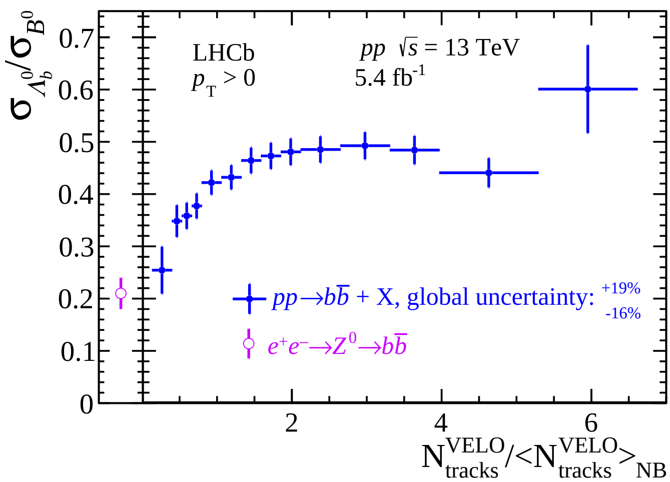

Figure 1. Ratio of Λ_b^0 to B^0 cross section as a function of the track multiplicity in the VELO detector normalized to the average multiplicity in minimum bias pp events.

This result indicates that the hadronization of b quarks is modified in high-multiplicity environments.

LHCb has also studied the modification of charm quark hadronization by studying $D_s^\pm$ production relative to $D^\pm$ production as a function of multiplicity in pPb collisions at $\sqrt{s_{NN}}$ = 8.16 TeV [5]. The resulting $D_s^\pm/D^\pm$ ratio is shown in Fig. 2. The measured ratio shows an enhancement of D_s^+ in high-multiplicity events, independent of rapidity. These results agree with previous results from both the LHCb and ALICE experiments [6–9]. The data are better described by models including final state effects such as coalescence or color reconnection, although no model provides and accurate description of the data over the entire kinematic range of the measurement.

3 Conventional and exotic charmonium production

Charmonium suppression could be a signal of color screening by the Quark-Gluon Plasma (QGP), which would cause the charmonium to disassociate. Charmonium states with different binding energies will disassociate at different energies. As a result, studying the suppression of different charmonium states can reveal the temperature of the medium produced in high-energy hadron collisions. LHCb recently measured χ_c production relative to J/ψ production in both pPb and pp collisions, where χ_c refers to the combination of χ_{c1} and χ_{c2} states [10]. The double ratio of production ratios of different quarkonium states is shown in Fig. 3. The LHCb results show no suppression of the χ_c states. Because their binding energies are just above the expected QGP freeze-out temperature, these results indicate that charmonium suppression in pp and pPb collisions is not a product of QGP formation.

LHCb also recently performed measurements of charmonium production in pp collisions as a function of multiplicity [11]. LHCb measured the $\psi(2S)/J/\psi$ production ratio, and the results are shown in Fig. 4. The LHCb measurement shows suppression at high multiplicity for promptly produced particles and no suppression for charmonia from b hadron decays.

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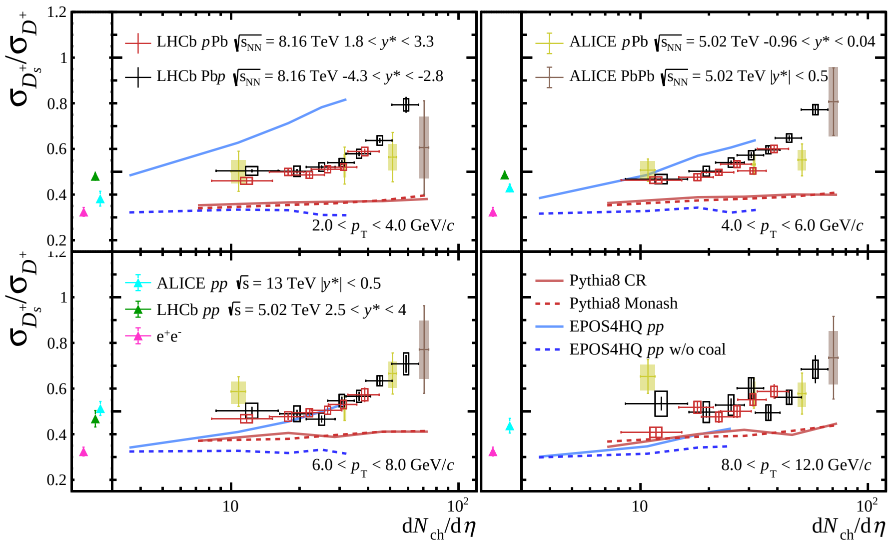

Figure 2. Ratio of D_s^+ to D^+ cross sections as a function of the charged particle pseudorapidity density in different transverse momentum regions. Statistical uncertainties are shown as error bars and systematic uncertainties are shown as boxes.

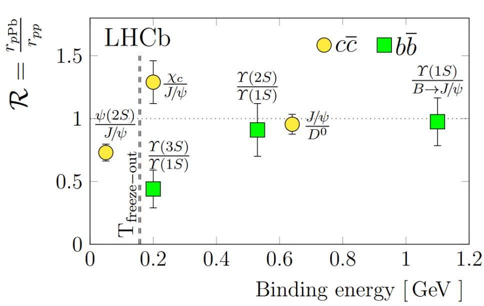

Figure 3. Ratio of production ratios in pPb to pp collisions. The particle species used in each production ratio are shown in the data point labels. The double ratios are shown as a function of the binding energy of the quarkonium state. The dashed line shows the estimated QGP freeze-out temperature.

The results agree with predictions from a co-mover model, which describes how charmonium disassociates by interacting with nearby hadrons. This ratio was also measured in pPb collisions, and the results also agree with co-mover predictions.

In addition to conventional charmonium states, the LHCb experiment has also studied exotic charmonium production in heavy-ion collisions. LHCb measured $\chi_{c1}(3872)$ production relative to $\psi(2S)$ production in pp and pPb collisions [12]. LHCb measured the nuclear modification factor of the $\chi_{c1}(3872)$ meson at $\sqrt{s_{\text{NN}}}$ = 8.16 TeV. The measured nuclear modification factor is shown in Fig. 5. The resulting modification is larger than that of the $\psi(2S)$, although the uncertainties are large. These results indicate that conventional charmonium states are modified differently than exotic states.

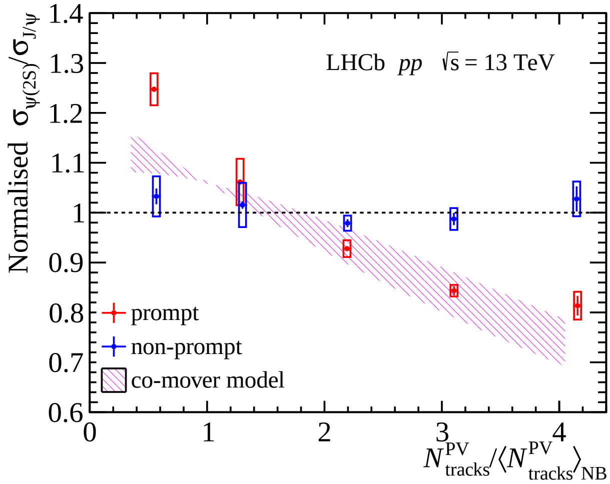

Figure 4. The ratio of $\psi(2S)$ to J/ψ production cross sections in pp collisions at $\sqrt{s}$ = 13 TeV. The ratio is normalized such that the mean value is unity. The ratio is shown as a function of the multiplicity of tracks originating from a collision point normalized to the mean value in minimum bias pp collisions.

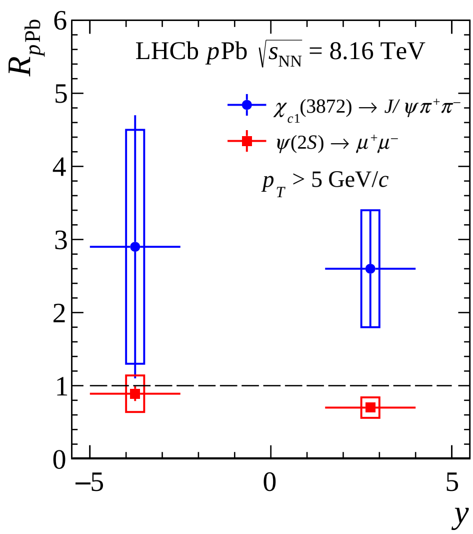

Figure 5. Nuclear modification factor R_{pPb} of $\chi_{c1}(3872)$ and $\psi(2S)$ mesons at $\sqrt{s_{NN}}$ = 8.16 TeV. The statistical uncertainties are shown as error bars, while the systematic uncertainties are shown as boxes.

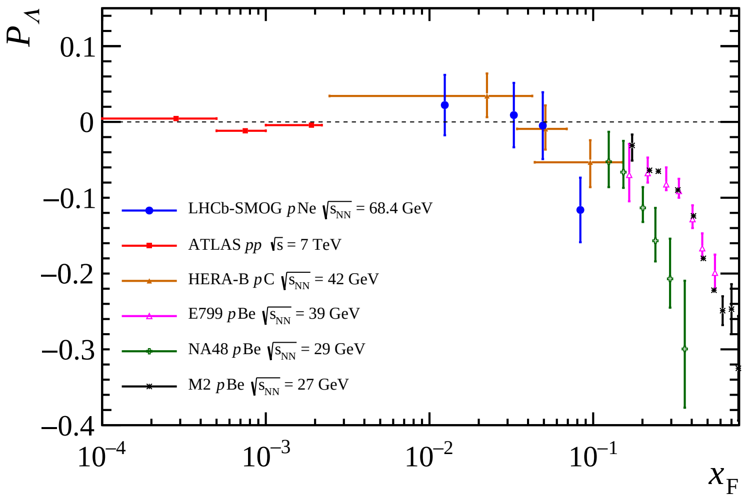

Figure 6. Transverse polarisation of Λ baryons as a function of x_F for various collision systems and center-of-mass energies.

4 Fixed-target physics

The LHCb experiment operates in fixed-target mode using the SMOG system. The fixed-target configuration provides complementary kinematic coverage to other hadron collider experiments. LHCb recently measured the transverse polarization of Λ baryons produced in fixed-target pNe collisions with $\sqrt{s_{NN}}$ = 68.4 GeV [14]. This measurement probes transverse-momentum dependent fragmentation functions at larger Feynman x (x_F) than that accessible to other LHC experiments. Results are shown in Fig. 6. The measured Λ polarization is in broad agreement with measurements across a wide range of collision systems and center-of-mass energies.

5 LHCb in Run 3

The LHCb detector recently underwent a major upgrade which included replacement of the entire tracking system, as well as a new software-only trigger system [15]. The new detector is capable of studying more central PbPb collisions than the original LHCb detector, reaching centralities of 30%. Additionally, a new gas target cell called SMOG2 was installed. This dedicated gas cell is located upstream of the VELO and allows for a two-order-of-magnitude increase in gas pressure. The upgraded detector is capable of collecting data in both collider and fixed-target modes simultaneously and has done so throughout 2024. As a result, this upgrade will enable the expansion of LHCb's already rapidly growing heavy-ion physics program.

6 Summary

The LHCb experiment has a broad and growing heavy-ion physics program. Its forward acceptance, vertexing and particle identification capabilities, and gas injection system allow LHCb to play a unique role in the heavy-ion physics landscape. Recent upgrades will further expand this program and allow LHCb to make major contributions to high-energy nuclear physics for the foreseeable future.

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