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LHCb Overview

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Abstract. The LHCb experiment has a complete heavy ion physics program, including studies of pp, pA, AA, and UPC events delivered by the Large Hadron Collider, along with a rapidly expanding fixed-target capability. With unique acceptance and detector capabilities, LHCb reaches across the widest range of Bjorken x that is available in the laboratory, accesses an incomparably broad array of light and heavy quark states, and provides measurements of forward bulk phenomena, all down to very low p_T. These proceedings discuss results from LHCb as presented at the Quark Matter 2023 conference in Houston, TX.

1 Introduction

LHCb is a general-purpose single arm spectrometer covering forward angles at the Large Hadron Collider [1]. The forward coverage is unique among LHC experiments, and allows access to the very low x regions inside the nucleus, probing $x \sim 10^{-5}$ or lower. Particles produced in the forward direction acquire a large boost from multi-TeV LHC beams, which gives heavy quark hadrons clearly displaced vertices, and permits reconstruction of charged tracks with very low transverse momentum p_T. In addition, LHCb has full hadron identification capabilities and a fast data acquisition system that allows large statistical samples to be accumulated.

2 Low x physics with identified particles

LHCb measurements of D^0 meson production in pPb collisions at a center of mass energy per nucleon $\sqrt{s_{NN}} = 5$ TeV provide the most stringent constraints on the gluon distribution in nuclei for $x < 10^{-3}$ [2]. These constraints are vital when searching for the onset of gluon saturation. A new measurement of D^0 production in pPb collisions at 8.16 TeV provides even more powerful constraints, with reduced uncertainties and reach into even lower x ranges [3]. At forward rapidity, where the proton beam goes into the LHCb spectrometer, these data are consistent with updated calculations based on parton distribution functions (PDFs). At backward rapidity, when the Pb nucleus is moving into the spectrometer, the data deviate from PDF calculations. This may indicate that additional final-state effects, such as energy loss or modification of charm hadronization, come into play in this region.

LHCb has also studied light meson production in pPb collisions, which provide different probes for constraining PDFs. Precise measurements of π^0 meson production in pPb collisions show similar behavior to D mesons: agreement with PDF calculations at forwards rapidity, and tension at backward rapidity [4]. To help clarify the origin of these effects, LHCb has produced new measurements of η and η' mesons in pPb collisions [5]. The π^0, η, and η' nuclear modification factors all agree within uncertainties (see Fig. 1), showing these nuclear effects have little or no dependence on the meson mass.

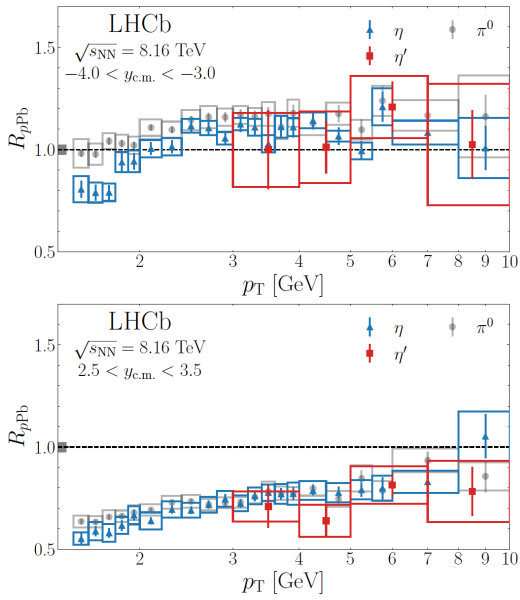

Figure 1. The nuclear modification factor for π^0, η, and η' mesons [5]. No mass dependence is observed.

3 Medium modification of hadronization

LHCb's precision access to the charm and bottom sector allows these heavy quarks to be used as probes of the non-perturbative hadronization process. New results on charm in pPb collisions have shown evidence that D_s^+ production is enhanced at far backward rapidity, and that the enhancement depends on both collision multiplicity and p_T [6, 7]. The first measurements of the charmed strange baryon Ξ_c^+ in pPb collisions provide entirely new constraints on charm hadronization, baryon production, and strangeness enhancement in small systems [8].

LHCb has also shown that multiplicity-dependent strangeness enhancement extends to the very heavy bottom sector [9], in regions where multiplicity is high and p_T is relatively low. New results on bottom baryon production show that the fraction of b quarks that hadronize into baryons has a strong dependence on collision multiplicity [10]. However, as multiplicity approaches zero, the fragmentation fraction observed in e^+e^- collisions is obtained as shown in Fig. 2. These results show that the underlying event activity has an affect on the hadronization process, and that additional mechanisms beyond vacuum fragmentation (such as quark coalescence) play an important role in hadron formation at the LHC.

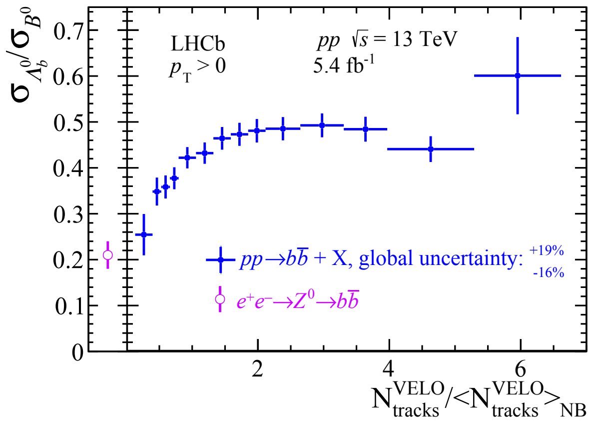

Figure 2. The ratio of Λ_b^0 to B^0 cross sections measured in pp collisions as a function of multiplicity [10]. When projected to zero multiplicity, the ratio measured in e^+e^- collisions is reproduced.

4 Charmonium suppression

Suppressed production of quarkonia states has long served a signature for the formation of deconfined quark gluon plasma (QGP). Using a unique fixed-target system, the LHCb collaboration has investigated the onset of J/ψ suppression in pNe and PbNe collisions at $\sqrt{s_{NN}}$ = 68.5 GeV [12]. Figure 3 shows the ratio of J/ψ to D^0 cross sections as a function of the number of binary nucleon-nucleon collisions N_{coll}. In this ratio, initial state effects on charm production (such as modifications of the nuclear PDF) largely cancel, leaving final state effects dominant. No anomalous J/ψ suppression is observed, leading to the conclusion that charmonia suppression in QGP is not a large effect in these collision systems.

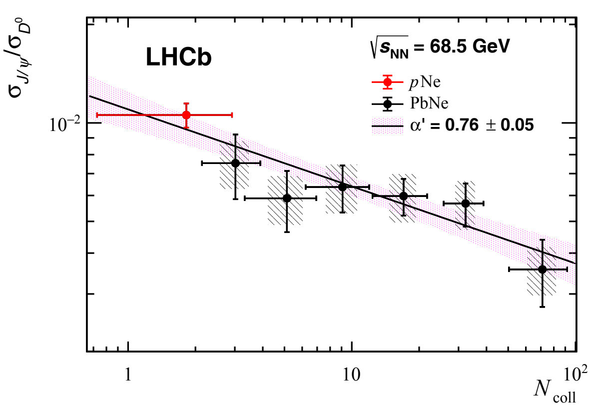

Figure 3. The ratio of J/ψ to D^0 cross sections as a function of N_{coll} in fixed-target collisions [12].

In order to fully interpret J/ψ suppression, the fate of higher charmonia states that contribute to J/ψ yields through feeddown must also be quantified. Especially important are the χ_c states, which contribute a significant fraction of the inclusive prompt J/ψ cross section. New LHCb measurements in Fig. 4 show little variation in χ_c feeddown to J/ψ between

pp, forward rapidity pPb, and backward rapidity Pbp collisions [11]. This first measurement of χ_c in pPb at the LHC provides new constraints on the energy available to dissociate charmonia and the possible formation of QGP in small collision systems.

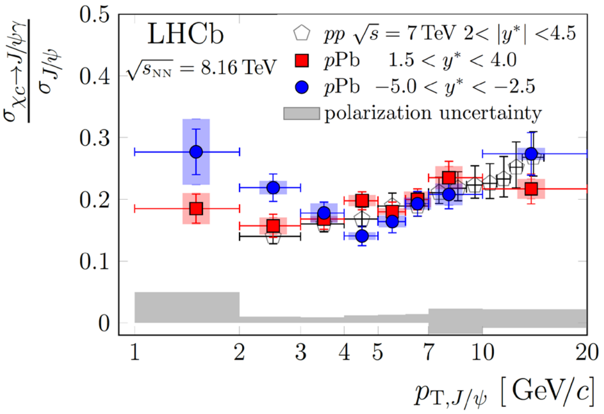

Figure 4. The fraction of J/ψ mesons produced via feeddown from χ_c decays in pp and pPb collisions at forward and backward rapidity [11].

5 Flow in PbPb

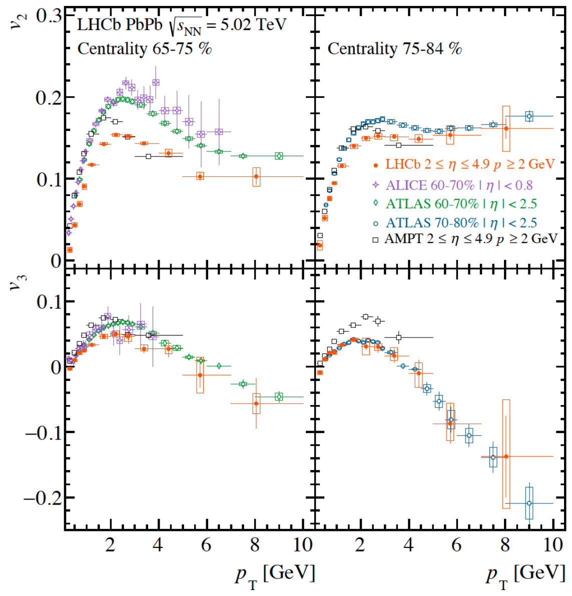

Figure 5. The first flow measurements from LHCb [13]. Charged particle v_2 and v_3 in peripheral PbPb collisions are shown in the top and bottom rows, respectively.

The first ever flow measurements from LHCb are now available in Ref. [13]. Using the two-particle correlation method, the v_2 and v_3 flow coefficients for charged particles are extracted from peripheral PbPb collisions, as shown in Fig. 5. LHCb data cover the rapidity interval $2 < \eta < 4.9$, and show trends similar to midrapidity measurements, although with generally smaller magnitude. The AMPT generator reproduces these trends, but overestimates the magnitude. LHCb data at forward rapidity can be used as new constraints on hydrodynamics models, in this largely unexplored rapidity region.

6 Ultra-peripheral collisions

In addition to measurements of hadronic interactions, LHCb is well suited to measure photon- and pomeron-induced processes that occur in ultra-peripheral collisions (UPCs) of Pb nuclei. Figure 6 shows the ratio of $\psi(2S)/J/\psi$ cross sections measured in PbPb UPC events [14], as compared to a range of model calculations. In this ratio, many of the systematic uncertainties on the data cancel, as do many of the scale uncertainties on the calculations, providing enhanced discriminatory power. The ratio is higher than expected from the STARLIGHT generator, and broadly consistent with pQCD calculations.

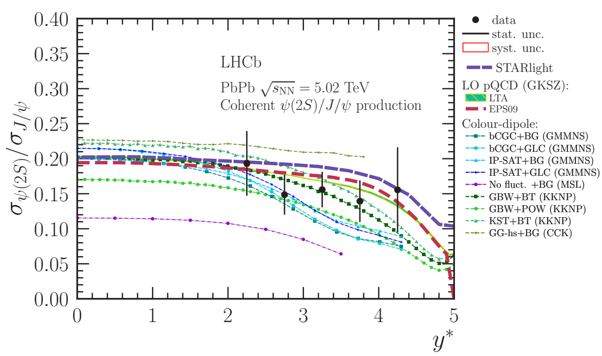

Figure 6. The ratio of $\psi(2S)$ to J/ψ cross sections measured in ultra-peripheral PbPb interactions [14].

7 Outlook

The LHCb collaboration is pursuing a vigorous program of upgrades that will directly enhance the heavy ion physics program. Prior to Run 3, all tracking detectors in LHCb were upgraded with higher granularity, which enables reconstruction of charged tracks in PbPb events with centralities up to 30%. Additionally, LHCb has advanced the state of the art in large scale detector readout by removing all hardware triggers in favor of a full streaming readout system. This allows LHCb to sample the full delivered luminosity of the LHC, including *pp* collisions at ~30 MHz [15].

A new storage cell for gases has been installed in front of the LHCb apparatus [16]. This upgraded fixed-target system, SMOG2, will provide greatly enhanced rates of beam+gas collisions. A key feature this system enables is the ability to simultaneously collect p+gas data and collider *pp* data. Figure 7 shows the invariant mass spectrum of $K^-\pi^+$ and $\mu^+\mu^-$ in the left and right panels, respectively, collected during an 18 minute trial run of pAr collisions with SMOG2. Thousands of D^0 meson candidates and hundreds of J/ψ meson candidates were collected in this short period. When extrapolated to the months and years of running that is currently on the LHC schedule, SMOG2 will permit high-statistics measurements of a large range of heavy quark states in p+gas and ion+gas collisions, accessing a relatively high-x region that is complementary to collider data.

Additional upgrades are being planned for LHC Run 5 and beyond, with the goal to increase LHCb's tracking and PID capability to cover the entire centrality range of PbPb collisions. A detailed program based on precision measurements of b-quarks, higher charmonia and bottomonia, and exotic hadrons in central PbPb collisions is being developed [17]. Additionally, discussions are underway about further upgrading the fixed-target system by including a spin-polarized gas jet. This would bring spin physics to the LHC, greatly increasing the physics scope of the LHCb experiment and the LHC complex as a whole [18].

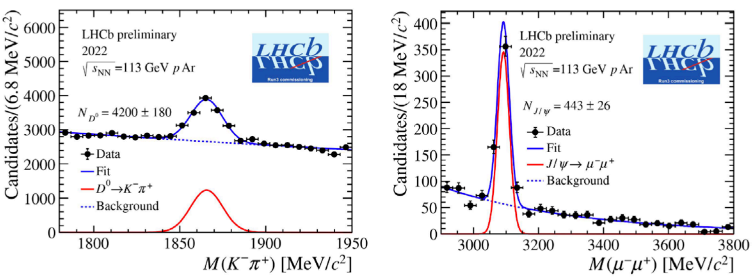

Figure 7. Early performance studies of the SMOG2 fixed-target system. These data were collected in 18 minutes of the LHC proton beam on fixed-target Ar collisions.

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