Shedding light on light-flavour-particle production in small systems at the LHC with ALICE

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Abstract. The measurement of light-flavour-particle production in small collision systems at the LHC has shown features that resemble phenomena seen in heavy-ion collisions. The historical signatures of the quark–gluon plasma (QGP) formation, such as collective flow and the enhanced production of strange hadrons, were also observed in high-multiplicity proton–proton (pp) and proton–lead (p–Pb) collisions. In this article, new results on light-flavour-particle production measured in high-multiplicity triggered events are presented, reaching charged-particle values of semi-peripheral Pb–Pb collisions. In addition, this paper presents the first Run 3 results on the production of π, K, p, and Ω multi-strange baryons in pp collisions at $\sqrt{s}$ = 13.6 TeV and $\sqrt{s}$ = 900 GeV, the highest and the lowest collision energies at the LHC.

1 Introduction

Studies of high-multiplicity proton–proton (pp) and proton–lead (p–Pb) collisions at the LHC have revealed that small collision systems show features traditionally attributed to the creation of a medium in thermal and kinematic equilibrium. Historical signatures of quark–gluon plasma (QGP) formation, such as the increased production of strange hadrons, i.e. strangeness enhancement [1], were also observed in high-multiplicity pp and p–Pb collisions. These observations triggered an extensive discussion on whether there can be a coherent understanding of particle production across different hadronic interaction systems. In this context, the charged-particle multiplicity appears to be a crucial observable, which allows for a direct comparison among small and large systems. The evolution of the ratio of light-flavour-particle yields to pion yield as a function of the charged-multiplicity is found to smoothly connect different collision systems and energies. Particles with a larger strangeness content are observed to be produced more abundantly with increasing multiplicity, saturating for central Pb–Pb collisions [2, 3]. The investigation of light-flavour-particle production at high-multiplicity in pp collisions is a crucial point of the ALICE physics programme, with focus on connecting pp results at charged-particle multiplicity values similar to the ones measured in semi-central nucleus–nucleus collisions. In addition, studying strangeness production at low multiplicity values can provide insights into the understanding of production mechanisms at play further away from the saturation. At the LHC this can be done at low collision energy. In this paper, new results on π, K, and p production measured in high-multiplicity triggered pp events collected in Run 2 are presented. Finally, the first Run 3 results on the production

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of π, K, p, $\Omega^- + \overline{\Omega}^+$ baryons in pp collisions at $\sqrt{s}$ = 13.6 TeV and $\sqrt{s}$ = 900 GeV are presented, the highest and the lowest collision energies reached so far at the LHC.

2 Production of π, K, and p in high-multiplicity pp collisions

During the LHC Run 1 and Run 2, the ALICE detector [4] provided tracking and identification of pions, kaons, and protons using the Inner Tracking System (ITS), the Time Projection Chamber (TPC), and the Time of Flight (TOF). The high-multiplicity (HM) data sample was selected using a dedicated trigger, based on the combined information from the V0 scintillators, covering the pseudorapidity regions $2.8 < \eta < 5.1$ and $-3.7 < \eta < -1.7$, and the ITS detector, located at midrapidity. The V0 detectors were also used to select event classes with different charged-particle multiplicity values. In HM events the charged-particle multiplicity in V0 scintillators is about 5× larger than in minimum-bias events. This trigger selects 0.1% of pp cross-section. The multiplicity dependence of identified kaons and proton yields relative to pions is shown for pp, p–Pb, and Pb–Pb collisions systems in Fig 1. For all particle species, the hadron yields as a function of the charged-particle multiplicity evolves continuously among different collision systems and energies. The new results in high-multiplicity triggered events are displayed in red, extending the pp multiplicity range to the region of semi-peripheral Pb–Pb collisions.

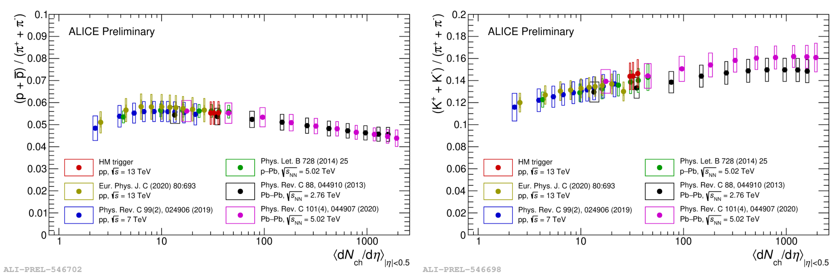

Figure 1. Ratio of p/π (left) and K/π (right) yields as a function of the charged-particle multiplicity for pp, p–Pb, and Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV. The new results on π, K, and p production in high-multiplicity triggered events are displayed in red.

3 First results on light-flavour-particle production with Run 3 data

Since the beginning of the LHC Run 3 data-taking, the upgraded ALICE experiment [5] has collected unprecedentedly large samples of pp collisions from the lowest LHC collision energy of $\sqrt{s}$ = 900 GeV to the highest LHC collision energy of $\sqrt{s}$ = 13.6 TeV, which is also the highest collision energy ever achieved in a laboratory. At the end of Run 3 the experiment is expecting to collect a data sample with an integrated luminosity of ≈ 200 pb^{-1}, corresponding to about 10^{12} inelastic collisions. This sample will be larger by three orders of magnitude with respect to the minimum bias sample collected in Run 2. The analyses presented in this section exploit the data collected by ALICE in 2022. The events are selected with a minimum bias event trigger requiring coincident signals in the FT0A and FT0C detectors to be synchronous with the bunch-crossing time defined by the LHC clock. The FT0 detector [6], one of the additions to the ALICE experiment in Run 3, consists of two arrays of Cherenkov modules placed asymmetrically on the opposite sides of the interaction point and is also used to select event classes with different charged-particle multiplicity values (FT0M multiplicity classes). The final results are reported for the INEL > 0 event class, defined by requiring at least one reconstructed primary charged particle within the pseudorapidity interval $|\eta| < 1$. Figure 2 shows the K/π and p/π p_{T}-dependent yield ratios for pp collisions at $\sqrt{s}$ = 13.6 TeV and $\sqrt{s}$ = 900 GeV. The 900 GeV yields are found to be in agreement with the ALICE results from Run 1 [7], showing a significantly improved statistical uncertainty. In fact, the sample of pp collisions at $\sqrt{s}$ = 900 GeV collected by ALICE in 2022 is larger by two orders of magnitude with respect to the Run 1 sample. The yield ratios obtained in pp collisions at 13.6 TeV are consistent within uncertainties with the results measured at 13 TeV from Run 2 [8]. The wealth of data recorded in Run 3 will also open the possibility to evaluate the source of systematic uncertainties more differentially, improving the overall measurement precision.

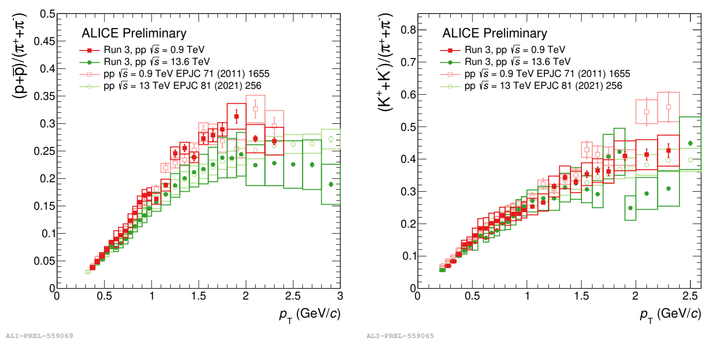

Figure 2. p/π (left) and K/π (right) p_{T}-dependent yield ratios for pp collisions at $\sqrt{s}$ = 13.6 TeV and $\sqrt{s}$ = 900 GeV collected in Run 3, compared to the ALICE results from Run 1 and Run 2. The new results from Run 3 are indicated by full markers, while the Run 1 [7] and Run 2 [8] results are marked with open squares and open circles, respectively.

3.1 Ω baryon production at $\sqrt{s}$ = 13.6 TeV and $\sqrt{s}$ = 900 GeV

The large minimum-bias sample of pp collisions at $\sqrt{s}$ = 13.6 TeV already collected by ALICE in Run 3 during 2022, larger by a factor 40 with respect to the full Run 2 sample, provides the unique opportunity to study the production of Ω baryons with higher statistical precision and unprecedented multiplicity granularity with respect to previous results. Moreover, the increased statistics available for pp collisions at $\sqrt{s}$ = 900 GeV, allows ALICE to extend the study of strange hadron production to the Ω baryons at this collision energy. This measurement reaches the lowest multiplicity region explored at the LHC and complements the results of lighter hadrons obtained in Run 1 at 900 GeV, which included $\mathrm{K^0_S}$, ϕ, Λ, and Ξ hadrons [9]. The ALICE experiment identifies Ω baryons by reconstructing their weak decay daughter tracks in the central pseudorapidity region using the ITS and the TPC detectors. The ratio of the p_{T}-integrated $\Omega^- + \overline{\Omega}^+$ yields to pions is shown in Fig. 3 as a function of the charged-pion multiplicity for different FT0M multiplicity classes at 13.6 TeV and for the inclusive INEL > 0 sample at 900 GeV. For reference, the ALICE results on Ω production in pp collisions at $\sqrt{s}$ = 7 TeV are also shown [2]. The increase of Ω/π ratio with multiplicity is studied with a higher differential precision and is in agreement with the previous ALICE measurements. The ratio measured at 900 GeV follows the same trend with multiplicity observed for higher energies.

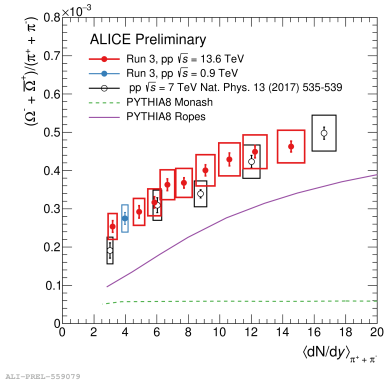

Figure 3. $\Omega^- + \overline{\Omega}^+$ to pion yield ratio as a function of the charged-pion multiplicity for different FT0M multiplicity classes at $\sqrt{s}$ = 13.6 TeV and for the inclusive INEL > 0 sample at $\sqrt{s}$ = 900 GeV.

4 Conclusions

The measurement of light-flavour-particle production in pp collisions at different multiplicity values is crucial to investigate similarities and differences between small and large collision systems. For all light-flavour-particle species, the evolution of the yield ratios to pions with charged-particle production smoothly connects different collision systems and energies. The new results presented by ALICE on π, K, and p production in high-multiplicity triggered events extend this observation to pp multiplicity ranges of semi-peripheral Pb–Pb collisions. Moreover, this article presents the first Run 3 results on the production of π, K, p, and $\Omega^- + \overline{\Omega}^+$ baryons in pp collisions at $\sqrt{s}$ = 13.6 TeV and $\sqrt{s}$ = 900 GeV, the highest and lowest collision energies reached so far at the LHC. The measurement of π, K, and p production in pp collisions at $\sqrt{s}$ = 900 GeV is consistent with the previous results obtained by ALICE in Run 1, showing a significantly improved statistical precision. The Ω/π enhancement with multiplicity in pp collisions at $\sqrt{s}$ = 13.6 TeV is in agreement with Run 1 and Run 2 results, reaching a higher statistical precision and multiplicity granularity. The first measurement of Ω production in pp collisions at $\sqrt{s}$ = 900 GeV complements the results of lighter strange hadrons obtained in Run 1 at the same collision energy, and the Ω/π ratio is found to be consistent with the results obtained at higher energies.

References

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