Soft QCD results at the LHC with ALICE: focus on small collision systems

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1. Introduction

High-energy hadronic collisions are dominated by soft interactions and the description of these processes relies on phenomenological models. Recent measurements at the LHC [1–3] show collective-like effects in pp and p–Pb collisions. However, so far no evidence for jet quenching in small systems [4] has been observed. In popular event generators like PYTHIA8 [5] the observed effects in small systems are only reproduced when novel final-state interactions (color ropes) are introduced. In EPOS-LHC [6], a qualitative description of the effects is done by the inclusion of a core (QGP) contribution in small systems. The soft QCD measurements in small systems provide important constraints to the event generators and provide insights into the recent measurements of collective-like effects. In this contribution, we discuss the recent soft QCD results in small collision systems from ALICE, which include the light-flavor hadron production, underlying event measurements and multi-differential studies using event shape observables.

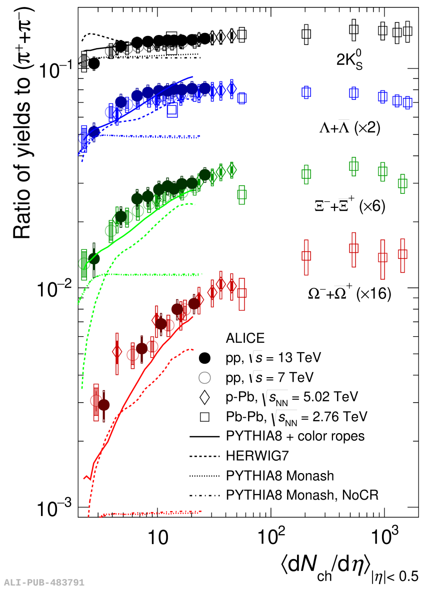

FIG. 1: Ratios of several strange particle to pion yield as a function of charged-particle multiplicity in pp collisions at $\sqrt{s}$ = 7 and 13 TeV, p–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV, and Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV [7].

2. Evolution of hadro-chemistry with multiplicity

Figure 1 shows the smooth evolution of the ratio of strange particle yields to the pion yield as a function of charged-particle multiplicity from pp to Pb–Pb collisions [7]. The strangeness enhancement for Pb–Pb collisions is historically proposed as a signature of QGP and such an enhancement is also seen for high-multiplicity pp and p–Pb collisions. The results suggest that the ratios seem to depend only on the final-state charged-particle multiplicity, irrespective of the collision system and energy. PYTHIA8 with color ropes seems to reproduce the qualitative trend in pp collisions. To explore the strangeness enhancement in pp collisions and to disentangle the initial and final-state effects, a multi-differential approach using two forward detectors of ALICE, i.e., the Zero Degree Calorimeters (ZDC) and V0 [8, 9] has been developed. The part of the energy in the initial stage

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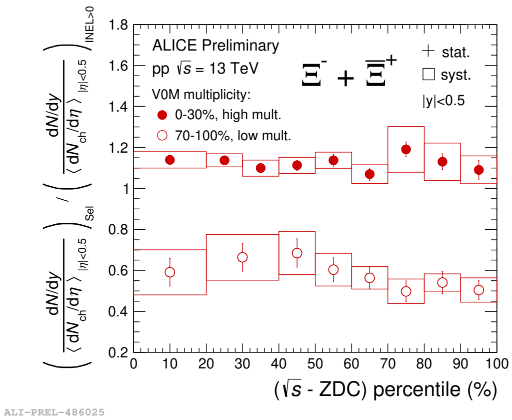

FIG. 2: Self-normalised ratio of the integrated yield of Ξ to charged-particle multiplicity as a function of effective energy for pp collisions at $\sqrt{s}$ = 13 TeV. To obtain the two series of points, the multiplicity estimated through the V0 estimator was fixed to two specific values as indicated in the legend.

available for particle production is related to what we call here the effective energy, $\sqrt{s} - E_{\rm ZDC}$. Fig. 2 shows the self-normalised ratio of the integrated yield of Ξ to charged-particle selected using effective energy event classes, when the multiplicity is fixed in a specific class through the V0 estimator. The self-normalisation is done with respect to the integrated yield of Ξ to the charged-particle multiplicity in INEL>0 events. Here, INEL>0 refers to the events with at least one charged particle in $|\eta| < 1$. As can be seen in Fig. 2, the self-normalised ratio is found to be independent of effective energy classes, suggesting that the effective energy may not play a significant role in strangeness enhancement.

3. Mean transverse momentum and particle ratios

Figure 3 shows the mean transverse momentum ($\langle p_{\rm T} \rangle$) of identified particles as a function of charged-particle multiplicity in pp collisions. An increasing trend is observed for all hadrons, indicating the hardening of the transverse momentum spectra with increasing multiplicity. Also, a mass ordering is observed, where massive particles have a higher mean transverse momentum. Figure 4 shows the $p_{\rm T}$-differential $\Lambda/{\rm K}^0_{\rm s}$ ratio for different multiplicity classes in pp, p–Pb and Pb–Pb collisions. An enhancement of the $\Lambda/{\rm K}^0_{\rm s}$ ratio is seen at intermediate-$p_{\rm T}$ for high multiplicity collisions and it is seen for all collision systems. The enhancement increases with increasing system size. In Pb–Pb collisions such an enhancement is attributed to radial flow and/or coalescence [3].

4. Underlying event measurements

The underlying event (UE) is the collection of particles not originating from the initial hardest scattering or the related fragmentation. Conventionally, UE analyses include the charged-particle density measurement in the toward side (or near side, NS), transverse side (TS), and away side (AS) with respect to the highest transverse momentum ($p_{\rm T}^{\rm leading}$) track (also referred to as leading particle) at the midrapidity ($|\eta|$ <0.8). Toward, away and transverse sides in the azimuthal plane with respect to the leading particle is illustrated in Fig. 5. The charged-particle density as a function of $p_{\rm T}^{\rm leading}$ for the transverse side in p–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV is shown in Fig. 6. A steep rise is seen in the event activity at low-$p_{\rm T}^{\rm leading}$, while for $p_{\rm T}^{\rm leading} > 5$ GeV/c, the charged-particle density is nearly insensitive to any variation in the $p_{\rm T}^{\rm leading}$. A similar behavior is also observed in pp collisions [10]. For what concerns the comparison with models, PYTHIA8 (Angantyr) [11] describes the qualitative trend observed in the data for $p_{\rm T}^{\rm leading} > 5$ GeV/c, while EPOS-LHC predict a behavior different from what observed in data even in the plateau region.

To search for the possible presence of jet-like region modifications in small systems, similarly to what is done in [13] we have calculated ratios of yields $I_{\rm pp,p-Pb,Pb-Pb}$. They have been obtained from the yields of different topological regions, as a function of $\langle N_{\rm ch}^{\rm TS} \rangle$ for different multiplicity classes of pp, p–Pb, and