Strangeness production in p–Pb and Pb–Pb collisions with ALICE at LHC

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Abstract. The main goal of the ALICE experiment is to study the properties of the hot and dense medium created in ultra-relativistic heavy-ion collisions. The measurement of the (multi-)strange particles is an important tool to understand particle production mechanisms and the dynamics of the quark-gluon plasma (QGP). We report on the production of K^0_S, $\Lambda(\overline{\Lambda})$, $\Xi^-(\overline{\Xi}^+)$ and $\Omega^-(\overline{\Omega}^+)$ in proton-lead (p–Pb) collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV and lead-lead (Pb–Pb) collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV measured by ALICE at the LHC. The comparison of the hyperon-to-pion ratios in the two colliding systems may provide insight into strangeness production mechanisms, while the comparison of the nuclear modification factors helps to determine the contribution of initial state effects and the suppression from strange quark energy loss in nuclear matter.

1. Introduction

Strangeness production has been extensively studied in relativistic heavy-ion collisions. Its measurement represents an important tool to investigate the properties of the strongly interacting system created in the collision, as there is no net strangeness content in the initially colliding nuclei. In these proceedings we briefly discuss the technique used to identify K^0_S, $\Lambda(\overline{\Lambda})$, $\Xi^-(\overline{\Xi}^+)$ and $\Omega^-(\overline{\Omega}^+)$ and to measure their transverse momentum ($p_{\rm T}$) spectra. Then we describe the main results about baryon anomaly, strangeness nuclear modification factor and strangeness enhancement.

2. Strange particle identification with the ALICE detector

The ALICE detector was designed to study heavy-ion physics at the LHC. At mid-rapidity, tracking and vertexing are performed using the Inner Tracking System (ITS), consisting of six layers of silicon detectors, and the Time Projection Chamber (TPC). The two innermost layers of the ITS and the V0 detector (scintillation hodoscopes covering the forward pseudo-rapidity region on either side of the interaction point) are used for triggering. The V0 is also used to estimate centrality in Pb-Pb collisions as well as multiplicity in p-Pb collisions. A complete description of the ALICE sub-detectors can be found in [1].

The single-strange (K^0_S and Λ) and multi-strange (Ξ and Ω) particles are reconstructed via their characteristic weak decay topologies into two and three particles, respectively. Tracks reconstructed by the TPC and the ITS are combined to select candidates satisfying a set of geometrical criteria. In addition, particle identification is performed by a selection on the

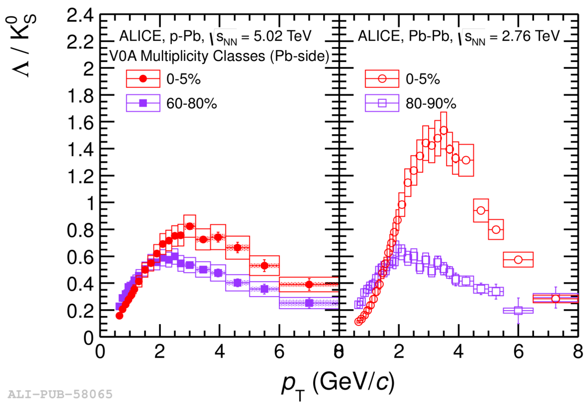

Figure 1. $(\Lambda+\overline{\Lambda})/K^0_S$ as a function of p_T in the highest and a low-multiplicity class in p–Pb (left) and Pb–Pb (right) collisions. Open boxes are total systematic uncertainties and shaded boxes represent the uncorrelated-over-multiplicity component.

specific energy loss in the TPC for the daughter tracks. Particle yields as a function of p_T are determined, in various multiplicity/centrality intervals, using an invariant mass analysis. Acceptance and efficiency corrections are calculated using Monte Carlo simulations. For more details, we refer to [2, 3, 4].

3. Results

Transverse momentum spectra for K^0_S, $\Lambda(\overline{\Lambda})$, $\Xi^-(\overline{\Xi}^+)$ and $\Omega^-(\overline{\Omega}^+)$ have been published in [6, 2] for Pb–Pb collisions and in [3, 4] for p–Pb collisions. In both systems the hardening of the spectral shape from low- to high-multiplicity collisions has been observed. Moreover, in the context of Blast Wave model, it has been shown that spectra for K^0_S and Λ are well predicted using parameters from a simultaneous fit to $\pi^{\pm}$, $K^{\pm}$ and p spectra in high multiplicity Pb–Pb and p–Pb collisions. This is also true for Ξ and Ω in p–Pb collisions, while in Pb–Pb collisions they cannot be described in a common freeze-out scenario, as they would require a lower mean transverse flow velocity and a higher kinetic freezeout temperature to be described properly [5].

The p_T-differential $(\Lambda+\overline{\Lambda})/K^0_S$ ratio is shown in Fig. 1 in the highest and a low-multiplicity class for p–Pb and Pb–Pb collisions. The presence of a peak in the 2 - 4 GeV/c p_T region and the multiplicity dependence of its characteristics are qualitatively similar in the two collision systems. In Pb–Pb collisions this phenomenon has been interpreted as a redistribution of baryons and mesons in momentum, when centrality increases, as consequence of the increased radial flow [6]. The flattening of the $(\overline{p}+p)/\phi$ ratio as a function of p_T in 0-10% central Pb–Pb collisions is further evidence supporting an hydrodynamical evolution of the system since due to the similar masses the boost from radial flow is almost the same. This data can also be described by parton recombination models [7].

The nuclear modification factor is defined as the ratio of the p_T spectra in Pb–Pb (R_{AA}) or p–Pb (R_{pPb}) and in pp collisions scaled by the number of nucleon-nucleon collisions. It has been shown that the strong suppression of hadron production at high p_T observed at the LHC in Pb–Pb collisions is not due to an initial-state effect but may be due to jet quenching in hot QCD matter [8]. In Fig. 2 the R_{AA} as a function of p_T for multi-strange baryons in central (0-10%) collisions is shown and compared with those for lighter hadrons (π, K and p). R_{AA} for Ξ is similar to the one for p, especially at high p_T ($>$ 6 GeV/c), while π and K at low p_T ($<$ 3 GeV/c) follow a clearly different trend, which can be interpreted as a consequence of having different masses in a radial flow scenario. R_{AA} for Ω is above unity, which might be the result of the larger strangeness enhancement compared to Ξ [2]. In the right canvas of the same figure, the R_{pPb} as a function of p_T in minimum-bias p–Pb collisions is shown for the same particles. In this case, there is no suppression for π, K and p at high p_T ($>$ 6 GeV/c), as verified for unidentified particles [8]. In the so-called Cronin region ($2 < p_T < 6$ GeV/c) an increase of

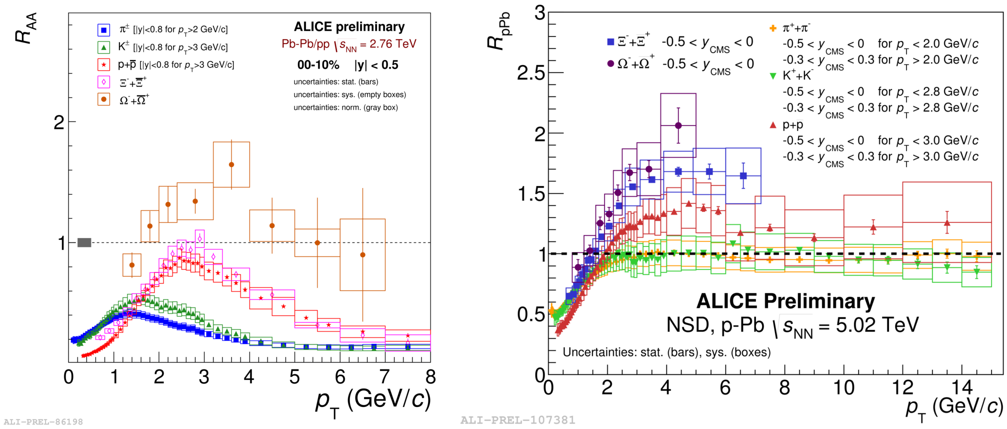

Figure 2. R_{pPb} in p–Pb collisions (left) and R_{AA} in 0-10% most central Pb–Pb collisions (right) as a function of p_{T} for π, K, p, Ξ and Ω particles. Open boxes are total systematic uncertainties.

the R_{pPb} with the mass of the particles is visible.

The strangeness enhancement is known as one of the proposed signatures for the QGP formation in relativistic heavy-ion collisions. Rafelski and Müller's expectation, first proposed in 1982 [9], is that QGP formation should lead to a higher abundance of strangeness per participating nucleon than in pp interactions. This phenomenon has been actually observed at SPS [10], RHIC [11] and the LHC [2], and has been found to increase with centrality and with the strangeness content of the particle, and decrease as the centre-of-mass energy increases. Statistical hadronization models (SHM) based on a grand-canonical approach have been demonstrated to be able to predict particle yield ratios in heavy-ion collisions over a large energy scale [12]. In this description, the energy dependence of strangeness enhancement has been understood as the consequence of a suppression of strangeness production due to the reduced phase-space volume in reference pp collisions (canonical suppression) [13]. At SPS and RHIC the strangeness enhancement has been studied looking at the ratio between the yield in nucleus–nucleus collisions and those in pp interactions at the same energy normalized to the mean number of participants ($\langle N_{part}\rangle$). It has been shown that this is not the ideal way to isolate the enhancement component due to strangeness content, since the production rates of charged particles do not scale linearly with N_{part} [14]. A better observable is the ratio to pion yields, shown in Fig. 3 for Λ, Ξ and Ω as a function of $\langle dN_{ch}/\mathrm{d}\eta\rangle_{|\eta|<0.5}$ for Pb–Pb, p–Pb and pp collisions. In the case of multi-strange baryons, the ratio is shown to increase by up to a factor of about 2-3 going from pp collisions to Pb–Pb collisions and is more pronounced for the Ω; for the Λ a possible increase is not significant within the systematic uncertainty. It is shown that the predictions from statistical hadronization models using a chemical freezeout temperature of 156 MeV [15, 16] are comparable with the ratios measured in the most central Pb–Pb collisions for all the three particles. Looking at the p-Pb data, an increase of the (multi-)strange baryon-to-meson ratios with multiplicity is observed. The increase is seen to be more pronounced for particles with a larger strangeness quantum number. In particular $2\Lambda/(\pi^-+\pi^+)$ and $(\Xi^-+\overline{\Xi}^+)/(\pi^-+\pi^+)$ ratios slightly exceed the saturation limit observed for Pb–Pb, while the $(\Omega^-+\overline{\Omega}^+)/(\pi^-+\pi^+)$ ratio is not higher than the one observed in peripheral Pb–Pb. Comparison of hyperon-to-pion ratios as a function of pion multiplicity to the trends observed in statistical hadronisation models, where the local conservation of the strangeness is required (as in a canonical ensemble), indicates that the behaviour is qualitatively consistent with the lifting of canonical suppression with increasing multiplicity [4].

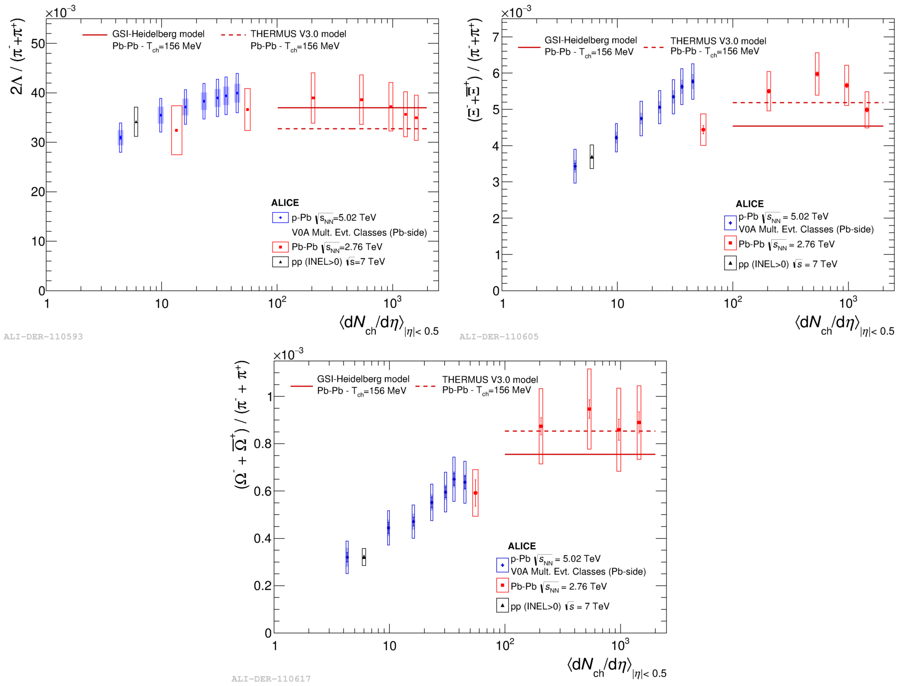

Figure 3. $2\Lambda/(\pi^-{+}\pi^+)$, $(\Xi^-{+}\overline{\Xi}^+)/(\pi^-{+}\pi^+)$ and $(\Omega^-{+}\overline{\Omega}^+)/(\pi^-{+}\pi^+)$ ratios as a function of $\langle dN_{ch}/\mathrm{d}\eta\rangle_{|\eta|<0.5}$ for p–Pb (filled blue cross) and Pb–Pb (filled red square) collisions. Open boxes are total systematic uncertainties and shaded boxes show the uncorrelated-over-multiplicity component. Lines represent predictions from SHMs [15] (continuous) and [16] (dashed).

4. Conclusions

The production of (multi-)strange particles was measured in Pb–Pb and p–Pb collisions with the ALICE detector. The multiplicity dependence of the $(\Lambda{+}\overline{\Lambda})/\mathrm{K}^0_S$ ratio and the hardening of the spectra with increasing multiplicity point to similar collective behaviour. As observed for unidentified particles, R_{AA} for Ξ is clearly suppressed at high p_{T}, while R_{pPb} does not show any suppression. The fact that relative strangeness production in p–Pb not only increases with multiplicity but also bridges pp and Pb–Pb collision values is an important recent observation.

References

[1] Aamodt K *et al.* (ALICE Collaboration) 2008 *JINST* **3** S08002
[2] Abelev B *et al.* (ALICE Collaboration) 2014 *Phys. Lett. B* **728** 216-227
[3] Abelev B *et al.* (ALICE Collaboration) 2014 *Phys. Lett.* B **728** 25-38
[4] Adam J *et al.* (ALICE Collaboration) 2016 *Phys. Lett.* B **758** 389-401
[5] Melo I, Tomasik B 2015 *nucl-th*/1509.05383
[6] Abelev B *et al.* (ALICE Collaboration) 2013 *Phys. Rev. Lett.* **111** 222301
[7] Abelev B *et al.* (ALICE Collaboration) 2015 *Phys. Rev.* C **91** 024609
[8] Abelev B *et al.* (ALICE Collaboration) 2013 *Phys. Rev. Lett.* **110** 082302
[9] Rafelski J and Müller B 1982 *Phys. Rev. Lett.* **48** 1066
[10] Antinori F *et al.* (NA57 Collaboration) 2006 *J. Phys.* G **32** 427-441
[11] Abelev B *et al.* (STAR Collaboration) 2008 *Phys. Rev.* C **77** 044908
[12] Stachel J, Andronic A, Braun-Munzinger P and Redlich K 2014 *J. Phys. Conf. Ser.* **509** 012019
[13] Hamieh S, Redlich K and Tounsi A 2000 *Phys. Lett.* B **486** 61-66
[14] Aamodt K *et al.* (ALICE Collaboration) 2011 *Phys. Rev. Lett.* **106** 032301
[15] Andronic A, Braun-Munzinger P and Stachel J 2009 *Phys. Lett.* B **673** 142-145
[16] Cleymans J, Kraus I, Oeschler H, Redlich K and Wheaton S 2006 *Phys. Rev.* C **74** 034903