# Strangeness Production at LHC energies as measured with ALICE

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**Abstract.** The main objective of the ALICE experiment is to study the properties and the evolution of the high-energy density system created in relativistic heavy-ion collisions at the LHC. For that purpose, ALICE has unique particle identification capabilities that enable the detection of weakly-decaying particles in the high-multiplicity environment created in lead-lead (Pb-Pb) collisions.

In this work, we discuss the systematic measurements of strange and multi-strange hadrons performed by ALICE for proton-proton (pp), proton-lead (p-Pb) and Pb-Pb collisions. Production rates measured for p-Pb and Pb-Pb are compared to predictions from statistical hadronization models and to measurements performed in pp collisions. These data are also used for a brief discussion on strangeness enhancement.

## 1. Introduction

The study of strange and multi-strange particle production is an important tool not only for the understanding of particle production mechanisms in proton-proton collisions but also for investigating the dynamics of the quark-gluon plasma (QGP) phase of nuclear collisions. The measurement of strangeness production rates relates to many signatures of this phase, such as strangeness enhancement and the thermalization of particle production rates. In these proceedings, we will briefly discuss the measurement techniques utilized to obtain the spectra of the weakly-decaying strange particles, $K_S^0$, $\Lambda$, $\bar{\Lambda}$, $\Xi^-$, $\bar{\Xi}^+$, $\Omega^-$ and $\bar{\Omega}^+$ throughout a variety of colliding systems, including pp, p-Pb and Pb-Pb. We will then discuss the implications of these measurements for the QGP properties.

## 2. Strange and multi-strange particle analysis

The strange and multi-strange hadrons $K_S^0$, $\Lambda$, $\bar{\Lambda}$, $\Xi^-$, $\bar{\Xi}^+$, $\Omega^-$ and $\bar{\Omega}^+$ are reconstructed via their characteristic weak decay topologies. In this process, tracks measured by the ALICE Time Projection Chamber (TPC) and the silicon Inner Tracking System (ITS) [1] are combined into candidates if they satisfy a set of quality and geometrical criteria (see [2, 3] for details). Particle identification based on the energy loss while traversing the TPC gas is also utilized to select particles of the expected decay daughter species in each case. Signal extraction is then performed in invariant mass space to isolate the desired particle yields, and efficiency corrections are calculated by making use of Monte Carlo simulations with full propagation of particles through the ALICE geometry with GEANT3 [4, 5].

The full analysis details as well as the resulting corrected transverse momentum spectra for weakly-decaying strange and multi-strange hadrons have been reported elsewhere [2, 3]. This discussion will focus on a few specific aspects related to the study of the QGP.

## 3. Strangeness and thermal models

It has been suggested that hadrons are produced in approximate chemical and thermal equilibrium in high-energy interactions. In nucleus-nucleus collisions, a grand-canonical statistical model is usually employed to describe the observed yields of each species. The successful description of strangeness production rates may require the addition of an empirical undersaturation factor $\gamma_s$, but recent studies have demonstrated that this factor is unnecessary (i.e. $\gamma_s \to 1$) at LHC energies [6]. The $K_S^0$ yields measured in central Pb-Pb collisions are consistent with thermally equilibrated particle production rates, as can be seen in Fig. 1, while the strange and multi-strange baryons are slightly underpredicted by no more than $2\sigma$ by the models [7, 8, 9]. It has been suggested, based on lattice and Hadron Resonance Gas (HRG) calculations, that the transition temperature may exhibit flavour hierarchy which would explain these deviations from thermal expectations [10]. Testing for such a scenario is in principle possible using a net strangeness measurement; however, there exist a number of difficulties in theory, such as limitations in the HRG models, as well as from experiment, such as detector acceptance limitations.
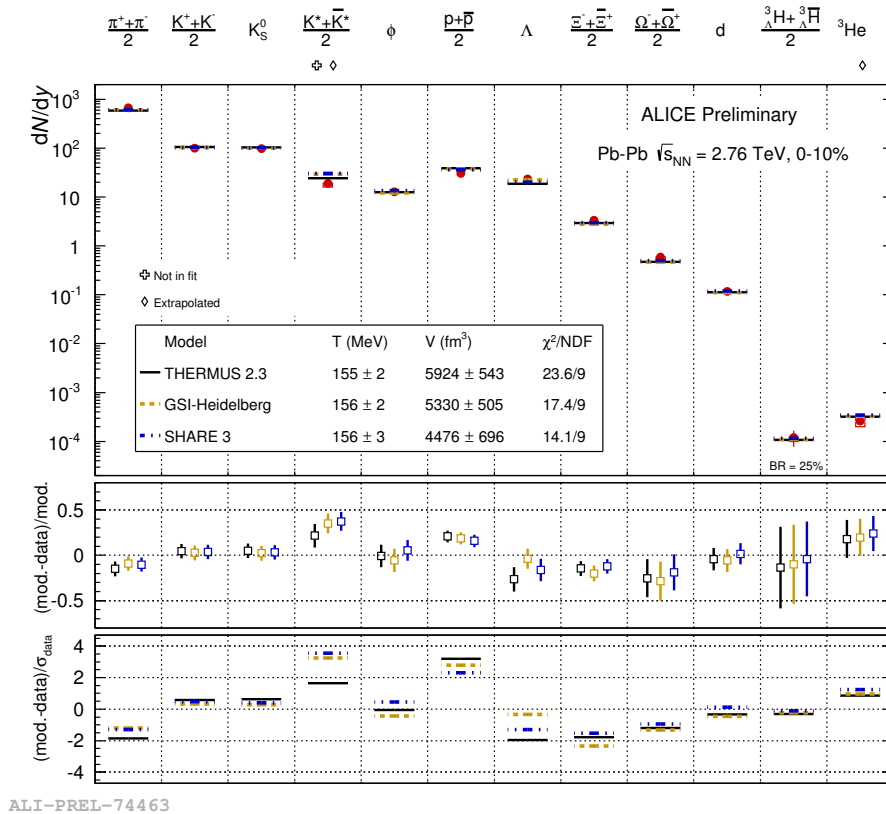


**Figure 1.** Grand canonical thermal fit to ALICE central Pb-Pb (0-10%) particle production rates using the GSI-Heidelberg model [6], THERMUS 2.3 [8], and the SHARE 3 model [9].

## 4. Strangeness enhancement

One of the proposed signatures of a deconfined partonic phase in the system evolution is an enhancement of strange quark production rates in a nuclear collision with respect to a hadron gas scenario [11]. Such an increase in strangeness production has been observed by STAR in gold-gold (Au-Au) [12] and also more recently by ALICE in Pb-Pb collisions. The strangeness enhancement factor is usually quantified by comparing the production rates of strange hadrons per participant nucleon as observed in nuclear collisions to the production rates per participant nucleon observed in pp at the same energies. These ratios are shown for $\Xi$ and $\Omega$ in Fig. 2, where one observes an enhancement of strangeness production by up to a factor of approximately 3 for $\Xi^-$ and 6 for $\Omega^- + \bar{\Omega}^+$. These factors are smaller than what was observed at lower energies, which is mostly attributed to the decrease of canonical suppression in the pp reference and the ensuing rise of $\Xi$ and $\Omega$ production in this more elementary system.
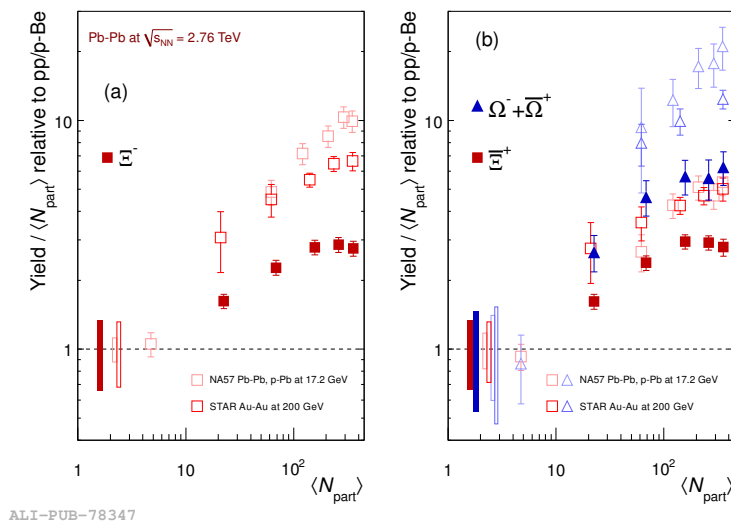


**Figure 2.** $\Xi$ and $\Omega$ production rates per participant nucleon in nuclear collisions relative to the observed value in pp collisions. Left panel: enhancement factors for $\Xi^-$. Right panel: enhancement factors for $\bar{\Xi}^+$ and $\Omega^- + \bar{\Omega}^+$. In both panels, the enhancement factors are compared to values from nuclear collisions from NA57 [13, 14] and STAR [12]. Figure from [3].

However, recent measurements have shown that the number of participant nucleons, $N_{part}$, may not be an appropriate scaling variable to isolate the enhancement component that is due to strangeness content, since the production rates of charged particles do not scale linearly with $N_{part}$ [15]. In order to factor out the overall increase of particle production and isolate the strangeness-related increase, one can compute the ratio of $(\Xi^- + \bar{\Xi}^+)$ and $(\Omega^- + \bar{\Omega}^+)$ production rates to $(\pi^- + \pi^+)$ yields. This has been done as a function of $dN_{ch}/d\eta$ not only for Pb-Pb but also for p-Pb collisions in ALICE, as shown in Fig. 3 and Fig. 4 for $\Xi$ and $\Omega$, respectively. The multi-strange baryon production relative to pions is shown to increase by up to a factor of about 2-3 going from pp collisions to Pb-Pb collisions, and seems to reach saturation for central Pb-Pb collisions. These saturation values compare favourably to predictions from statistical hadronization models using a chemical freezeout temperature of approximately 155 MeV [6, 8]. In this context, the p-Pb data show a monotonically increasing multi-strange particle production with respect to pions, with $\Xi/\pi$ ratios that slightly exceed the saturation limit observed for Pb-Pb, while the $\Omega/\pi$ ratio is not higher than the one observed in peripheral Pb-Pb. This indicates that any thermal description of observed multi-strange yields will thus be worse in p-Pb than in Pb-Pb.
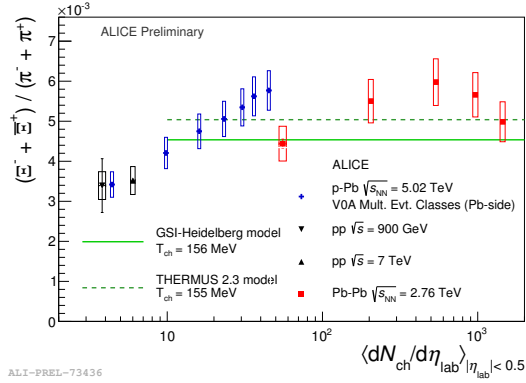
**Figure 3.** $(\Xi^- + \bar{X}i^+)/(\pi^- + \pi^+)$ ratio as a function of multiplicity for pp, p-Pb and Pb-Pb collisions shown together with predictions from statistical hadronization models.
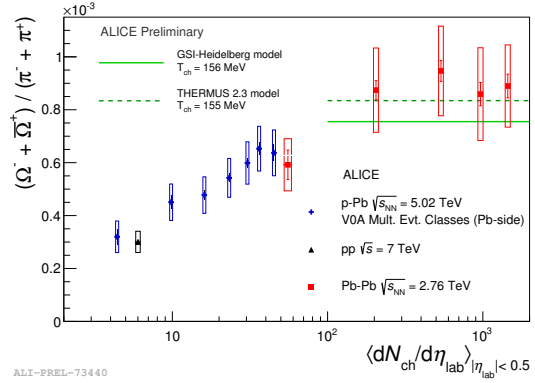
**Figure 4.** $(\Omega^- + O\bar{m}ega^+)/(\pi^- + \pi^+)$ ratio as a function of multiplicity for pp, p-Pb and Pb-Pb collisions shown together with predictions from statistical hadronization models.

## 5. Conclusions

ALICE has performed a comprehensive set of strange hadron measurements in which several quantities relevant to the onset of deconfinement, such as strangeness enhancement and statistical hadronization, have been studied in Pb-Pb. These measurements were also performed systematically in p-Pb collisions as a function of charged-particle multiplicity. Many qualitative observations traditionally related to the presence of a QGP phase, such as the monotonic increase of relative multi-strange baryon production according to multiplicity, have also been made in these smaller systems. These measurements represent an important milestone in advancing the understanding of hadrochemistry and nuclear collisions in general, and are expected to be further complemented by higher energy measurements starting in 2015 as well as by similar studies in pp collisions as a function of multiplicity.

## 6. Acknowledgements

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