GLOBAL PROPERTIES OF STRANGE PARTICLE PRODUCTION IN *pp* AND Pb–Pb COLLISIONS WITH THE ALICE DETECTOR*

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The production of strange and identified hadrons was measured by the ALICE experiment in the new regime of LHC energies. ALICE's unique particle identification capabilities are based on energy loss, Time of Flight, and decay topology. Thus transverse momentum spectra of pions, kaons, protons, Λs, Ξs, and Ωs were measured in *pp* collisions at $\sqrt{s} = 900$ GeV and $\sqrt{s} = 7$ TeV, as well as in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. This allows the precise determination of integrated yields and mean transverse momenta. The results are discussed with respect to their dependence on $\sqrt{s}$ and to expectations from thermal models.

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1. Introduction

The measurement of bulk particle production is a crucial ingredient for the understanding of heavy-ion collisions. Most of the hadrons produced in a heavy-ion collision consist of a combination of u, d, and s valence quarks. The observed yields can be correctly described within hadro-chemical equilibrium models over a wide range of beam energies and collision systems [1,2]. Temperature T and baryo-chemical potential μ_B at chemical freeze-out have been extracted using thermal fits. This allows to further study the phase diagram of strongly interacting matter. The thermal concept has been extended to *pp* collisions using additional degrees of freedom [3,4]. The precise

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measurement of the production yields of the most abundant strange particles is therefore required. The relevant particles in this context are pions, kaons, protons, Λs, Ξs, and Ωs. The measurement of the complete collection of particles is of importance not only for a consistent interpretation in a thermal model, but also because weak decays of strange particles feed into the states with lower mass, *i.e.*

$$\begin{aligned} \Lambda &\longrightarrow p\pi\,(63.9\%)\,, \\ \Xi &\longrightarrow \Lambda\pi\,(99.87\%)\,, \\ \Omega &\longrightarrow \Lambda K\ (67.8\%)\,. \end{aligned}$$

In order to allow for a consistent comparison to particle production models, the ALICE experiment defines primary particles as particles produced in the collision including products of strong and electromagnetic decays, but excluding feed-down from weak decays of strange particles.

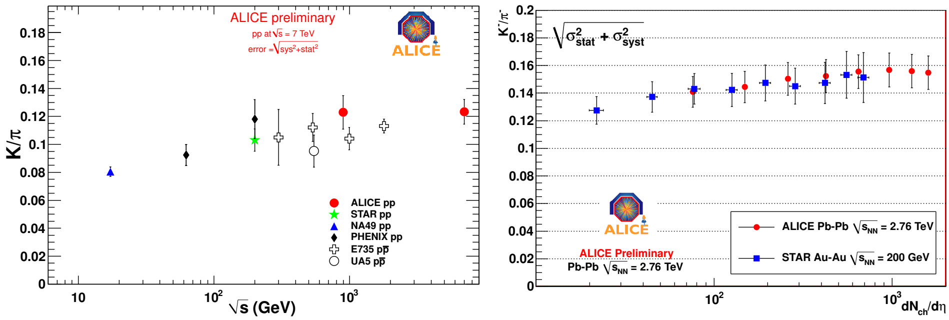
2. Measurement techniques

Charged pions, kaons, and protons are directly identified based on their specific energy loss in the Inner Tracking System (ITS) and the Time Projection Chamber (TPC) as well as Time-of-Flight measurements in the TOF detector [7, 8]. The decays of K^0_{S}, Λs, Ξs, and Ωs are reconstructed as secondary vertices [9, 10]. The particle identification capabilities of the ALICE experiment and the relevant detectors are described in detail in [11]. Using the tracking detectors ITS and TPC, the transverse momentum p_{T} and the topology of the particles are measured in a magnetic field of 0.5 T. In the case of reconstructed decays, the momentum of the mother particle is calculated from the daughter tracks. In order to account for the full tracking acceptance of ALICE being $|\eta| < 0.8$, the particle yields are measured within $|y| < 0.5$ for identified hadrons.

3. Dependence on $\sqrt{s}$ and collision system

With the comprehensive ALICE data in *pp* and Pb–Pb collisions [5, 6, 8, 9, 10, 12], the production of strange particles can be interpreted over a broad range of energies.

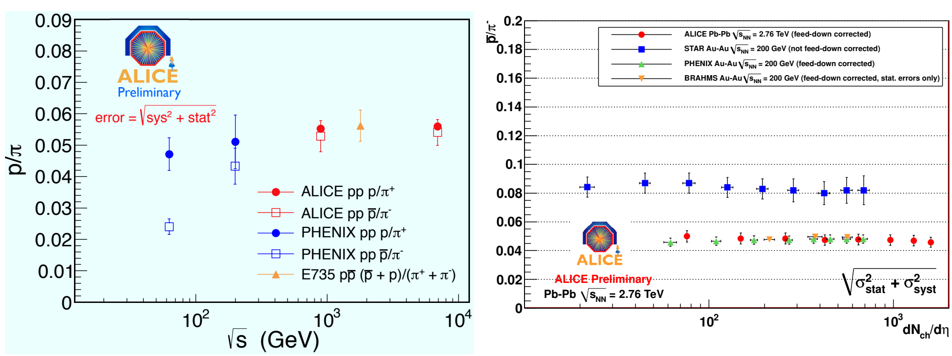
The production of kaons normalized to the number of pions shows only a weak increase from SPS to LHC energies in *pp* collisions (see Fig. 1 (a)). Future measurements at the top LHC energy of 14 TeV will show whether similar values of this ratio as in Pb–Pb collisions can be reached also in elementary reactions. Similar to RHIC energies, the kaon production increases with centrality in Pb–Pb collisions from approximately 0.125 in peripheral to 0.16 in central collisions. Please note the agreement between peripheral Pb–Pb collisions and the measurement in *pp* reactions.



(a) (b)

Fig. 1. Production yields of kaons as a function of $\sqrt{s}$ in *pp* collisions and as a function of centrality in Pb–Pb collisions (right) compared with data from other experiments.

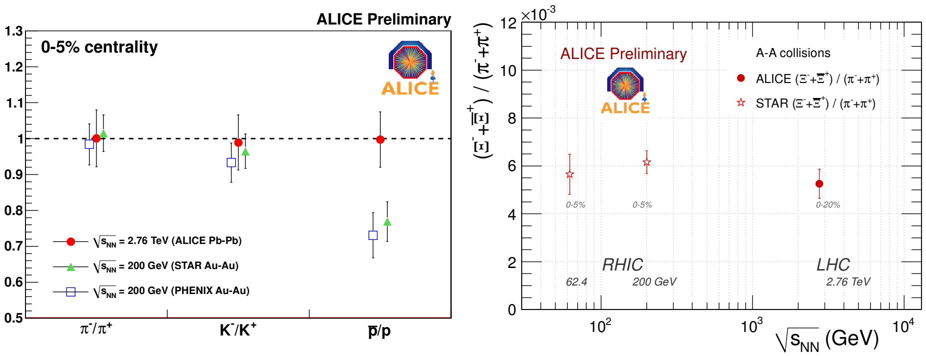
In *pp* collisions, the proton yield relative to the pion yield remains basically constant from RHIC to LHC energies whereas the anti-proton yield shows a slight increase until it reaches the same value as the proton yield in the LHC energy regime (see Fig. 2 (a)). In contrast to strange particles, the p/π-ratio shows no dependence on centrality in Pb–Pb collisions (see Fig. 2 (b)). The comparison with lower energy data is not unambiguous since feed-down corrections are implemented differently in the experiments.



(a) (b)

Fig. 2. Production yields of protons as a function of $\sqrt{s}$ in *pp* collisions as a function of $\sqrt{s}$ (left) and as a function of centrality in Pb–Pb collisions (right).

Also the yields of the multi-strange particles Ξ and Ω in Pb–Pb collisions do not change from RHIC to LHC energies if they are normalized to pions as shown in Fig. 3. An interesting feature of strange particle production is the enhanced production in Pb–Pb relative to *pp* collisions. While the double ratio of p/π in *pp* to Pb–Pb collisions is close to unity, the K/π, Ξ/π, and Ω/π ratios show a significant increase proportional to the strangeness content. A comparison with similar variables at RHIC and SPS energies shows that this effect is decreasing with increasing $\sqrt{s_{NN}}$.



(a) (b)

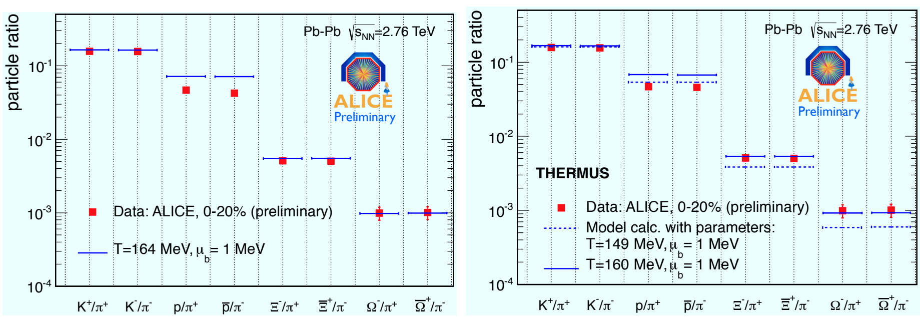
Fig. 3. Particle to anti-particle ratios at RHIC and LHC energies (left). Ξ/π-ratio as a function of $\sqrt{s_{NN}}$ in Pb–Pb collisions (right).

In contrast to RHIC energies, at the LHC energy regime the particle to anti-particle ratios are consistent with unity within the uncertainties of the measurement (see Fig. 3 (a)). The same observation holds true for *pp* collisions. In a thermal view, this implies a missing constraint on the baryo-chemical potential μ_B which is consistent with zero within the systematic uncertainties of the measurement.

4. Comparison with thermal model expectations

Hadro-chemical equilibrium models apply the concepts of relativistic quantum thermodynamics to high energy heavy-ion or elementary collisions. Particle ratios are calculated with only two parameters, the temperature T and baryo-chemical potential μ_B. These parameters are usually determined with a fit to experimental data. Predictions for LHC data were made based on parameterizations [13, 3]. Figure 4 shows a comparison of the ALICE data in Pb–Pb collisions to the model described in [13] for a temperature of $T = 164$ MeV and a baryo-chemical potential of $\mu_B = 1$ MeV. A perfect agreement between data and model within the systematics uncertainties in the measurement is observed for all particles containing at least one strange valence quark, *i.e.* K, Ξ, and Ω. These values for (T, μ_B) were also predicted from extrapolations from RHIC data. The only tensions between model and data beyond the systematics of the measurement are found in the preliminary proton yields being approximately 30–40% below the expected value.

These observations are to a large extent independent of the detailed implementation of thermal models. Figure 4 shows a fit with the THERMUS software [14] to the ALICE data where similar trends are observed. Since the baryo-chemical potential is constrained to very small values in the LHC energy regime, a difference in the observed yields can only be compensated by a change in temperature. This would require temperatures of the order of $T \approx 149\,\mathrm{MeV}$. In this case, the production yields of Ξ and Ω cannot be described anymore (see Fig. 4).



(a) (b)

Fig. 4. ALICE Pb–Pb data and a calculation based on the model from [13] (left) and the THERMUS code (right).

From the experimental point of view, further investigations on the applied feed-down corrections — which are substantially larger for protons than for kaons and pions — will help to clarify the discrepancy. The thermal model calculations will also be more conclusive once more measured particle yields become available, in particular the measurement of Λs and deuterons in Pb–Pb collisions.

It must also be noted, that similar features can also be observed when interpreting the particle production in *pp* collisions at the LHC energy regime within a thermal model [15]. In this case, the strangeness correlation radius R_C can serve as an additional degree of freedom describing the chemical equilibration of strangeness production in sub-volumes of the fireball. However, a variation of R_C only influences the strange particle yields and not the p/π-ratio. Despite the absolute value of the p/π-ratio being difficult to describe within a thermal model, the information of the double ratios still remains valid and interesting information can be deduced in the near future with more particle ratios available. In that sense, the p/π-ratio being the same in both collision systems is consistent with model expectations [16].

5. Conclusion and outlook

With its excellent particle identification and tracking capabilities, the ALICE experiment has provided an almost complete set of the measurement of strange particle production already one year after the start of Pb–Pb data taking. All yields of particles containing at least one strange valence quark show agreement with predictions from thermal model calculations. The observed deviations in the case of protons will require further efforts on the experimental side (with a particular focus on feed-down corrections) as well as on the theoretical side.

In the future, more sophisticated measurements of identified hadron production will be pursued. One of the possibilities is to address the chemical composition of high-multiplicity events in *pp* collisions. The available statistics within the ALICE Collaboration is already now sufficient to reach similar multiplicities as in Cu–Cu collisions at RHIC. Another interesting observable for future analyses is given by the measurement of the particle composition inside jets which will have to make extensive use of the particle identification via the relativistic rise of the dE/dx in the TPC.

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