# Strangeness production in the NA61/SHINE experiment at the CERN SPS energy range

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**Abstract.** NA61/SHINE is a multi-purpose fixed-target experiment located at the H2 beamline of the CERN North Area. One of the main goals of the experiment is to study the phase transition and search for the critical point of the strongly interacting matter. Strangeness production is a long-known valuable probe for understanding particle production in high-energy physics due to the absence of strange valence quarks in the initial collision state.

This talk will present the results of strangeness production in p+p, Be+Be, and Ar+Sc collisions in the SPS energy range ( $\sqrt{s_{NN}} = 5.1 - 17.3 \text{ GeV}$ ) measured by NA61/SHINE. The talk will emphasise the importance of the results for discussion of the onset of deconfinement and onset of fireball. The obtained results will be compared to available world data and selected theoretical models.

# 1 Introduction

NA61/SHINE is a fixed-target experiment, which is located at the H2 beamline of the CERN North Area and takes its beams from the CERN SPS [1]. The NA61/SHINE detector layout is presented in Figure 1.



Figure 1. Schematic view of the NA61/SHINE detector system.

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It is a large acceptance hadron spectrometer equipped with a set of Time Projection Chambers and Time-of-Flight detectors, which allows for charged particle momentum measurements and identification. The high-resolution forward calorimeter, the Projectile Spectator Detector (PSD), measures the energy of spectators, which is related to the centrality of the collision. Thanks to modular construction, PSD modules can be used to optimize centrality selection for different energies and systems.

One of the main scientific goals of the experiment is to study the phase transition and search for the critical point of the strongly interacting matter. In order to study the phase diagram of the strongly interacting matter, the NA61/SHINE experiment performed the two-dimensional scan in collision energy and system size.

#### 2 Results on strangeness production

Strangeness production is a long-known valuable probe for understanding particle production in high-energy physics due to the absence of strange valence quarks in the initial collision state [2].

When compiling the results for different system sizes and collision energies, intriguing results ought to be seen. Figure 2 presents the energy dependence of the inverse slope parameter T of transverse mass  $m_T$  spectra of charged kaons. A plateau structure is clearly visible and was first observed in heavy-ion collisions [3]. It was interpreted by the Statistical Model of Early Stage [4] as a result of the coexistence of two phases of strongly interacting matter: hadron gas and quark-gluon plasma. The results for different system sizes – from the lightest proton-proton to the heaviest Pb+Pb – show qualitatively similar behaviour for the inverse slope parameter, though the magnitude of T naturally increases with the system size.



**Figure 2.** Inverse slope parameter T of  $K^+$  (*left*) and  $K^-$  (*right*)  $m_T$  spectra as a function of collision energy for p+p, Be+Be, Ar+Sc and Pb+Pb/Au+Au collisions.

Figure 3 shows the multiplicity ratio of positively charged kaons and pions at mid-rapidity and in  $4\pi$  acceptance. A rapid increase and following plateau were observed for large systems [5] and interpreted as a sign of the occurring phase transition. While the results from small systems, such as p + p and Be+Be, indicate no such structure, the results from the intermediate system, Ar+Sc, are quite surprising as quantitatively, they lay a lot closer to heavier systems, nevertheless, without an indication of the maximum.



**Figure 3.**  $\langle K^+ \rangle / \langle \pi^+ \rangle$  ratio in full  $4\pi$  phase space (*left*) and  $\langle K^+ \rangle / \langle \pi^+ \rangle$  ratio at mid-rapidity (*right*) as a function of collision energy for p+p, Be+Be, Ar+Sc and Pb+Pb/Au+Au collisions.

The first two panels of Fig. 4 present the system size dependence of  $\langle K^+ \rangle / \langle \pi^+ \rangle$  ratio at mid-rapidity, and the last panel shows the system size dependence of the inverse slope parameter *T* of positively charged kaons. Data points are obtained by NA61/SHINE for *p* + *p* [6], Be+Be [7] and Ar+Sc (preliminary results), and by NA49 for Pb+Pb [5] at 150A GeV/*c* beam momentum. An increase in both observables is visible when going from small systems to intermediate and large, which can be interpreted as a signature of the beginning of the formation of large clusters of strongly interacting matter, i.e. onset of fireball. The results are then compared with various dynamical and statistical models. The predictions of dynamical models without phase transition – EPOS [8], UrQMD [11] and SMASH [10] – agree with the results from small systems, failing to describe the results from larger systems. In contrast, PHSD [9], the model with phase transition, well describes the results from larger systems. Both tested statistical models – SMES [12], with the phase transition, and HRG [11], without one, tend to overestimate the data, especially for small systems. Clearly, none of the tested models can describe the data well for the full number of wounded nucleons  $\langle W \rangle$  range.



**Figure 4.** The system size dependence of  $\langle K^+ \rangle / \langle \pi^+ \rangle$  ratio at mid-rapidity compared to dynamical (*left*) and statistical (*middle*) models; the system size dependence of inverse slope parameter T of  $K^+ m_T$  spectra compared to dynamical models (*right*).

# 3 Conclusions

This contribution concentrates on the compilation of selected results on strangeness production in various collision systems at the CERN SPS energy range. As was shown, presented results are of high importance when discussing the onset of deconfinement and the onset of fireball. However, continuous theoretical input is crucial to allow models to describe existing data.

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