PROCEEDINGS OF SCIENCE

Highlights from NA61/SHINE

Seweryn Kowalski* for the NA61/SHINE Collaboration

Institute of Physics, University of Silesia,
75 Pułku Piechoty 1, Chorzow, Poland

E-mail: seweryn.kowalski@us.edu.pl

The NA61/SHINE experiment aims to discover the critical point of strongly interacting matter and study the properties of the onset of deconfinement. For this purpose, we perform a two-dimensional scan of the phase diagram by varying the collisions' energy and system size. In this contribution, the NA61/SHINE results from a strong interaction measurement program will be presented. In particular, the latest results from different reactions p+p, Be+Be, Ar+Sc, and Pb+Pb on charged kaons spectra, charged pions ratios, protons intermittency, flow, and higher-order moments of multiplicity and net-charge fluctuations are planned to be discussed. The NA61/SHINE data will be compared to models' predictions and the results from other experiments at the same energy range. Finally, the motivation, NA61/SHINE plans of the measurements after LS2 in heavy-ion collisions at the Super Proton Synchrotron energies will be shown.

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PoS(CPOD2021)002

1. Introduction

The NA61/SHINE detector [1] is a large acceptance hadron spectrometer with excellent capabilities in charged particle momentum measurements and identification by a set of eight Time Projection Chambers as well as Time of- Flight detectors. The high-resolution forward calorimeter, the Projectile Spectator Detector, measures energy flow around the beam direction, which in nucleus–nucleus reactions is primarily a measure of the number of projectile spectators (non-interacted) nucleons and is thus related to the violence (centrality) of the collision. A set of beam detectors identifies beam particles and precisely measures their trajectories.NA61/SHINE performed a two-dimensional scan in collision energy (13A–150A GeV/c) and system size (p+p, Be+Be, Ar+Sc, Xe+La, Pb+Pb) (see Figure 1) to study the phase diagram of the strongly interacting matter. The main goals of NA61/SHINE are the search for the critical point and a study of the onset of deconfinemnet.

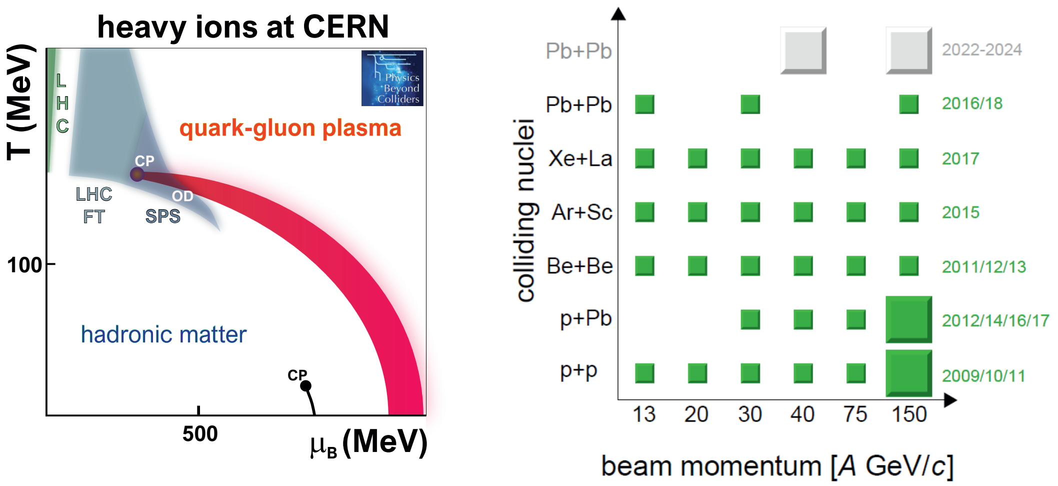

Figure 1: NA61/SHINE system size and energy scan (right),the phase diagram of the strong interactive matter (left)

2. Study of the onset of deconfinement

The Statistical Model of the Early Stage (SMES) [2] predicts a 1^{st} order phase transition from the Quark-Gluon Plasma (QGP) to a hadron matter phase between top AGS and top SPS energies. In the transition region, constant temperature and pressure in the mixed-phase and an increase of the number of internal degrees of freedom are expected.

A plateau ("step") in the energy dependence of the inverse slope parameter T was observed by the NA49 experiment in Pb+Pb collisions for m_T spectra of $K^{\pm}$. It was expected for the onset of deconfinement due to the presence of a mixed phase of hadron gas (HRG) and quark–gluon plasma (QGP). In p + p interactions at SPS energies, the inverse slope parameter T of m_T spectra shows qualitatively similar energy dependence as in central Pb+Pb collisions ("step"), and such behavior seems to emerge also in Be+Be and Ar+Sc reactions, as visible in Figure 2. The values of the T parameter in Be+Be collisions are slightly above those in p + p interactions. The T parameter in Ar+Sc reactions is found between those in p + p/Be+Be and Pb+Pb collisions.

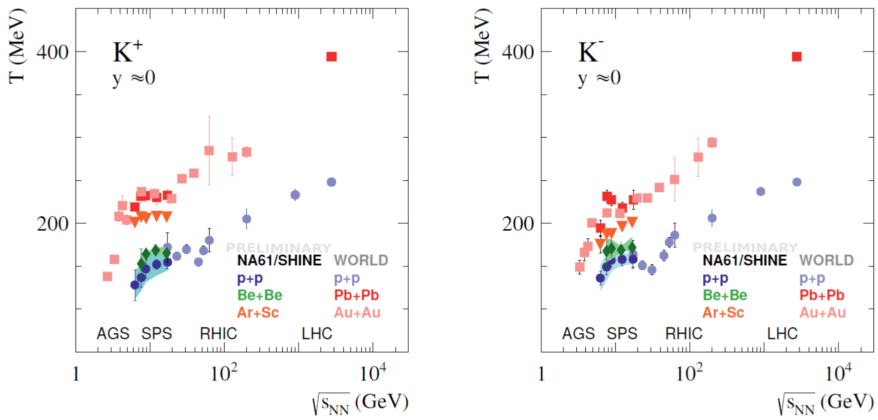

Figure 2: Inverse slope parameter T of m_T spectra of $K^{\pm}$ as function of collision energy [3–12].

Rapid changes of the ratios K^+/π^+ at mid-rapidity and $\langle K^+\rangle/\langle\pi^+\rangle$ as function of collision energy ("horn") were observed in Pb+Pb collisions by the NA49 experiment. TThe SMES model predicted these as a signature of the onset of deconfinement. These two ratios, together with new NA61/SHINE results from Be+Be and Ar+Sc collisions, are shown in Figure 3. A plateau-like structure is visible in p+p interactions. The ratio K^+/π^+ at mid-rapidity as well as the ratio of total yields from Be+Be collisions is close to the p+p measurements. For the five analysed energies of Ar+Sc collisions, the ratio K^+/π^+ at mid-rapidity and $\langle K^+\rangle/\langle\pi^+\rangle$ are higher than in p+p collisions but show a qualitatively similar energy dependence - no horn structure visible.

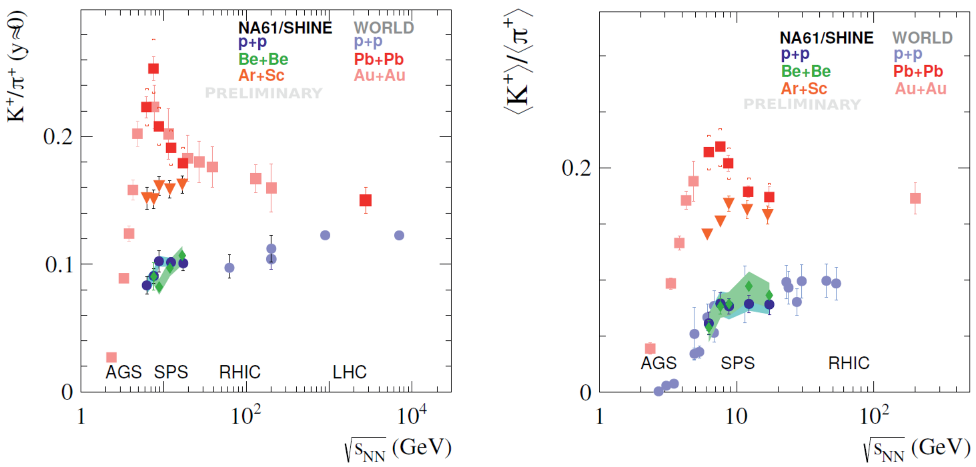

Figure 3: Ratio of yields K^+/π^+ at mid-rapidity and the ratio of total yields $\langle K^+\rangle/\langle\pi^+\rangle$ produced in p+p, Be+Be, Ar+Sc and Pb+Pb collisions as function of collision energy [3–12].

The comparison of the p + p data with the corresponding measurements in central Pb+Pb and Au+Au collisions (Figure 4) uncovers a similarity between the collision energy dependence in p+p interactions and central heavy-ion collisions - a rapid change of collision energy dependence of

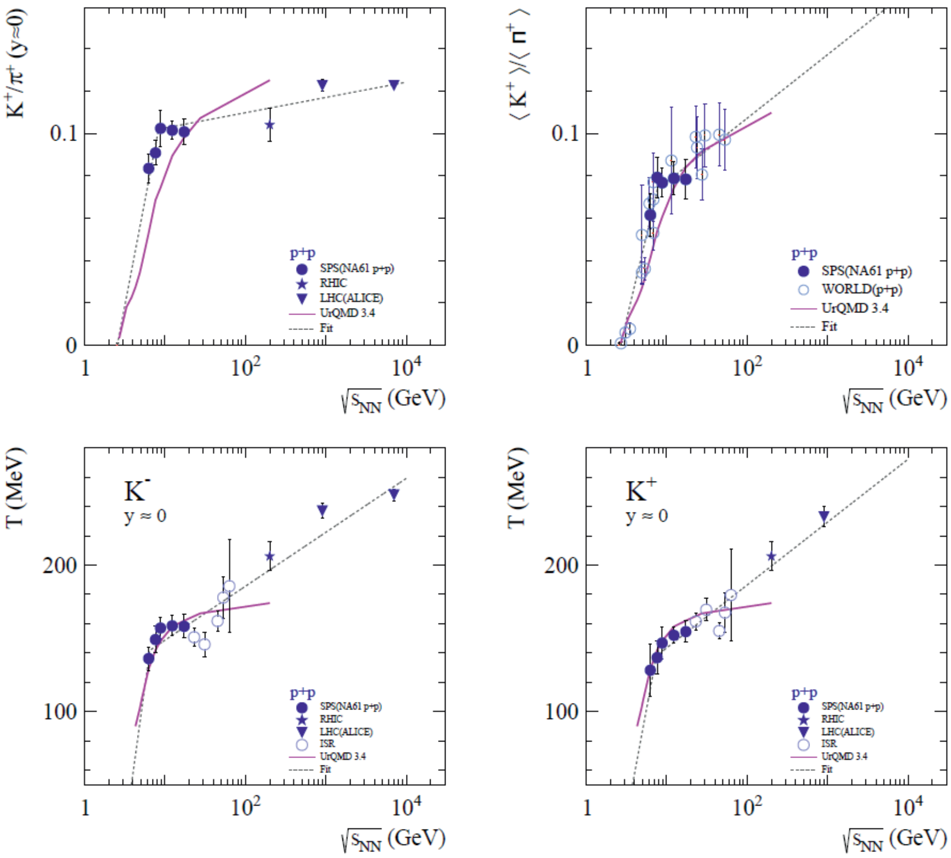

Figure 4: Energy dependence of the K^+/π^+ ratio in inelastic p+p interactions at mid-rapidity (top-left) and in the full phase-space (top-right) as well the inverse slope parameter T of transverse mass spectra at mid-rapidity for K^- (bottom-left) and K^+ (bottom-right) mesons. Two straight lines fit the data in order to locate a position of the break in the energy dependence.The experimental results are compared with predictions of the resonance-string model, UrQMD [13]

basic hadron production properties in the same energy range. The fitted break energy is in the range between 6.5 to 8.3 GeV. These values are surprisingly close to the energy of the beginning of the horn and step structures in central Pb+Pb collisions - the transition energy being approximately 8 GeV (see Figure 2).

3. Search for the critical point

In the recent analysis of NA61/SHINE, a special interest is devoted to fluctuations of conserved charges (electric, strangeness, or baryon number) [14, 15]. The non-monotonic dependence on such fluctuations in the NA61/SHINE energy – system size scan can be expected as a signal of a critical point (CP). To compare fluctuations in systems of different sizes, the quantities are constructed by division of cumulants κ_i of the measured distribution, where i is the order of the cumulant. For second, third, and fourth-order cumulants intensive quantities are defined as: κ_2/κ_1, κ_3/κ_2 and κ_4/κ_2. Their reference values for multiplicity fluctuations are 0 (no fluctuations) and 1 (independent particle production). The system size and energy dependence of second, third and fourth order cumulant ratio of negatively charged hadron multiplicity in p+p, Be+Be, and Ar+Sc interactions are presented in Figure 5. So far, there are no prominent structures observed which could be related to a critical point.

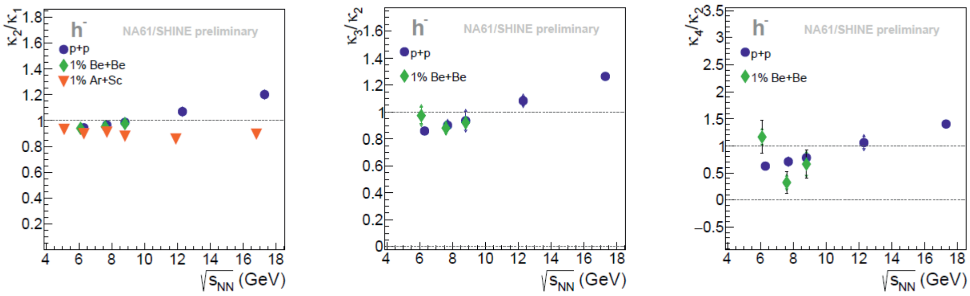

Figure 5: System size and energy dependence of $\kappa_2/\kappa_1[h^-]$, $\kappa_3/\kappa_2[h^-]$ and $\kappa_4/\kappa_2[h^-]$. Statistical uncertainty was obtained with the bootstrap method and it is indicated as a dashed black bar. Systematic uncertainty/bias: p+p - corrected data with an estimate of systematic uncertainty; Be+Be - uncorrected data with estimate of systematic bias. Systematic uncertainty/bias is indicated with a green bar.

In the second-order phase transition, the correlation length diverges. The system becomes scale-invariant, leading to enhanced multiplicity fluctuations with unique properties revealed by scaled factorial moments. If the system is self-similar, factorial moments follow a power-law dependence on the momentum bin, which can signify CP appearance.

Figure 6 presents the dependence of the second scaled factorial moments of mid-rapidity proton multiplicity distributions for 0-20% most central Ar+Sc at 150*A* GeV/c and 0-10% most central Pb+Pb at 30*A* GeV/c collisions, and no indication of a power-law increase with the number of bins is observed.

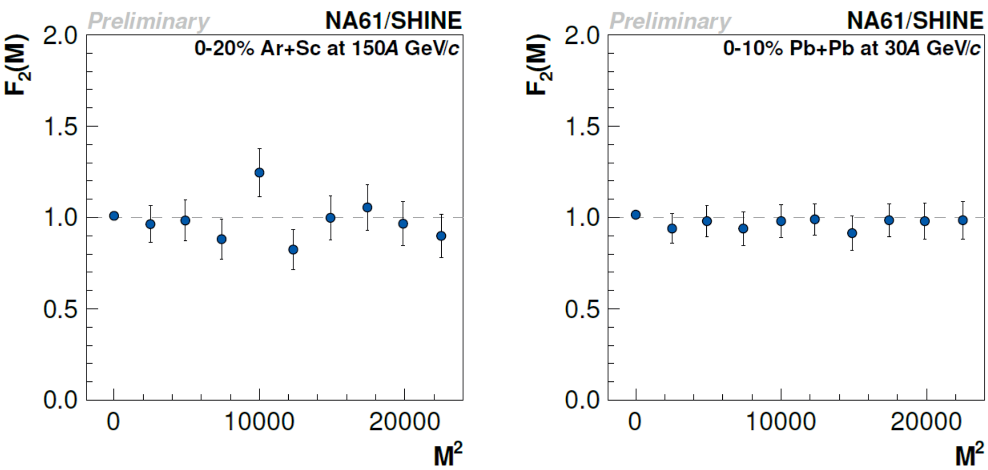

Figure 6: Results on the dependence of the second scaled factorial moment of the mid-rapidity proton multiplicity distributions for Ar+Sc at 150*A* GeV/c (left) and Pb+Pb at 30*A* GeV/c (right). Result obtained for M from 1 to 32. Only statistical uncertainties shown.

4. Strangeness production in p+p interactions at 158 GeV/c

Hyperons are excellent probes of the dynamics of proton-proton interactions, as strange constituent quarks are not present in the initial state of this process. Therefore hyperon production has been studied in a long series of experiments in elementary hadron+hadron interactions. However, the experimental situation in this field remains inconclusive.

New data from p+p collisions on Ξ^- and $\overline{\Xi}^+$ hyperon production are presented. The event sample consists of 53 million registered interaction trigger events obtained at 158 GeV/c beam momentum corresponding to $\sqrt{s_{NN}} = 17.3$ GeV/c. The results refer to primary Ξ^- and $\overline{\Xi}^+$ produced in strong and electromagnetic processes and are corrected for geometrical detector acceptance and reconstruction efficiency. This data was used to calculate the enhancement factors, E_s, as a ratio of rapidity density for hyperons production in mid-rapidity in nucleus-nucleus collisions per the number of wounded nucleons divided by the corresponding value from p+p interactions [16] at given collision energy. The enhancement factors are presented in Figure 7 and the NA61/SHINE results on Ξ^- and $\overline{\Xi}^+$ production in p+p interactions created a new reference for the recalculation of the strangeness enhancement observed in the NA57 p+Be and A+A data.

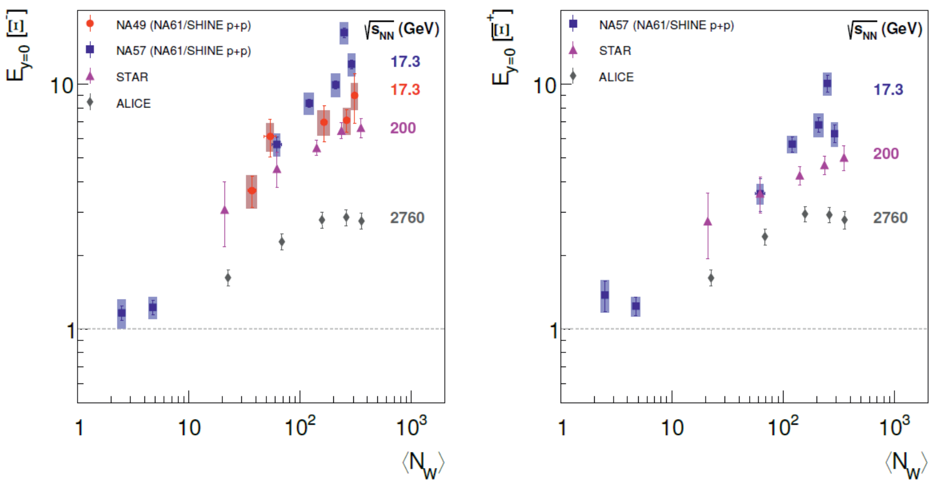

Figure 7: The strangeness enhancement factor E_s at the mid-rapidity as a function of the average number of wounded nucleons calculated as a ratio of rapidity density for Ξ^- (left) and $\overline{\Xi}^+$ production (right) in nucleus-nucleus interactions per number of wounded nucleons divided by the corresponding value for p+p interactions [16] This result is compared to data from the NA57 experiment at the SPS [17], the STAR experiment at the RHIC [18] and the ALICE experiment at the LHC[19].

5. Measurement of open charm (D^0 and $\overline{D^0}$ meson) production as an extension of the strong interaction program

NA61/SHINE proposes to measure open charm (D^0 and $\overline{D^0}$ meson) production in central Pb+Pb collisions [20] with an upgraded detector system at the CERN SPS. It will be the first precision measurements of open charm production in heavy-ion collision in the CERN SPS energy

PoS(CPOD2021)002

domain. The proposed measurements of D0 and D0 production in central Pb+Pb collisions at the SPS will be possible after upgrading the NA61/SHINE experimental set-up by:

- Construction of a Vertex Detector (VD), which will provide precise tracking downstream of the target and thus reduce by many orders of magnitude the background below the D0 and D0 peaks.
- Replacement of the TPC electronics will increase the read-out rate by a factor of about 10 (up to 1 kHz).
- Upgrade of the trigger and data acquisition systems (TDAQ) as required by the VD and TPC upgrades.
- Upgrade of the particle spectator detector (PSD) used for centrality determination.
- Construction of a new ToF detector (MRPC) for particle identification.

The upgrade of TPC read-out, TDAQ, PSD, DCS, MRPC, and VD is ongoing

The new NA61/SHINE data on electromagnetic effects in Ar+Sc collisions at 40 A GeV/c which I presented at this Conference are described in detail in Ref. [21].

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PoS(CPOD2021)002

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PoS(CPOD2021)002