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Multi-Strange production at FAIR energies

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Nuclear collisions at FAIR energies are envisaged to produce net-baryon densities $\approx$ 5 - 6 times higher than the normal nuclear matter density. At such high densities, baryons start melting into their constituents, the quarks and gluons, forming a mixed or even deconfined medium. Such a state will be explored experimentally at the upcoming Facility for the Antiproton and Ion Research (FAIR). In such collisions, production of multi-strange hadrons plays a major role in investigating the characteristics of the medium. Enhanced production of strange quarks and therefore, of (anti)hyperons is believed to be an important signature of the formation of partonic medium.

The yields of (anti)hyperons have been investigated in the at 40 AGeV - top FAIR SIS300 energy using the hadronic-string model (UrQMD) and hadronic and partonic modes of the transport model (AMPT). It is seen that multi-strange (anti)hyperons are very sensitive to the partonic medium and the enhancement is very dominant at FAIR energy.

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1. Introduction

One of the main objectives of relativistic heavy-ion collision experiments is to study the strongly interacting nuclear matter under extreme conditions of temperature and/or baryon chemical potential. Under these conditions, nuclear matter is expected to undergo a transition to a medium of free quarks and gluons, known as quark-gluon plasma (QGP) [1]. Several signatures have been proposed to probe creation of such a novel state of matter. One of the proposed signatures is the relative enhancement of strangeness production, measured by the ratios of their yields in A+A collisions in comparison to that in p+p collisions or in peripheral collisions. The idea is based on the assumption that the dominant mechanism of production of $s\bar{s}$ in QGP is via gluon fusion ($gg \rightarrow$ s$\bar{s}$) followed by the chemical equilibration time ($\tau_{QGP}^{eq} \approx$ 10 fm/c), contrary to the case of a pure hadronic scenario, where such reactions are almost absent [2].

One important production process for multi-strange hyperons as implemented in transport models are strangeness exchange reactions like $\Lambda K^- \rightarrow \Xi^-\pi^0$, $\Lambda\Lambda \rightarrow \Xi^- p$ and $\Lambda\Xi^- \rightarrow \Omega^- n$, $\Xi^- K^- \rightarrow \Omega^-\pi^-$ [3]. These multistep processes depend on the density of the medium, and, hence, the production of multi-strange baryons has the potential to probe the density and the EOS of the medium.

In experiments at AGS and SPS up to beam energies of 30 AGeV mostly non-strange and singly-strange or at the most doubly-strange particles were studied and no Ω^- hyperons were found up to beam energies of 30 AGeV [4]. This is due low rate capability of the detectors used so far (AGS and SPS). In contrast, the Compressed Baryonic Matter (CBM) experiment at the future Facility for Antiproton and Ion research (FAIR) is designed for unprecedented reaction rates (up to 10 MHz), and will allow precision studies of multi-strange (anti-) hyperon production in heavy-ion collisions at beam energies close or even below the thresholds for pp collisions, which is an unchartered territory [5].

Therefore, we present the results of a systematic study of the production of multi-strange hyperons in central Au + Au collisions at 40 AGeV using different transport models. We have fitted the strange quark number dependence of the yields and have made extrapolations at FAIR energy even for multi-strange particles having larger number of strangen quarks. This article is arranged in the following manner: in Section-II we present a brief description of the basic features of the models. In Section-III, we present the model predictions for the production of particles with higher strangeness contents. Finally, the results obtained are comprehensively discussed in Section-IV.

2. Models

We have used the microscopic transport models UrQMD (version UrQMD 3.4) [6] and AMPT (version AMPT 1.26t4) [7].These models were extensively used earlier to explain the strangeness production data from AGS to RHIC energies. In this section, we give a brief description of the basic features of these models.

2.1 UrQMD

The UrQMD microscopic transport model is based on strings which produce hadrons by fragmentation. The rescattering of the strings and the products of their interaction are taken into account. The production of particles proceeds via the decay of meson and baryon resonances or string excitation and fragmentation

2.2 AMPT

In the AMPT transport model, the HIJING model is used to obtain initial spatial and momentum distribution of hard minijet partons and soft strings which undergo rescattering described by Zhangs parton cascade (ZPC). ZPC includes two-body scattering with scattering cross-section for parton-parton scattering obtained from pQCD with screening mass. Then the produced partons or strings undergo hadronization by Lund String Fragmentation model (in default mode) or by quark coalescence model (in string melting mode) which is similar to ACOLOR model approach. The interaction of the produced hadronic matter is then further treated by ART. In order to examine whether hyperon production is sensitive to the degrees of freedom in the collision volume, both the string melting (partonic matter) and the default mode (hadronic matter) of the AMPT model are used for calculating the particle yields.

3. Results

Particle yields of multi-strange hyperon in central Au+Au collisions (b $<$ 3 fm) at energy 40 AGeV using 1 million events are calculated. The analysis is done using the particles produced in the mid-rapidity region, -0.5 $<$ y $<$ 0.5.

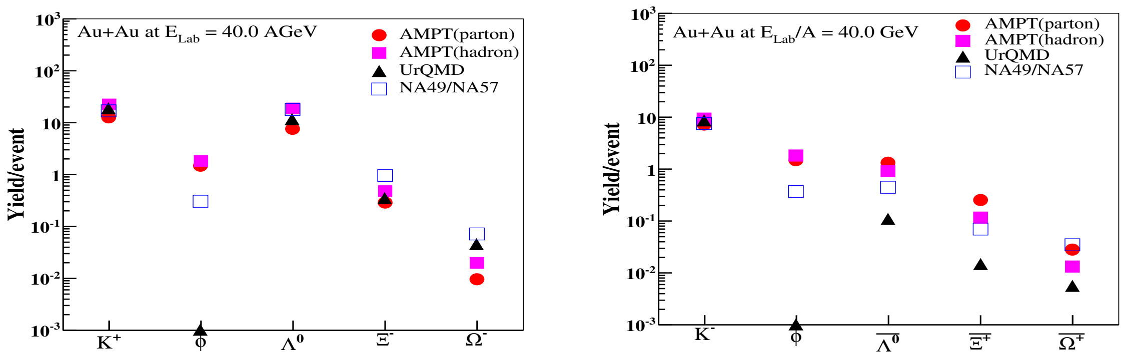

Figure 1: Mean multiplicities of strange particles at E$_{Lab}$ = 40 AGeV using various models. The solid symbols corresponds to model calculation and open symbol represents experimental data [8].

3.1 Yields of strange particles at 40AGeV

In order to have a closer look at the strangeness content of various particles produced at top FAIR energy, Fig. 1 has been plotted. In the figure the average yields of various strange particles at E$_{Lab}$ = 40 AGeV are plotted and compared with the SPS results (NA49 and NA57) [8]. It can be seen from the figure that the average yields of multi-strange hyperon decreases systematically with increasing number of strange quarks. Two clearly distinct slopes are seen, one for the mesons and another for the baryons. While kaon yield is reproduced, ϕ is underestimated by all models. In the baryon sector, the models underestimate the data points for $|s| \geq 2$ and all models have similar results for antihyperons expect for $\bar{\Omega}^+$. The average yield measured by AMPT (partonic) for $\bar{\Omega}^+$ nearly match with the data point.

3.2 Strangeness quantum number dependence of excitation function of hyperon

To understand the mechanism of strange particle production, Fig. 2 we have been plotted the average yields of the strange particles with respect to the strangeness quantum number in Au + Au collisions at 40 A GeV. It is interesting to note that, all models show similar structures, a peak corresponding to strangeness quantum number -1, and the curve falls on both sides with faster fall for hyperons with positive strangeness quantum number. For AMPT (partonic), the reduction is slower in comparison to other models showing enhanced production of multi-strange hyperon. It appears that while the yields of positive s increases in the partonic mode, it reduces for negative s particles.

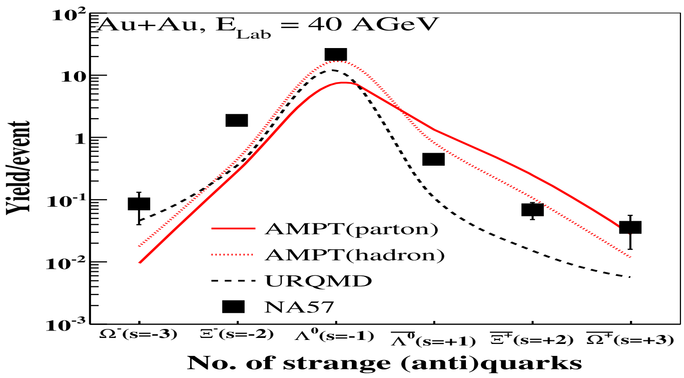

Figure 2: [Average yields of strange hyperons with strangeness quantum number for Au + Au collisions at 40 A GeV by different models.

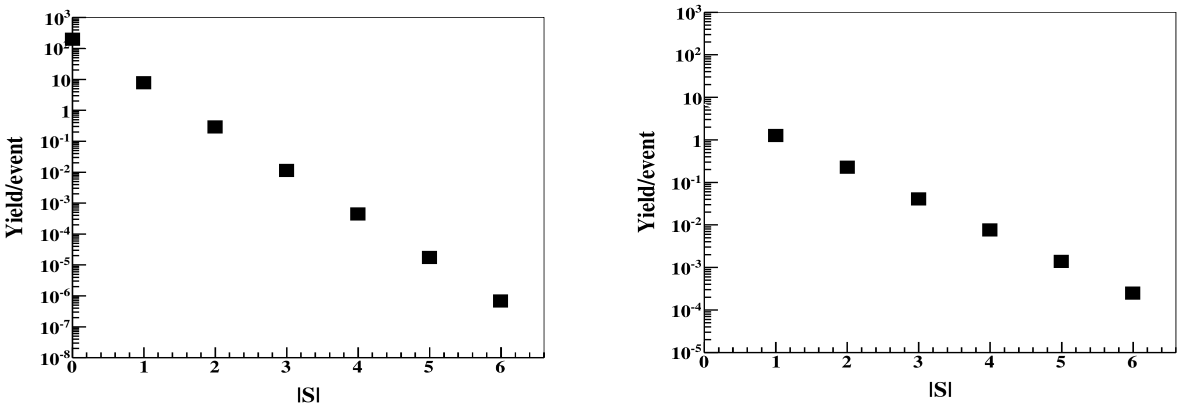

Figure 3: Average yields of multi-strange particles as a function of higher strange quark content. Left panel corresponds to average yields of hyperons and Right panel represents average yields of antihyperons

4. Conclusion

The measurement of strange particle yields in nuclear collisions at FAIR energy is an important observable for studying the properties of the colliding medium. It has been argued earlier that, the yields of strange quarks and therefore, those of the yields of strange mesons and baryons increases in a deconfined medium. The yields of multi-strange hyperons could also be increased by exchange mechanism more prominently in a medium with higher baryon content. Very high net baryon density at the nuclear collisions at FAIR energy coupled to the enhanced production of strange baryons by charge exchange reaction makes it an interesting place for studying the multi-strange production. The predictions of the AMPT model indicates that the production of multi-strange hyperons is significantly enhanced in the partonic in comparison to the hadronic scenario. The partonic form of AMPT shows higher sensitivity to multi-strange hyperons as compared to the singly-strange particles.

In an attempt to extrapolate the model results towards the particles with higher strange quark number and/or of higher mass, we have fitted the dependence of yield with strangeness shown in Fig. 3 with polynomial functions for positive and negative strangeness separately. It should be noted that production of particles beyond 3 quarks require special treatment and as per this simplistic model the yields of strange objects with 6 (anti)strange quarks could be of the order of $(10^{-4})10^{-6}$. Experimental verification of these predictions requires a detector system with high intreaction rates, such an experimental setup- the Compressed Baryonic Matter (CBM) detector system, is being designed at FAIR in Darmstadt, Germany.

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