Particle production and strangeness enhancement in PHQMD model

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Introduction

Ongoing experimental and theoretical research on strongly interacting matter and the quark-gluon plasma (QGP) aim to elucidate the phase structure of quantum chromodynamics (QCD). An increase in the yield of particles with higher strangeness content is widely regarded as a key indicator of QGP formation [1]. The 'horn' structure in the excitation function of the K^+/π^+ ratio, observed in experiments such as AGS, SPS, and STAR, has been linked to strangeness enhancement [2].

In this study, we examine the horn structure using the Parton-Hadron-Quantum-Molecular-Dynamics (PHQMD) model [3]. A prior study [4] explained the horn structure, included chiral symmetry restoration (CSR) in the Parton-Hadron-String Dynamics (PHSD) model to explore its effects on particle production, emphasizing the roles of both CSR and deconfinement for strangeness enhancement.

The advanced PHQMD model incorporates these features and enables switching between the ON and OFF QGP states. This capability facilitates the study of how the QGP phase influences the formation of the horn structure.

PHQMD

The PHQMD model is a versatile tool designed to study the dynamics of heavy-ion collisions, including cluster and hypernuclei formation, across a wide range of beam energies from a few hundred AMeV to ultra-relativistic energies. The PHQMD is a hybrid approach, combining the PHSD model with the Quantum Molecular Dynamics (QMD). PHSD handles the complex interactions involved in QGP formation and partonic interactions; and QMD deals with baryon propagation. Clusters in PHQMD form dynamically via continuous potential interactions and are identified using methods like the Simulated Annealing Clusterization Algorithm or the Minimum Spanning Tree method, ensuring accurate modeling of the collision process. 'QGP ON' refers to a scenario where the energy density in a given region exceeds 0.5 GeV/fm$^{\mathbf{3}}$, causing hadrons to dissolve into quarks and gluons, which are then modeled using the PHSD approach.

Results and Discussion

The results from PHQMD Au+Au collisions considering b_{max} = 3.2 fm at mid-rapidity ($|y| < 0.1$) have been compared with the top central 0-5% Au+Au collisions data of various experiments.

Fig. 1 shows K^-/K^+ ratios at BES energies are significantly less than unity. Since, strangeness is strictly conserved and produced in $s\bar{s}$ pairs so there are no additional production channels for K^+ relative to K^-. But at low energies, the s quark is predominantly found in anti-kaons (K^- and $\bar{K}^0$) and hyperons like Λ and Σ, while the $\bar{s}$ quark primarily resides in kaons (K^+ and K^0). As a result, the associated production of K^- and hyperons, particularly Λ, leads to a relative suppression of K^- compared to K^+.

The lower values of the $\bar{p}/p$ ratios at fig. 2 reflects the presence of a large net-proton population and significant baryon stopping in these collisions. With increasing collision energy, the $\bar{p}/p$ ratio of PHQMD data rises and approaches unity at top RHIC energies, suggesting that higher beam energies result in greater collision transparency, where proton

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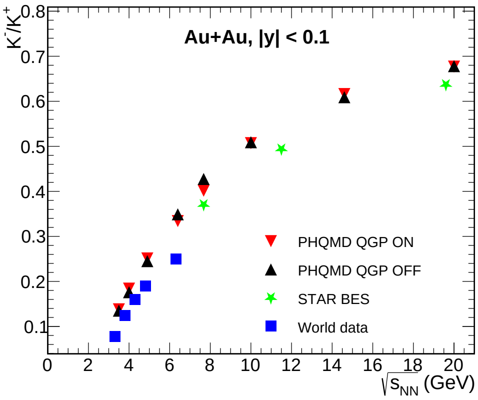

FIG. 1: K^-/K^+ ratio of PHQMD model at mid-rapidity ($|y| < 0.1$) for Au+Au collisions considering $b_{max} = 3.2$ fm and compared with 0-5% central mid-rapidity data.

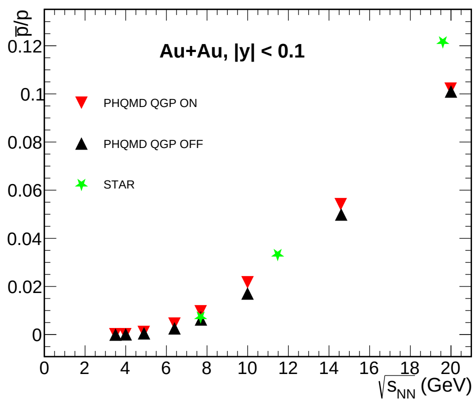

FIG. 2: $\bar{p}/p$ ratio of PHQMD model at mid-rapidity ($|y| < 0.1$) for Au+Au collisions considering $b_{max} = 3.2$ fm are compared with 0-5% central mid-rapidity data.

and antiproton production at mid-rapidity is predominantly driven by pair production.

PHQMD model has been able to replicate the horn structure so closely, aligning with experimental data. A clear distinction between the QGP ON and QGP OFF states is observed in the PHQMD K^+/π^+ particle ratio within the 6-10 GeV energy range as shown in fig. 3. The K^+/π^+ ratio from PHQMD

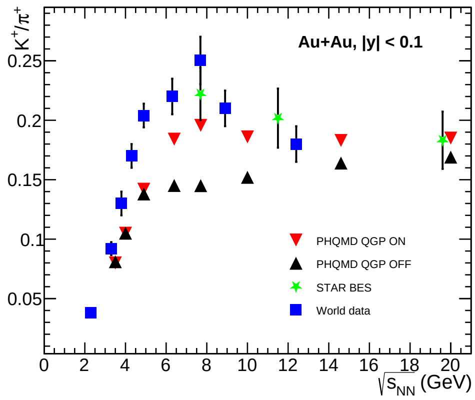

FIG. 3: K^+/π^+ ratios of PHQMD model at mid-rapidity ($|y| < 0.1$) for Au+Au collisions considering $b_{max} = 3.2$ fm are compared with 0-5% central mid-rapidity data.

data for QGP ON scenario closely follow the trend seen in published data, while the horn structure is absent in the PHQMD QGP OFF case. We hope that this model will be able to explain other phenomena related to formation of QGP at this low energy.

Acknowledgments

RD acknowledges the Inspire Fellowship [DST/INSPIRE Fellowship/2020/IF200305], and AS is grateful for financial support from grant SR/MF/PS-02/2010. The authors also extend thanks to the PHQMD group, especially Prof. Elena Bratkovskaya, for her valuable suggestions.

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