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Strangeness freeze-out: role of system size and missing resonances

Sandeep Chatterjee[1,⋆], *Sabita* Das[2], *Ajay Kumar* Dash[3], *Debadeepti* Mishra[3], *Bedangadas* Mohanty[3], and *Subhasis* Samanta[3]

[1] *AGH University of Science and Technology, al. Mickiewicza 30, 30-059 Krakow, Poland*
[2] *Institute of Particle Physics and Key Laboratory of Quark & Lepton Physics (MOE), Central China Normal University, Wuhan-430079, China*
[3] *National Institute of Science Education and Research, HBNI, Jatni-752050, India*

Abstract. The conventional approach to treat strangeness freezeout has been to consider a unified freezeout scheme where strangeness freezes out along with the non-strange hadrons (1CFO), with or without an additional parameter accounting for out-of-equilibrium strangeness production (γ_S). Several alternate scenarios have been formulated lately. Here, we will focus on flavor dependent freezeout with early freezeout of strangeness (2CFO) in comparison to 1CFO and its variants with respect to the roles played by the system size and missing resonances predicted by different theoretical approaches but yet to be seen in experiments. In contrast to the performance of 1CFO with/without γ_S that is insensitive to system size, 2CFO exhibits a clear system size dependence- while for Pb+Pb the χ^2/NDF is around 0-2, for smaller system size in p+Pb and p+p, the χ^2/NDF> 5 and larger than 1CFO+γ_S. This clearly shows a system size dependence of the preference for the freezeout scheme, while 2CFO is preferred in Pb+Pb, 1CFO+γ_S is preferred in p+Pb and p+p. We have further investigated the role of the missing resonances on strangeness freezeout across SPS to LHC beam energies.

1 Introduction

Freezeout is the latest phenomenon to occur prior to the detection of the produced hadrons in relativistic heavy ion collisions. This makes it imperative to decipher the nitty-gritty of the freezeout stage to probe the properties of the hadronic matter as well as the quark gluon plasma that is produced as a result of the collision. In general, various quantities could freezeout at different times: in this article we will discuss freezeout of the hadron multiplicity. This stage is usually referred to as chemical freezeout (CFO). An ideal gas of all known hadrons and resonances known as the hadron resonance gas (HRG) model has been amazingly successful in providing a description of CFO within a thermodynamic framework. For detailed information on the work presented here as well as references, we request the reader to Refs. [1–3] on which the work below is based upon.

In this article, we discuss the performance of several freezeout schemes with system size as well as the systematic uncertainties due to the missing resonances from the hadron spectrum on the model predictions [1–3]. A grand canonical ensemble (GCE) description of the thermal state of QCD medium

⋆e-mail: Sandeep.Chatterjee@fis.agh.edu.pl

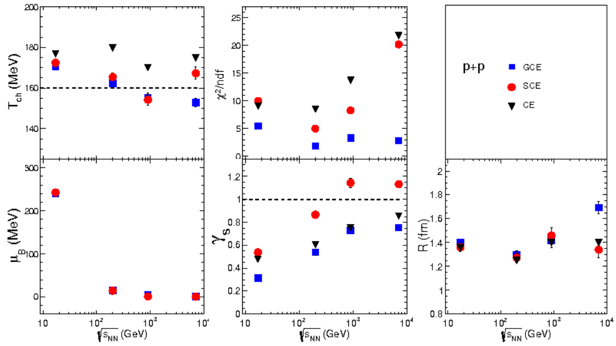

Figure 1. (Color online) A comparison of the performance of the HRG model fits to p+p data in different ensembles [1].

requires four parameters: temperature T and three chemical potentials μ_B, μ_Q and μ_S corresponding to the three conserved charges of QCD namely the baryon number B, electric charge Q and strangeness S respectively. Since phase space integrated hadron multiplicities are fitted, one also requires the volume V. Such a scheme where all hadrons freezeout together in the same thermal state is referred to as 1CFO. One often accounts for possible non-equilibrium production of strange hadrons by intoducing an additional parameter γ_S. We will refer to this as 1CFO+γ_S. Since freezeout is mainly a competition between hadron collisions and fireball expansion rates, it is possible to have flavor-dependent freezeout owing to flavor hierarchy in the hadron-hadron cross sections. The simplest version of such a multiple freezeout scenario is 2CFO where hadrons with strange valence quarks freezeout at a different thermal state as compared to those with only non-strange valence quarks.

An important aspect in the application of thermal models across different system sizes is the choice of the ensemble. It has been a standard practice to treat the mid-rapidity data of heavy-ion collisions in GCE while smaller collision systems like proton-heavy ion and proton-proton collisions have been treated in canonical ensemble (CE). While for 4π acceptance in data, it is clear that one has to work in the CE where the charges are conserved exactly, for analysis of a part of the phase space of the produced particles, e.g mid-rapidity data, the CE choice may not always be appropriate. The other aspect which we also investigate in this article are the systematic uncertainties in the HRG predictions due to our incomplete knowledge of the hadron spectrum.

2 Results

In Fig. 1 we show the comparative performance of the different ensembles in describing the mid-rapidity p+p data. Clearly at the LHC energies, GCE works much better than the other ensembles. Henceforth, we show results only in the GCE. In Fig. 2 we have plotted the system size dependence of the performance of different freezeout schemes as well the extracted best fitted freezeout parameters. It is interesting to note that there is a clear system size dependence of the preferred freezeout scheme- 2CFO is preffered in Pb+Pb while 1CFO+γ_S is preferred in smaller systems like p+Pb and p+p.

Finally, in Fig. 3, we show the flavor hierarchy in freezeout parameters T and VT^3 obtained in heavy ion collisions in 2CFO freezeout scheme. We plot the beam energy depedence of the ratio T_S/T_{NS} and $V_S T_S^3/V_{NS} T_{NS}^3$. The plot suggests that flavor hierarchy in freezeout parameters is most prominent between $\sqrt{s_{NN}} \sim 10 - 100$ GeV. The results have been plotted for two different hadron

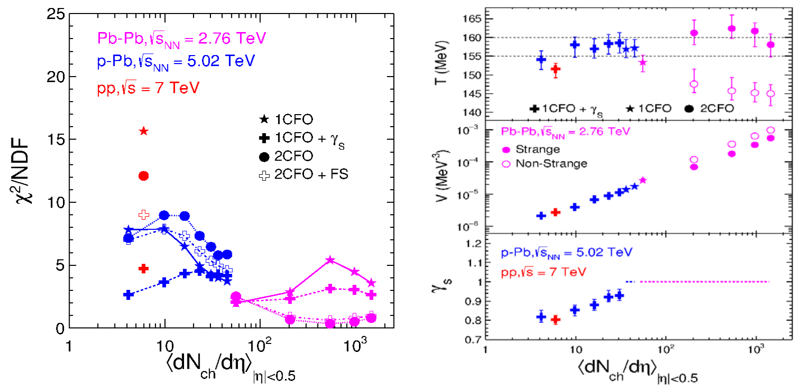

Figure 2. (Color online) Left: System size dependence of the goodness of fit in terms of χ^2/N_{df} compared over three different freezeout schemes- 1CFO, 1CFO+γ_S and 2CFO. Right: The thermal parameters corresponding to the best fits are shown [2].

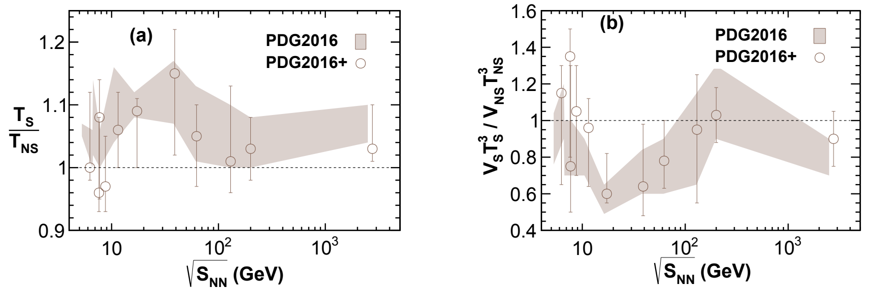

Figure 3. (Color online) The influence of the systematic uncertainties of the hadron spectrum on flavor hierarchy in thermal parameters [3].

spectra: PDG 2016 (that includes only the confirmed resonances from PDG 2016) and PDG 2016+ (that, in addition to PDG2016 also include the other resonacnes that have an unconfirmed status in PDG 2016). We find the extracted flavor hierarchy in T and VT^3 not influenced by such systematic uncertainties of the HRG model.

3 Conclusion

We have presented our recent works on various aspects of strangeness freezeout in relativistic collisions within the framework of the thermal model. GCE performs best in describing the mid-rapidity yields in small p+p collisions at the LHC. We showed that while early freezeout of strangeness is preferred in heavy ion collisions over unified freezeout, in small systems 1CFO with γ_S performs best. This could be due to the difference in hadronic interactions in small versus large systems. Finally, we also showed that the observed flavor hierarchy in heavy-ion collisions is stable under systematic uncertaintites due to the hadron spectrum which is an important input in thermal models.

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