Freeze-out Systematics due to the Hadron Spectrum

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Introduction

The underlying physics behind the chemical freeze-out surface in high-energy heavy-ion collisions is of keen interest. The Hadron Resonance Gas (HRG) is quite successful in explaining the mean hadron yields[1] as well as the moments of conserved charges[2] of QCD like Baryon number (B), Strangeness (S) and Charge (Q) with a few thermal parameters. But, in the standard data analysis framework in the calculation of freeze-out parameters the resonances which are predicted by various theoretical studies but are yet to be confirmed experimentally are left out. We study the role of such missing resonances in two different freeze-out schemes; single freeze-out (1CFO), in which all hadrons freeze-out at the same surface and flavor dependent double freeze-out (2CFO)[3], in which strange and non-strange hadrons freeze-out at different surfaces.

Model

The HRG partition function $Z(T, \mu_{B,Q,S})$ for a thermodynamical state (T, μ_B, μ_Q, μ_S), where T is the temperature and μ_B, μ_Q and μ_S are the chemical potential corresponding to the conserved charges B, Q and S respectively, can be written as

$$\begin{aligned}\ln Z &= \sum_i VT^3 \frac{a g_i}{2\pi^2} \int dp p^2/T^3 \\ &\quad \times \ln\left(1 + a e^{-\left(\sqrt{p^2+m_i^2}+\mu_i\right)/T}\right) \end{aligned} \tag{1}$$

where $a = -1(+1)$ for mesons(baryons), g_i is the degeneracy, m_i is the mass of the ith hadron and μ_i is the hadron chemical potential which can be factorized as

$$\mu_i = B_i\mu_B + Q_i\mu_Q + S_i\mu_S \tag{2}$$

The summation in Eq.1 runs over all established resonances from the PDG and is taken into account when estimating the influence of the missing resonances on the freeze-out parameters. The total yield of the ith hadron N_i^t is the sum of primordial yield N_i^p and that feed-down contributions from higher mass particles.

In this work, we extract one dimensionful parameter T and two dimensionless parameters μ_B/T and VT^3. Since the scale of this problem, i.e. the mass of the hadron determines the freeze-out T and is expected to have a lesser influence on the dimensionless parameters μ_B/T and VT^3.

Again the freeze-out surfaces can also be estimated by comparing higher moments of conserved charges in theory and experiment. The advantage of this is that it is enough to know only the quantum numers of the unconfirmed states. The conserved charge susceptibilities χ can be computed from the partition function[2]

$$\chi_{BQS}^{ijk} = \frac{\partial^{i+j+k}(P/T^4)}{\partial_i(\mu_B/T)\partial^j(\mu_Q/T)\partial^k(\mu_S/T)} \tag{3}$$

where the pressure P is obtained as : $P = \frac{T}{V}\ln Z$. The mean M and variance σ of the conserved charges in terms of susceptibilities for the respective charge c are : $M_c = VT^3\chi_c^1$ and $\sigma_c = VT^3\chi_c^2$. In this study, we have calculated σ^2/M of B and Q to ascertain the in-

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fluence of the systematics of the hadron spectrum.

Results and Discussions

The analysis has been performed with two different hadron spectrums: the first set (PDG-2016) consists of only the confirmed hadrons and resonances from PDG 2016. The second set (PDG-2016+) includes all the resonances in PDG-2016 and the suspected resonances from PDG-2016 as listed in Table 1 of the reference[4]

Figure 1 shows the thermal parameters extracted from 1CFO (left) and 2CFO (right) fits. In the top panels, the extracted T has been plotted for different beam energies. We find that the freeze-out T in 1CFO as well as the strange and non-strange temperatures in 2CFO, are lower when we include more resonances. The data from conserved charges shown in dotted and dotted pink lines for PDG-2016 and PDG-2016+[4] also supports this cooling behavior of the system on addition of more resonances.

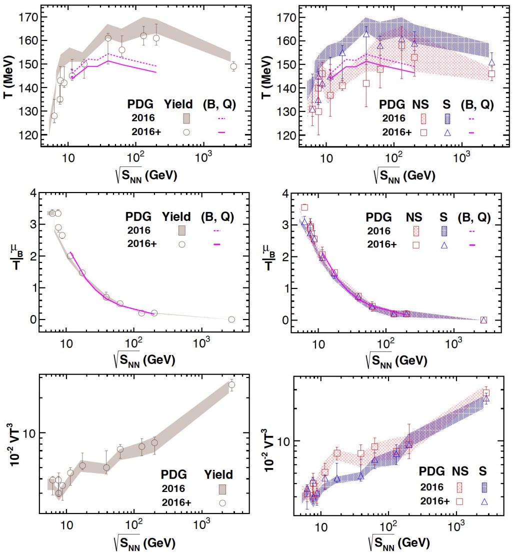

FIG. 1: . Thermal parameters T (top panel), μ_B/T (middle panel), VT^3 (bottom panel) as a function of beam energies. The left panel are for 1CFO fits, whereas the right panel is for 2CFO fits.

In the middle panel, the quantity μ_B/T as a function of beam energies is plotted for both 1CFO (left) and 2CFO (right) fits. This baryon fugacity parameter seems to be quite stable across freeze-out schemes, experimental data of yields and conserved charge fluctuation as well as the different hadron spectrum. Finally, the phase space volume factor VT^3 is plotted in bottom panel for various $\sqrt{s_{NN}}$. This parameter also seems quite stable against addition of extra resonances in PDG-2016+[4]. However unlike μ_B/T, this shows a flavor dependent structure similar to T.

Thus, we find that freeze-out T is most influenced by systematics of hadron spectrum and the dimensionless parameters μ_B/T and VT^3 are more stable towards this. The lowering of T upon addition of extra resonances can be interpreted in two ways. Firstly, upon addition of extra resonances, the required μ_s/μ_B from strangeness neutrality condition shifts towards lower T. This cooling occurs only for strange sectors. The second way is through the feed-down of these additional resonances. Although such a cooling effect should take place for both non-strange as well as strange sectors, the feed-down to the non-strange sector is from all resonances while that to the strange hadrons is only from the strange sector. This would mean while the first factor cools only the strange T, the second factor cools both flavors, albeit more strongly the non-strange T. This is the reason behind the survival of the flavor hierarchy on addition of the extra resonances.

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References

[1] S. Chatterjee *etal.*, Adv. in High Eng. Phys., 2015, 349013 (2015).
[2] F. Karsch and K. Redlich, Phys. Lett. B 695, 136 (2011),
[3] S. Chatterjee, R. Godbole, and S. Gupta, Phys. Lett. B727, 554 (2013).
[4] S. Chatterjee, D. Mishra, B. Mohanty and S. Samanta, arxiv:1708.08152