The role of small hard-core radius of Λ in resolving the puzzle of $^3_\Lambda H$ production in high energy nuclear collisions

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Introduction

The CFO of hadrons is successfully described by different versions of HRGM in a wide energy range. However, there are some observables which are not well understood and can be used to work out the correct EoS of QCD matter. One of them is a production of (anti-)(hyper-)nuclei in relativistic heavy-ion collisions. This problem is interesting because the typical binding energy of such objects are significantly less than the typical CFO temperatures. There are, however, several problems, if one needs to describe light nuclei production within HRGM. One of them is the second virial coefficients of the mixture of light nuclei and hadrons. Possible solution of this problem within induced surface tension (IST) EoS is discussed further in this study.

Second Virial Coefficient of Light Nuclear Clusters

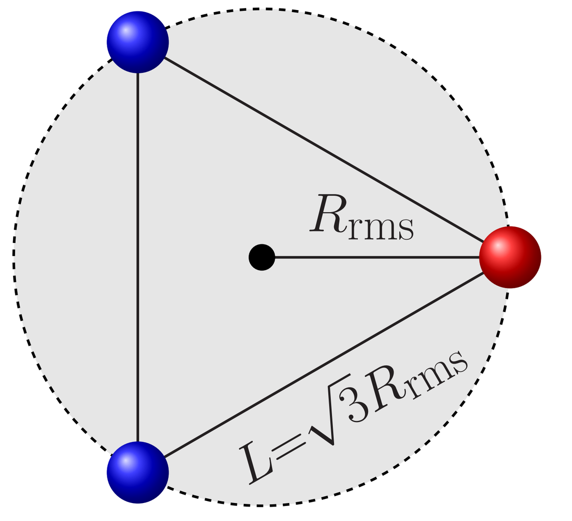

Figure 1: Visualisation of classical model of light nuclei with $A=3$

Light nuclei are roomy clusters and one can use simple approximation of second classical virial coefficient b_{Ah} for the mixture of such nuclei and hadrons. For the case of nucleus of A constituents which can be divided into N_s sorts, one can write:

$$b_{Ah} = \sum_{k=1}^{N_s} n_k \frac{2\pi}{3} (R_k + R_h)^3$$

Using this approximation one can derive IST EoS for mixture of hadrons and nuclei. The resulting system of equations coincides with the original IST EoS:

$$p = T \sum_{k=1}^{N} \phi_k \exp\left[\frac{\mu_k - pV_k - \Sigma S_k}{T}\right], \quad \Sigma = T \sum_{k=1}^{N} R_k \phi_k \exp\left[\frac{\mu_k - pV_k - \alpha\Sigma S_k}{T}\right]$$

if one introduce following notations:

$$R_A = \sum_{k=1}^{N_s} n_k R_k, \; S_A = \sum_{k=1}^{N_s} n_k S_k, \; V_A = \sum_{k=1}^{N_s} n_k V_k$$

We use also approximate and complementary, named Bag Model Radii (BMR):

$$R_A = \left[\sum_{k=1}^{N_s} n_k \left(R_k + \bar{R}\right)\right]^{1/3} - \bar{R}, \; S_A = 4\pi R_A^2, \; V_A = \frac{4\pi}{3} R_A^3$$

In this work we consider two CFO scenarios: single and separate freeze-out of hadrons and light nuclei. Model parameters: $R_\pi = 0.15$ fm, $R_K = 0.395$ fm, $R_\Lambda = 0.085$ fm, $R_m = 0.42$ fm, $R_b = 0.365$ fm and $\alpha = 1.25$. T, μ_B and V are set as fit parameters (for ALICE energy $\mu_B = 0$). $\gamma_S = 1$ and $\mu_{I3} = 0$

Results

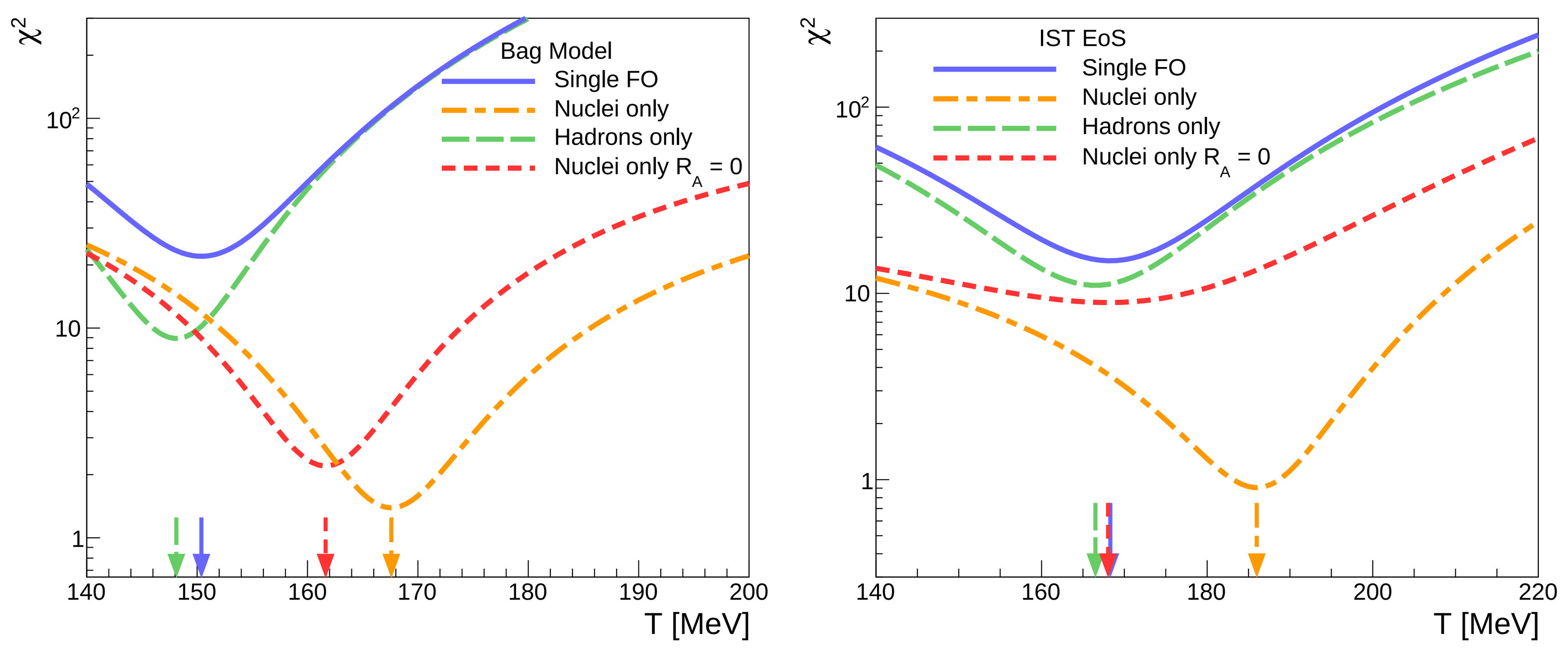

Figure 2: Temperature dependence of χ^2_{tot}, χ^2_h and χ^2_A of ALICE data measured at $\sqrt{s} = 2.76$ TeV obtained with the BMR-Λ EoS (left) and of STAR data measured at $\sqrt{s} = 200$ GeV obtained with the IST-Λ EoS (right).

In this study we perform a thorough analysis of the CFO problem of hadrons and light nuclei at top RHIC energy $\sqrt{s} = 200$ GeV and at LHC energy $\sqrt{s} = 2.76$ TeV.

Description	T_h, MeV	T_A, MeV	V_A, fm^3	χ^2/dof
Single CFO, ISTΛ	150.29 ± 1.92	150.29 ± 1.92	13145 ± 2233	1.433
Single CFO, BMRΛ	150.39 ± 1.90	150.39 ± 1.90	11201 ± 2009	1.293
Separate CFO, ISTΛ	148.12 ± 2.03	169.25 ± 5.57	3898 ± 1272	0.753
Separate CFO, BMRΛ	148.12 ± 2.03	167.59 ± 5.39	3123 ± 1198	0.676

Table 1: The results obtained by the advanced HRGM for the fit of ALICE data

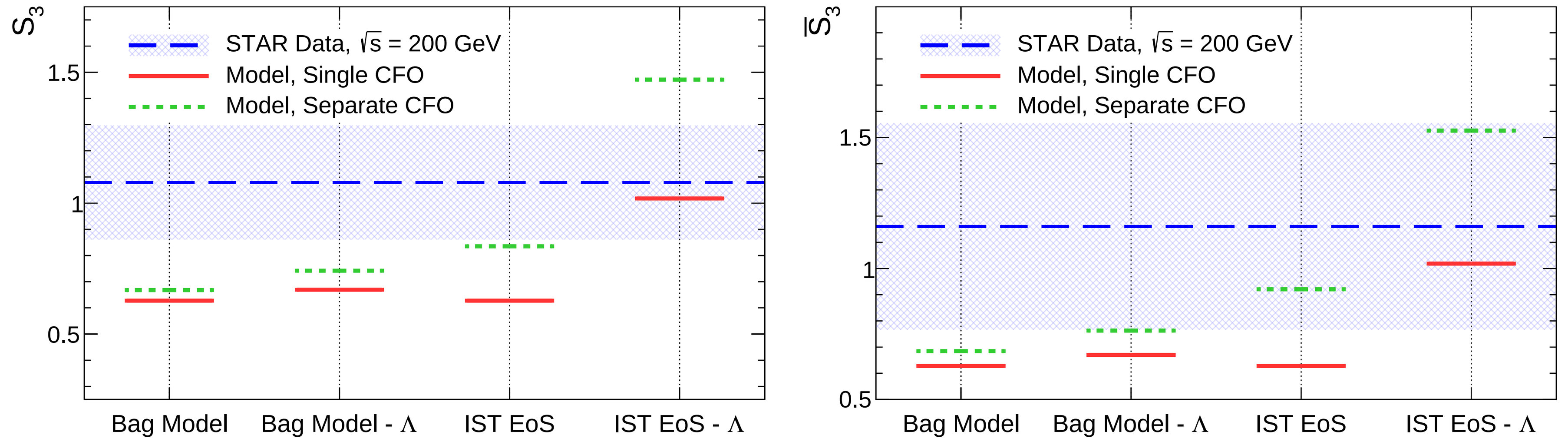

Figure 3: S_3 (upper) and $\bar{S}_3$ (lower) ratio measured at $\sqrt{s} = 200$ GeV by STAR Collaboration vs. theoretical description obtained for different CFO scenarios and EoS.

As an independent indicator of the CFO scenario for the STAR energies we used the S_3 and $\overline{S}_3$ ratios $\left(S_3 = {}^3_\Lambda H / \left({}^3He \times \frac{\Lambda}{p}\right)\right)$ which were not included into fit.

Description	T_h, MeV	T_A, MeV	μ_B^h, MeV	μ_B^A, MeV	V_A, fm^3	χ^2/dof
Single CFO, ISTΛ	168.30 ± 3.85	168.30 ± 3.85	30.12 ± 3.27	30.12 ± 3.27	2056 ± 375	1.069
Single CFO, BMRΛ	167.43 ± 3.84	167.43 ± 3.84	30.00 ± 3.26	30.00 ± 3.26	1667 ± 355	1.339
Separate CFO, ISTΛ	166.51 ± 4.07	185.99 ± 9.09	28.84 ± 5.37	34.30 ± 4.81	1093 ± 278	0.995
Separate CFO, BMRΛ	166.51 ± 4.07	182.69 ± 14.1	28.84 ± 5.37	33.30 ± 4.94	831 ± 455	1.459

Table 2: The results obtained by the advanced HRGM for the fit of STAR data

Conclusions

Using the IST EoS, an advanced HRGM is worked out. Using this model in combination with small radii of Λ hyperon, one can accurately describe experimental data on light nuclei and even data on $^3_\Lambda$H. From HRGM it is seen that light nuclei are better described with $T_{CFO} \approx 168$ MeV both at ALICE and STAR energies. On the other hand, the chemical freeze-out of hadrons at these energies occurs under different conditions.

References

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