A strong influence of weak decays on chemical freeze-out parameters of hadrons measured in high energy nuclear collisions found within the advanced Hadron Resonance Gas Model

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22nd edition PANIC Lisbon Portugal Particles and Nuclei International Conference

Introduction

A central goal of ultrarelativistic heavy ion collisions is to use collider experiments to recreate droplets of Big Bang matter in the laboratory where their material properties as well as the QCD phase diagram can be investigated. Studying heavy ion collisions may give us a path to a more complete understanding of how particles are produced in high energy collisions in QCD. Mainly such experiments are aimed at exploring of the QCD phase diagram, especially to detect signals of colour deconfinement, to detect signals of chiral symmetry restoration, to locate the critical endpoint of QCD phase diagram. In order to resolve all abovementioned tasks we need a very good tool to analyze the data!

Induced Surface Tension Equation of State (EOS)

IST EOS is a thermodynamically self-consistent equation of state, it is a system of coupled equations between the pressure p of considered system and the induced surface tension coefficient Σ, which are as follows [1].

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

,

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

- IST EOS allows one to go beyond the Van der Waals approximation, since it reproduces 2-nd, 3-rd and 4-th virial coefficients of the gas of hard spheres for $\alpha = 1.245$.
- Number of equations in IST EOS is 2 and it does not depend on the number of different hard-core radii!

Success of IST EOS is not accidental, since IST EOS is a truncated version of Morphological Thermodynamics. For a convex rigid body r immersed into a fluid with:

- pressure p,
- (induced) mean surface tension coefficient Σ,
- (induced) mean curvature tension coefficient K (bending rigidity)
- (induced) mean Gaussian curvature tension Ψ (Gaussian bending rigidity) one has:

Grand potential Ω = (Landau) free energy (rigid body inside fluid)

$$\Delta\Omega = -V_r \cdot p - S_r \cdot \Sigma - C_r \cdot K - X_r \cdot \Psi$$

Here V_r is an eigenvolume, S_r is an eigensurface, C_r is an eigenperimeter, X_r is an Euler characteristics [2]. For low densities $S_r \cdot \Sigma \simeq C_r \cdot K$ and, hence, the curvature effects can be accounted by IST EOS [1]. Also in the grand canonical ensemble the Euler characteristics can be absorbed in the baryonic chemical potential.

Results for Chemical Freeze-out Parameters

For fitting were used experimental data of the STAR Collaboration for energies: 7.7 - 200 GeV. Local fit parameters for each collision energy (5): T, μ_B, μ_{I_3}, μ_S, γ_S. Global fit parameters (5): R_π, R_K, R_{mesons}, $R_{baryons}$, R_Λ. It is crucial that inclusion of weak decays should be made according to experimental analysis.

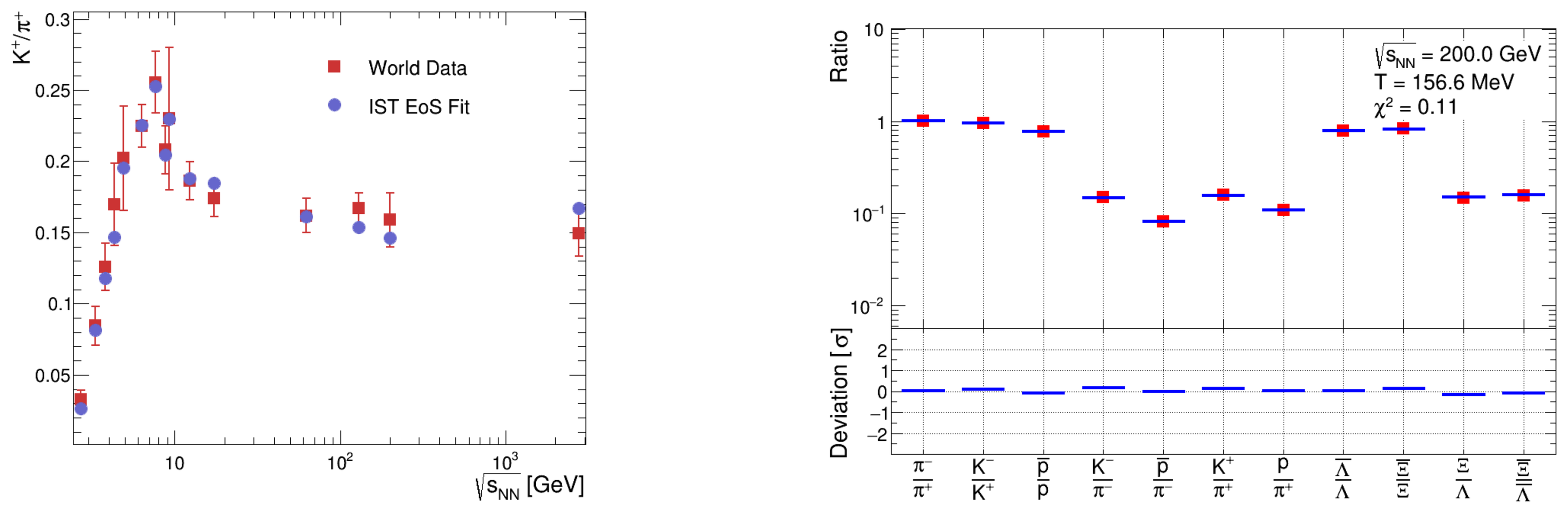

Figure 1: (left) Energy dependence of K^+/π^+ ratio for the measured world data and obtained with the IST EOS at $\sqrt{s} = 2 - 2760$ GeV. (right) Particle ratios (upper) and (lower) deviation of the theoretical description obtained by IST EoS from the data ratio measured at $\sqrt{s} = 200$ GeV by STAR Collaboration.

K^+/π^+ is the most problematic ratio for description by different models. IST EOS with additional radii for kaons and pions provides an excellent description of experimental world data.

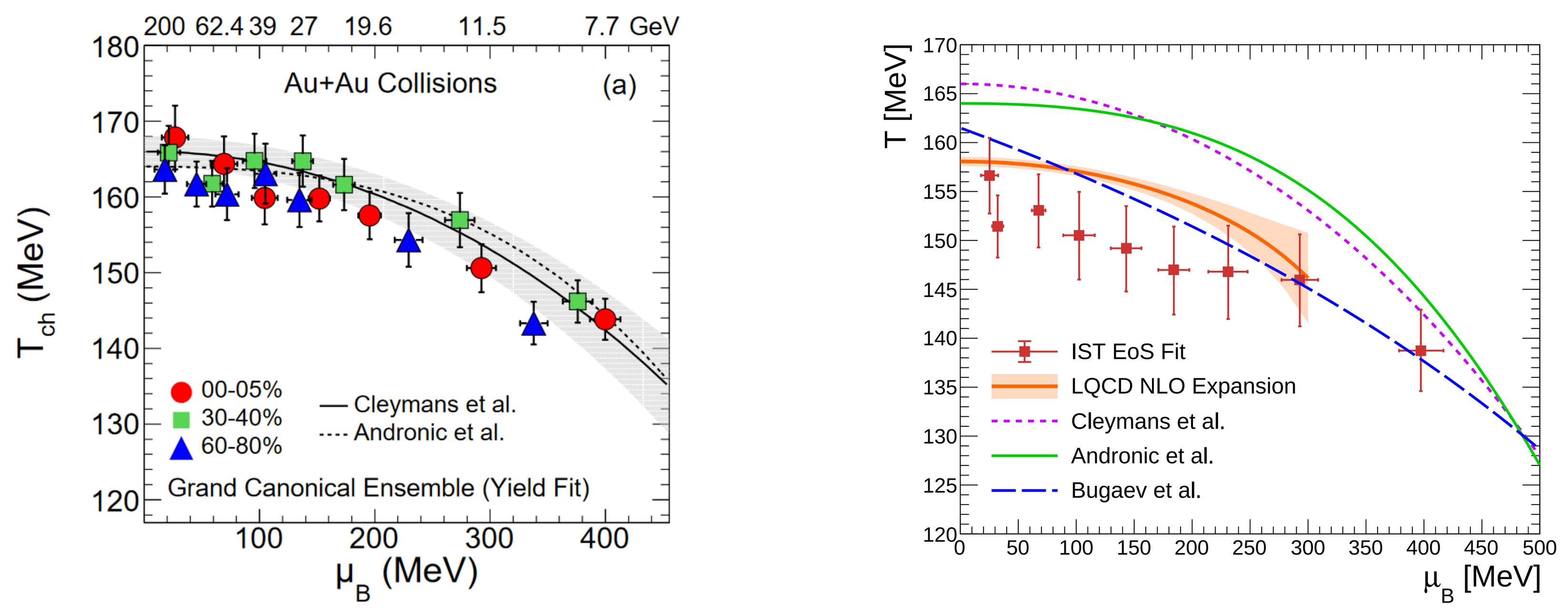

Figure 2: Parametrization of the chemical freeze-out temperature (T_{ch}) on baryon chemical potential (μ_B) dependence made by J. Cleymans and A. Andronic [3, 4] (left) and obtained with the IST EOS [5] (right).

The results obtained with IST EOS with inclusion of weak decays in accordance with experimental data allow us to decrease temperature of chemical freeze-out on 10 MeV. As a result the chemical freeze-out points found by IST EOS belong to the hadronic phase (the left panel of Fig. 2) as it is supposed to be.

Conclusions

IST EOS is the best tool to describe the particle yields and to get chemical freeze-out parameters. Inclusion of weak decays:

- Brings the chemical freeze-out temperature to the right track. It gets lower than LQCD predictions for pseudocritical T
- Provides an excellent decription of the STAR data
- Now the chemical freeze-out parameters of STAR and ALICE data are consistent with each other.

References

[1] K. A. Bugaev et al., Nucl. Phys. A. 970 (2018)
[2] P.-M. König, R. Roth, and K. R. Mecke, Phys. Rev. Lett. 93 (2004) 160601
[3] A. Andronic, P. Braun-Munzinger, and J. Stachel, Nucl. Phys. A 834 (2010)
[4] J. Cleymans, H. Oeschler, K. Redlich, and S. Wheaton, Phys. Rev.C 73, 034905 (2006).
[5] K. A. Bugaev et al., Ukr. J. Phys. 61 (2016), No 8, 659