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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Outline

- Motivation and introduction
- IST EOS
- Features and advantages of the IST EOS
- New fit: model parameters and data
- Newest results of the IST EOS with inclusion of weak decays for STAR data
- Conclusions

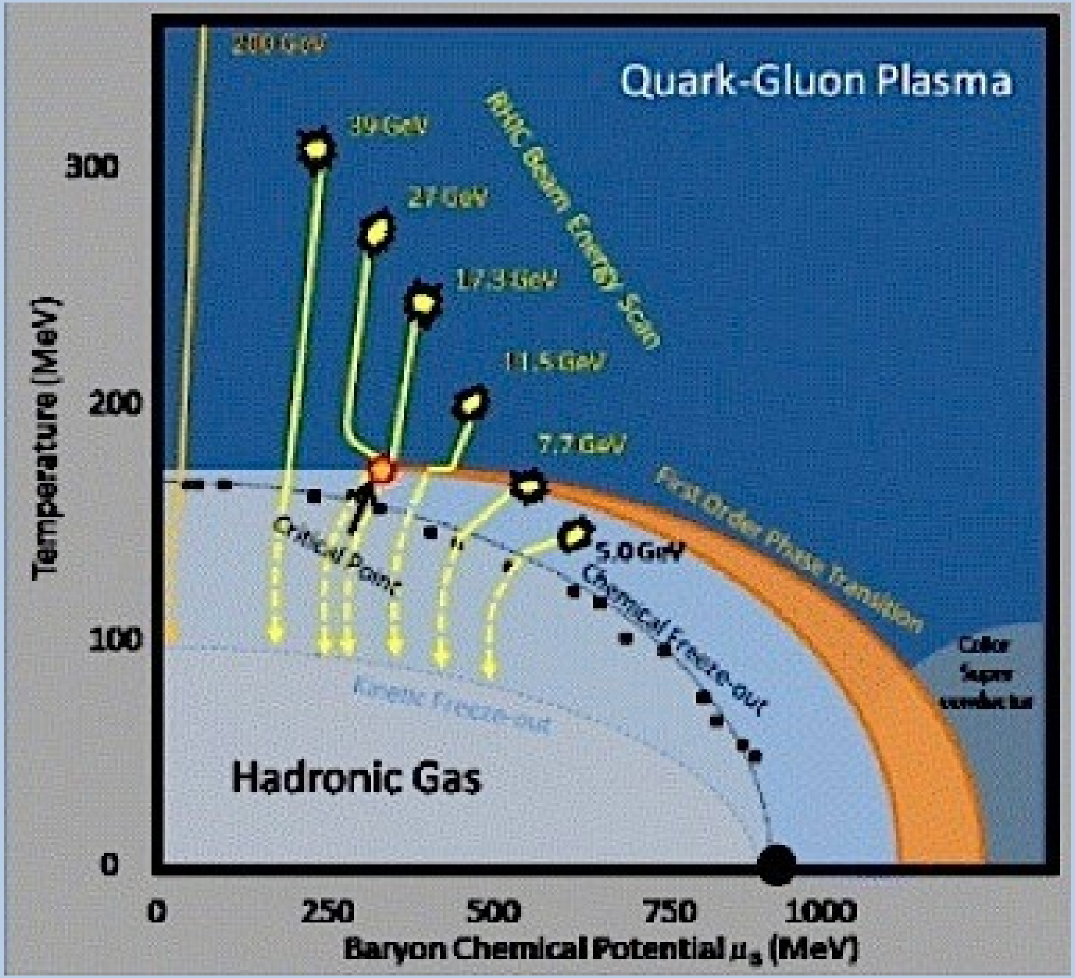
Motivation

The main goal to study heavy ion physics is understanding theory of strong interaction - QCD.

Exploring of the QCD phase diagram:

- detect signals of colour deconfinement;
- detect signals of chiral symmetry restoration;
- locate critical endpoint of QCD phase diagram.

In order to resolve these tasks we need a very good tool to analyze the data!



Induced Surface Tension EOS

pressure

induced surface tension coefficient

$$\begin{cases} p = T \sum\limits_{k=1}^{N} \phi_k \exp\left[\frac{\mu_k - pV_k - \Sigma S_k}{T}\right], \\ \Sigma = T \sum\limits_{k=1}^{N} R_k \phi_k \exp\left[\frac{\mu_k - pV_k - \alpha \Sigma S_k}{T}\right]. \end{cases}$$

R_k , V_k and S_k are hard-core radius, eigenvolume and eigensurface of hadron of sort k

Advantages

➔ It 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 α = 1.245.

➔ Number of equations is 2 and it does not depend on the number of different hard-core radii!

V.V. Sagun, K.A.Bugaev, A.I. Ivanytskyi, D.R. Oliinychenko, EPJ Web Conf 137 (2017);
K.A.Bugaev, V.V. Sagun, A.I. Ivanytskyi, E. G. Nikonov, G.M. Zinovjev et. al., Nucl. Phys. A 970 (2018) 133-155

Success of IST EOS is not accidental!

IST EOS is truncated version of Morphological Thermodynamics

For a convex rigid body r immersed into a fluid with:

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

Grand potential Ω = (Landau) free energy

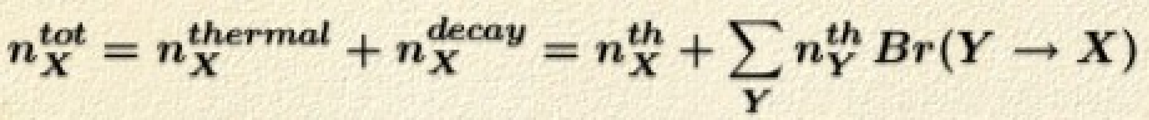
$\Delta \Omega = - V_r\, p - S_r\, \Sigma - C_r\, K - X_r\, \Psi$ (rigid body inside fluid)

Here V_r is eigenvolume, S_r eigensurface, C_r eigenperimeter, X_r — Euler characteristics. **P.-M. König, R. Roth, and K. R. Mecke, Phys. Rev. Lett. 93 (2004) 160601**

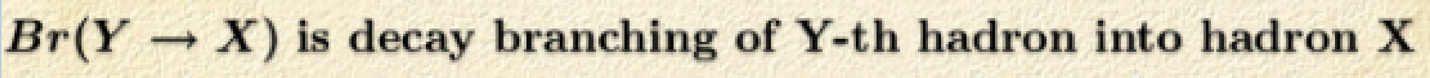
Resonances width

- The resonance width is taken into account in thermal densities as it is crucial in a thermal model

- For instance, description of pion yields cannot be achieved without it inclusion: m_σ = 484 ± 24 MeV, width Γ_σ = 510 ± 20 MeV



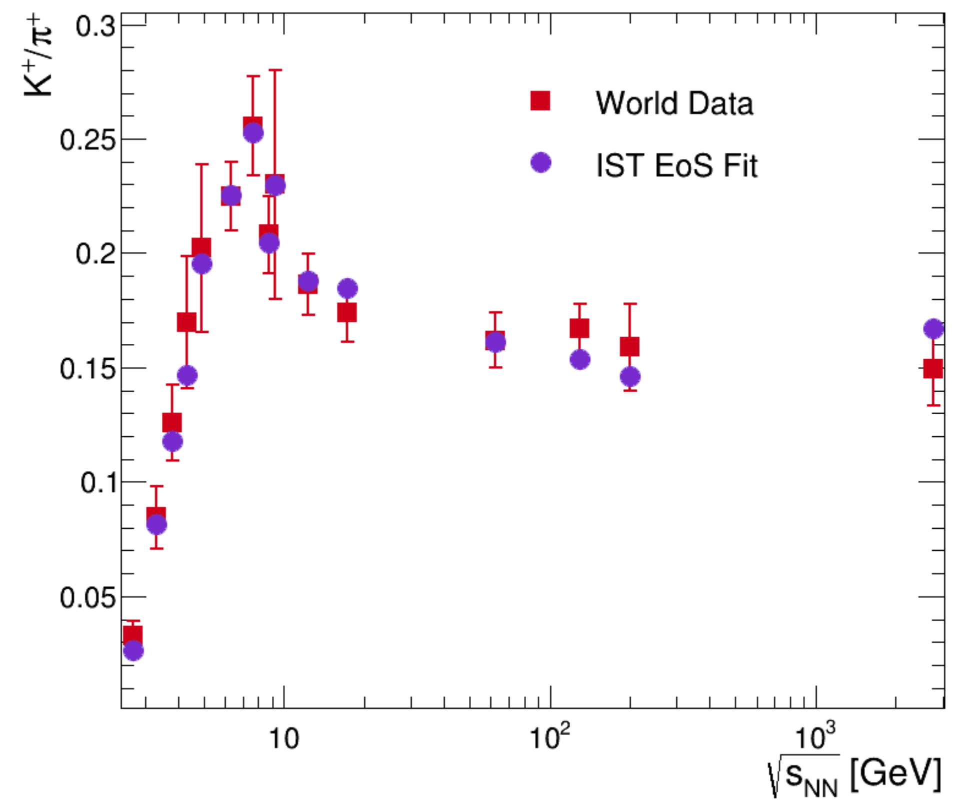
$$n_X^{tot} = n_X^{thermal} + n_X^{decay} = n_X^{th} + \sum_Y n_Y^{th}\, Br(Y \to X)$$



$Br(Y \to X)$ is decay branching of Y-th hadron into hadron X

- Fit of the particle ratios gives smaller systematic uncertainties than fitting of yields

Results of the IST EOS without weak decays



- K^+/pi$^+$ is the most problematic ratio for decription by different models
- IST EOS with additional radii for kaons and pions provides a good decription of experimental world data

New fit: model parameters and data

- For fitting was used experimental data from STAR Collaboration at energies: 7.7 — 200 GeV.

- Local fit parameters for each collision energy (5):

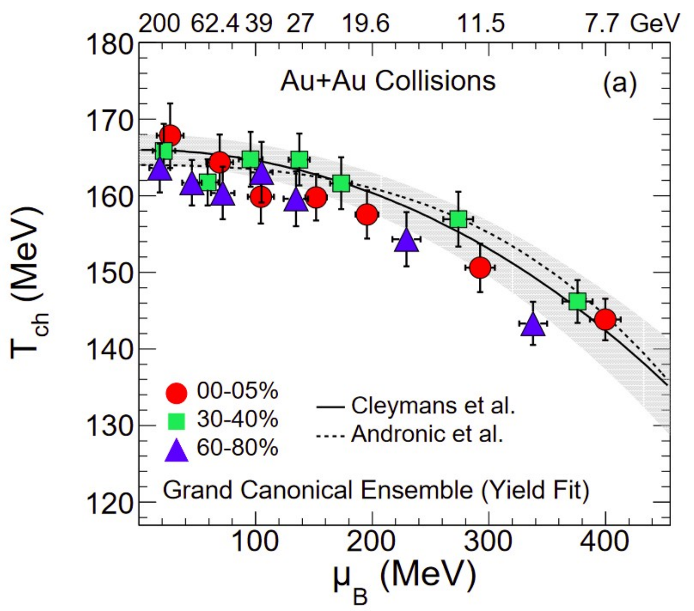
$$\mathbf{T, \mu_B, \mu_{I3}, \mu_S, \gamma_S}$$

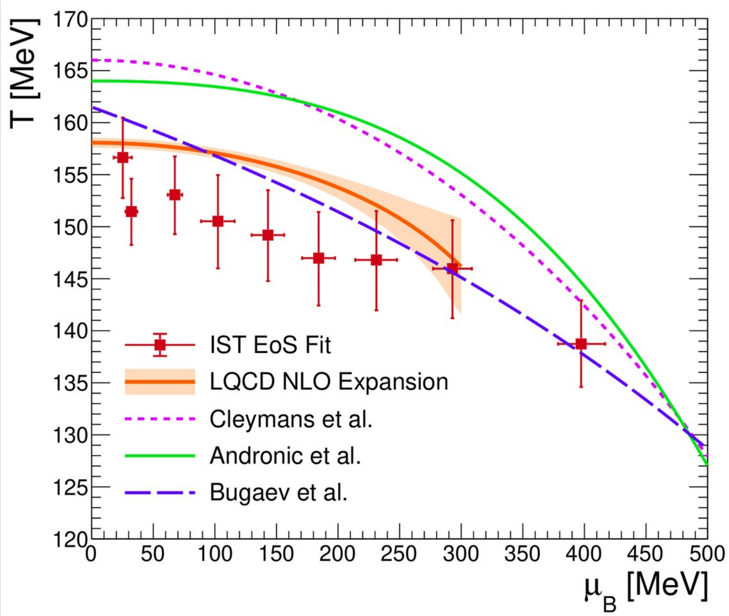
- Global fit parameters (5):

$$\mathbf{R_\pi, R_K, R_{mesons}, R_{baryons}, R_\Lambda}$$

- **IMPORTANT** that inclusion of weak decays should be made according to experimental analysis

Results of the IST EOS with inclusion of weak decays for STAR data





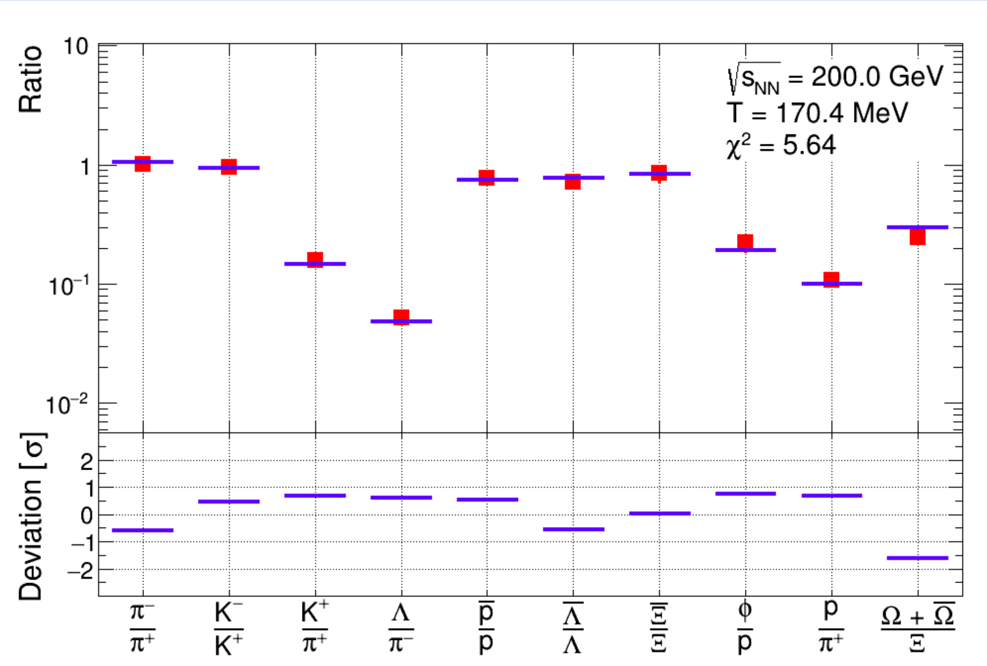
STAR Collaboration

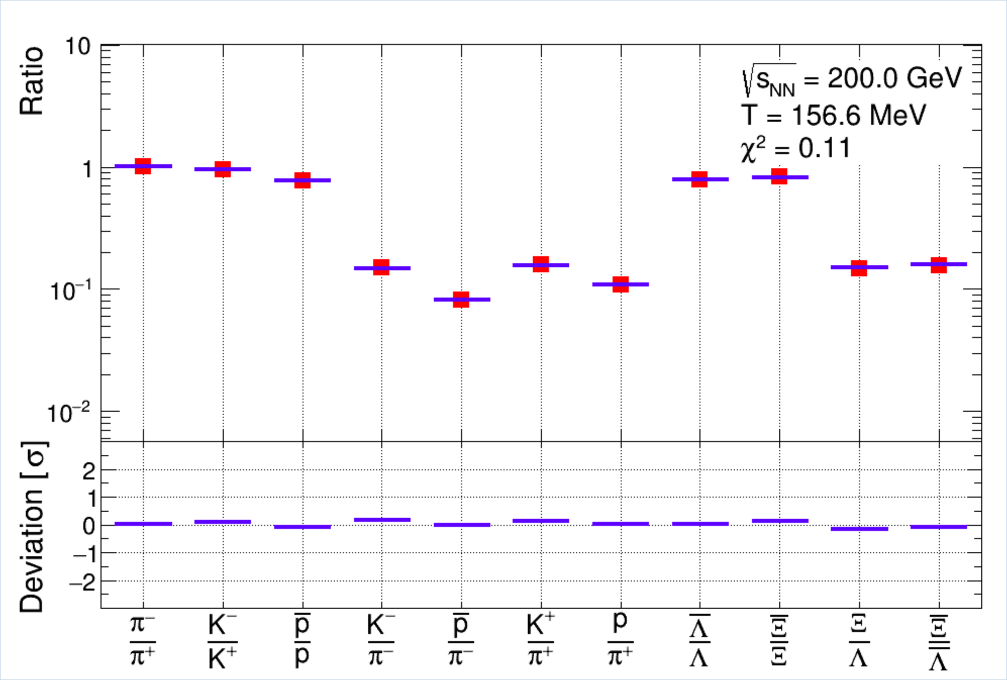
Data with √s> 27 GeV has T~160-170 MeV

Inclusion of weak decays **decrease** temperature of chemical freeze-out **on 10 MeV!**

A. Andronic, P. Braun-Munzinger, and J. Stachel, Nucl.Phys.A 834, 237c (2010).
K. A. Bugaev et al., Ukr. J. Phys. 61, (2016), No 8, 659
J. Cleymans, H. Oeschler, K. Redlich, and S. Wheaton,Phys. Rev.C 73, 034905 (2006).
B. Szabolcs et al., Phys. Rev. Lett. 125, 052001 (2020)

Results of the IST EOS with inclusion of weak decays for STAR data





Without inclusion of weak decays

With inclusion of weak decays

- Inclusion of weak decays **greatly** improves the decription of particle ratios in the experimental data (**50 times better** in this case)

Conclusions

- IST EOS is a good tool to decribe the particle yields and to get chemical freeze-out parameters

- Inclusion of weak decays:
    - Brings the chemical freeze out T 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 T of STAR and ALICE data are consistent with each other