Chemical freeze-out of hadrons within the advanced Hadron Resonance Gas Model

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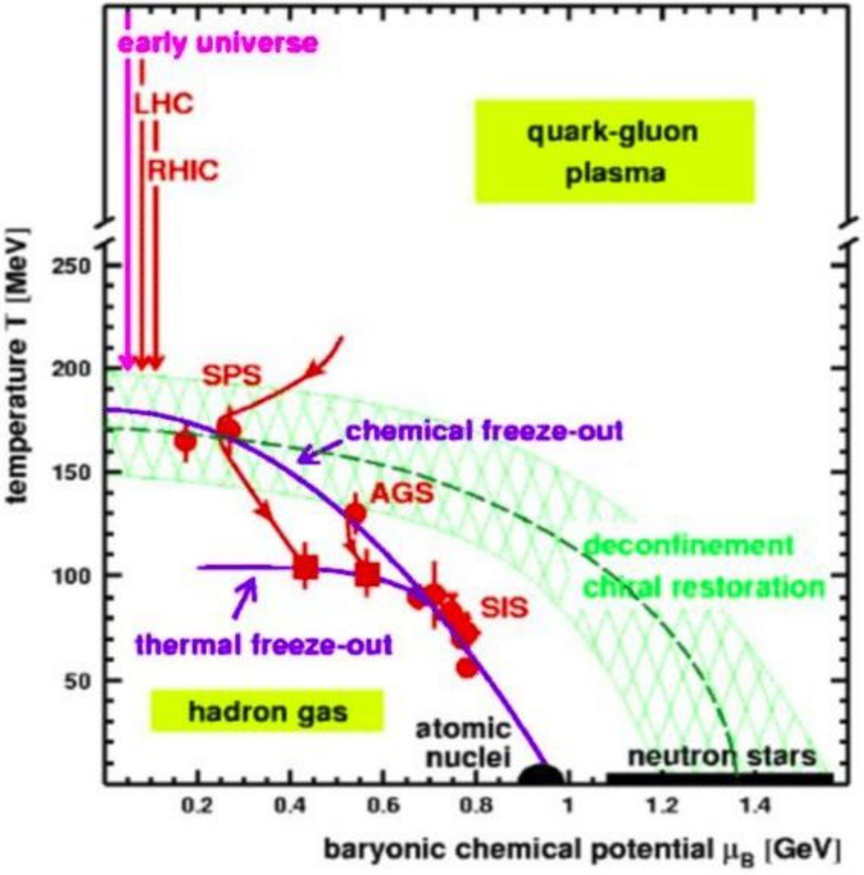
Motivation

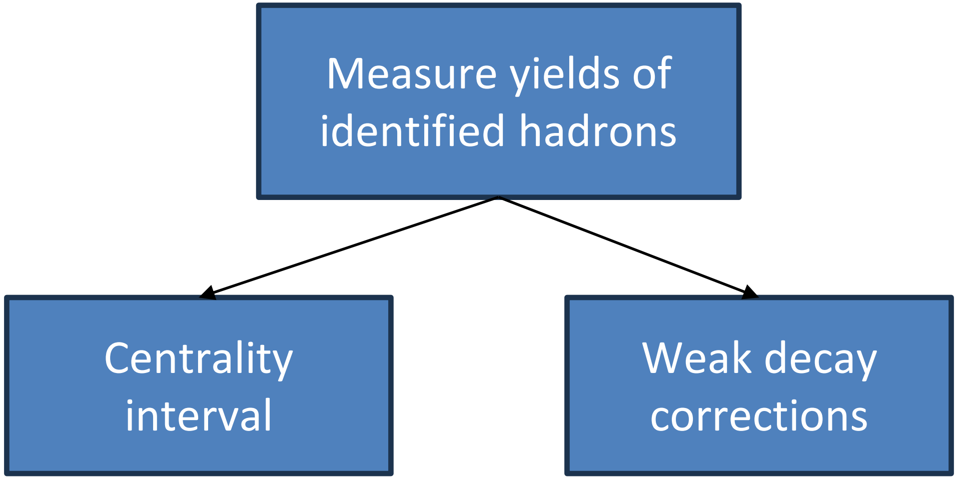
Exploring of the QCD phase diagram:

- 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 good tool to analyze the data.



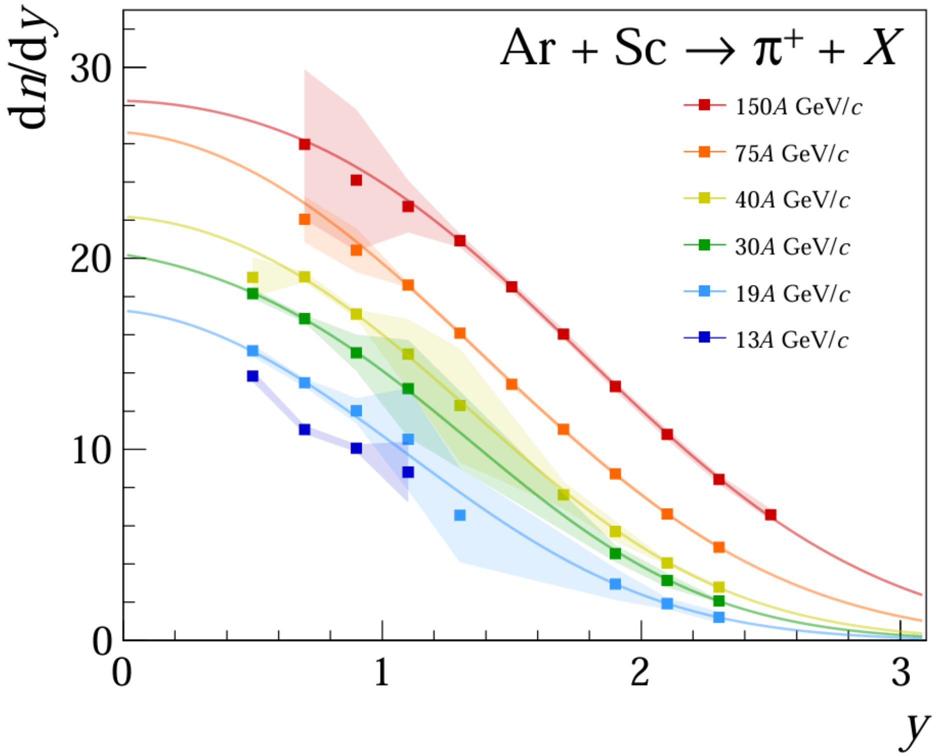
Motivation



Measure yields of identified hadrons

Centrality interval

Weak decay corrections



- Theoretical model should make feed-down corrections consistently with experimental analysis
- Particle ratios should be taken within the same centrality interval

Induced Surface Tension EOS

System of coupled equations between the pressure p and the induced surface tension coefficient Σ:

$$\begin{cases} p = \sum_{k=1}^{N} p_k^{Id}(T, \nu_k^P) \\ \Sigma = \sum_{k=1}^{N} R_k p_k^{Id}(T, \nu_k^S) \end{cases}$$

$$n_k^{Id}(T, \mu) = \frac{g_k}{2\pi^2\hbar^3} \int_0^\infty \frac{p^2 dp}{\exp[(E-\mu)/T] \pm 1}$$

$$p_k^{Id}(T, \mu) = \frac{g_k}{2\pi^2\hbar^3} \int_0^\infty \frac{p^4 dp}{3E} \frac{1}{\exp[(E-\mu)/T] \pm 1}$$

Effective chemical potentials:

$$\nu_k^S = \mu_k - pV_k - \alpha\Sigma S_k$$

$$\nu_k^P = \mu_k - pV_k - \Sigma S_k$$

V. V. Sagun et al., EPJ Web of Conferences 137 (2017) 09007

K. A. Bugaev et al., Nucl. Phys. A 970 (2018) 133-155

Induced Surface Tension EOS

Particle number density of kth sort:

$$n_k = \frac{a_{22} n_k^{Id}(T, \nu_k^{Id}) - a_{12} R_k n_k^{Id}(T, \nu_k^{S})}{a_{11} a_{22} - a_{12} a_{21}}$$

$$a_{11} = 1 + \sum_{k=1}^{N} V_k n_k^{Id}(T, \nu_k^{P})$$

$$a_{22} = 1 + \alpha \sum_{k=1}^{N} S_k R_k n_k^{Id}(T, \nu_k^{S})$$

$$a_{12} = \sum_{k=1}^{N} S_k n_k^{Id}(T, \nu_k^{P})$$

$$a_{21} = \sum_{k=1}^{N} V_k R_k n_k^{Id}(T, \nu_k^{S})$$

Advantages

- 2 equations, its number does not depend on the number of different hard core radii
- Allow one to go beyond the Van der Waals approximation, since it reproduces 2nd, 3rd and 4th virial coefficients of the gas of hard spheres for α = 1.245

V. V. Sagun et al., EPJ Web of Conferences 137 (2017) 09007

K. A. Bugaev et al., Nucl. Phys. A 970 (2018) 133-155

IST EOS settings

Experimental data: STAR Collaboration

Energies: **7.7 — 200 GeV**

Local fit parameters: **T, μ_B, μ_{I3}, μ_S, γ_S**

Global fit parameters: **R_π, R_K, R_{mesons}, $R_{baryons}$, R_Λ**

Global parameters were fixed as:

R_π = 0.15 fm,

R_K = 0.395 fm,

R_{mesons} = 0.42 fm,

$R_{baryons}$ =0.365 fm,

R_Λ = 0.085 fm

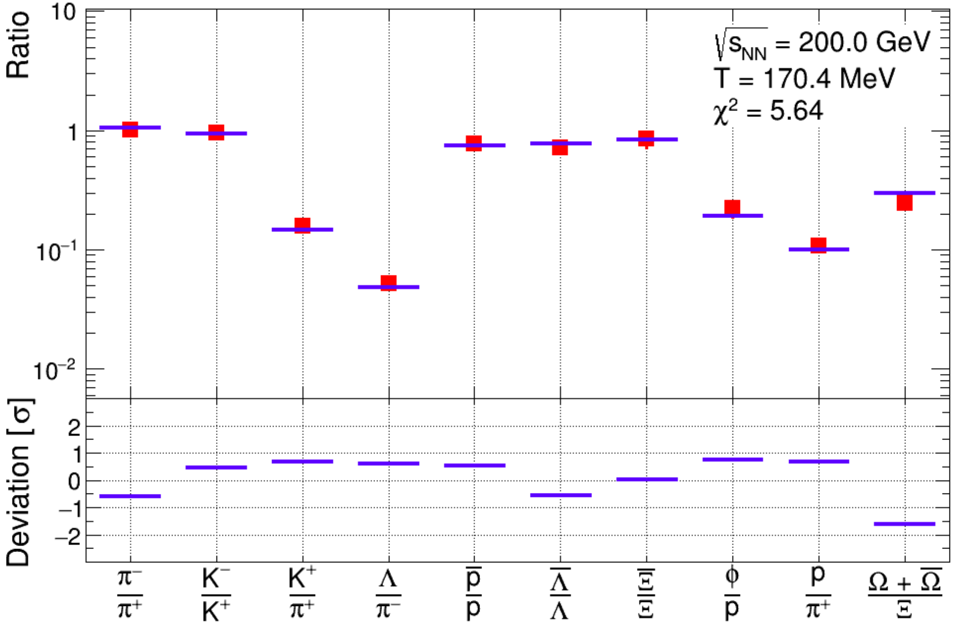
A. Andronic et al., Nucl. Phys. A 834 (2010) 237c

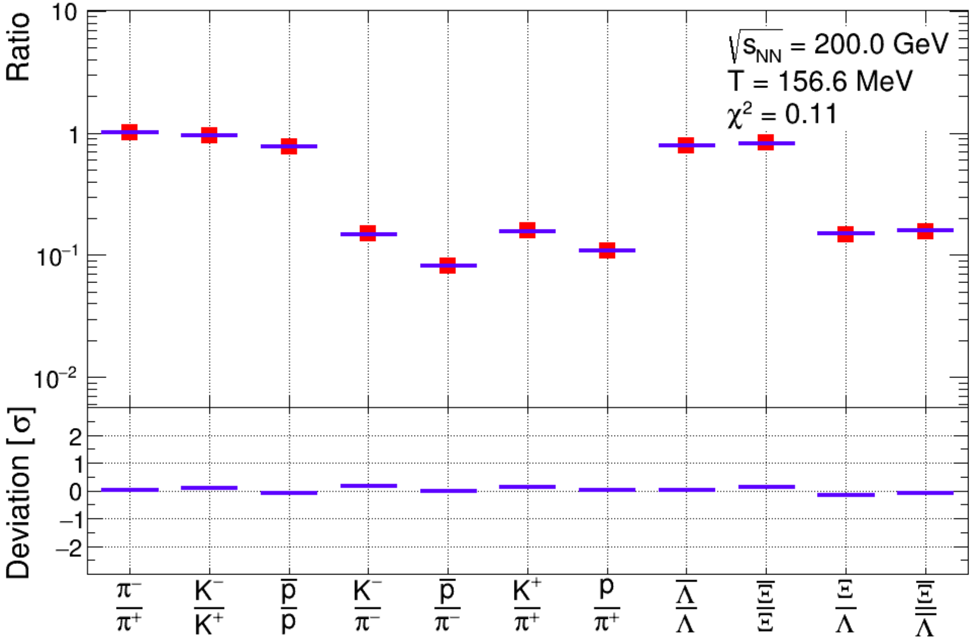
K. A. Bugaev et al., Ukr. J. Phys. 61 (2016) no. 8, 659

J. Cleymans et al., Phys. Rev. C 73 (2006) 034905

S. Borsanyi et al., Phys. Rev. Lett. 125 (2020) 052001

IST EOS fit result of STAR data at 200 GeV



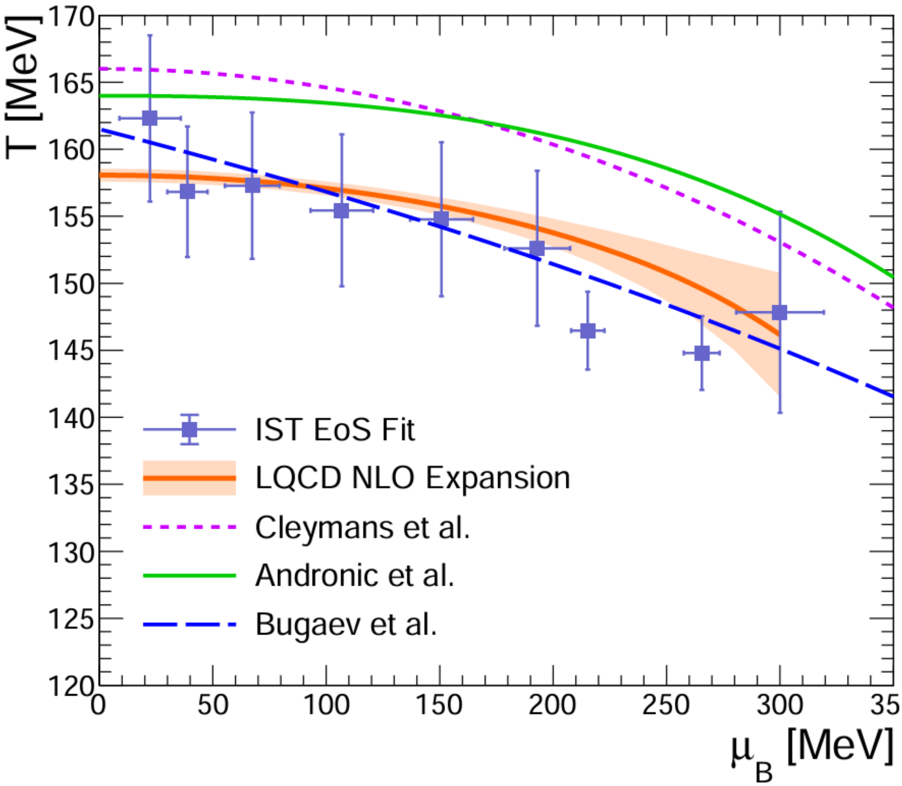


- Inclusion of weak decays **greatly** improves the description of particle ratios in the experimental data (**50 times better** in this case).

Inclusion of weak decays for STAR data in the IST EOS

Fit by STAR Collaboration for $\sqrt{s}$>200 GeV has T~154 MeV

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



A. Andronic et al., Nucl. Phys. A 834 (2010) 237c

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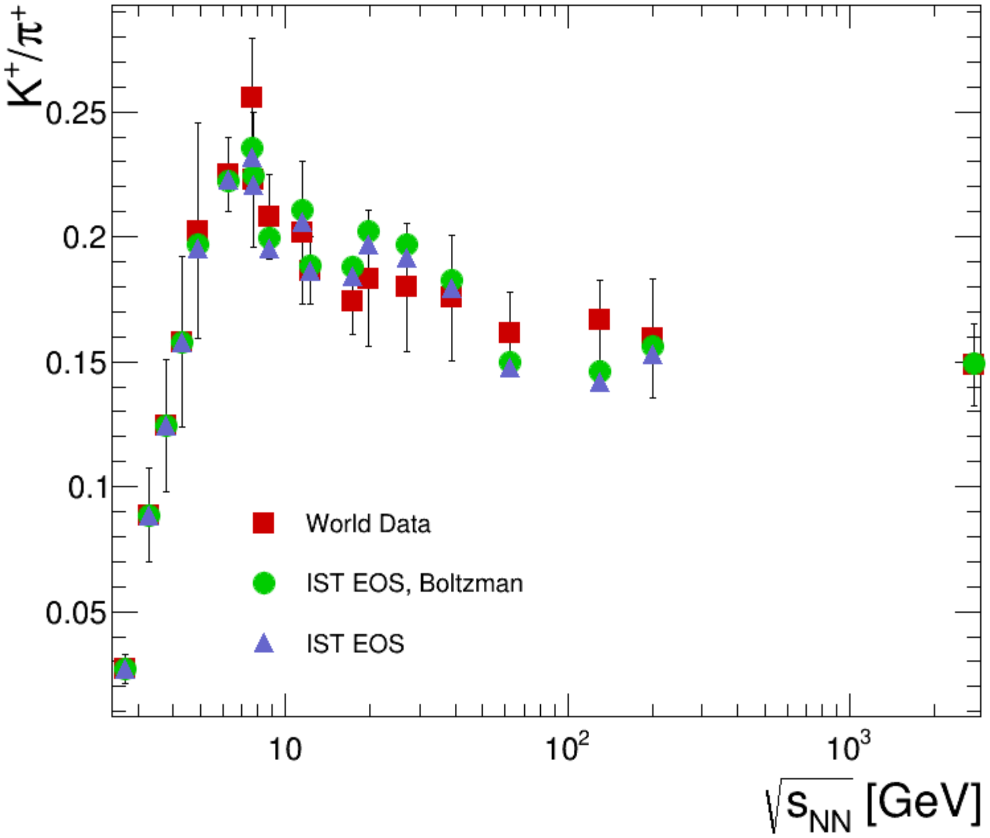
Results of the IST EOS with weak decays for K^+/π^+ ratio



- K^+/π^+ is the most problematic ratio for decription by different models
- Inclusion of weak decays greatly improves the description of particle ratios in the experimental data

Conclusions

- IST EOS is a good tool to decribe particle yields and to get chemical freeze-out parameters
- An updated version of this model allows the fitting of ratios, taking into account both inclusive and exclusive feed-down corrections consistently with experimental analysis
- Brings the chemical freeze-out temperature to the right track. It gets lower than LQCD predictions for pseudocritical T
- Provides a good description of the particle ratios from the existing experimental data
- The chemical freeze-out parameters from the IST EOS fits for STAR and NA49 data are close to the LQCD calculations.

Back up

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: $m_\sigma = 484 \pm 24$ MeV, width $\Gamma_\sigma = 510 \pm 20$ MeV

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

$\mathrm{Br}(\mathrm{Y} \to \mathrm{X})$ – decay branching of Yth hadron into X

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