Freezeout conditions and dynamical fluctuations within UrQMD and HRG approaches at high density

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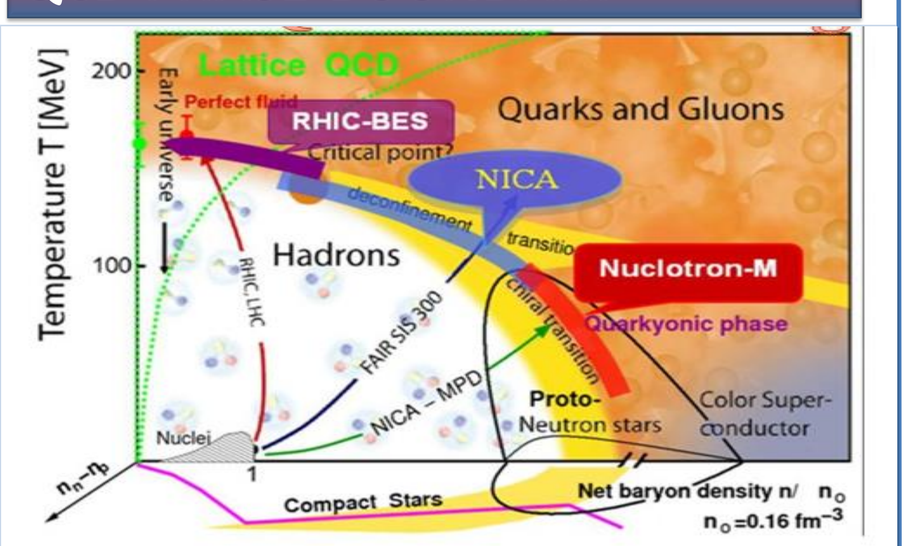
ABSTRACT

The dependence of different particle ratios on the beam energy, which can be related to the chemical potential, is studied within the hadron resonance gas (HRG) and Ultra-relativistic Quantum Molecular Dynamic (UrQMD) approach. For UrQMD two different types of phase transitions are taken into consideration; crossover and first order, while HRG implements fully statistical aspects in describing the particle production and their correlations in their final state. The calculations cover energies ranging from 3 to 39 GeV. The freezeout parameters, temperature (T) and baryon chemical potential , are deduced by fitting the particle ratios estimated from hybrid UrQMD with the calculation from HRG at 11.5, 19.6, 27, and 39 GeV, which are chosen to compare with STAR BES. The results agree well with the parameters which are independently determined from statistical fitting of the experimentally measured particle ratios. A significant fluctuation occurs when the QGP undergoes phase transition to the hadronic one.

Furthermore, the net-charge fluctuations for UrQMD ratios K/π, P/π and K/P, and from HRG are compared with the available STAR and NA49 measurements. The good agreement justifies the conclusion that both UrQMD and HRG are suitable to explain both freezeout parameters and the dynamical net-charge fluctuations.

QCD PHASE-BOUNDARY



The Models

1-Hadron Resonance Gas (HRG)

All thermodynamics, like number density, pressure, energy density and entropy can be extracted from the partition function [1]

$$\ln Z(T,\mu,V) = \sum_i \ln Z_i^1(T,V) = \sum_i \pm \frac{V g_i}{2\pi^2} \int_0^\infty p^2 dp \ln\left\{1 \pm \exp\left[\frac{\mu_i - \varepsilon_i(p)}{T}\right]\right\} \quad (1)$$

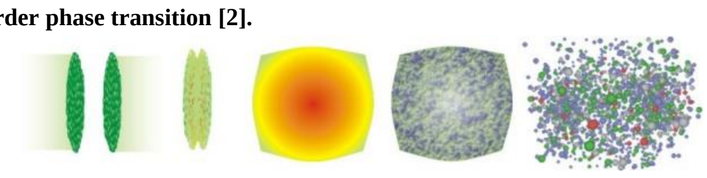
where + and - signs stand for bosons and fermions, respectively, $\varepsilon_i = \sqrt{p^2 + m_i^2}$

$$\mu_i = B_i\mu_B + S_i\mu_S + Q_i\mu_Q$$

μ_{Bi}, μ_S, μ_Q are the chemical potentials related to baryon number, strangeness and electric charge, respectively.

2- Ultra relativistic Quantum Molecular Dynamic (UrQMD) Model

UrQMD event-generator [2] is a well-known approach enabling simulations of high-energy collisions. It implements a large set of Monte Carlo solutions for a large number of paired partial-differential equations describing the evolution of phase-space densities. Its large number of unknown parameters could be fixed from experimental results and theoretical assumptions [2]. Two types of phase transition; first order and crossover, can be assumed. In case of crossover, equations of state of fluid dynamical evolution are utilized in the hybrid UrQMD event-generator, while MIT bag model and HRG approaches are used in case of first-order phase transition [2].



RESULTS AND DISCUSSION

Freezeout parameters at high density

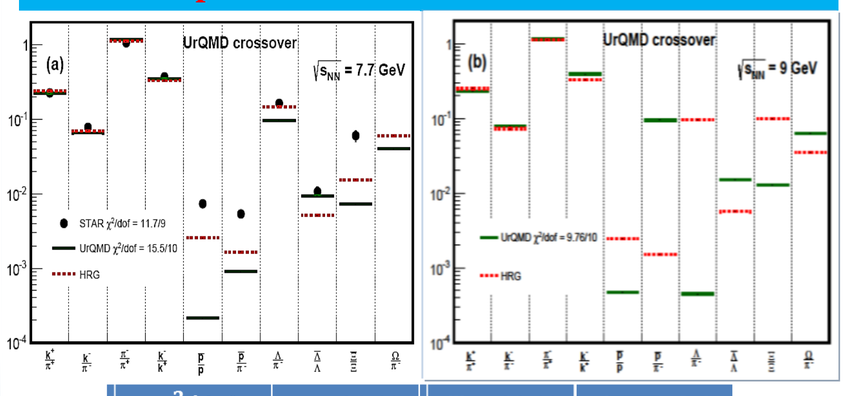
The basic idea is to adjust calculations of particle ratios in a HRG model to experimental data. T_{CH} and μ_b are taken from the best-matching HRG result.

At NICA energies there is lack of experimental data so far; mostly we have some results from STAR BES.

Therefore we used UrQMD calculations as a kind of interpolation. This is acceptable if we can show that T_{CH} and μ_b derived from STAR data and UrQMD are in good agreement.

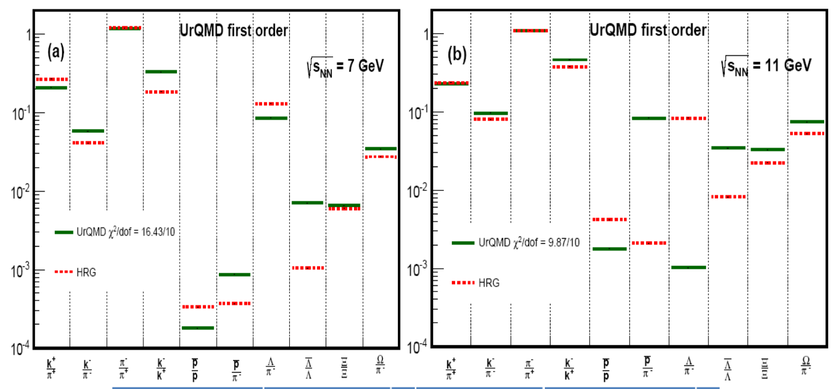
Throughout these energies, **ten particle** ratios are calculated.

Crossover phase-transition

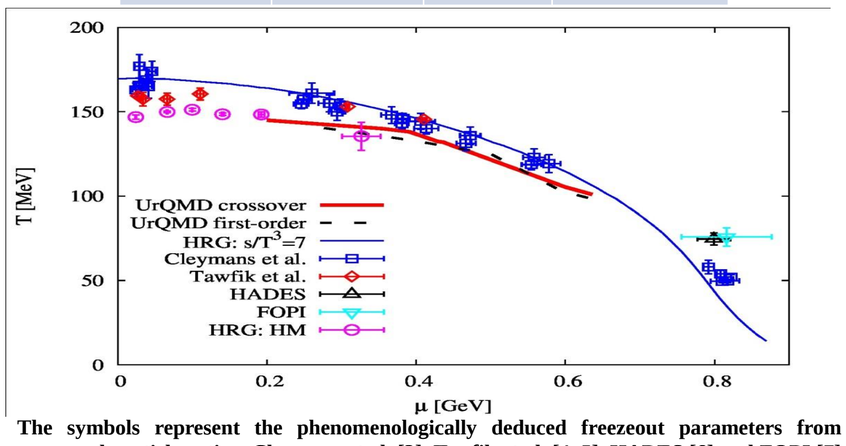


χ^2/dof	μ_b MeV	T_{CH} MeV	$\sqrt{s_{NN}}$ GeV
3	101	636	6.3/6
5	105.5	599	5/6
7.7	132	436	15.5/10
9	132.4	429	9.76/10
11.5	138.1	391	8.95/10
13	140	355	10.47/10
19.6	145	200	8.58/10
27	147	160	8.403/10
39	150	120	14.7/10

First-order phase-transition



χ^2/dof	μ_b MeV	T_{CH} MeV	$\sqrt{s_{NN}}$ GeV
3	99	630	6.4/6
5	103	595	5.2/6
7	125	551	16.43/10
11	133	395	9.87/10
19	142	250	8.43/10
27	143.5	165	3.16/10
39	145	125	6/10

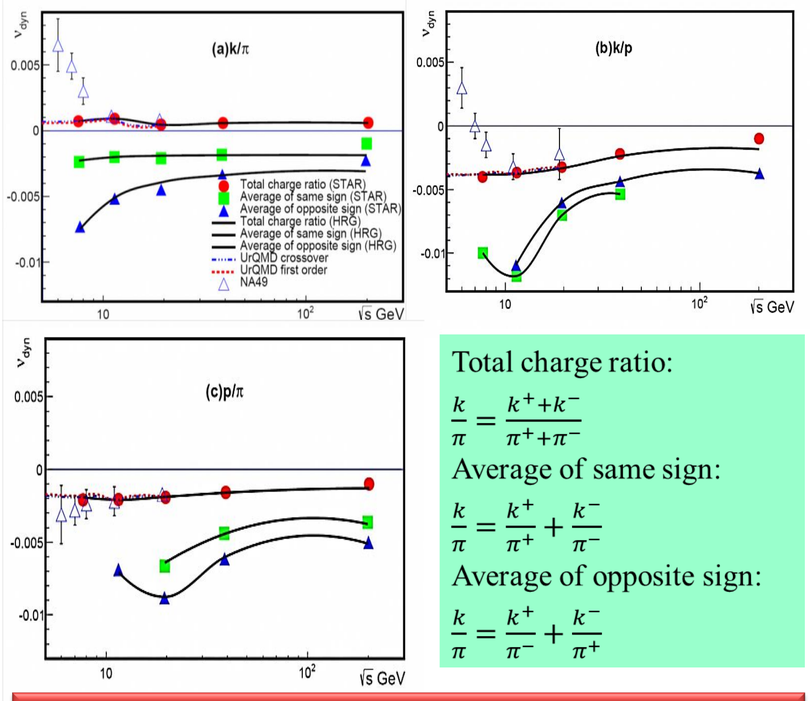


The symbols represent the phenomenologically deduced freezeout parameters from measured particle ratios: Cleymans et al. [3], Tawfik et al. [4, 5], HADES [6] and FOPI [7] and measured higher-order moments: SU(3) Polyakov linear-sigma model (PLSM) [8] and HRG [9].

Dynamical Net-charge fluctuations

Phase transition has well known signatures such as fluctuations of the net charge [10]. A significant fluctuation occurs when the QGP undergoes phase transition to the hadronic one. The Relativistic Heavy Ion Collider (RHIC) start to search for the QCD critical point by making an energy scan of Au+Au collisions from low energy ($\sqrt{S_{NN}}$=7.7 GeV) up to high energies ($\sqrt{S_{NN}}$=200 GeV). The net charge fluctuations as a signal of quark-gloun plasma (QGP) are calculated in terms of the parameter ν_{dyn}, which is derived as given below:

$$\nu_{dyn,p/\pi} = \frac{\langle N_p(N_p-1)\rangle}{\langle N_p\rangle^2} + \frac{\langle N_\pi(N_\pi-1)\rangle}{\langle N_\pi\rangle^2} - 2\frac{\langle N_p N_\pi\rangle}{\langle N_p\rangle\langle N_\pi\rangle} \quad (2)$$



Total charge ratio:

$$\frac{k}{\pi} = \frac{k^+ + k^-}{\pi^+ + \pi^-}$$

Average of same sign:

$$\frac{k}{\pi} = \frac{k^+}{\pi^+} + \frac{k^-}{\pi^-}$$

Average of opposite sign:

$$\frac{k}{\pi} = \frac{k^+}{\pi^-} + \frac{k^-}{\pi^+}$$

CONCLUSION

- Resulting freezeout parameters from hybrid UrQMD agree well with the HRG calculations, in which higher-order moments of the net-proton multiplicity are utilized.
- Resulting freezeout parameters seem not influenced by the type of the quark-hadron phase-transition.
- Charge dependences of dynamical net-charge fluctuations are calculated for k/π, k/p and p/π ratios from ν_{dyn} by using UrQMD and HRG approaches and compared with NA49 and STAR measurements.
- Dynamical fluctuations:
  - excellently agree with the STAR BES, NA49 at top SPS
  - disagree at low SPS energies.

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