Higher order fluctuations of strangeness and flavor hierarchy

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Introduction

Experimentally, one cannot explore the entire phase space of the events coming from a *Heavy Ion Collision* (HIC). This leads to fluctuations in conserved quantum number multiplicities which can be determined from charged particle distributions.

Modeling the HICs, we can use these fluctuations to extract the parameters (temperature T and chemical potential μ_B) at which the chemical freeze-out (FO) takes place.

Fluctuations

Once the partition function $\mathcal{Z}$, which describes the system, is set, the moments of the multiplicity distribution for a conserved charge are related to the fluctuations χ of the same charge, defined as follows:

$$\chi_{lmn}^{BSQ} = \frac{\partial^{l+m+n}\left(\ln \mathcal{Z}/(VT^3)\right)}{\partial\left(\mu_B/T\right)^l \partial\left(\mu_S/T\right)^m \partial\left(\mu_Q/T\right)^n}$$

mean: $M = \langle N\rangle = VT^3\chi_1,$

variance: $\sigma^2 = \langle(\delta N)^2\rangle = VT^3\chi_2,$

skewness: $S = \frac{\langle(\delta N)^3\rangle}{\sigma^3} = \frac{VT^3\chi_3}{(VT^3\chi_2)^{3/2}},$

kurtosis: $k = \frac{\langle(\delta N)^4\rangle}{\sigma^4} - 3 = \frac{VT^3\chi_4}{(VT^3\chi_2)^2};$

Such fluctuations can be calculated using various theoretical approaches, e.g. lattice QCD or the *Hadron-Resonance Gas* (HRG) model.

HRG model and FO

A system of interacting hadrons in the ground state can be described by a ***gas of non-interacting hadrons and resonances***.

The particle properties are taken from the *Particle Data Group*; we took into account particles with mass up to 2 GeV.

After the transition we call ***chemical freeze-out*** the point in the evolution at which inelastic scatterings of hadrons stop, so that hadron yields (and the higher moments) detected in the experiment are related to the microscopic situation immediately after the hadronization.

Experimental corrections

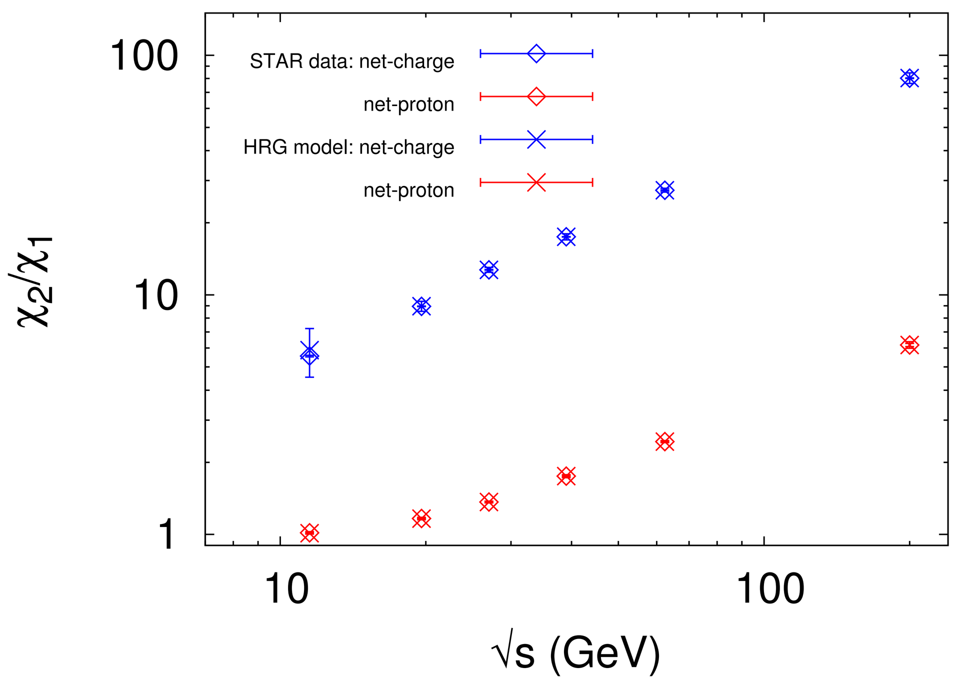
Various corrections can be implemented in the HRG model, in order to get closer to the experimental conditions:

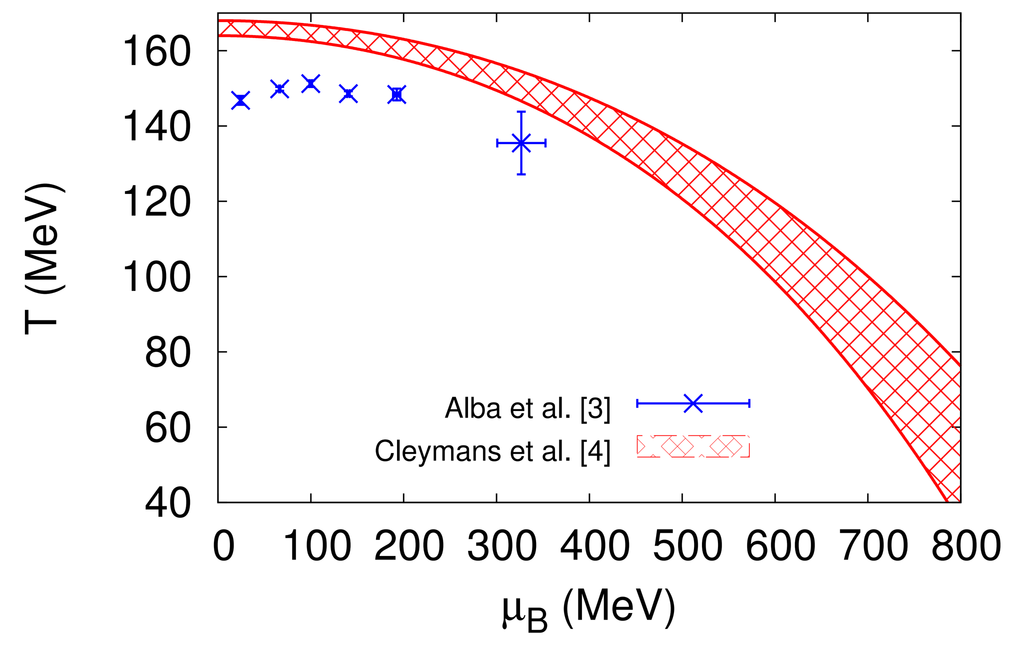
- cuts in the acceptance and kinematics of particle distributions (η and p_T);
- feed down corrections (weak decay and hadronic resonance decay);

Using the HRG model we can also perform finite density analyses. Each conserved charge can be broken down into contributions from individual particle species.

Net-electric charge and net-proton analysis

By fitting, for every collision energy, σ^2/M for the net-electric charge and net-proton data recently published by the STAR collaboration [1, 2], we successfully extract the freeze-out parameters (μ_Q and μ_S are fixed in order to satisfy the conditions $N_Q = 0.4N_B$ and $N_S = 0$).



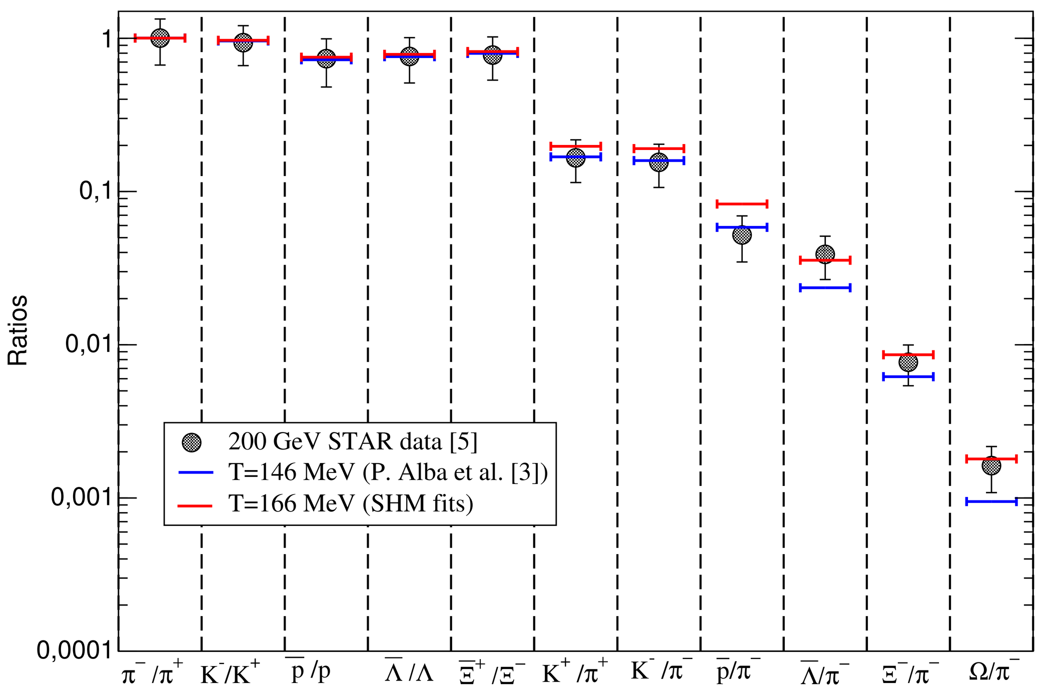


Cross-check with ratios of hadron yields

Using these new freeze-out parameters we successfully reproduce the ratios of yields for those particles which give the dominant contribution to electric charge and baryon number.

For the ratios of strange over non-strange particle yields, the agreement is generally worse.

This might be a signal for a *flavor hierarchy* in the chemical FO. We expect that higher order moments show a stronger sensitivity, allowing a better determination of the freeze-out parameters for strange hadrons.

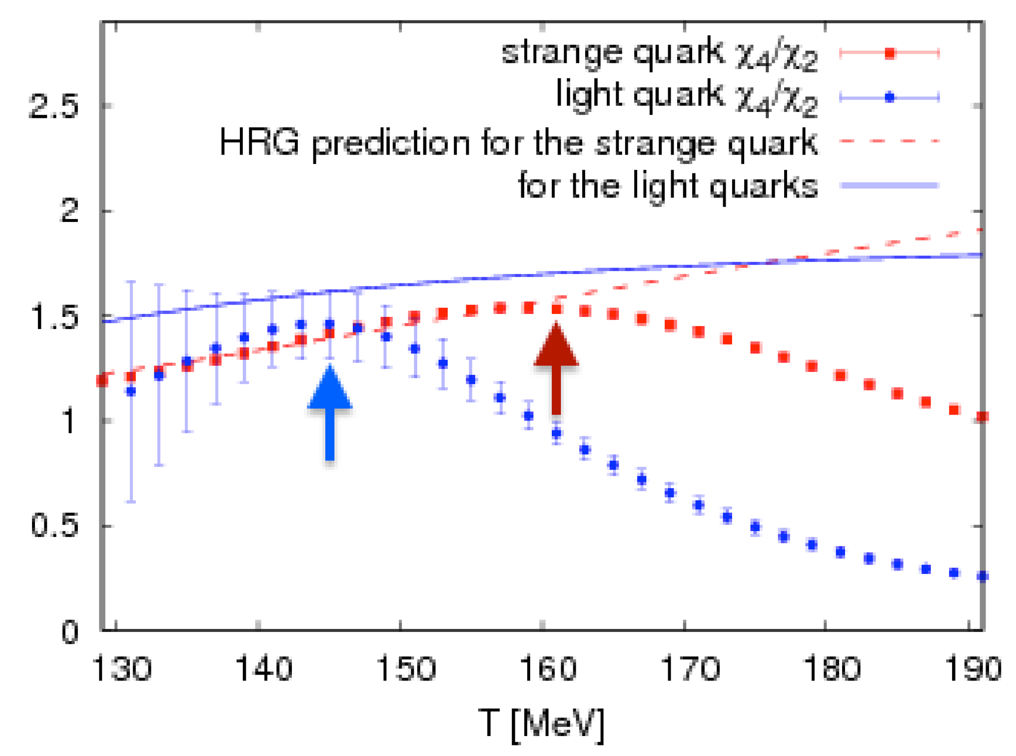


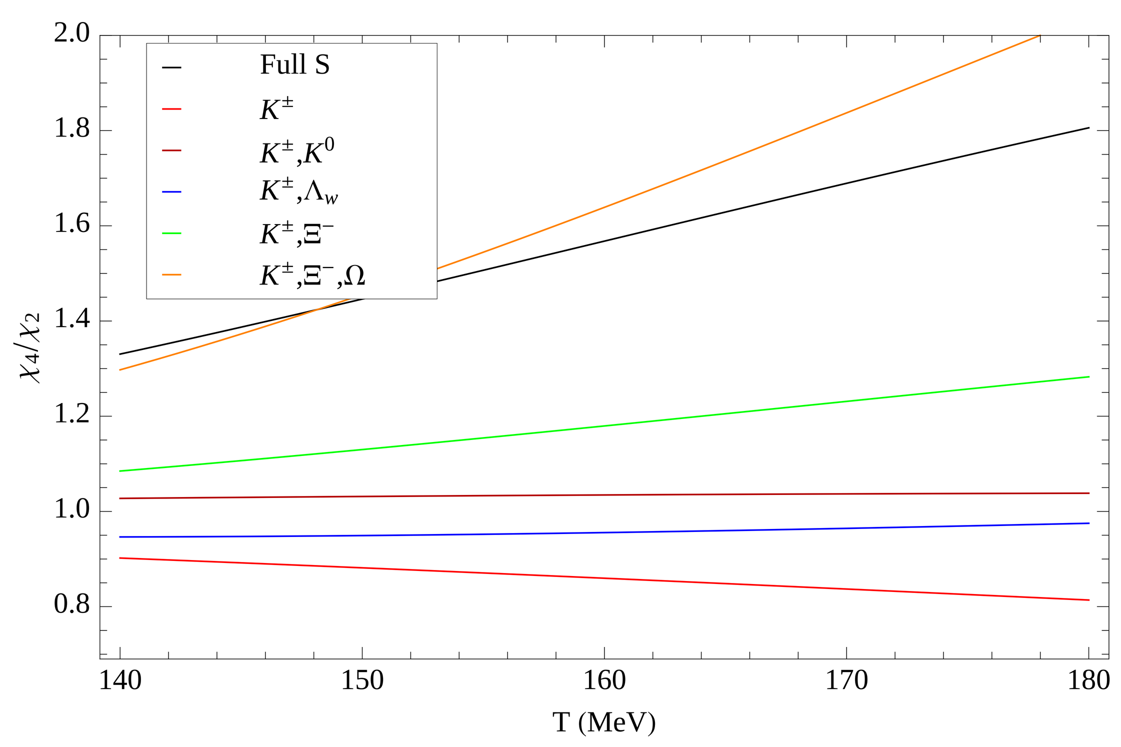
Higher order strangeness fluctuations

At the moment no efficiency corrected data for the moments of the strangeness multiplicity distribution has been published. Simulations of χ_4/χ_2 from lattice QCD are available [6]. In the hadronic phase they agree with the full HRG model results in chemical equilibrium, and they indicate a potential sensitivity of higher moments to a flavor hierarchy.

Within the HRG model we investigate different combinations of strange hadrons which could be measured experimentally in order to determine the χ_4/χ_2 that shows the highest sensitivity to the chemical freeze-out temperature.

For all the curves (except full HRG) the following cuts apply: $0.2 < p_T < 2$ GeV, $|\eta| < 0.5$. A study for lower moments, which can be measured with higher accuracy, is in progress.





Conclusions & Outlook

We determined FO parameters from net-electric charge and net-proton data from STAR. The analysis of particle ratios for these FO conditions shows problems in reproducing the ratios of strange over non-strange particles. A possible explanation would be a flavor hierarchy in the chemical FO. This idea is supported by recent lattice QCD results [6]. We propose to use higher order moments of the strangeness multiplicity distribution to study this issue in more detail.

References

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