

XXVIIth International Conference on Ultrarelativistic Nucleus-Nucleus Collisions
(Quark Matter 2018)

Cross-correlations of conserved charges from the lattice

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Abstract

We present a lattice calculation on the cross-correlations of conserved charges (baryon number, electric charge and strangeness) near the transition temperature. We extrapolate to small baryo-chemical potentials, and thus we cover typical STAR energies. We confront our finding to the latest STAR data set on cross-correlations. In this work we present continuum lattice results with resolution up to $N_t = 16$.

Keywords: lattice QCD, cross-correlations, phase diagram, finite density

1. Introduction

Correlations of conserved charges are important observables for the finite-density investigations. In this work we focus on the off-diagonal combinations. One possible way to extend lattice results to finite density is to perform Taylor expansions of the thermodynamic observables around chemical potential $\mu_B = 0$ [1, 2, 3, 4, 5]: fluctuations of conserved charges are directly related to the Taylor expansion coefficients of such observables. They allow for a comparison between theoretical and experimental results to extract the chemical freeze-out temperature T_f and chemical potential μ_{Bf} as functions of the collision energy [6, 7, 8, 9]. The higher order fluctuations are also an important signature for the critical endpoint, as they give access to the correlation length [3, 10, 11].

In this work we use analytical continuation from imaginary chemical potential [12, 13, 14, 15, 16]. It agrees well with the results of the Taylor expansion as shown for the transition temperature [17].

We simulate the lower-order fluctuations at imaginary chemical potential and extract the higher order fluctuations as derivatives of the lower order ones at $\mu_B = 0$. This method has been successfully used in the past and proved to lead to a more precise determination of the higher order fluctuations, compared to their direct calculation [18, 19, 17].

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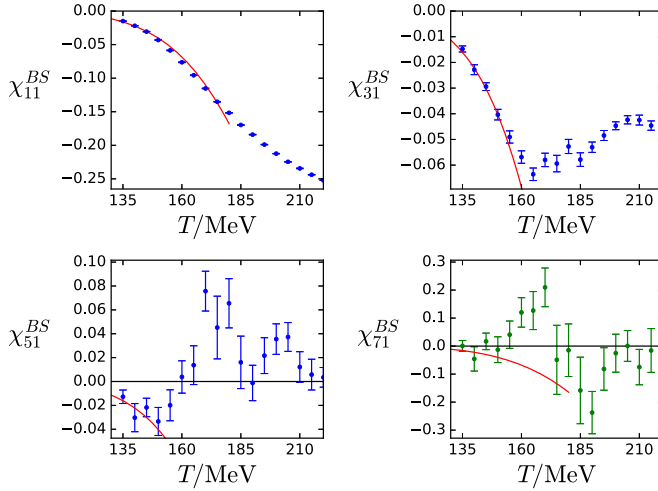


Fig. 1. Results for χ_{11}^{BS} , χ_{31}^{BS} , χ_{51}^{BS} and an estimate for χ_{71}^{BS} on a $N_t = 12$ lattice as functions of the temperature, obtained from the single-temperature analysis. We plot χ_{71}^{BS} in green to point out that its determination is guided by a prior, which is linked to χ_{31}^{BS} . The red curve in each panel corresponds to the Hadron Resonance Gas (HRG) model result. [20]

2. Cross-correlations on an $N_t = 12$ -lattice

We first present an analysis with high precision on an $N_t = 12$ lattice. A more detailed description as well as precise information on the lattice set-up can be found in ref. [20, 21]. In the following we use the notation $\chi_{i,j,k}^{B,Q,S} = \frac{\partial^{i+j+k}(p/T^4)}{(\partial\hat{\mu}_B)^i(\partial\hat{\mu}_Q)^j(\partial\hat{\mu}_S)^k}$, with $\hat{\mu} = \mu/T$. We make the ansatz

$$\chi_{01}^{BS}(\hat{\mu}_B) = \chi_{11}^{BS}\hat{\mu}_B + \frac{1}{3!}\chi_{31}^{BS}\hat{\mu}_B^3 + \frac{1}{5!}\chi_{51}^{BS}\hat{\mu}_B^5 + \frac{1}{7!}\chi_{71}^{BS}\hat{\mu}_B^7 + \frac{1}{9!}\chi_{91}^{BS}\hat{\mu}_B^9 \quad (1)$$

where $\frac{\chi_{31}^{BS}}{\chi_{71}^{BS}}$ and $\frac{\chi_{51}^{BS}}{\chi_{91}^{BS}}$ are constrained by a prior, normally distributed with $\mu = -1.25$ and $\sigma = 2.75$ and the independent fit parameters are χ_{11}^{BS} , χ_{31}^{BS} and χ_{51}^{BS} . The results which we obtain from a fully correlated fit to this ansatz and its first three derivatives $\chi_{11}^{BS}(\hat{\mu}_B)$, $\chi_{31}^{BS}(\hat{\mu}_B)$ and $\chi_{51}^{BS}(\hat{\mu}_B)$ are presented in fig. 1. To connect to experimental results, we calculate the ratio of the cumulants of the net-baryon number distribution as functions of temperature and chemical potential by means of their Taylor expansion in powers of μ_B/T . This is possible by combining different diagonal and non-diagonal fluctuations to obtain a result at the strangeness neutral point and with $\langle n_Q \rangle = 0.4\langle n_B \rangle$. Our results for $S_B\sigma_B^3/M_B$ and κ_B/σ_B^2 are shown in fig. 2. Here M_B is the mean, σ_B^2 is the variance, S_B is the skewness and κ_B the kurtosis of the the baryon number distribution.

3. Cross-correlations in the continuum

Now we will present our preliminary results on the cross-correlations in the continuum. The curves shown in fig. 3 are not final, as they do not yet include a full analysis of the systematic error. To extrapolate to the continuum we need to incorporate the temperature and the $1/N_t^2$ dependence of our data in this fit ansatz. We expect our results for $\chi(T)$ to lie on a smooth curve. We implement this information by fitting the results with a spline in the temperature direction. For the $1/N_t^2$ we fit a linear function through the data from lattices with the sizes $32^3 \times 10$, $40^3 \times 10$, $40^3 \times 12$, $48^3 \times 12$, $48^3 \times 16$ and $64^3 \times 16$. Our whole analysis is done in one combined fit. Therefore now the fit parameter in ansatz similar to eq. (1) become functions of T and N_t .

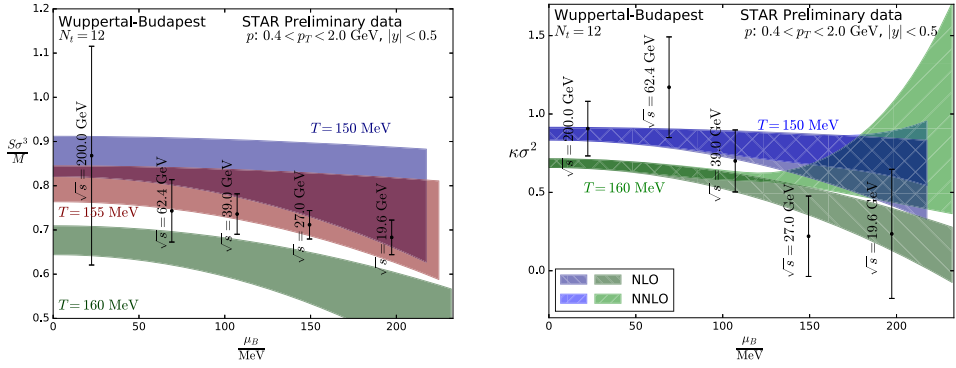


Fig. 2. $S_B \sigma_B^3 / M_B$ (left panel) and $\kappa_B \sigma_B^2$ (right panel) extrapolated to finite chemical potential. The left panel is extrapolated up to $O(\mu_B^2)$. In the right panel, the darker bands correspond to the extrapolation up to $O(\mu_B^2)$, whereas the lighter bands also include the $O(\mu_B^4)$ term. [20]

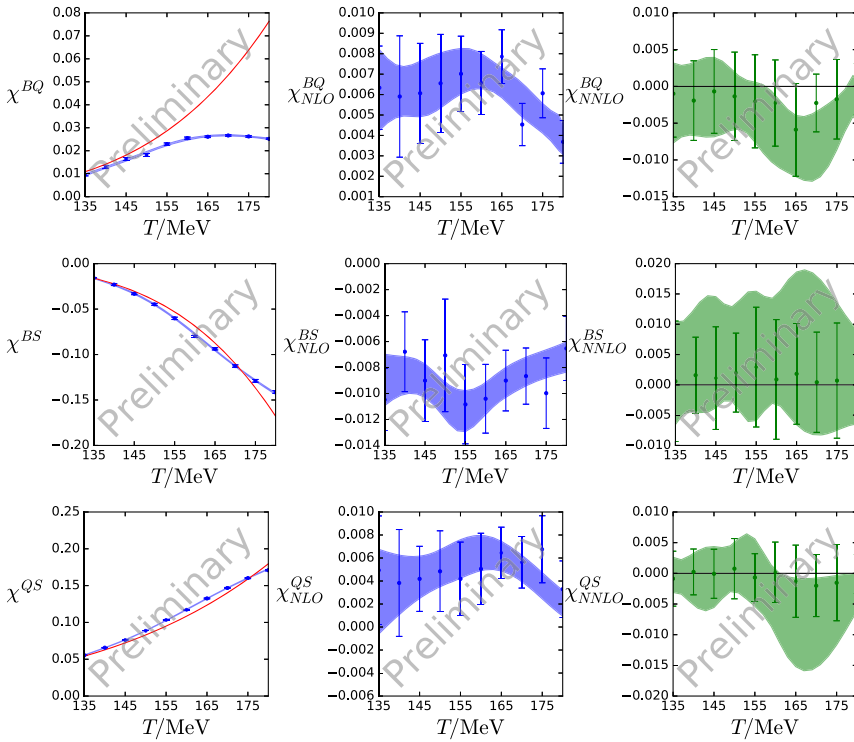


Fig. 3. Preliminary results for the cross-correlations in the continuum. The NNLO contribution is plotted in green, as it is again constrained by a prior. The red curves correspond to the HRG model results.

Acknowledgements. This project was funded by the DFG grant SFB/TR55. This work was supported by the Hungarian National Research, Development and Innovation Office, NKFIH grants KKP126769 and K113034. An award of computer time was provided by the INCITE program. This research used resources of the Argonne Leadership Computing Facility, which is a DOE Office of Science User Facility supported under Contract DE-AC02-06CH11357. The authors gratefully acknowledge the Gauss Centre for Supercomputing e.V. (www.gauss-centre.eu) for funding this project by providing computing time on the GCS Supercomputer JUQUEEN[22] at Jülich Supercomputing Centre (JSC) as well as on HAZELHEN at HLRS Stuttgart, Germany. This material is based upon work supported by the National Science Foundation under grants no. PHY-1654219 and OAC-1531814 and by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics, within the framework of the Beam Energy Scan Theory (BEST) Topical Collaboration. C.R. also acknowledges the support from the Center of Advanced Computing and Data Systems at the University of Houston.

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