Higher-order baryon number susceptibilities

Interplay between chiral and nuclear liquid-gas transitions

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Abstract

We use an improved version of the SU(3) flavour parity-doublet quark-hadron model to investigate the higher order baryon number susceptibilities near the chiral and the nuclear liquid-gas transitions. The resulting phase diagram of the model agrees qualitatively with expectations from lattice QCD. We observe a strong interplay between the chiral and liquid-gas transition at intermediate baryo chemical potentials.

Introduction

The parity-doublet model, as used in [2, 1], serves as an effective approach to describe the strongly interacting hadronic as well as quark matter in a consistent approach based on a single partition function.
In this model, the grand-canonical potential includes thermal contributions from the hadrons (Ω_{hadron}), the quarks (Ω_{quark}), the scalar and vector fields (V) and the Polyakov loop respectively:

$$\Omega_{\text{net}} = \Omega_{\text{hadron}} + \Omega_{\text{quark}} + V + U \tag{1}$$

With proper parametrisation [1] the model is able to describe nuclear matter with a **nuclear matter compressibility value** of **267 MeV**; which is in reasonable agreement with the phenomenologically obtained **range of about 200 - 280 MeV**; a **binding energy** of **-16 MeV** and a **saturation density** of **0.14 fm^{-3}**. Considering that excluded-volume correction are accounted for within the model, usually resulting in a very stiff hadronic equation of state, a compressibility value as low as the one mentioned above is more than satisfactory.
Moreover, applying this model to compact neutron-star matter, at $T = 0$ MeV, we have obtained a **symmetry energy value** of **30.02 MeV** and a **slope parameter value** of **56.86 MeV**; which fall squarely within the "astrophysics zone" of the $L - S_{\text{v}}$ diagram.

Results

The $T - \mu_{\text{B}}$ diagram (Fig.1) from the model shows both first-order transitions; along with their respective critical points; which switch to smooth crossovers, with decreasing μ_{B}, eventually merging into a single crossover at $\mu_{\text{B}} \approx 400$ MeV. It also shows the isentropes corresponding to different S/A values.

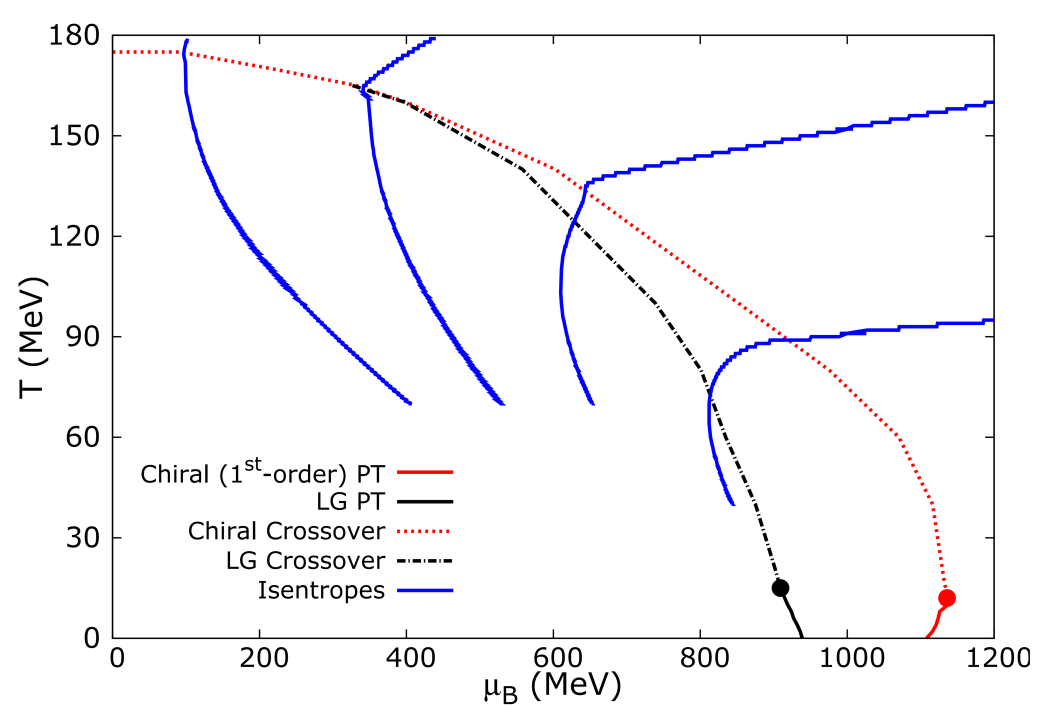

Figure 1: T-μ_{B} diagram showing the 1st-order liquid-gas (LG) phase transition (bold, black line), the 1st-order, chiral phase transition (bold, red line), the LG crossover (dashed, black line), the chiral crossover (dashed, red line), the LG Critical Point (black dot), the chiral Critical Point (red dot) and the isentropes (bold, blue lines) for S/A values 4, 10, 28 and 121, from right to left, respectively.

In Fig. 2, we plot the ratio of the normalised cumulants, $\chi_3^{\text{B}}/\chi_2^{\text{B}}$ and $\chi_4^{\text{B}}/\chi_2^{\text{B}}$ of the net baryon number; defined as:

$$\frac{\chi_{\text{n}}^{\text{B}}}{T^2} = n!\, c_{\text{n}}^{\text{B}}(T) = \frac{\partial^{\text{n}}(P(T,\mu_{\text{B}})/T^4)}{\partial(\mu_{\text{B}}/T)^{\text{n}}}\,; \tag{2}$$

as functions of temperature and baryo-chemical potential. We notice a considerable influence of the LG transition on the extracted cumulant ratios, even far away from the LG critical point. As a result, both transitions affect the net baryon number susceptibilities in the intermediate region between the two crossovers.

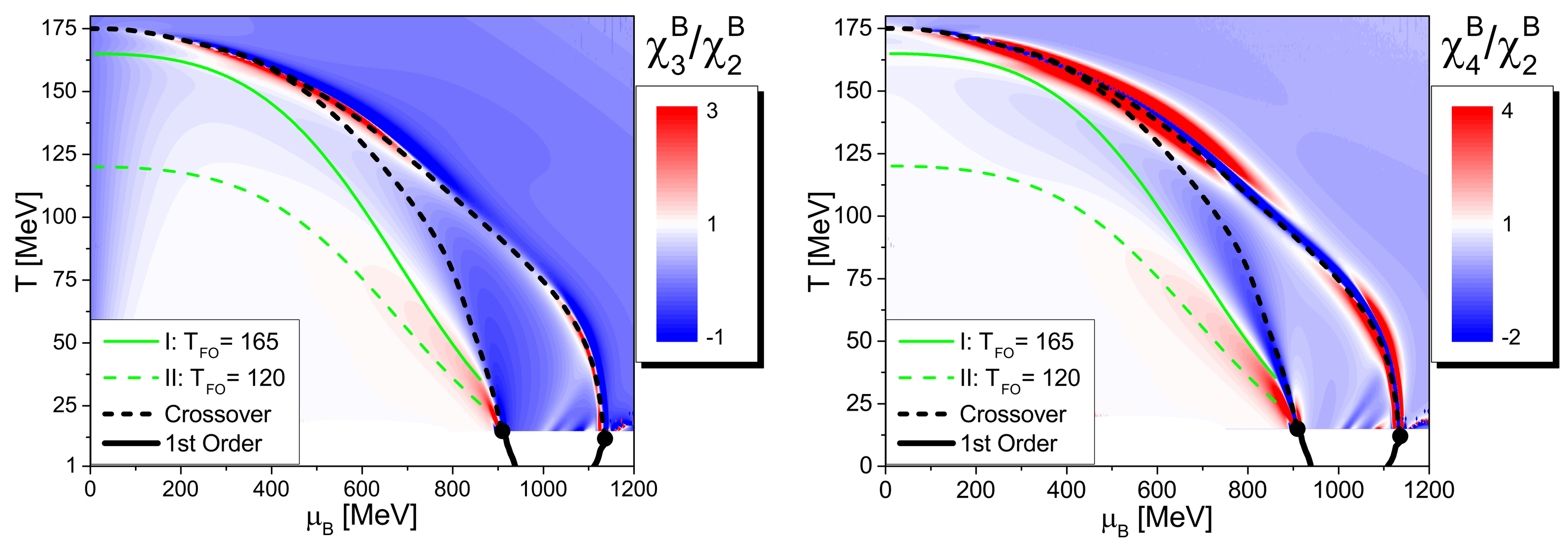

Figure 2: Phase diagrams with χ_3^B/χ_2^B and χ_4^B/χ_2^B, with the green (dotted and bold) lines representing freeze-out curves.

To demonstrate the effect of this interplay on observable susceptibility ratios, we investigate so called freeze-out curves shown in Fig. 2. The extracted values of the normalised cumulant ratios, along these freeze-out curves, are shown as function of the collision energy $\sqrt{s_{\text{NN}}}$ in Fig. 3.

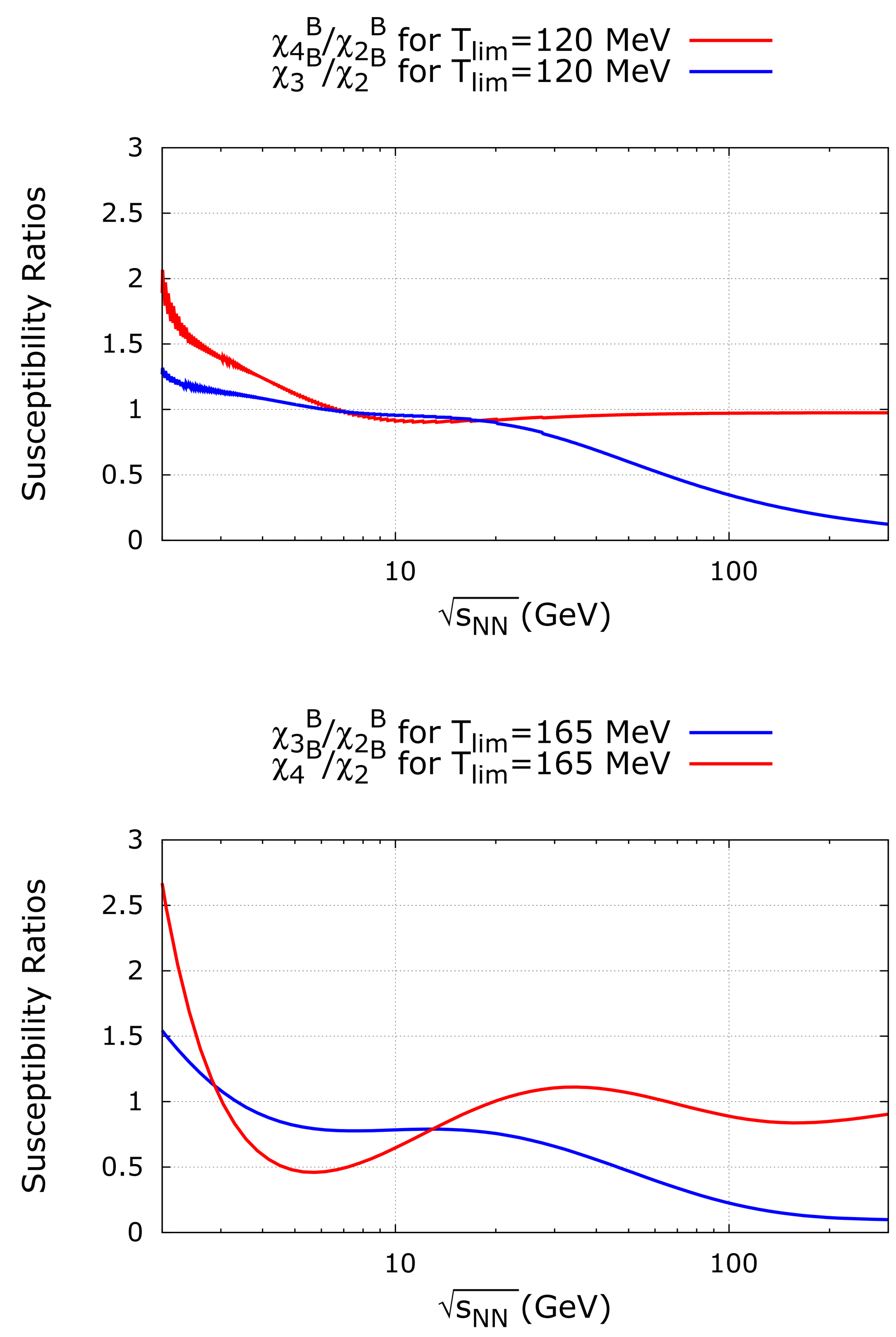

Figure 3: Susceptibility ratios as function of beam energy along the freeze-out lines with T_{lim} = 120 MeV and 165 MeV.

Conclusion

We have presented an improved version of the hadronic, three-flavour, parity-doublet model including a de-confinement transition to quarks and gluons.
We have employed the model to study the interplay between the nuclear liquid-gas transition and the chiral transition at large temperatures. We find that this interplay does have an effect on the equation of state and the extracted susceptibilities in a significant range of the phase diagram.
Furthermore, we have studied the beam energy dependence of the normalized cumulants from our model for different freeze-out conditions.
Our work highlights the fundamental importance of consistently including the properties of interacting nuclear matter in an effective model of the QCD equation of state for interpreting experimental data of particle fluctuations in heavy-ion collisions.

References

[1] A. Mukherjee, J. Steinheimer and S. Schramm, arXiv:1611.10144 [nucl-th].
[2] J. Steinheimer, S. Schramm and H. Stöcker, J. Phys. G **38** (2011) 035001.