Baryon-number fluctuations

The phase diagram from the QχP model

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The quark-hadron chiral parity-doublet (QχP) model [2], serves as an effective method to describe the strongly interacting hadronic, as well as quark, matter in a consistent approach based on a single partition function.

- The grand-canonical potential:

$$\Omega_{\rm net} = \Omega_{\rm hadron} + \Omega_{\rm quark} + V + U \qquad (1)$$

includes thermal contributions from the scalar and vector fields (V) and the Polyakov loop (U), too.

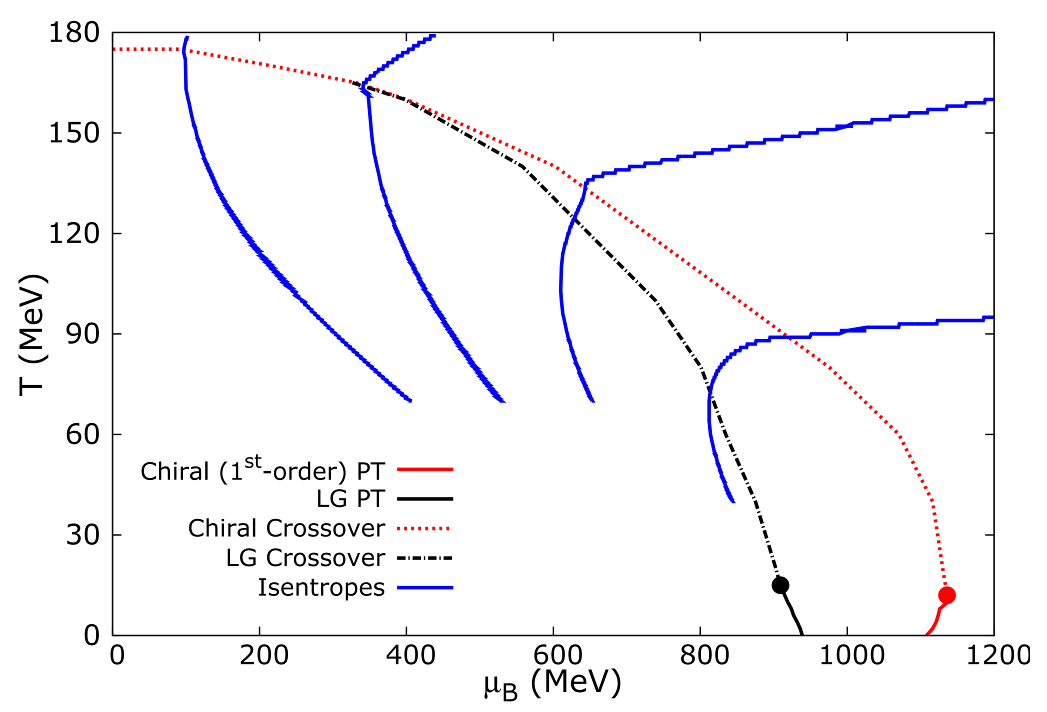
- A nuclear matter (in)compressibility = 267 MeV,
- A binding energy = -16 MeV and
- A saturation density = 0.14 fm^{-3} is obtained.
- Excluded-volume corrections are accounted for within the model.

When applied to isospin-asymmetric neutron-star matter, at $T = 0$ MeV [1]:

- A symmetry energy (S_v) = 30.02 MeV and
- A slope parameter (L) = 56.86 MeV is obtained.
- The S_v and L values are in excellent agreement with experiment.

The $T - \mu_B$ diagram below shows:

- Both first-order transitions,
- Their respective critical points, and
- The smooth crossovers, with decreasing μ_B; eventually merging into a single crossover at $\mu_B \approx 400$ MeV.
- The isentropes corresponding to different S/A values are also shown.

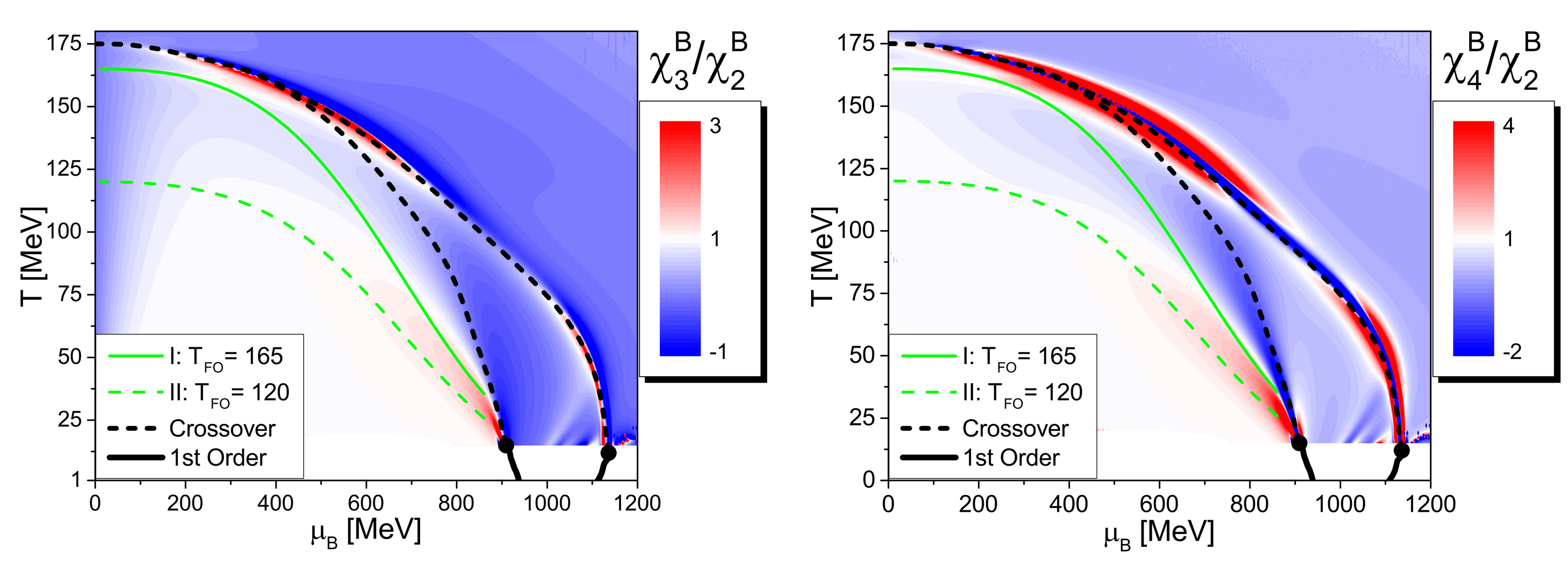


The ratios of the normalised cumulants, χ_3^B/χ_2^B and χ_4^B/χ_2^B of the net baryon number:

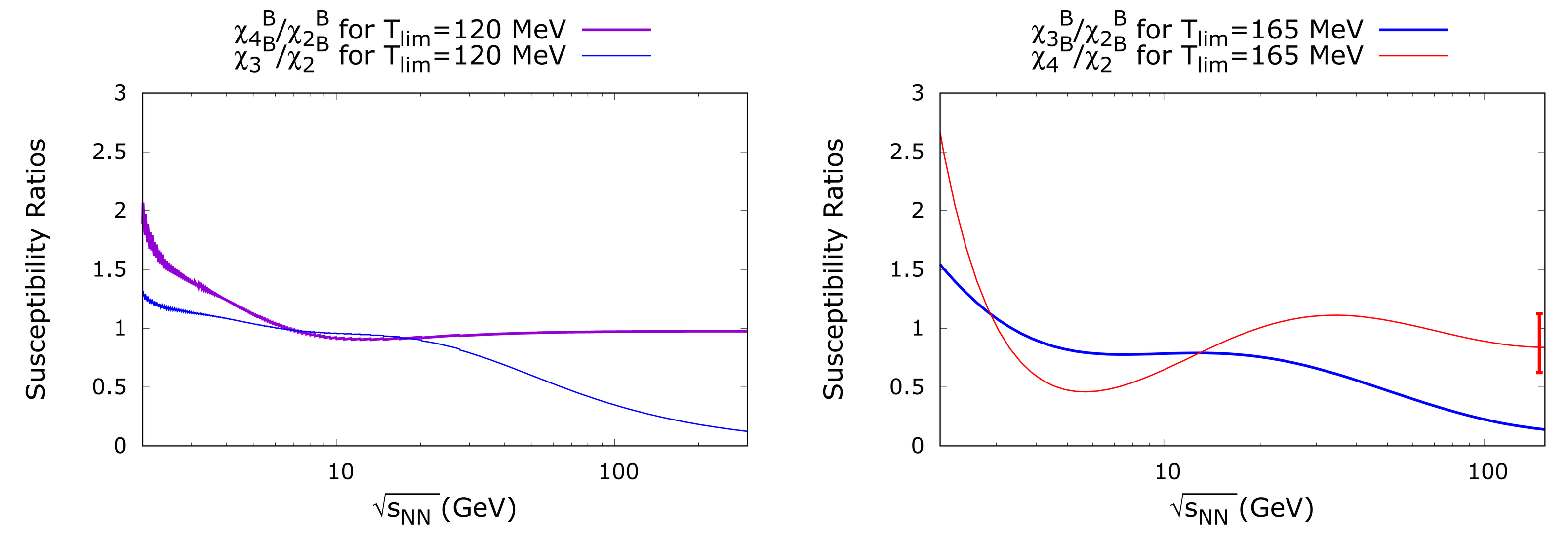
$$\frac{\chi_n^B}{T^2} = n!\, c_n^B(T) = \frac{\partial^n (P(T,\mu_B)/T^4)}{\partial(\mu_B/T)^n}\,; \qquad (2)$$

as functions of temperature and baryo-chemical potential; are shown below. We notice:

- A considerable influence of the LG transition on the cumulant ratios, even far away from the LG critical point, and
- Both transitions affecting the net baryon-number susceptibilities in the intermediate region between the two crossovers.

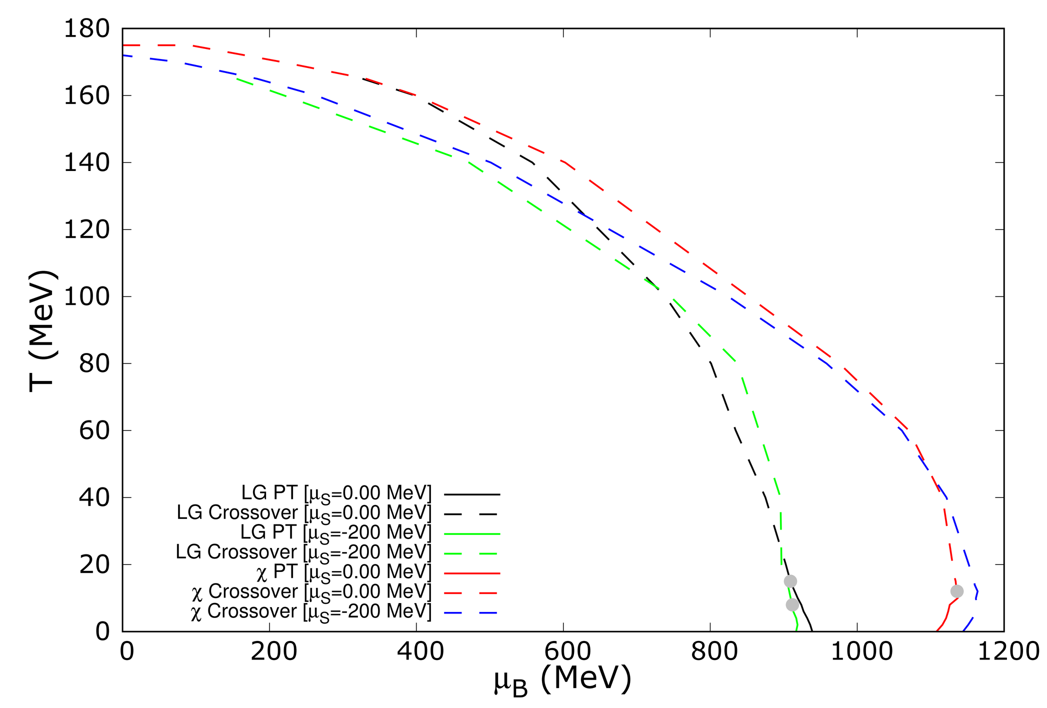


To demonstrate the effect of this interplay on observable susceptibility ratios, we extract the values of the normalised cumulant ratios, along the freeze-out curves, as functions of the collision energy $\sqrt{s_{\rm NN}}$:

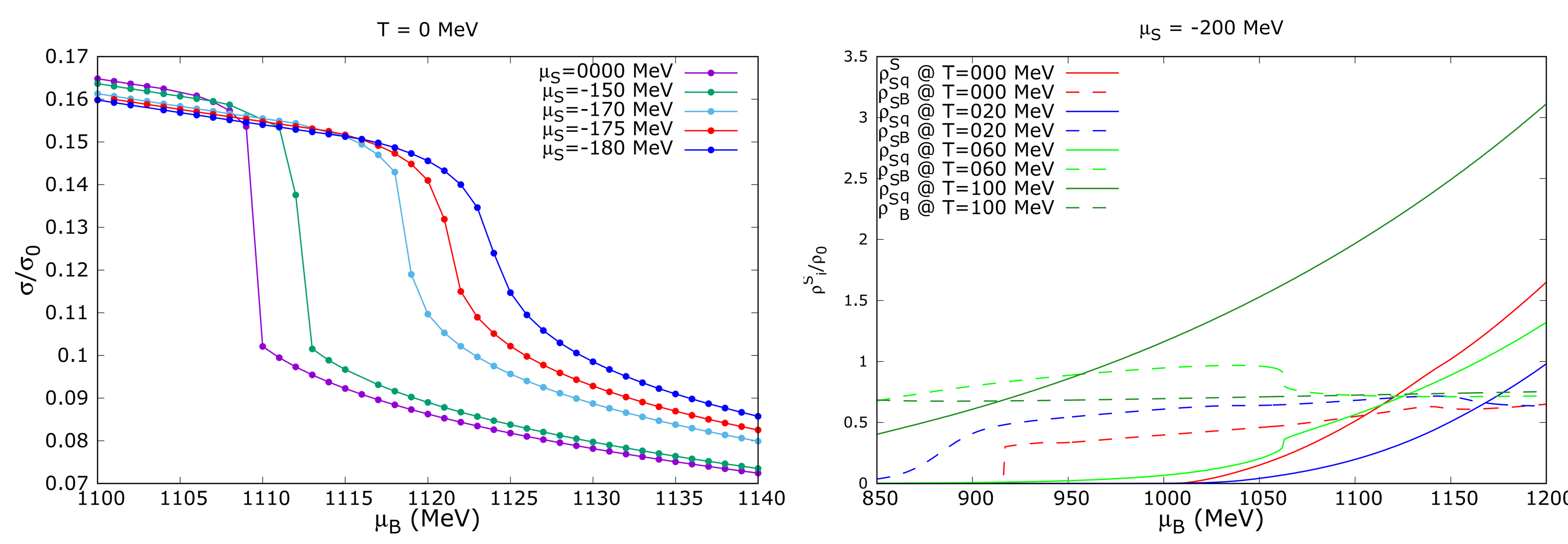


A study of the non-zero strangeness phase diagram of the model [3] reveals that:

- Both, the LG and the chiral/deconfinement phase transitions are modified, and
- The entire chiral phase boundary becomes a crossover, as shown:



Shown further are the scalar condensates $\left(\sigma = \left\langle \overline{\psi}\psi \right\rangle\right)$ and the relative abundances of non-strange baryons and hyperons, as functions of μ_B.



As evident, for a $\mu_S \neq 0$ MeV, an early appearance of hyperons and strange-quarks results in a softening of the change in degrees-of-freedom across the phase transition, thereby modifying the transition to a crossover.

Summary

- An improved version of the hadronic, three-flavour, parity-doublet (effective) model of the QCD; including a deconfinement transition to quarks and gluons; is presented.
- The fundamental importance of consistently including the properties of interacting nuclear matter is highlighted.
- The influence of a non-zero net-strangeness on the interpretations of experimental data from heavy-ion collisions, where strangeness may fluctuate locally, is made apparent.

References

[1] A. Mukherjee, S. Schramm, J. Steinheimer, and V. Dexheimer. The application of the Quark-Hadron Chiral Parity-Doublet Model to neutron star matter. *Astron. Astrophys.*, 608:A110, 2017.

[2] A. Mukherjee, J. Steinheimer, and S. Schramm. Higher-order baryon number susceptibilities: interplay between the chiral and the nuclear liquid-gas transitions. *Phys. Rev.*, C96(2):025205, 2017.

[3] Ayon Mukherjee, Abhijit Bhattacharyya, and Stefan Schramm. Effects of a non-zero strangeness-chemical potential in strong interaction models. 2018.