The phase diagram of QCD at finite baryon density

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Under ordinary conditions, quarks are confined inside hadrons. When matter is heated or compressed, hadrons start to overlap, and assigning a quark to one hadron or another becomes ambiguous. Quark confinement gives way to a plasma of deconfined quarks and gluons. We are in the process of determining the boundary between these two regimes as a function of temperature T and baryon chemical potential μ. At the same time an experimental search for quark-gluon plasma formation in Heavy-Ion collisions is ongoing at RHIC (Brookhaven) and soon at LHC (CERN).

Monte Carlo simulations at non-zero chemical potential are afflicted by the notorious "sign problem": the fermion determinant is complex, which prevents its interpretation as a probability density. To circumvent this problem, we perform simulations at imaginary $\mu = i\mu_I$ where the sign problem is absent, fit our phase boundary $T_c(i\mu_I)$ by a truncated Taylor expansion, then analytically continue this polynomial back to real μ. Control over systematic errors is possible for $\mu \leq \pi T$, which covers the range of Heavy Ion experiments.

Fig. 1 illustrates our results for a QCD-like theory with 3 flavors of equal-mass quarks [2]. Fig. 2 is the summary of our current results for the case of 2 light u, d quarks ($m_u = m_d$) and 1 strange quark, for various masses [4].

RCNP provides a small but greatly appreciated fraction of our computer resources for this ambitious project.

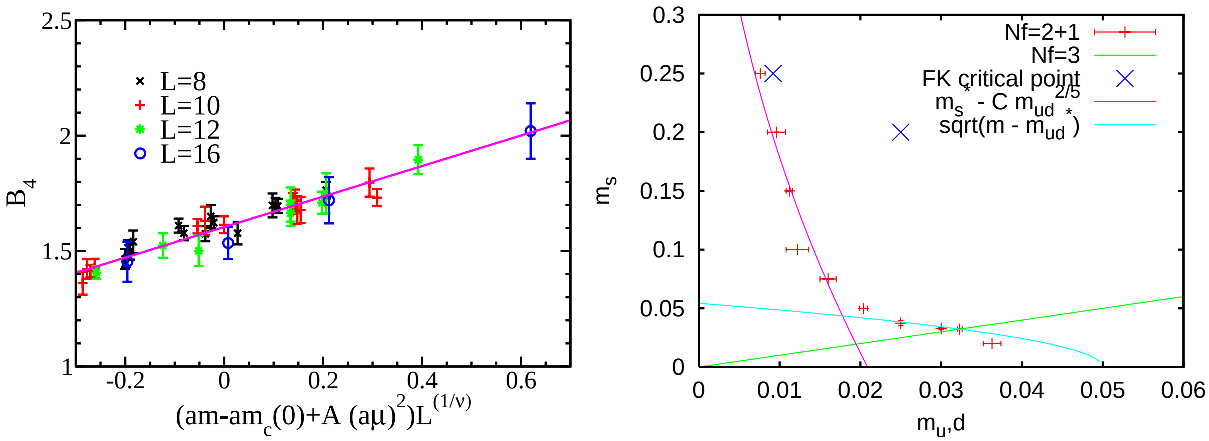

Figure 1: Left: Binder cumulant of the quark condensate, as a function of quark mass and imaginary chemical potential, for 3-flavor QCD. Results for all volumes collapse on a universal finite-size scaling curve; from [2]. Right: Current results in (2+1)-flavor QCD, showing the line in the plane $(m_{u,d}, m_s)$ where the finite-temperature transition is second-order at $\mu = 0$; from [4].

References

[1] P. de Forcrand and O. Philipsen, "The QCD phase diagram for small densities from imaginary chemical potential," Nucl. Phys. B **642** (2002) 290 [arXiv:hep-lat/0205016], **140** citations.

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[4] O. Philipsen and P. de Forcrand, "QCD phase diagram at small baryon densities from imaginary mu: Status report," arXiv:hep-lat/0409034.