QCD phase transitions and quark spectral functions

Christian S. Fischer, Jan Lücker and Jens Müller
JLU Gießen

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

Abstract

We investigate the QCD phase diagram by solving the Dyson-Schwinger equations of QCD at finite temperature and chemical potential. From the quark propagator we extract order parameters for the chiral and the deconfinement transition. Moreover we investigate the propagation of quarks in the quark-gluon plasma by analyzing its spectral functions.

Order parameters 1: chiral symmetry breaking

We extract the quark condensate from the quark propagator:

$$\langle\bar\psi\psi\rangle = Z_2 N_c T \sum_n \int \frac{d^3p}{(2\pi)^3} \mathrm{Tr}_D \left[S(\vec{p}^2,\omega_n)\right]$$

- large for broken chiral symmetry
- small for (approximately) restored chiral symmetry

Order parameters 2: deconfinement

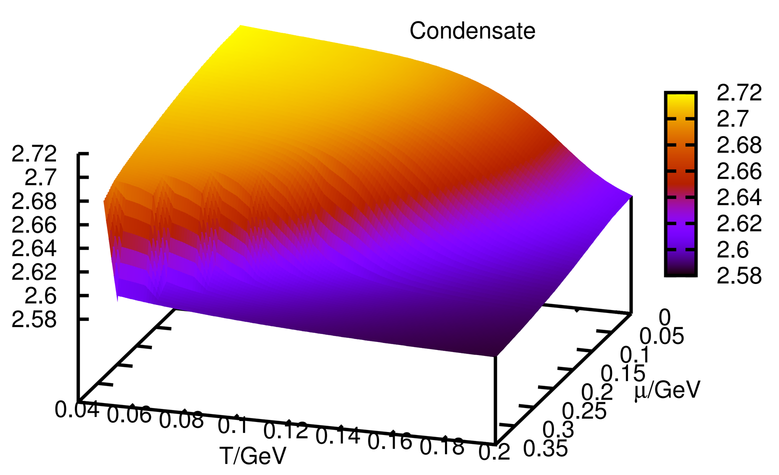
For confinement/deconfinement we use dual condensates [7, 8, 9].

$$\Sigma_n = \int \frac{d\varphi}{2\pi} e^{-i\varphi n} \langle\bar\psi\psi\rangle_\varphi,$$

where $\langle\bar\psi\psi\rangle_\varphi$ is the condensate with generalised, $U(1)$-valued quark boundary conditions $\psi(\vec{x}, 1/T) = e^{i\varphi}\psi(\vec{x}, 0)$. The quark loop is evaluated at $\varphi = \pi$ to break Roberge-Weiss symmetry.

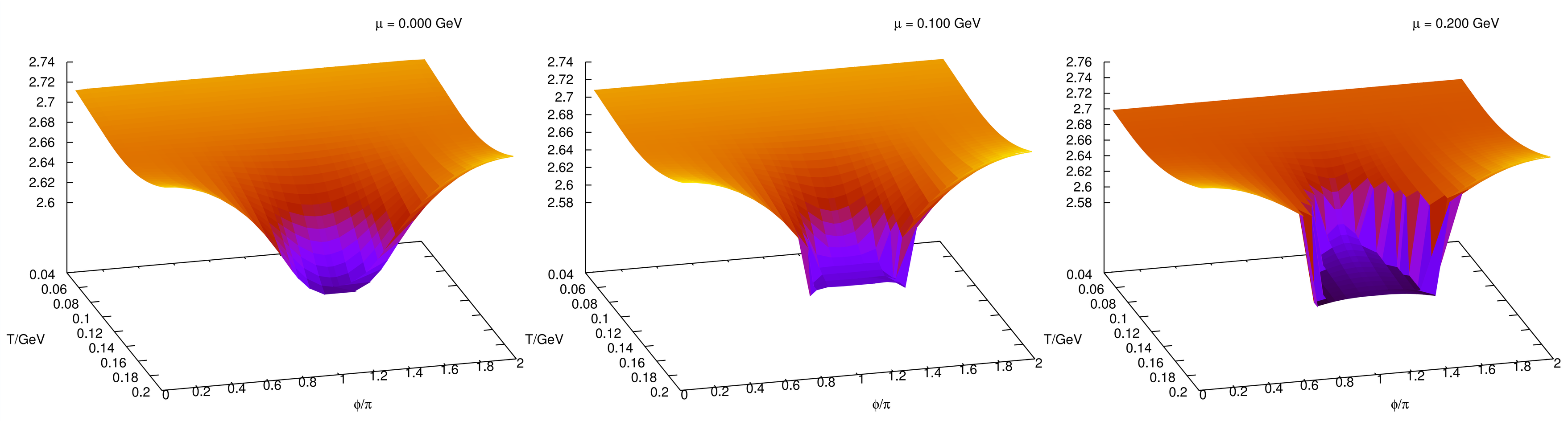
- Σ_{+1}, the dressed Polyakov loop equals the ordinary Polyakov loop for $m \to \infty$
- Σ_{-1}, the conjugated dressed Polyakov loop, differs from Σ_{+1} for $\mu > 0$

Results 1: chiral transition



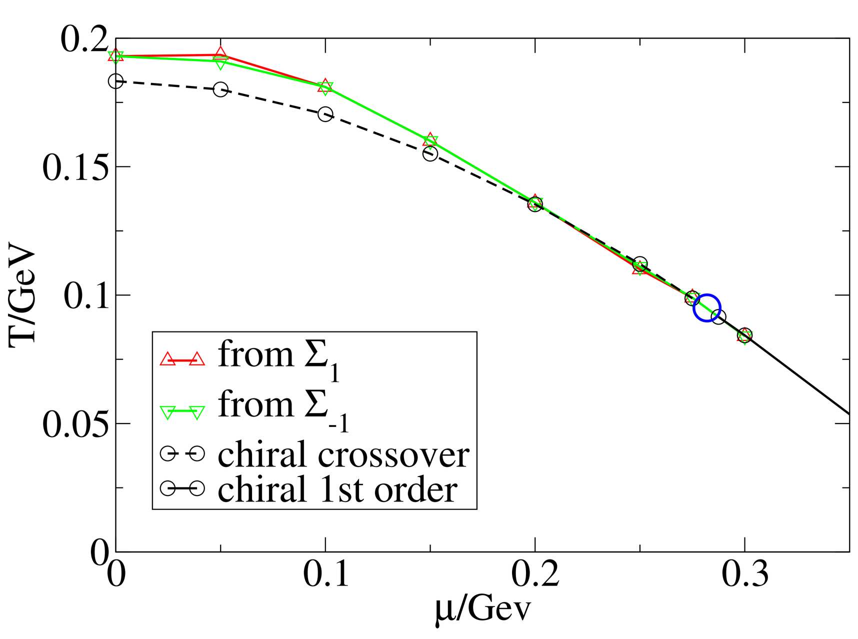
- The pseudocritical temperature at $\mu = 0$ is $T_c \approx 183MeV$
- At quark chemical potential $\mu \approx 280MeV$ the crossover turns into a first order phase transition, indicating a critical endpoint

Results 2: deconfinement



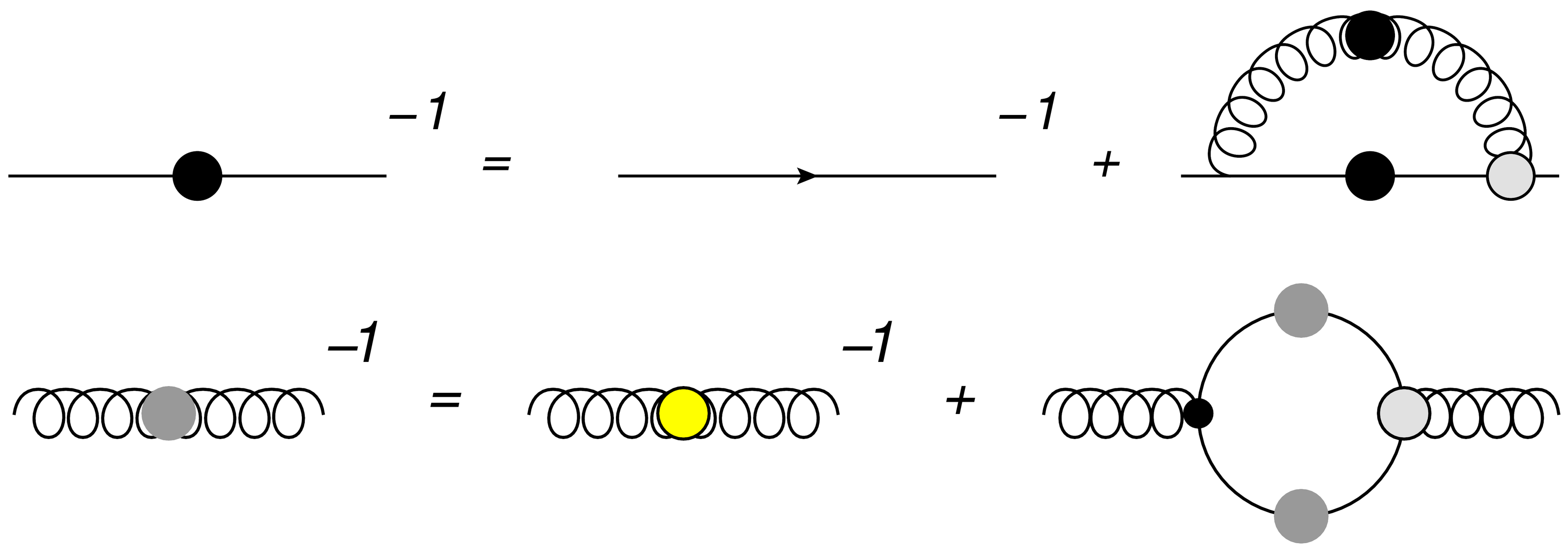
- In the confined phase, the condensate is nearly independent of the boundary condition
- In the deconfined phase a "valley" developes
- For larger values of μ the valley becomes steeper, developing a first order phase transition in φ

Results 3: the phase diagram



- The deconfinement temperatures for quarks and antiquarks differ for moderate μ → similar to PQM studies, Ref. [6]
- At densities close to the critical endpoint deconfinement and chiral transition coincide
- So far, no sign of a quarkyonic phase
- At large μ baryonic contributions play a role → better truncation scheme needed

The truncation scheme

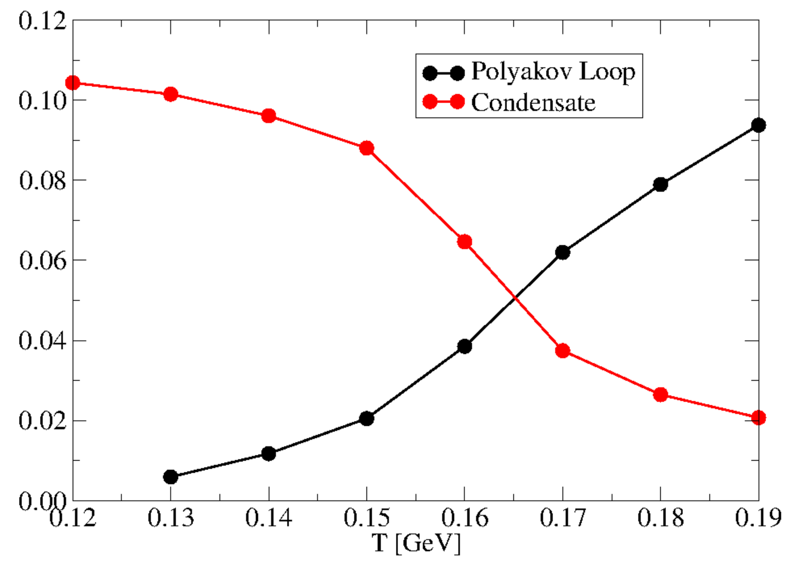


Quark and Gluon DSE

For the quark-gluon vertex we use a phenomenological *ansatz*.
For the gluon propagator we

- use lattice results for the quenched propagator (yellow dot in gluon DSE) and
- add the quark loop to account for unquenching effects ($N_f = 2$)

Behaviour of the order parameters

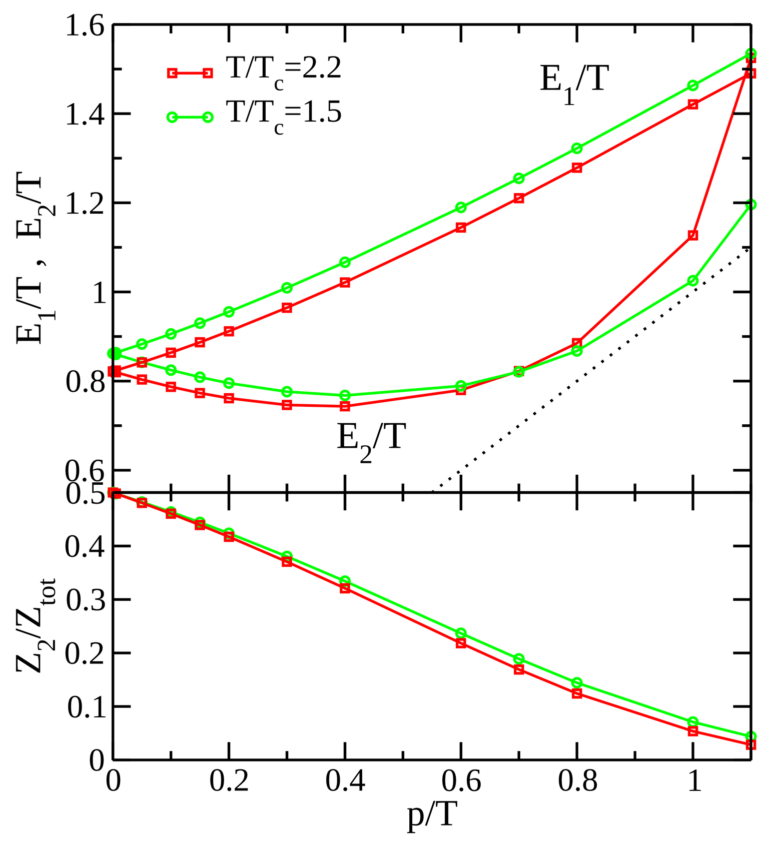


- Dressed Polyakov loop can be calculated from DSEs [4] and FRGs [5].
- Physical quark masses → both transitions are crossovers at $\mu = 0$
- Both transitions in the same temperature regime, pseudo-critical temperatures may differ

Ansatz for quark spectral function

$$\rho_\pm(\omega, |p|) = 2\pi\left[Z_1\delta(\omega \mp E_1) + Z_2\delta(\omega \pm E_2)\right]$$
+ continuum part from Landau damping

Dispersion relations at $\mu = 0$ (quenched)



- E_1 : quark, E_2 : plasmino
- quantitative agreement with lattice results [10]
- $p \to 0$ agree with analytical results from HTL
- $p > T$ plasmino dies out
- dispersion relations stay timelike due to continuum part

Literature

[1] J. A. Mueller, C. S. Fischer, D. Nickel, Eur. Phys. J. **C70** (2010) 1037-1049. [arXiv:1009.3762 [hep-ph]].

[2] C. S. Fischer, A. Maas and J. A. Muller, Eur. Phys. J. C **68** (2010) 165 [arXiv:1003.1960 [hep-ph]].

[3] C. S. Fischer, J. A. Mueller, Phys. Rev. **D80** (2009) 074029. [arXiv:0908.0007 [hep-ph]].

[4] C. S. Fischer, Phys. Rev. Lett. **103** (2009) 052003. [arXiv:0904.2700 [hep-ph]].

[5] J. Braun, L. M. Haas, F. Marhauser, J. M. Pawlowski, Phys. Rev. Lett. **106** (2011) 022002. [arXiv:0908.0008 [hep-ph]].

[6] T. K. Herbst, J. M. Pawlowski and B. J. Schaefer, Phys. Lett. B **696** (2011) 58 [arXiv:1008.0081 [hep-ph]].

[7] C. Gattringer, Phys. Rev. Lett. **97** (2006) 032003. [hep-lat/0605018].

[8] F. Synatschke, A. Wipf, C. Wozar, Phys. Rev. **D75** (2007) 114003. [hep-lat/0703018].

[9] E. Bilgici, F. Bruckmann, C. Gattringer, C. Hagen, Phys. Rev. **D77** (2008) 094007. [arXiv:0801.4051 [hep-lat]].

[10] F. Karsch, M. Kitazawa, Phys. Lett. **B658** (2007) 45-49. [arXiv:0708.0299 [hep-lat]].