Two-color QCD with chiral chemical potential

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XIth Quark Confinement and the Hadron Spectrum

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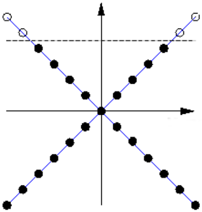
Outline

- Introduction. Motivation.
- Previous phenomenological studies.
- Lattice setup.
- Results and conclusion.

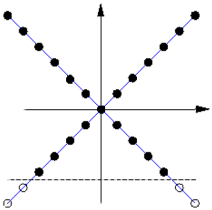
Chiral chemical potential

$$S_f = \int \bar{\psi}(\partial_\mu \gamma_\mu + igA_\mu \gamma_\mu + m + \mu_5 \gamma_0 \gamma_5)\psi$$

$$\langle \bar{\psi}\gamma_0\gamma_5\psi \rangle = \langle \psi_R^\dagger \psi_R - \psi_L^\dagger \psi_L \rangle > 0$$



Right-handed Fermi sea



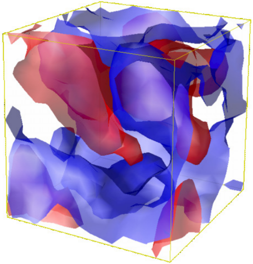
Left-handed Fermi sea

"chirally imbalanced matter"

Chiral chemical potential

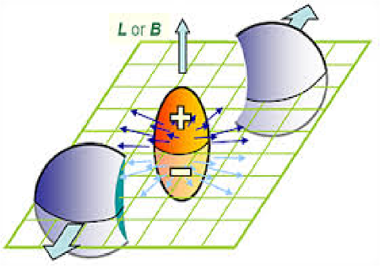
In QCD fluctuations of topological charge may lead to creation of difference between left and right-handed quarks density (chirally imbalanced matter).

$$\partial_\mu j_5^\mu \sim F_a^{\mu\nu} \tilde{F}^a_{\mu\nu}$$



P. V. Buividovich, T. Kalaydzhyan, M. I. Polikarpov, arXiv:1111.6733[hep-lat]

Chiral chemical potential



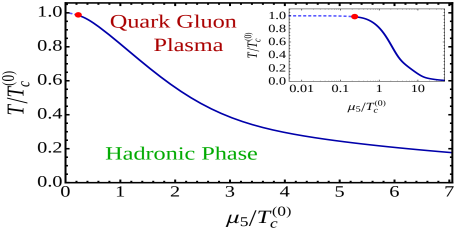
- Chiral magnetic effect and other non-dissipative phenomena. Occur in deconfinement.
- Interesting to study phase diagram.
- No sign problem contrary to chemical potential μ - lattice simulations.

Phenomenological studies

- M. N. Chernodub and A. S. Nedelin, Phase diagram of chirally imbalanced QCD matter, Phys. Rev. D**83**, 105008 (2011), arXiv: 1102.0188(hep-ph)
- K. Fukushima, M. Ruggieri and R. Gatto, Chiral magnetic effect in the PNJL model, Phys.Rev. D**81**, 114031(2010), arXiv:1003.0047(hep-ph)
- A. A. Andrianov, V. A. Andrianov, D. Espriu, X. Planells, Chemical potentials and parity breaking: the Nambu-Jona-Lasinio model, Eur. Phys. J. C**74**, 2776 (2014), arXiv: 1310.4416(hep-ph)
- +Talks by A. A. Andrianov (Parallel I: A1, Monday), D. Espriu (Parallel IV: D4, Tuesday)

Phenomenological studies

M. N. Chernodub and A. S. Nedelin, Phase diagram of chirally imbalanced QCD matter, Phys. Rev. D**83**, 105008 (2011), arXiv: 1102.0188(hep-ph).



At large μ_5 crossover transforms to the first order phase transition (details differ in different papers).

Aim (optimistic)

The aim of our study: phase diagram of QCD in the plane of the chiral chemical potential and temperature: $\mu_5 - T$.

Computations

- The code is developed on the basis of the code of A. Schreiber, Humboldt University, Berlin.
- Parameters (lattice steps etc) are taken from
  E.-M. Ilgenfritz et al., Two-color QCD with staggered fermions at finite temperature under the influence of a magnetic field, Phys.Rev. D**85** (2012) 114504, arXiv: 1203.3360[hep-lat]
- Simulations were performed at GPUs of supercomputer K100 and computers of Berlin group.

Chiral chemical potential on the lattice

For staggered fermions:

$$S_f = \frac{1}{2}\sum_{x\mu}\eta_\mu(x)(\bar\psi_{x+\mu}U_\mu(x)\psi_x - \bar\psi_x U^\dagger_\mu(x)\psi_{x+\mu}) + ma\sum_x \bar\psi_x\psi_x +$$

$$+\frac{1}{2}\mu_5 a\sum_x s(x)(\bar\psi_{x+\delta}U_{x+\delta,x}\psi_x - \bar\psi_{x+\delta}U^\dagger_{x+\delta,x}\psi_x)$$

Here
$\delta = (1,1,1,0)$
$s(x) = (-1)^{x_2}$ corresponds to $\gamma_0\gamma_5$
$U_{x+\delta,x}$ is a product of gauge fields along the ways $x \to x+\delta$ (averaged over 6 different ways)

Lattice setup

- $SU(2)$ gauge group for simplicity
- For gauge fields we adopted Wilson action

$$S_g = \frac{\beta}{4} \sum_{x,\mu\neq\nu} \mathrm{tr} \left(1 - U_\mu(x) U_\nu(x+\mu) U_\mu^\dagger(x+\nu) U_\nu^\dagger(x)\right)$$

- 4 tastes of dynamical staggered fermions (without rooting)
- 2 values of μ_5: $460 MeV$, $920 MeV$
- Small $ma = 0.01$
- For each point N configurations $\sim O(1000)$

Observables

- Polyakov loop $\langle L \rangle$:

$$L = \frac{1}{N_\sigma^3} \sum_{n_1,n_2,n_3} \frac{1}{2} \mathrm{tr} \left(\prod_{n_4=1}^{N_\tau} U_4(n_1, n_2, n_3, n_4) \right)$$

- Chiral condensate $a^3 \langle \bar{\psi}\psi \rangle$:

$$a^3 \langle \bar{\psi}\psi \rangle = -\frac{1}{N_\tau N_\sigma^3} \frac{1}{4} \frac{\partial}{\partial(ma)} \log(Z) = \frac{1}{N_\tau N_\sigma^3} \frac{1}{4} \langle \mathrm{tr}(D + ma)^{-1} \rangle$$

Observables. Susceptibilities

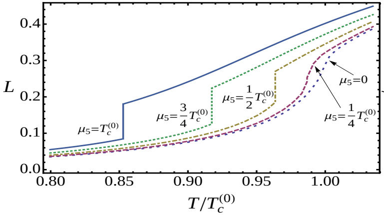
- Polyakov loop susceptiblity:

$$\chi_L = N_\sigma^3(\langle L^2 \rangle - \langle L \rangle^2)$$

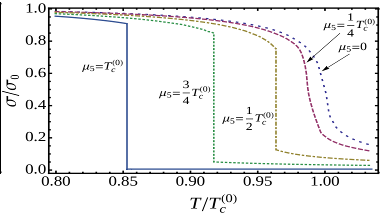
- Chiral susceptibility:

$$\chi = \frac{1}{N_\tau N_\sigma^3} \frac{1}{16} (\langle (\text{tr}(D + ma)^{-1})^2 \rangle - \langle \text{tr}(D + ma)^{-1} \rangle^2)$$

M. N. Chernodub and A. S. Nedelin, arXiv: 1102.0188(hep-ph)

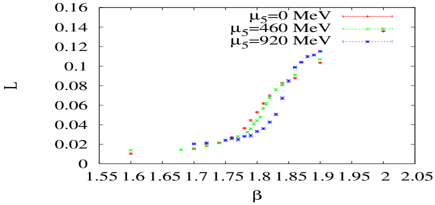


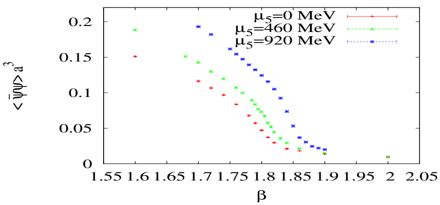
Polyakov loop



Chiral condensate

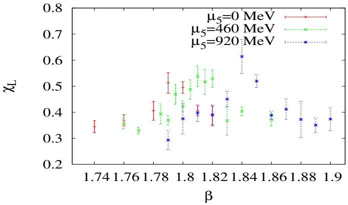
Results (Lattice 6×16^3)



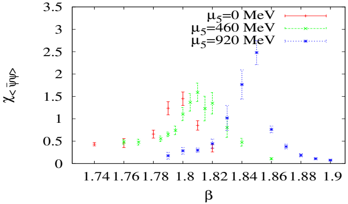


Results. Susceptibilities

Lattice 6×16^3



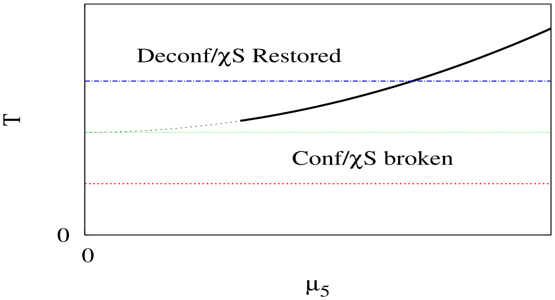
Polyakov loop susceptibility



Chiral susceptibility

Results. Varying μ_5

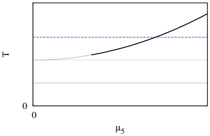
Observables with respect to μ_5(β, lattice size are fixed) in different phases. Lattice 10×28^3



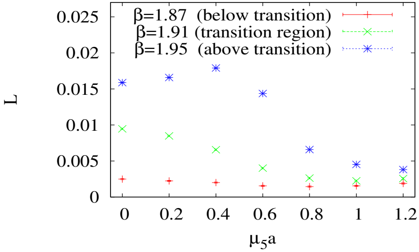
Tentative phase diagram

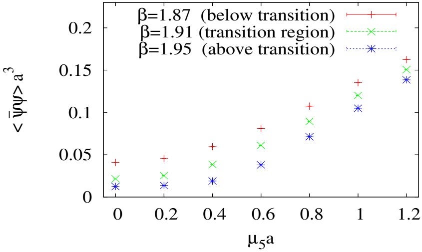
Results. Varying μ_5

Observables with respect to μ_5(β, lattice size are fixed) in different phases.
Lattice 10×28^3



Phase diagram





Conclusions

Conclusions:

- T_c slightly increases when μ_5 grows - contrary to some predictions of phenomenological studies.
- The transition seems to become sharper.

Possible issues (plans for future work):

- Discretization errors (ongoing study)
- SU(3) instead of SU(2)
- Rooting - 4 identical tastes of staggered fermions

Thank you!