Two-Color Lattice QCD with Non-zero Chiral Chemical Potential

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based on arXiv:1503.06670, JHEP 1506 (2015) 094

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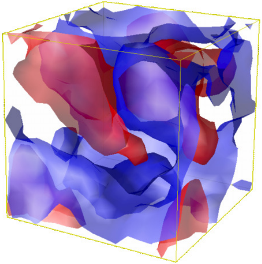
Introduction

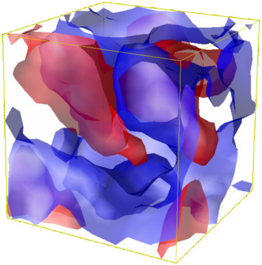
Topological fluctuations in QCD.



arXiv:1111.6733, P.V. Buividovich, T. Kalaydzhyan, M.I. Polikarpov

Introduction

Topological fluctuations in QCD.



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Anomaly:

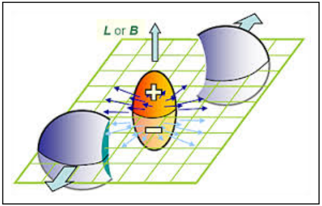
$$\partial_\mu j_\mu^{(5)} = C F_{\mu\nu}^{(a)} \tilde{F}_{(a)}^{\mu\nu} \longrightarrow \text{Nonzero chiral density } \rho_5$$

CME

Possible manifestation: Chiral Magnetic Effect

$\rho_5 \ \& \ \vec{B} \quad \rightarrow \quad \vec{\jmath} \ \parallel \ \vec{B}$

$\vec{\jmath} = \frac{N_c}{2\pi^2} \mu_5 \vec{B}$



Phase is important!

Phase diagram of the QCD with μ_5

- Effective models (NJL, PNJL, PLSM$_q$ etc.)
  arXiv: 1102.0188, 1110.4904, 1305.1100, 1310.4434
- Dyson-Schwinger equations
  arXiv:1505.00316
- Large N_c universality
  arXiv:1111.3391
- Lattice QCD (no sign problem)

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Contradictions between different approaches $\Longrightarrow$ Question is not settled.

Chiral chemical potential for staggered fermions

$$S_f = \frac{1}{2}\sum_{x\mu}\eta_\mu(x)(\bar{\psi}_{x+\mu}U_\mu(x)\psi_x - \bar{\psi}_x U^\dagger_\mu(x)\psi_{x+\mu}) + ma\sum_x \bar{\psi}_x\psi_x +$$
$$+\frac{1}{2}\mu_5 a\sum_x s(x)(\bar{\psi}_{x+\delta}\bar{U}_{x+\delta,x}\psi_x - \bar{\psi}_{x+\delta}\bar{U}^+_{x+\delta,x}\psi_x)$$

$s(x) = \eta_1(x)\eta_2(x)\eta_3(x) = (-1)^{x_2}$
$\delta = (1,1,1,0)$

Flavour basis: $\delta S_f \to \mu_5 \bar{q}\gamma_5\gamma_4 \otimes 1 q$

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

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

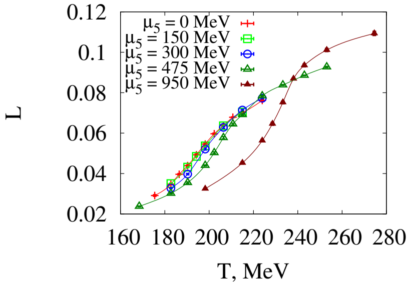
- Susceptibilities χ_L, $\chi_{\bar{\psi}\psi}$

Lattice setup

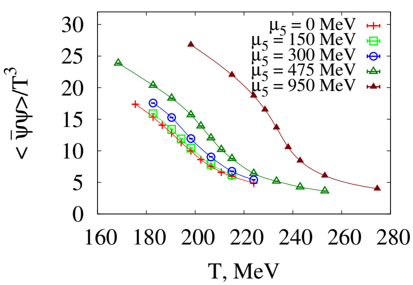
Gauge group: $SU(2)$
Wilson plaquette action
Lattice sizes:

- $6 \times 20^3, m_q = 12$ MeV for susceptibilities
- $10 \times 28^3, m_q = 18$ MeV for large μ_5 and chiral limit.

Results for small lattice

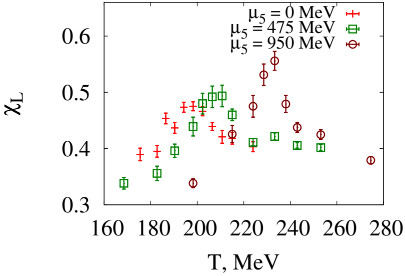


Polyakov loop

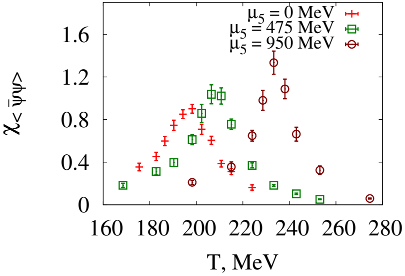


chiral condensate

Results for small lattice. Susceptibilities

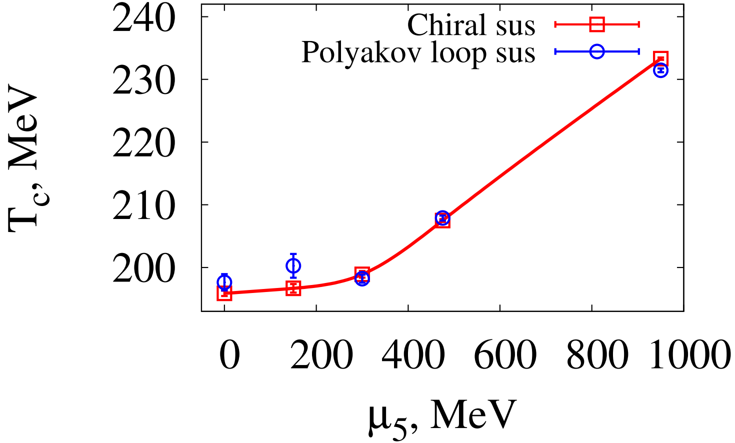


Polyakov loop susceptibility

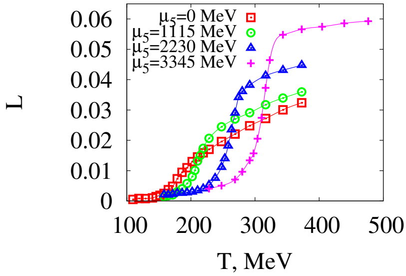


chiral susceptibility

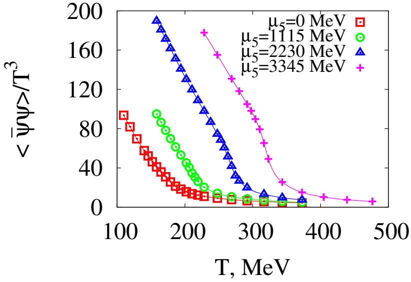
Critical temperature vs μ_5



Results for large lattice

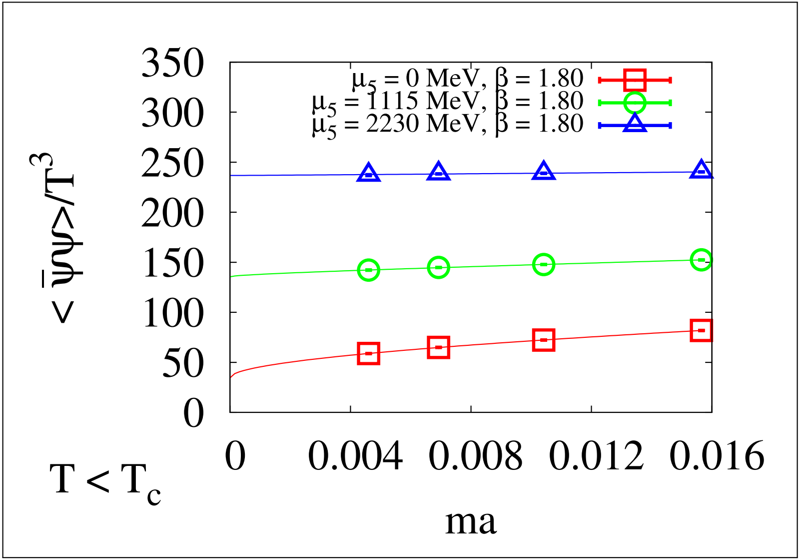


Polyakov loop



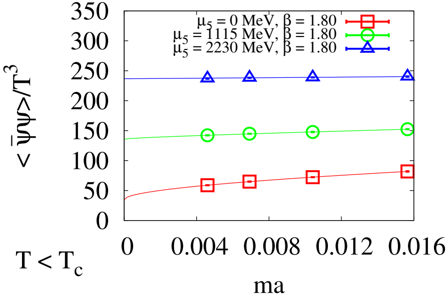
chiral condensate

Chiral limit. $T = 119$ MeV



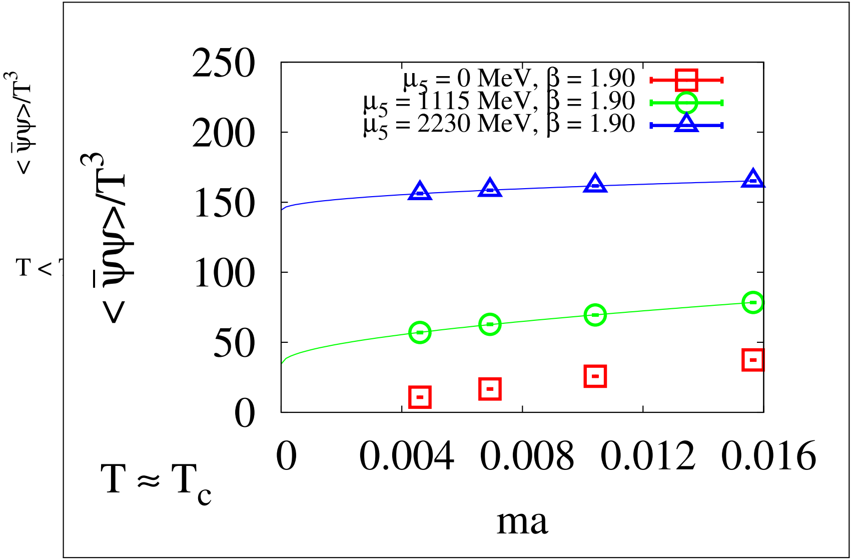
Fit: $f(ma) = a_0 + a_1\sqrt{ma} + a_2 ma$

Chiral limit.

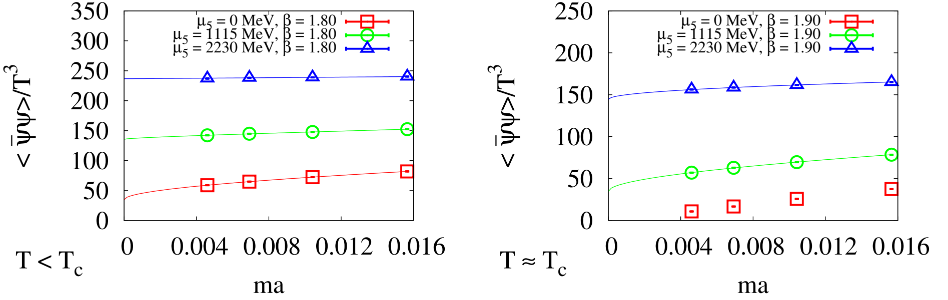


$T < T_c$

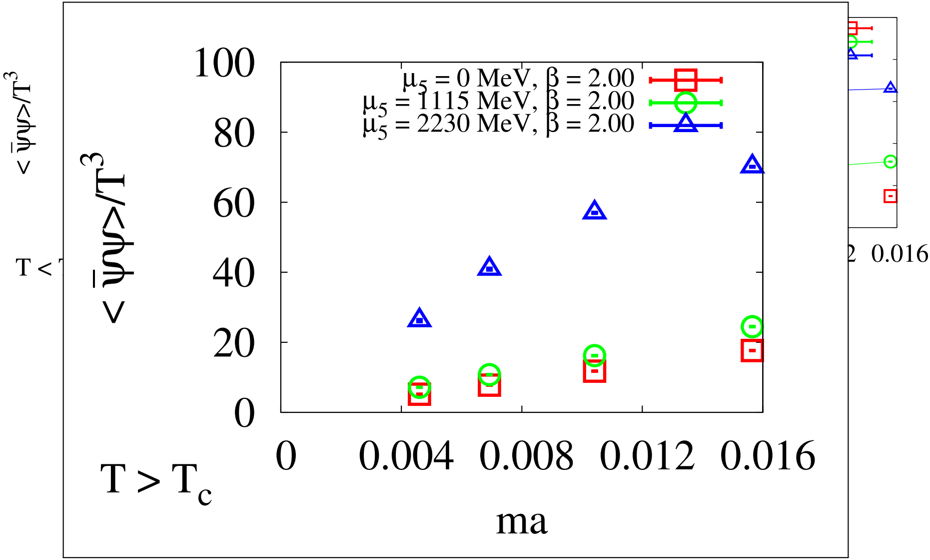
Chiral limit. $T = 178$ MeV



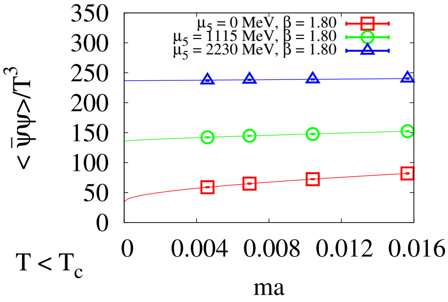
Chiral limit.



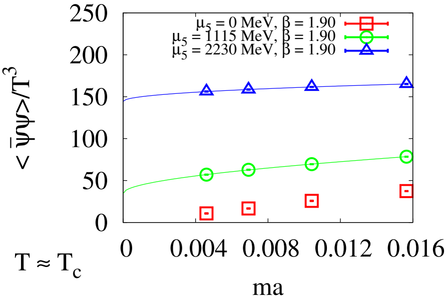
Chiral limit. $T = 268$ MeV



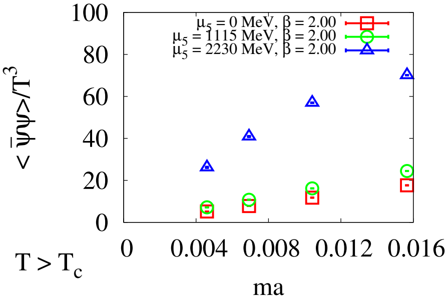
Chiral limit.



$T < T_c$

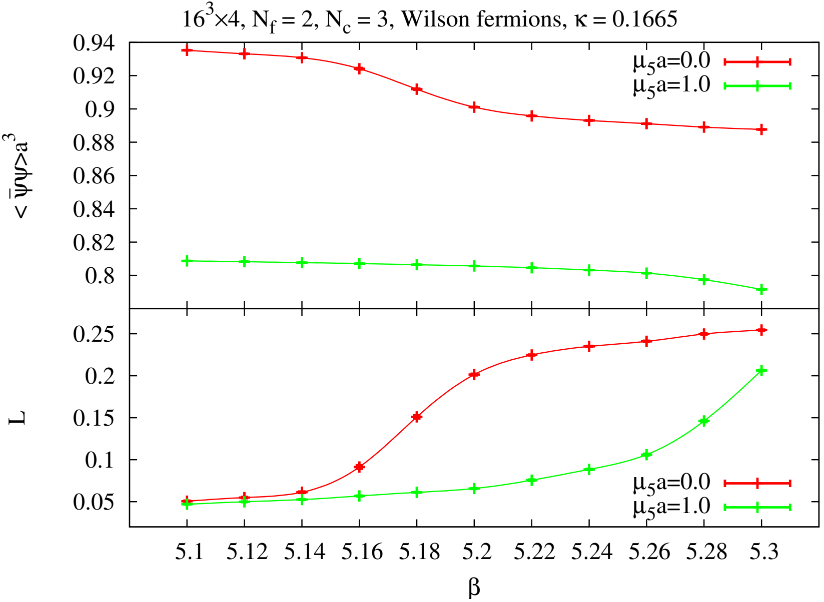


$T \approx T_c$

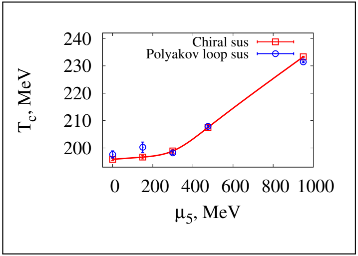


$T > T_c$

First results for $SU(3)$ gauge group, Wilson fermions.

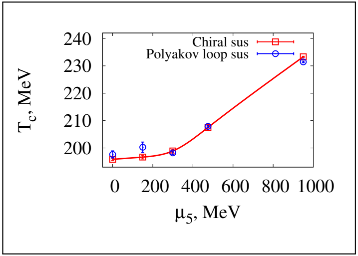


Conclusions



- $T_c \uparrow$, when $\mu_5 \uparrow$
- The situation is the same in the chiral limit
- The transition seems to become sharper
- No splitting of the χS breaking and confinement PT.
- Simulations with $N_c = 3$, $N_f = 2$, Wilson fermions are started. First results are in agreement.

Conclusions



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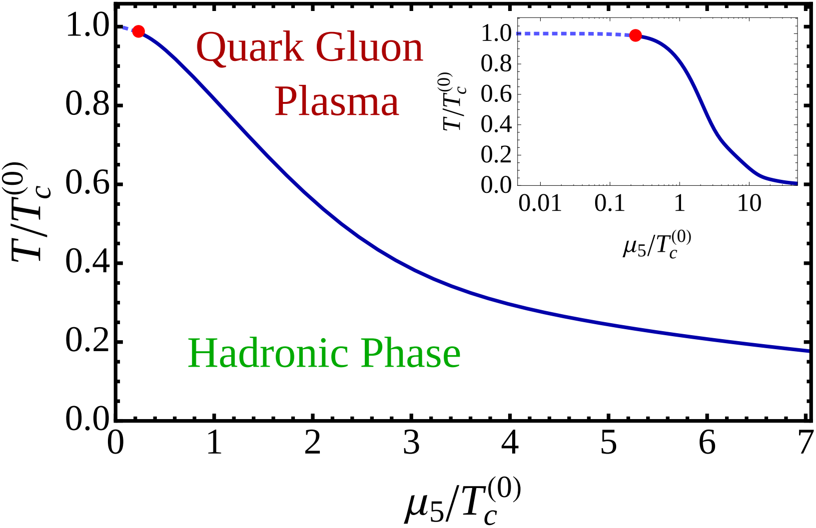
Thank you!

Backup


Quark Gluon
Plasma
Hadronic Phase
$T/T_c^{(0)}$
$\mu_5/T_c^{(0)}$
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
4
5
6
7
0.01
0.1
1
10

Bin Wang et al., arXiv:1505.00316