Chiral restoration and deconfinement in two-color QCD with two flavors of staggered quarks
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- Introduction
- Observables
- Setting the temperature scale
- Magnetic scaling
- Summary and outlook
Motivation

- two-color QCD as QCD-like theory where finite density is accessible
- preparations for finite density

**chiral properties**

- scale setting
- scaling behavior

**effective Polyakov loop potential**

- influence of quarks
- compare to effective model descriptions

→ next talk by Philipp Scior
Simulation setup

- $N_c = 2$ Wilson gauge action
- $N_f = 2$ staggered quarks via RHMC
- $N_t = 4, 6, 8$ with aspect ratio $N_s/N_t = 4$
- finite temperature: vary coupling $\beta$
- several masses

Symmetry breaking

- continuum: $\text{SU}(2N_f) \rightarrow \text{Sp}(N_f)$
- staggered: $\text{SU}(2N_f) \rightarrow \text{O}(2N_f)$, here: $\text{SU}(4) \simeq \text{O}(6) \rightarrow \text{O}(4)$
Order parameters

Polyakov loop coupling $\beta$

$m/T=0.004$
$m/T=0.012$
$m/T=0.02$
$m/T=0.04$
$m/T=0.08$
$m/T=0.4$

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Chiral condensate coupling $\beta$

$m/T=0.004$
$m/T=0.012$
$m/T=0.02$
$m/T=0.04$
$m/T=0.08$
$m/T=0.4$
Order parameters

- Chiral condensate
  - Coupling $\beta$
  - Values: 0, 0.05, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4

- Polyakov loop
  - Coupling $\beta$
  - Values: $m/T=0.006$, $m/T=0.018$, $m/T=0.03$, $m/T=0.06$, $m/T=0.12$, $m/T=0.6$

Diagrams showing $6x24^3$ simulations.
Order parameters

![Graph showing order parameters for chiral condensate and Polyakov loop](image)

- Chiral condensate
  - Coupling $\beta$
  - System size: $8x32^3$
- Polyakov loop
  - Coupling $\beta$
  - Systems: $m/T=0.04$, $m/T=0.16$, $m/T=0.6$, $m/T=0.8$
Chiral susceptibilities

- $4 \times 16^3$
  - $m/T = 0.004$
  - $m/T = 0.012$
  - $m/T = 0.02$
  - $m/T = 0.04$
  - $m/T = 0.08$
  - $m/T = 0.4$

- $6 \times 24^3$
  - $m/T = 0.006$
  - $m/T = 0.018$
  - $m/T = 0.03$
  - $m/T = 0.06$
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- $8 \times 32^3$
  - $m/T = 0.04$
  - $m/T = 0.16$
  - $m/T = 0.6$
  - $m/T = 0.8$
$N_t = 8, N_s = 32, m/T = 0.04$ data:

- approx. runtime: 80 GPU months
- using NVIDIA Tesla K20X
- Lichtenberg-Cluster @ TU Darmstadt
Ferrenberg-Swendsen reweighting

Example: $N_t = 4$
Ferrenberg-Swendsen reweighting

Example: $N_t = 4$

\[
\begin{array}{cccccccc}
3.5 & 4 & 4.5 & 5 & 5.5 & 6 & 1.855 & 1.86 & 1.865 & 1.87 & 1.875 & 1.88 & 1.885 & 1.89 & 1.895 & 1.9
\end{array}
\]

chiral susceptibility

coupling $\beta$

$N_t=4 \ N_s=16 \ m/T=0.02$

data

from F-S reweighting
Ferrenberg-Swendsen reweighting
Example: $N_t = 6$
Ferrenberg-Swendsen reweighting

Example: $N_t = 6$
Ferrenberg-Swendsen reweighting

Example: $N_t = 8$
Ferrenberg-Swendsen reweighting

Example: $N_t = 8$

![Graph showing chiral susceptibility vs. coupling $\beta$.](graph.png)

Data from F-S reweighting

$N_t=8, N_s=32, m/T=0.04$
Pseudo-critical line

![Graph showing the pseudo-critical line with data points and error bars for different values of \( N_t \).]
chiral extrapolation

\[ \beta_{pc}(m, N_t) = \beta_c(N_t) + d \cdot \left( \frac{m}{T} \right)^c \]

with \( c = \frac{1}{\beta \delta} = 0.38 \) from Basile et al. JHEP02(2005)044
chiral extrapolation

\[ \beta_{pc}(m, N_t) = \beta_c(N_t) + d \cdot \left( \frac{m}{T} \right)^c \]

with \( c = \frac{1}{\beta \delta} = 0.38 \) from Basile et al. JHEP02(2005)044
Temperature scale

leading scaling behavior:

$$\frac{T}{T_c} = \exp\{b(\beta - \beta_c)\}$$

-0.1  0  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8

from linear fit:

$$b = 2.54 \pm 0.02$$

$N_t=4$

$N_t=6$

$N_t=8$

$\beta_c$

$\log(N_t/4)$

data

fit

$\beta_c$

-0.1  0  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8

from linear fit:

$$b = 2.54 \pm 0.02$$

similar analysis using deconfinement transition in pure SU(2) (Smith et al. [1307.6339])
Critical exponents

\[ M_{h=0,t \to 0} \sim |t|^\beta \]
\[ \chi_{h=0,t \to 0} \sim |t|^{-\gamma} \]
\[ M_{t=0,h \to 0} \sim |h|^{1/\delta} \]

with reduced temperature \( t = \frac{T - T_c}{T_c} \), external symmetry breaking field \( h = \frac{H}{H_0} \)

pseudo-critical line:

\[ t_{\text{peak}} \sim h^{1/\delta \beta} \]

\[ \chi_{\text{peak}} \sim t_{\text{peak}}^{-\gamma} \sim h^{1/\delta - 1} \]
magnetic scaling

peak height: \( \chi_{\text{peak}} \sim m^{1/\delta - 1} \)

\[ \begin{array}{c|c|c|c|c|c|c|c|c|c|}
\hline
N_t & 4 & 6 & 8 \\
\hline
\chi & 3.70(23) & 4.33(27) & 5.0(1) \\
\hline
\end{array} \]

\( \delta: N_t=8: 3.85 \)
\( N_t=6: 4.33(27) \)
\( N_t=4: 3.70(23) \)
magnetic scaling

peak height: $\chi_{\text{peak}} \sim m^{1/\delta - 1}$

![Graph showing magnetic scaling with $\chi_{\text{peak}}$ as a function of $m/T$ for $N_t=4$, $N_t=6$, and $N_t=8$. The fits are also shown.](image1)

![Graph showing magnetic scaling with $\chi_{\text{peak}}$ as a function of $m/a_c$ for $N_t=4$, $N_t=6$, and $N_t=8$. The fits are also shown.](image2)
Summary and outlook

Summary

▶ first steps towards scale setting and determination of critical exponents
▶ successful use of Ferrenberg-Swendsen reweighting for $N_t = 4$ and $N_t = 6$

Outlook

▶ chiral properties need more work, especially at $N_t = 8$
▶ lines of constant physics
▶ finite density

see next talk

▶ effective Polyakov loop potentials, Polyakov loop correlators, ...
▶ in comparison to pure gauge simulations and effective theories