Z(N) dependence of the pure Yang-Mills gluon propagator in the Landau gauge near Tc

Orlando Oliveira, Paulo Silva

Centro de Física Computacional, Universidade de Coimbra, Portugal

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Outline

1. Introduction and Motivation
2. Results
3. Conclusions and Outlook


QCD Phase Diagram

- study of the phase diagram of QCD relevant e.g. for heavy ion experiments
- QCD has phase transition where quarks and gluons become deconfined for sufficiently high $T$
- Polyakov loop
  - order parameter for the confinement-deconfinement phase transition
  - $L = \langle L(\vec{x}) \rangle \propto e^{-F_q/T}$
  - Definition on the lattice:

$$L(\vec{x}) = \text{Tr} \prod_{t=0}^{N_t-1} U_4(\vec{x}, t)$$

- $T < T_c : L = 0$ (center symmetry)
- $T > T_c : L \neq 0$ (spontaneous breaking of center symmetry)

Lattice 2014
Center symmetry

- Wilson gauge action is invariant under a center transformation
- temporal links on a hyperplane $x_4 = \text{const}$ multiplied by
  \[ z \in \mathbb{Z}_3 = \{ e^{-i2\pi/3}, 1, e^{i2\pi/3} \} \]
- Polyakov loop $L(\vec{x}) \rightarrow zL(\vec{x})$
- $T < T_c$
  - local $P_L$ phase equally distributed among the three sectors
  \[ L = \langle L(\vec{x}) \rangle \approx 0 \]
- $T > T_c$
  - $\mathbb{Z}_3$ sectors not equally populated: $L \neq 0$

G. Endrödi, C. Gattringer, H.-P. Schadler, arXiv:1401.7228
C. Gattringer, A. Schmidt, JHEP 01, 051 (2011)
C. Gattringer, Phys. Lett. B 690, 179 (2010)
F. M. Stokes, W. Kamleh, D. B. Leinweber, arXiv:1312.0991
Landau gauge gluon propagator

- At finite T: two independent form factors

\[ D_{ab}^{\mu\nu}(\hat{q}) = \delta^{ab} \left( P_{\mu\nu}^T D_T(q^2_4, \vec{q}) + P_{\mu\nu}^L D_L(q^2_4, \vec{q}) \right) \]
$D_L$ and $D_T$ show quite different behaviours with $T$

Usually, the propagator is computed such that $\text{arg}(P_L) < \pi/3$ ($Z_3$ sector 0)

what happens in the other sectors?
Lattice setup

- spatial physical volume $\sim (6.5\text{fm})^3$
- 100 configs per ensemble

### Coarse lattices $a \sim 0.12\text{fm}$

| Temp. (MeV) | $L_s^3 \times L_t$ | $\beta$ | $a$ (fm) | $L_s a$ (fm) |
|-------------|---------------------|---------|----------|--------------|
| 265.9       | $54^3 \times 6$     | 5.890   | 0.1237   | 6.68         |
| 266.4       | $54^3 \times 6$     | 5.891   | 0.1235   | 6.67         |
| 266.9       | $54^3 \times 6$     | 5.892   | 0.1232   | 6.65         |
| 267.4       | $54^3 \times 6$     | 5.893   | 0.1230   | 6.64         |
| 268.0       | $54^3 \times 6$     | 5.8941  | 0.1227   | 6.63         |
| 268.5       | $54^3 \times 6$     | 5.895   | 0.1225   | 6.62         |
| 269.0       | $54^3 \times 6$     | 5.896   | 0.1223   | 6.60         |
| 269.5       | $54^3 \times 6$     | 5.897   | 0.1220   | 6.59         |
| 270.0       | $54^3 \times 6$     | 5.898   | 0.1218   | 6.58         |
| 271.0       | $54^3 \times 6$     | 5.900   | 0.1213   | 6.55         |
| 272.1       | $54^3 \times 6$     | 5.902   | 0.1209   | 6.53         |
| 273.1       | $54^3 \times 6$     | 5.904   | 0.1204   | 6.50         |

### Fine lattices $a \sim 0.09\text{fm}$

| Temp. (MeV) | $L_s^3 \times L_t$ | $\beta$ | $a$ (fm) | $L_s a$ (fm) |
|-------------|---------------------|---------|----------|--------------|
| 269.2       | $72^3 \times 8$     | 6.056   | 0.09163  | 6.60         |
| 270.1       | $72^3 \times 8$     | 6.058   | 0.09132  | 6.58         |
| 271.0       | $72^3 \times 8$     | 6.060   | 0.09101  | 6.55         |
| 271.5       | $72^3 \times 8$     | 6.061   | 0.09086  | 6.54         |
| 271.9       | $72^3 \times 8$     | 6.062   | 0.09071  | 6.53         |
| 272.4       | $72^3 \times 8$     | 6.063   | 0.09055  | 6.52         |
| 272.9       | $72^3 \times 8$     | 6.064   | 0.09040  | 6.51         |
| 273.3       | $72^3 \times 8$     | 6.065   | 0.09025  | 6.50         |
| 273.8       | $72^3 \times 8$     | 6.066   | 0.09010  | 6.49         |
How-to

- for each configuration, 3 gauge fixings after a $Z_3$ transformation

$$\mathcal{U}_4' (\vec{x}, t = 0) = z \mathcal{U}_4 (\vec{x}, t = 0)$$

- configurations classified according to $\langle L \rangle = |L| e^{i\theta}$

\[
\theta = \begin{cases} 
-\pi < \theta \leq -\pi/3, & \text{Sector -1,} \\
-\pi/3 < \theta \leq \pi/3, & \text{Sector 0,} \\
\pi/3 < \theta \leq \pi, & \text{Sector 1}
\end{cases}
\]
Conical cut for momenta above 1GeV; all data below 1GeV

Renormalization:

\[ D_{L,T}(\mu^2) = Z_R D_{L,T}^{\text{Lat}}(\mu^2) = 1/\mu^2 \]

Renormalization scale: \( \mu = 4 \) GeV

\( D_L \) and \( D_T \) renormalized independently

- within each \( Z(3) \) sector, \( Z_R^{(L)} \) and \( Z_R^{(T)} \) agree within errors
- each \( Z_3 \) sector is renormalized independently
  - \( Z_R \) do not differ between the different \( Z(3) \) sectors
Coarse lattices, below $T_c$

Longitudinal component

Transverse component
Introduction and Motivation

Results

Conclusions and Outlook

Fine lattices, below $T_c$

Longitudinal component

Transverse component

$\beta = 6.056$

$Lattice 2014$
Coarse lattices, above $T_c$

**Longitudinal component**

![Graph showing $D_\perp(p^2)$ vs. $p$ for three sectors.]

**Transverse component**

![Graph showing $D_T(p^2)$ vs. $p$ for three sectors.]

$L_{2014}$
Fine lattices, above $T_c$

**Longitudinal component**

**Transverse component**

$\beta = 6.064$

$D_v(p^2)$ vs $p$ (GeV) for different sectors.

$D_T(p^2)$ vs $p$ (GeV) for different sectors.

Lattice 2014
Polyakov loop history

**Modulus**

$D_L(0)$ versus Polyakov loop

$54^3 \times 6, \beta = 5.8941$

**Phase**

$D_L(0)$ versus Polyakov loop

$54^3 \times 6, \beta = 5.8941$
Polyakov loop history

Modulus

Phase

Lattice 2014
Removing configurations in wrong phase

Fine lattices

![Graph showing temperature (T) vs. D_L(0) for different sectors with and without cleaning.](Lattice2014)
Correlation between $L$ and the separation of $D$ between the different sectors

- This can be used to identify the phase transition
- Possible existence of different phases near and above $T_c$
- The dynamics differs in each sector

Outlook:

- understand physics of different sectors (e.g. mass scales)
- how quarks change the above picture?
- look at the distribution of eigenvalues of the Dirac operator

Gattringer, Rakow, Schafer, Soldner, PRD66(2002)054502

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