SIGNATURES OF THE YANG-MILLS DECONFINEMENT TRANSITION FROM THE GLUON TWO-POINT CORRELATOR

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- Center Symmetry
- Landau gauge results
- Center-symmetric effective action
- Results
- Conclusion and Outlook

INTRODUCTION

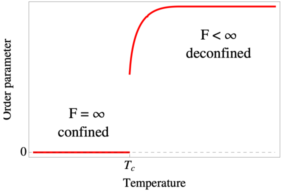
- Insight in the low-energy regime of QCD, especially a signal of the confinement/deconfinement transition.
- Most results are coming from non-perturbative, numerical (lattice) or semi-analytical (FRG and SD) methods.
- From this, we know that:
  - At some very high temperature T_c, hadrons become free quarks and gluons $\rightarrow$ quark-gluon plasma.
  - This transition is related to the breaking of the center symmetry of a gauge group when using pure Yang-Mills theory (infinitely heavy quarks):

$$\mathcal{L} = \frac{1}{4}(F^a_{\mu\nu})^2$$

CENTER SYMMETRY

- An order parameter for the confinement/deconfinement transition is the Polyakov loop:

$$\mathcal{P} \propto \langle P e^{i \int_0^\beta d\tau A_0(\tau,x)} \rangle \propto e^{-\beta F}$$



- In the confined phase, F is infinite $\rightarrow \mathcal{P} = 0$. In the deconfined phase, F is finite $\rightarrow \mathcal{P} \neq 0$.
- Under center symmetry $\mathcal{P} \rightarrow Z_N \mathcal{P}$, with Z_N the center elements of the gauge group. So, breaking of the center symmetry signals deconfinement.
- Confirmed by lattice data: second order transition for $SU(2)$, first order for $SU(3)$.

ENCODING OF THE TRANSITION

Polyakov loop:

$$\mathcal{P} \sim \left\langle P e^{i \int_0^\beta d\tau A_0(\tau, x)} \right\rangle \sim e^{-\beta F}.$$

Because the Polyakov loop is related to A_0, it is expected that the transition is encoded in (the tower of)

$$\langle A_0 \rangle, \langle A_0 A_0 \rangle, \ldots, \langle A_0^n \rangle.$$

For the appropriate choice of gauge, can the transition be reflected in the lowest order correlators?

LANDAU GAUGE CORRELATOR

In principle:

- $\langle A \rangle$ is found by minimizing the effective action $\Gamma[A]$. It represents the state of the system . $\langle A_0 \rangle \to$ order parameter.
- The two-point correlator derives from the effective action

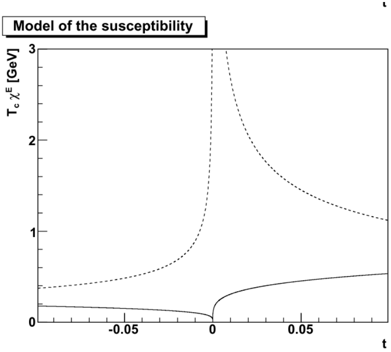
$$1 \Big/ \left. \frac{\partial^2 \Gamma}{\partial A^2} \right|_{A=\langle A \rangle} = \langle AA \rangle_c,$$

so for $SU(2)$, $\langle A_0 A_0 \rangle$ should diverge at T_c.

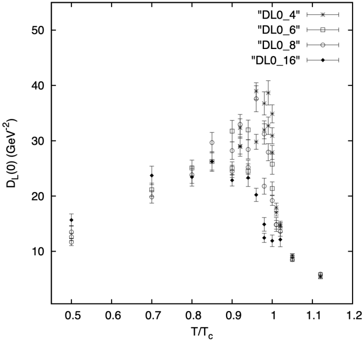
In practice:

- In the Landau gauge, $\partial_\mu A_\mu = 0$, then $\langle A_0 \rangle = 0$. $\to$ no order parameter.
- No evidence of divergence of $\langle A_0 A_0 \rangle$ was found on the (gauge-fixed) lattice and in the continuum.

$SU(2)$ LANDAU GAUGE CORRELATORS

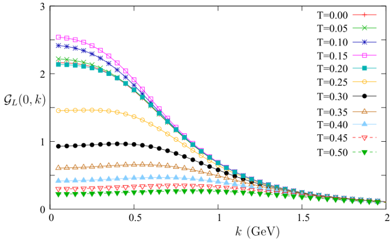


Electric susceptibility (zero momentum longitudinal propagator)

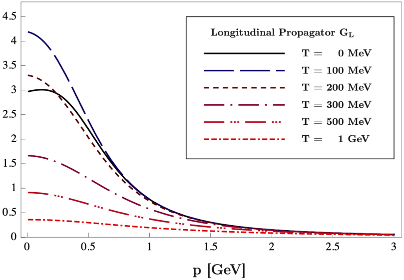


*T. Mendes and A. Cucchieri, PoS LATTICE2014, 183 (2015).

$SU(2)$ LANDAU GAUGE CORRELATORS



Longitudinal gluon propagator



*U. Reinosa, J. Serreau, M. Tissier, N. Wschebor, Phys. Rev. D, (2015)

*L. Fister and J. M. Pawlowski, [arXiv:1112.5440 [hep- ph]](2012).

BACKGROUND FIELD GAUGES

- A priori there is no reason to believe that the Landau gauge will provide the right environment to keep track of the centersymmetry breaking.
- In the Landau gauge the effective action is not explicitly center-symmetric $\Gamma[A] \neq \Gamma[A^U]$.
- This should not alter the physical results in principle, but it can lead to problems when approximations (loop calculations) are involved.
- To regain gauge invariance, one solution is to work with the Background Field Gauges.

BACKGROUND FIELD GAUGES

- Introducing a background field $\bar{A}$, the effective action is gauge-invariant $\Gamma_{\bar{A}}[A] = \Gamma_{\bar{A}^U}[A^U]$. Landau-deWitt gauge:

$$\bar{D}_\mu(A_\mu - \bar{A}_\mu) = 0, \text{ with } \bar{D}_\mu \equiv \partial_\mu - \left[\bar{A}_\mu, \cdot\right].$$

- In the Background field effective action one looks at $\tilde{\Gamma}[\bar{A}]$ by taking $\bar{A} = \langle A \rangle$.
  - The two-point function $\langle AA \rangle_c$ is not directly accessible from $\tilde{\Gamma}[\bar{A}]$,
  - Relies on the strict background independence of $\tilde{\Gamma}[\bar{A}]$, which is not easy to maintain in the presence of truncations.
- We propose the Center-symmetric Landau gauge, which fixes $\bar{A} = \bar{A}_c$. Then $\Gamma_{\bar{A}_c}[A] = \Gamma_{\bar{A}_c}[A^{U^c}]$.

OUR SETUP

- We work in the Landau-deWitt gauge with a background field $\bar{A}_\mu$:

$$\bar{D}_\mu(A_\mu - \bar{A}_\mu) = 0, \text{ with } \bar{D}_\mu \equiv \partial_\mu - \left[\bar{A}_\mu, \cdot\right].$$

- We take $\bar{A}$ and $\langle A \rangle$ in the temporal direction, $\propto \delta_{\mu 0}$, and along the diagonal color directions (σ^3 for $SU(2)$, (λ^3, λ^8) for $SU(3)$), so that $\Gamma[A, \bar{A}] \propto V(A, \bar{A})$. We write $\langle A \rangle = \delta_{\mu 0} \frac{T}{g} r \frac{\sigma^3}{2}$ and $\bar{A} = \delta_{\mu 0} \frac{T}{g} \bar{r} \frac{\sigma^3}{2}$.
- E.g. in $SU(2)$, under center transform $r \to 2\pi - r$ so centersymmetric value is $r_c = \pi$. For $SU(3)$, $r_c = (3/4\pi, 0)$.
- We fix $\bar{r} = r_c$: Center-symmetric Landau gauge. Center-symmetric phase when $r = r_c$, $\to$ order parameter.

CURCI-FERRARI MODEL

We have computed $\langle A \rangle$ and $\langle A(0,p)A(0,-p) \rangle$ up to first loop order in the finite temperature Curci-Ferrari model:

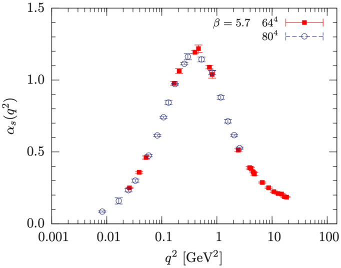
$$S = S_{YM} + S_{gf} + \int_{x,\tau} \frac{m^2}{2}(A^a_\mu - \bar{A}^a_\mu)^2$$

Several motivations:

- Perturbative gauge-fixed Yang-Mills breaks down at low energies (Landau pole, Gribov copies...), there is no analytical model for this region.
- A gluon mass term seems to dominate the (unknown) gauge-fixed action in the IR; decoupling behaviour on the lattice. CF could be an effective model.
- The CF model is renormalizable, avoids the Landau pole and lifts the degeneracy between Gribov copies.

CURCI-FERRARI MODEL

We use perturbation theory in the non-perturbative region. Actually, the coupling might not be that large in the deep IR.



*I.L. Bogolubsky, E.M. Ilgenfritz, M. Muller-Preussker, and A. Sternbeck. Phys.Lett., B676:69–73, 2009.

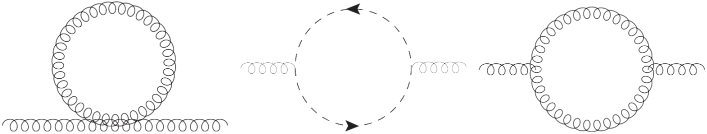
RESULTS - $T_c(MeV)$

	Lattice	FRG-BG[1]	CF-BG, 1-lp[2]	CF-BG, 2-lp[3]	CF-CS, 1-lp[4]
SU(2)	295	230	238	284	**265**
SU(3)	270	275	185	254	**267**

BG: Background effective action
CS: Centersymmetric Landau gauge
.

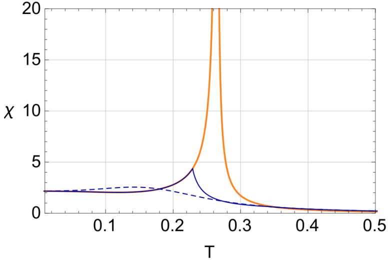
[1] L. Fister and J. M. Pawlowski, Phys.Rev. D88 (2013) 045010
[2] U. Reinosa, J. Serreau, M. Tissier and N. Wschebor, Phys.Lett. B742 (2015) 61-68.
[3] U. Reinosa, J. Serreau, M. Tissier and N. Wschebor, Phys.Rev. D93 (2016) 105002.
[4] **DvE, U. Reinosa, J. Serreau and M. Tissier, SciPost Phys. 12, 087 (2022)**

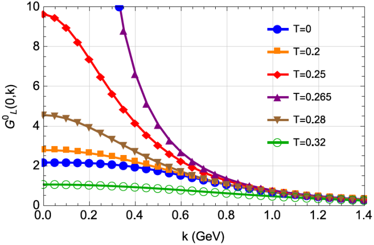
FEYNMAN DIAGRAMS GLUON PROPAGATOR

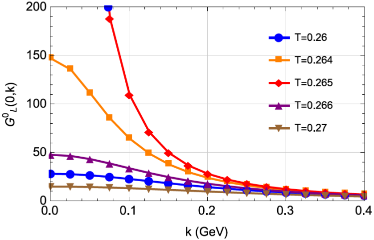


- Calculated in finite temperature trough Matsubara techniques: $\int d^d Q \to T \sum_q \int d^{d-1} q$
- We calculated the spatial integral with Feynman techniques, the Matsubara sums numerically.

RESULTS: SU(2) GLUON PROPAGATOR





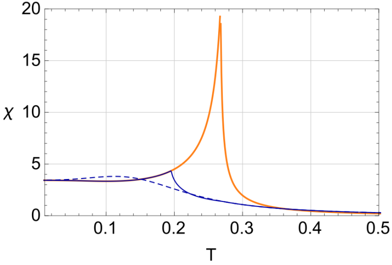


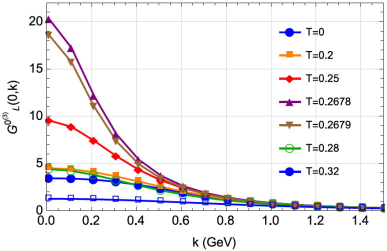
Landau gauge
Background field effective action
Centersymmetric Landau gauge

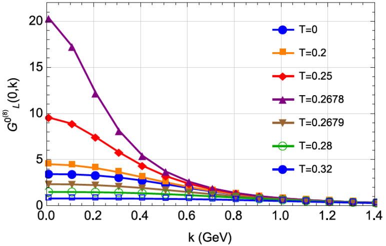
m=0.68 GeV, μ=1 GeV, g=7.5

*DvE, U. Reinosa, J. Serreau and M. Tissier, SciPost Phys. 12, 087 (2022).

RESULTS: SU(3) GLUON PROPAGATOR





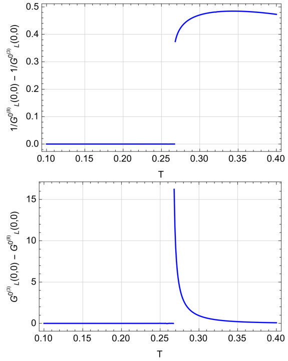


Landau gauge
Background field effective action
Centersymmetric Landau gauge

m=0.54 GeV, μ=1 GeV, g=4.9

*DvE, U. Reinosa, J. Serreau and M. Tissier, SciPost Phys. 12, 087 (2022).

SU(3) PROPAGATOR DIFFERENCE

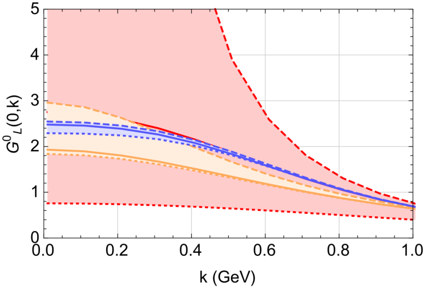


Confirmed by gauge-fixed lattice data, in collaboration with O. Oliveira and P. Silva.

CONCLUSION AND OUTLOOK

- We have performed, for the first time, calculations of the gluon one- and two-point correlator in the centersymmetric Landau gauge.
- We find a good agreement with lattice data for T_c.
- We find that for $SU(2)$, the deconfinement transition is signaled by a divergence of the longitudinal gluon propagator for $k \to 0$.
- For $SU(3)$, the difference between the propagators in the neutral color mode is an order parameter for the transition.
- Ideas for future works: RG improvement, transversal propagator and dynamically generated mass [with D. Dudal and D. Vercauteren].

RESULTS: SU(2) GLUON PROPAGATOR

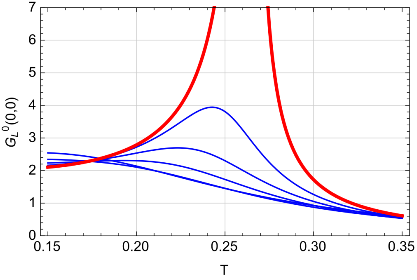


Landau gauge

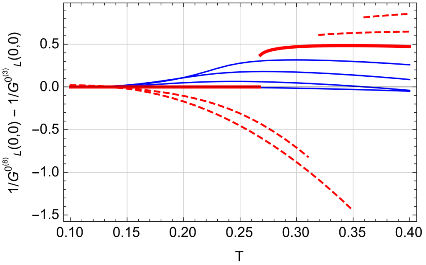
Background Field Effective action

Center-symmetric Landau Gauge

RESULTS: SU(2) GLUON PROPAGATOR



SU(3) PROPAGATOR DIFFERENCE



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