Deconfinement in pure gauge SU(3) Yang-Mills theory: the ghost propagator

Orlando Oliveira, Vítor Paiva, Paulo J. Silva*

Centro de Física da Universidade de Coimbra, Portugal

Abstract

The ghost propagator in Landau gauge is studied at finite temperature below and above T_c using lattice QCD simulations. For high temperatures, we find that the ghost propagator is enhanced, compared to the confined phase. The results suggest that the ghost propagator can be used to identify the phase transition, similarly to the gluon propagator case.

QCD phase diagram

- Relevant for heavy ion experiments
- Phase transition with quarks and gluons becoming deconfined at sufficiently high T
- Polyakov loop
  - order parameter for the confinement-deconfinement phase transition
  - $L = \langle L(\vec{x}) \rangle \propto e^{-F_q/T}$
  - $T < T_c : L = 0$
  - $T > T_c : L \neq 0$

QCD Green's functions

- In a QFT, the knowledge of all Green's functions give a complete description of the theory
- In QCD, propagators of fundamental fields encode information about non-perturbative phenomena (confinement/deconfinement, chiral symmetry breaking)
- Propagators are gauge dependent: Landau gauge

Landau gauge fixing on the lattice

- gauge fixing functional

$$F(U^g) = -\mathrm{ReTr} \sum_{x,\mu} \left[g(x)\, U_\mu(x)\, g^\dagger(x+\hat{\mu}) \right]$$

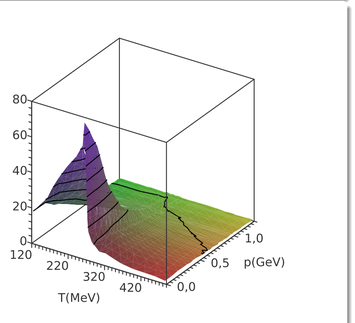
- First variation: Landau gauge condition $\partial_\mu A^a_\mu = 0$
- Second variation: Faddeev-Popov matrix

$$M^{ab}_{x,y} = \sum_\mu \Big(\mathrm{ReTr}\big[\{t^a, t^b\}(U_\mu(x) + U_\mu(x-\hat{\mu}))\big]\delta_{xy} - 2\mathrm{ReTr}\big[t^b t^a U_\mu(x)\big]\delta_{x+\hat{\mu},y} - 2\mathrm{ReTr}\big[t^a t^b U_\mu(x-\hat{\mu})\big]\delta_{x-\hat{\mu},y} \Big)$$

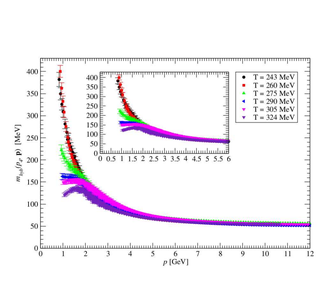
  - continuum limit $-\frac{1}{2}\left(\partial_\mu D^{ab}_\mu + D^{ab}_\mu \partial_\mu\right)$
  - in Landau gauge: $= -\partial_\mu D^{ab}_\mu$

Gluon and quark propagators at finite T

Longitudinal gluon



Running quark mass



PJS, O. Oliveira, P. Bicudo, N. Cardoso, Phys.Rev. D89 (2014) 074503

O. Oliveira, PJS, Eur.Phys.J. C79 (2019) 793

- strong suppression of the gluon longitudinal form factor above T_c
- $T > T_c$: quarks behave as quasiparticles with m~ 100MeV (for a bare quark mass $\sim$ 50 MeV)

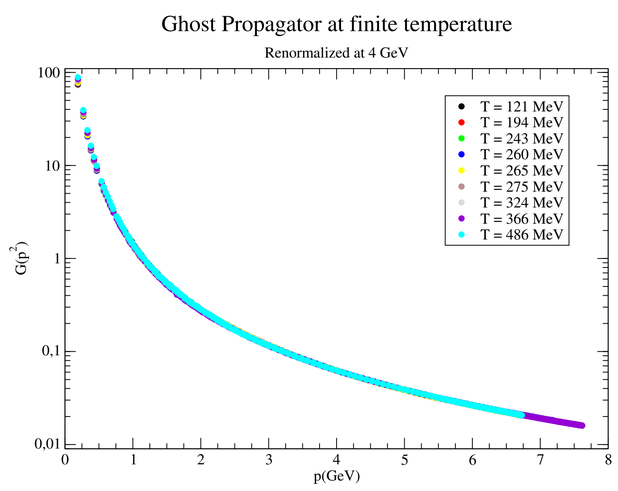
Ghost propagator

- inversion of the FP matrix
- two point sources for each config
- zero temporal momenta
- all data renormalized at $\mu = 4$GeV

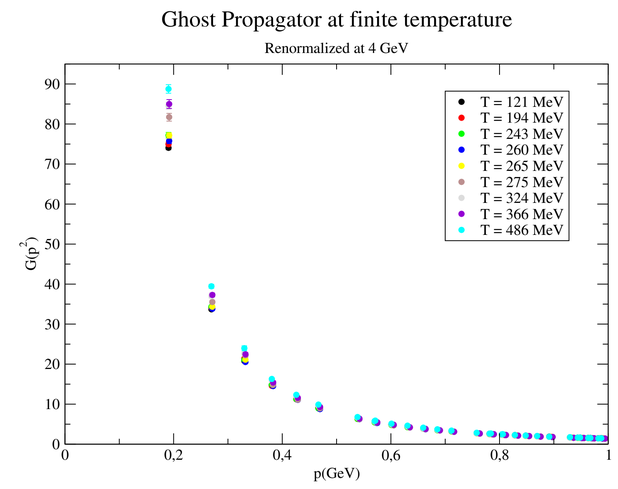
Lattice setup

Temp. (MeV)	β	L_s	L_t	a [fm]	1/a (GeV)
121	6.0000	64	16	0.1016	1.943
194	6.0000	64	10	0.1016	1.943
243	6.0000	64	8	0.1016	1.943
260	6.0347	68	8	0.09502	2.0767
265	5.8876	52	6	0.1243	1.5881
275	6.0684	72	8	0.08974	2.1989
324	6.0000	64	6	0.1016	1.943
366	6.0684	72	6	0.08974	2.1989
486	6.0000	64	4	0.1016	1.943

Ghost propagator – all momenta

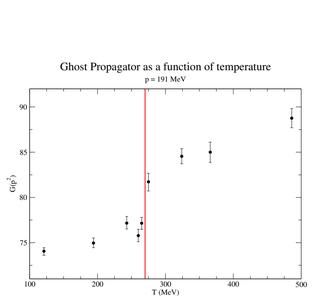


Ghost propagator — IR region

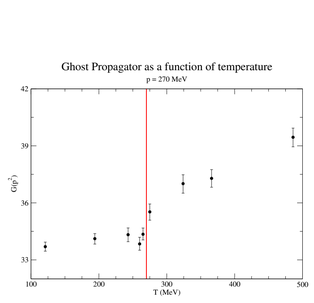


Ghost propagator as a function of T

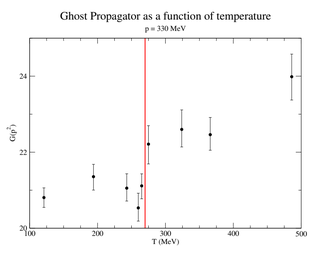
$p = 191$MeV



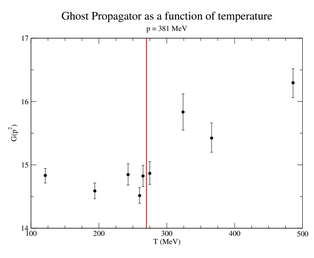
$p = 270$MeV



$p = 330$MeV



$p = 381$MeV



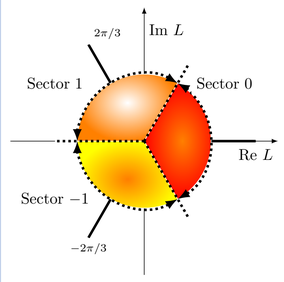
Center symmetry

- Wilson gauge action invariant under a center transformation
  - temporal links on a hyperplane $x_4 = const$ multiplied by $z \in Z_3 = \{e^{-i2\pi/3}, 1, e^{i2\pi/3}\}$
- Polyakov loop $L(\vec{x}) \rightarrow zL(\vec{x})$
- $T < T_c$
  - center symmetry
  - local P_L phase equally distributed among the three sectors

$$L = \langle L(\vec{x}) \rangle \approx 0$$

- $T > T_c$
  - spontaneous breaking of center symmetry
  - Z_3 sectors not equally populated: $L \neq 0$

Z_3 sectors



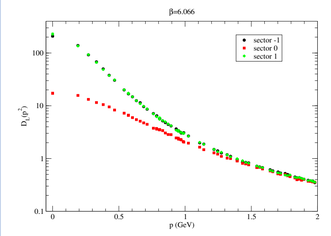
- for each configuration, 3 gauge fixings after a Z_3 transformation

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

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

Z_3 dependence: gluon and quark above T_c

Longitudinal gluon



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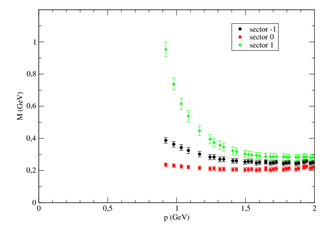


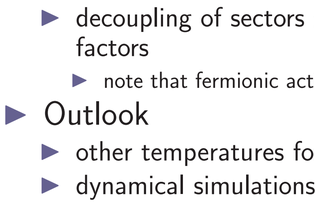
PJS, O. Oliveira, PRD **93** (2016) 114509

PJS, O. Oliveira, PoS(LATTICE2019)047

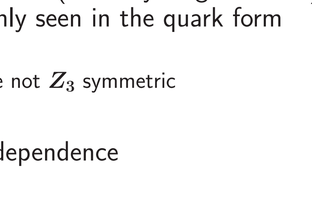
Z_3 dependence: ghost propagator

- Simulations on $72^3 \times 8$ lattices near T_c
  - $\beta = 6.058$, $T \sim 270$MeV
  - $\beta = 6.066$, $T \sim 274$MeV

Below T_c



Above T_c



Conclusions and Outlook

- Landau gauge ghost propagator at finite temperature
  - enhancement of the ghost form factor above T_c
  - similar to previous SU(3) results on smaller lattice volumes

    R. Aouane *et al*, Phys.Rev.D 85 (2012) 034501
  - early SU(2) studies conclude in favour of a nearly independent ghost propagator with the temperature

    A. Cucchieri *et al*, Phys.Rev.D 75 (2007) 076003
- Z_3 dependence — preliminary results
  - ghost propagator sensitive to the Z_3 sector above T_c
  - suppression of ± 1 sectors relative to the 0 sector
  - ± 1 sectors are indistinguishable (similarly to gluon case)
  - decoupling of sectors ± 1 only seen in the quark form factors
    - note that fermionic actions are not Z_3 symmetric
- Outlook
  - other temperatures for Z_3 dependence
  - dynamical simulations

Acknowledgements

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