GRADUIERTENKOLLEG
Masse-Spektrum-Symmetrie

# Landau gauge gluon and ghost propagators at non-zero temperature from lattice QCD

## Motivation and Aims

- Investigating the phase diagram of QCD at $T > 0$ on the lattice with the help of gluon and ghost propagators in Landau gauge.
- Providing ready-to use input data for Dyson-Schwinger or functional renormalization group eqs. for semi-analytic nonperturbative studies of the fermionic sector of QCD.
- Compare pure gauge theory, i.e. quenched QCD ($\Rightarrow$ first order phase transition) with two-flavour QCD ($\Rightarrow$ crossover phenomenon).
- Compute MOM-scheme renormalized gluon and ghost propagators in the non-perturbative range $[\,0.4, 3.0\,]$ GeV across phase transition (crossover) at fixed pion mass values $m_\pi \simeq 320, 400, 470$ MeV and $\infty$, resp.
- In the quenched case we study systematic effects: finite-size and Gribov copy effects, extrapolation to continuum limit.
- For full QCD provide proper fits of the momentum dependence for various temperature and pion mass values.

## Methods

- Lattice discretization of QCD with twisted mass formulation for fermionic action.
- Propagators computed from path integral represention with (hybrid) Monte Carlo method.
- Gauge potentials in terms of lattice link variables: $A_\mu(x+\hat{\mu}/2) = \frac{1}{2iag_0}(U_{x\mu} - U^\dagger_{x\mu})\,|_{traceless}$
- Landau gauge by maximizing $F_U[g] = \frac{1}{3}\sum_x \sum_\mu \mathfrak{Re}\,\mathrm{Tr}\Big(g_x U_{x\mu} g^\dagger_{x+\mu}\Big)$ w. r. to $g_x \in SU(3)$ employing *simulated annealing* + *overrelaxation*.
- Transverse and longitudinal gluon propagator in $q$-space (Matsubara frequency $\sim q_4 \equiv 0$):
  $D_T = \frac{1}{(d-2)8}\,\langle \sum_{i=1}^3 A_i^a(q)\,A_i^a(-q) - \frac{q_4^2}{q^2}\,A_4^a(q)\,A_4^a(-q)\rangle$.
  $D_L = \frac{1}{8}(1+\frac{q_4^2}{q^2})\,\langle A_4^a(q)\,A_4^a(-q)\rangle$
- Ghost propagator $G$ and its dressing function $J$ from Faddeev-Popov operator $M = -\partial D$:
  $G^{ab}(q) = a^2\sum_{x,y} < e^{-2\pi i k\cdot(x-y)/L}[M^{-1}]^{ab}_{xy} >= \delta^{ab}\,G(q) = \delta^{ab}\,\frac{J(q)}{q^2}$.

## Some Details

Standard lattice plaquette action for pure $SU(3)$ gauge theory

$$S_G = \beta\sum_x\sum_{\mu>\nu}\left[1-\frac{1}{3}\,\mathfrak{Re}\,\mathrm{Tr}\Big(U_{x\mu}U_{x+\mu;\nu}U^\dagger_{x+\nu;\mu}U^\dagger_{x\nu}\Big)\right],\ \beta = 6/g_0^2.$$

Symanzik-improved gauge action

$$S_G = \beta\sum_x[c_0\sum_{\mu<\nu}(1-\frac{1}{3}\,\mathfrak{Re}\ \mathrm{Tr}\ U^{1\times1}_{x\mu\nu}) + c_1\sum_{\mu\neq\nu}(1-\frac{1}{3}\,\mathfrak{Re}\ \mathrm{Tr}\ U^{1\times2}_{x\mu\nu})],$$

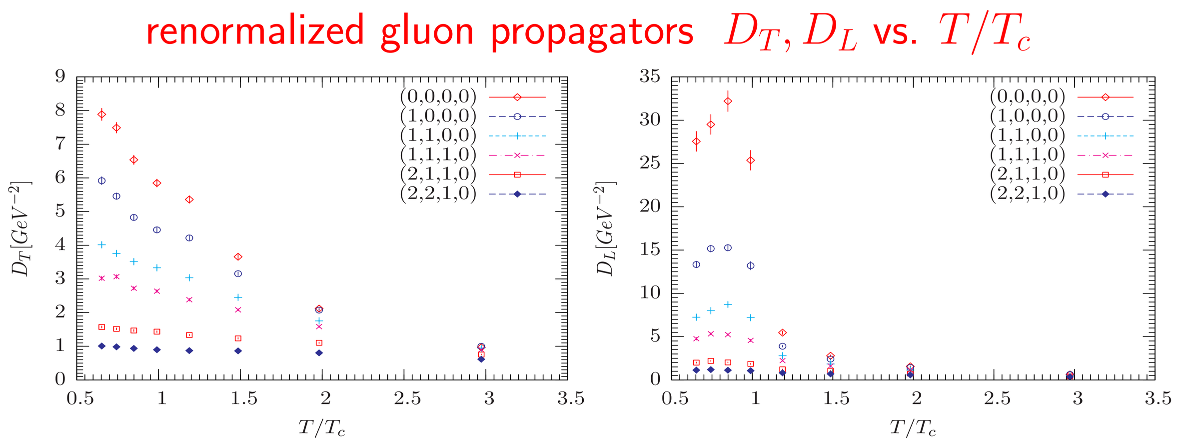
and twisted-mass fermionic action for full QCD

$$S_F = a^4\sum_x\bar{\psi}(x)\,[(D[U]+m_0) + i\,\mu\,\tau_3\,\gamma_5]\,\psi(x).$$

## Recent Results

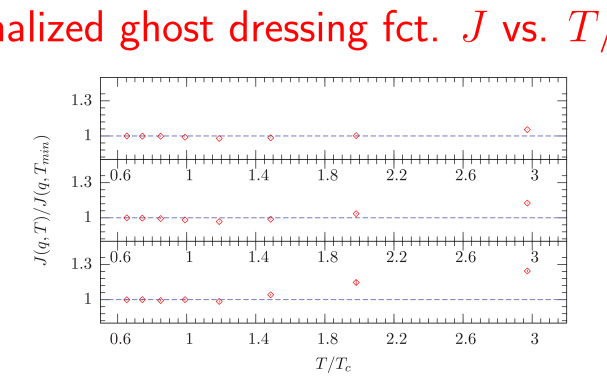
### Quenched QCD:

renormalized gluon propagators $D_T, D_L$ vs. $T/T_c$



Lattice momenta $(k_1, k_2, k_3, k_4 = 0)$, $\beta = 6.337$ and spatial extent $N_\sigma = 48$ are fixed. $T \equiv 1/(a(\beta)N_\tau)$ varies with imaginary time extent $N_\tau$.

renormalized ghost dressing fct. $J$ vs. $T/T_c$

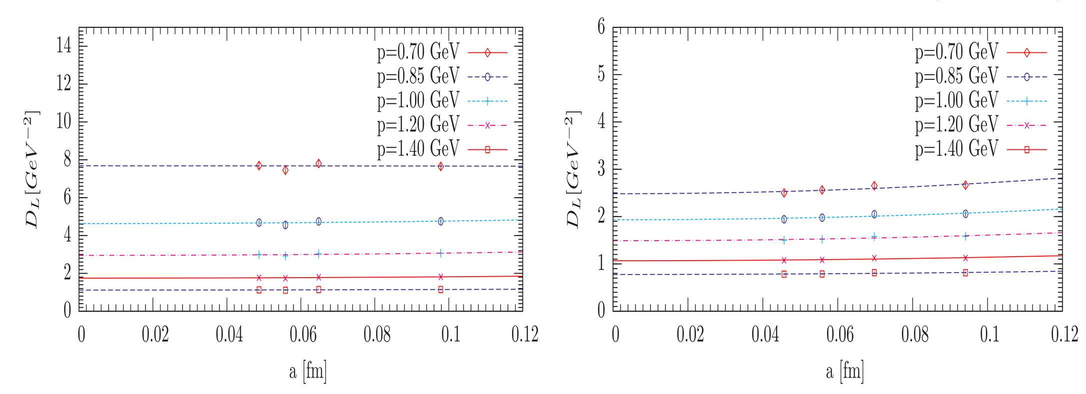


Lattice momenta $((k,k,k,0), k = 1,2,3)$, $\beta = 6.337$ and spatial size $N_\sigma = 48$ are fixed. Normalization applied with $J(q, T_{min})$, $T_{min} = 0.65\,T_c$. Lowest panel corresponds to $k = 1$.

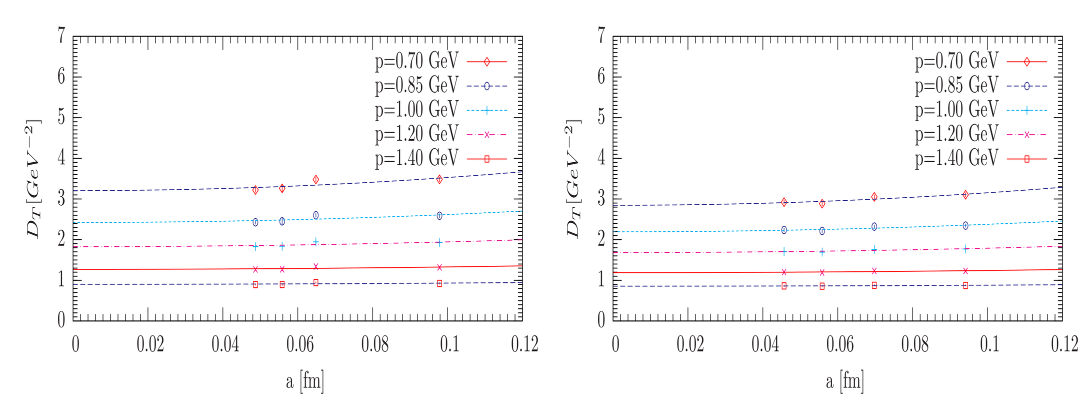
- Strong (smoother) response for $D_L(q)$ $(D_T(q))$ at $T \simeq T_c$.
- Therefore, $D_L$ good indicator for the deconfinement transition.
- $J(q)$ very weakly temperature dependent at $T_c$.

### Quenched QCD: Systematic effects

extrapolation of $D_L$ and $D_T$ to the continuum limit $(a \to 0)$:



$D_L$ vs. lattice spacing $a$ for a set for various fixd momenta $p$.
l.h.s. $T = 0.86\,T_c$; r.h.s. $T = 1.20\,T_c$. Extrapolation with $D(a;p) = D_0 + B\cdot a^2$.

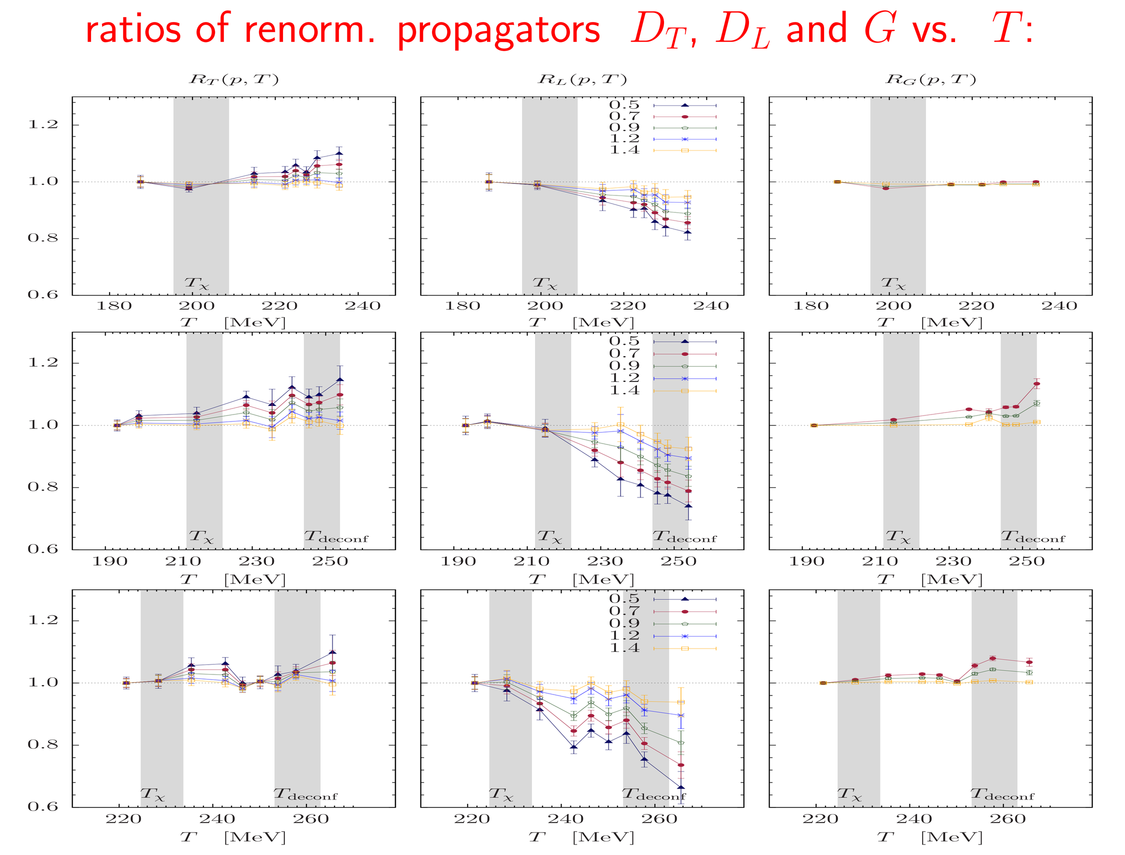


Same as above but for $D_T$. l.h.s. $T = 0.86\,T_c$; r.h.s. $T = 1.20\,T_c$.

- $D_L$ and $D_T$ nicely reach the continuum limit.
- Finite volume and Gribov copy effects were seen to be negligible in the momentum range considered.

### Full two-flavour QCD:

ratios of renorm. propagators $D_T$, $D_L$ and $G$ vs. $T$:



$R_T(q,T) = D_T(q,T)/D_T(q,T_{\min})$ (left), $R_L(q,T) = D_L(q,T)/D_L(q,T_{\min})$ (middle) $R_G(q,T) = G(q,T)/G(q,T_{\min})$ (right) versus $T$ for a few momentum values $p$ (in [GeV]). Pion masses values (from top to bottom) are $m_\pi \simeq 316$, $398$ and $469$ MeV. Lattice size $32^3\times12$, spacing $a \lesssim 0.09$ fm. Vertical bands indicate the chiral $(T_\chi)$ and deconfinement $(T_{deconf})$ pseudo-critical temperatures with their uncertainties.

- Quite smooth behaviour throughout the crossover region.
- $D_L$ more sensitive than $D_T$, $G$ again weakly $T$-dependent. $D_L$ seems to behave smoother for decreasing $m_\pi$.

## Publications


[1] R. Aouane, V.G. Bornyakov, E.-M. Ilgenfritz, V.K. Mitrjushkin, M. Müller-Preussker and A. Sternbeck, *Landau gauge gluon and ghost propagators at finite temperature from quenched lattice QCD*, Phys. Rev. D **85** (2012) 034501 [arXiv:1108.1735 [hep-lat]].

[2] R. Aouane, F. Burger, E.-M. Ilgenfritz, M. Müller-Preussker and A. Sternbeck, *Landau gauge gluon and ghost propagators from lattice QCD with $N_f = 2$ twisted mass fermions at finite temperature*, arXiv:1212.1102 [hep-lat], submitted to Phys. Rev. D.


## Talks and Posters

- Seminar talk: *On the Landau Gauge Gluon Propagator in Lattice QCD at Finite Temperature*, 49. Internationale Universitätswochen für Theoretische Physik, Schladming, 2011.
- Poster: *Landau Gauge Gluon and Ghost Propagators at Non-Zero Temperature on the Lattice*, Workshop Quarks, Gluons, and Hadronic Matter under Extreme Conditions, St. Goar, 2011.

## Collaborations

- tmfT Collaboration: HU Berlin, LNF/INFN Frascati, Univ. Bonn, Univ. Frankfurt/Main
- Collaboration with Univ. Regensburg, JINR Dubna, ITEP Moscow

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