Lattice computation of the Landau gauge quark propagator at finite temperature

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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
  - $L = \langle L(\vec{x}) \rangle \propto e^{-F_q/T}$
  - $T < T_c$: $L = 0$
  - $T > T_c$: $L \neq 0$

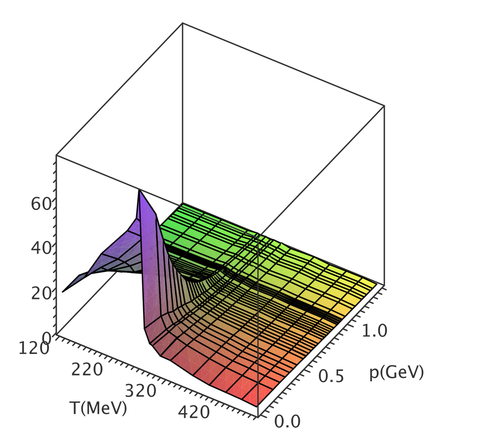
QCD Green's functions

- 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

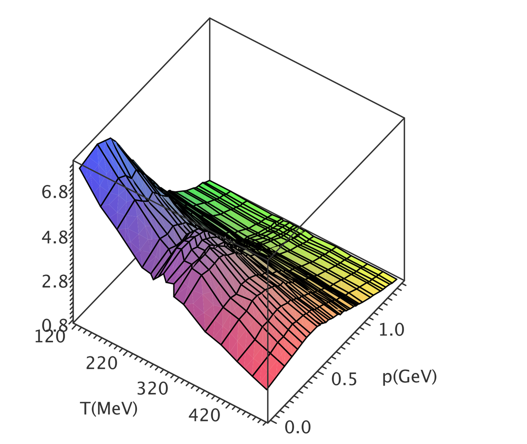
Gluon propagator at finite temperature

$$D^{ab}_{\mu\nu}(\hat{p}) = \delta^{ab}\left(P^T_{\mu\nu} D_T(p_4,\vec{p}) + P^L_{\mu\nu} D_L(p_4,\vec{p})\right)$$

D_L (longitudinal)



D_T (transverse)



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

Quark propagator at finite T

- $S(p_4,\vec{p})$ described by three form factors in momentum space

$$\frac{1}{i\gamma_4 p_4\,\omega(p_4,\vec{p}) + i\vec{\gamma}\cdot\vec{p}\,Z(p_4,\vec{p}) + \sigma(p_4,\vec{p})}$$

Lattice setup

- Quenched simulation (Wilson gauge action)
- Clover fermions, rotated sources

Sheikholeslami, Wohlert, Nucl. Phys. B259 (1985) 572

Heatlie et al, Nucl. Phys. B352 (1991) 266

- spatial physical volume $\sim (6.5\mathrm{fm})^3$
- 100 configurations per ensemble
- 2 point sources (with the exception of the highest T)

O. Oliveira, P. J. Silva, arXiv:1903.00263 [hep-lat]

T (MeV)	β	$L_s^3 \times L_t$	κ	κ_c	a (fm)	m_{bare} (MeV)	c_{sw}
243	6.0000	$64^3 \times 8$	0.1350 0.1342	0.13520	0.1016	10 53	1.769
260	6.0347	$68^3 \times 8$	0.1351 0.1344	0.13530	0.09502	11 51	1.734
275	6.0684	$72^3 \times 8$	0.1352 0.1345	0.13540	0.08974	12 54	1.704
290	6.1009	$76^3 \times 8$	0.1347	0.13550	0.08502	51	1.678
305	6.1326	$80^3 \times 8$	0.1354 0.1348	0.13559	0.08077	13 53	1.655
324	6.0000	$64^3 \times 6$	0.1342	0.13520	0.1016	53	1.769

Values for κ_c and c_{sw} computed from Luscher *et al*, Nucl. Phys. B491 (1997) 323

Continuum-like form factors

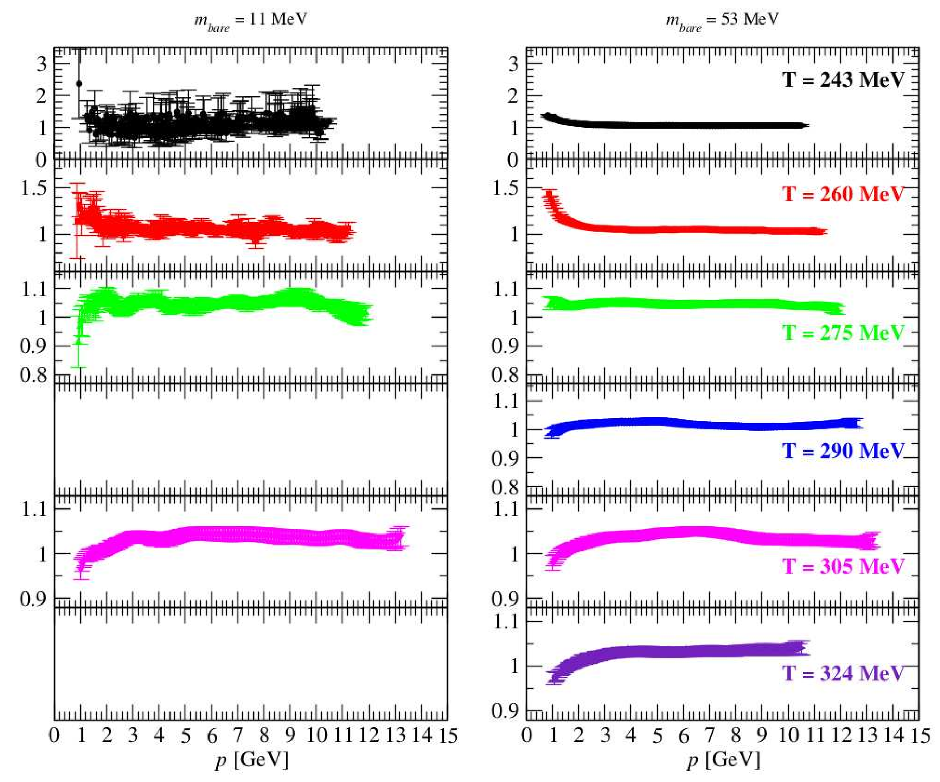
- quark wave function

$$Z_c(p_4,\vec{p}) = \frac{Z(p_4,\vec{p})}{\omega(p_4,\vec{p})}$$

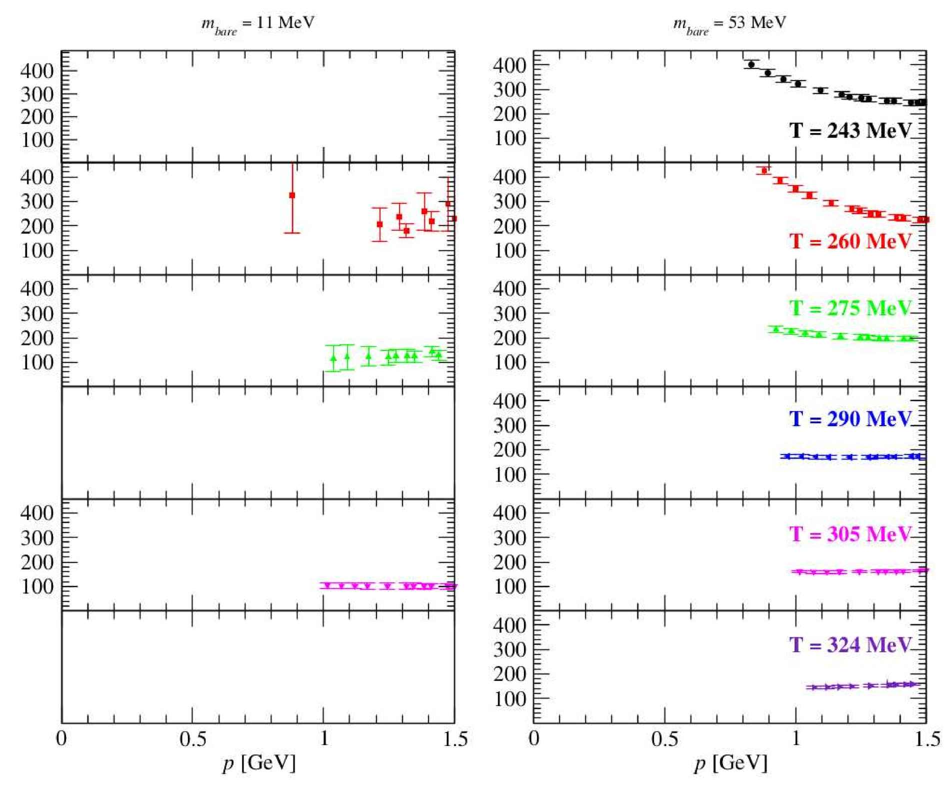
- running quark mass

$$M(p_4,\vec{p}) = \frac{\sigma(p_4,\vec{p})}{\omega(p_4,\vec{p})}$$

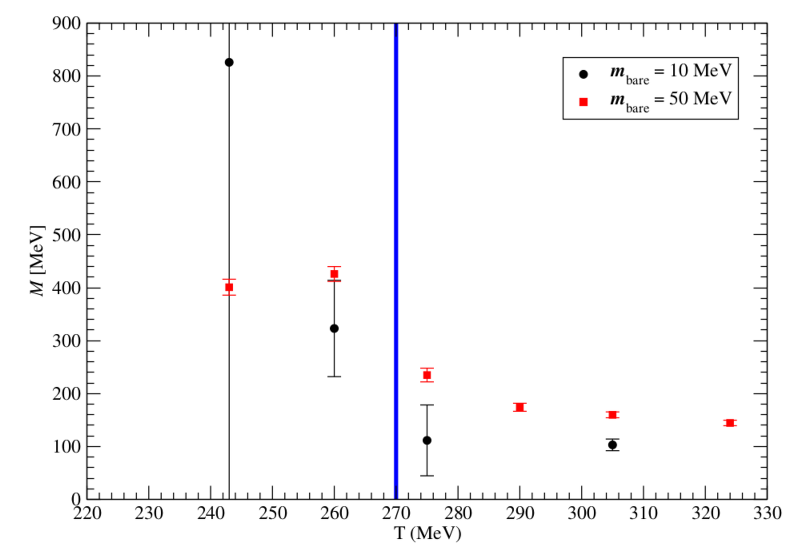
Bare quark wave function (lowest p_4)



Running quark mass (lowest p_4)

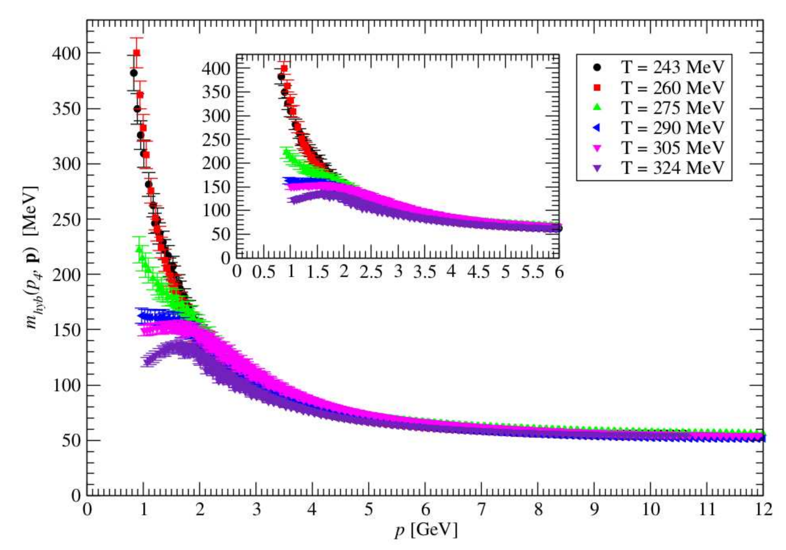


$M(p_4, \vec{p}=0)$ as function of T



$T > T_c$ — quasiparticle mass ~ 100MeV

Running quark mass (hybrid correction)



Center symmetry

- Wilson gauge action invariant under a center transformation
  - temporal links on a hyperplane $x_4 = const$ multiplied by

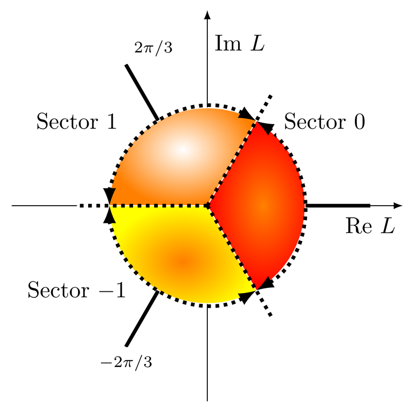
$$z \in Z_3 = \{e^{-i2\pi/3}, 1, e^{i2\pi/3}\}$$

- Polyakov loop $L(\vec{x}) \to zL(\vec{x})$
- $T < T_c$
  - 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



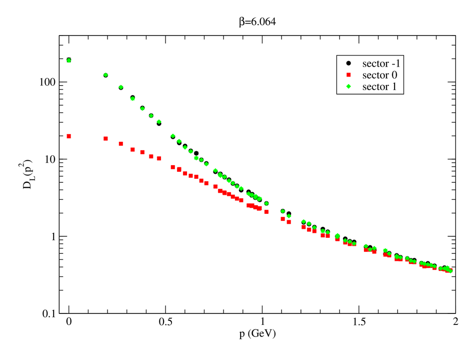
- for each configuration, 3 gauge fixings after a Z_3 transformation

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

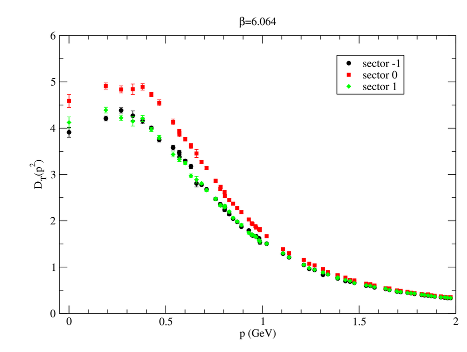
- configurations classified according to $\langle L \rangle = |L| e^{i\theta}$

Z_3 dependence: gluon propagator above T_c

D_L

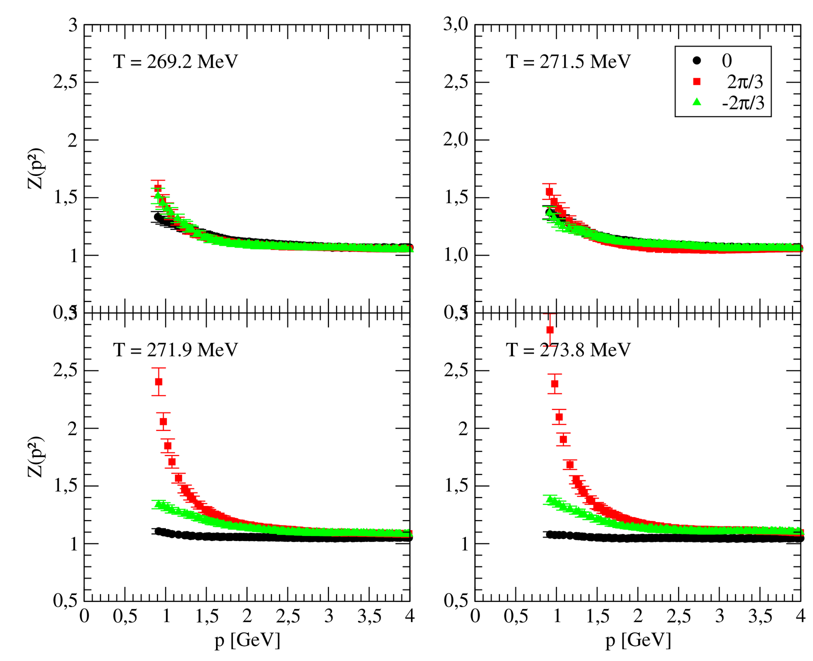


D_T

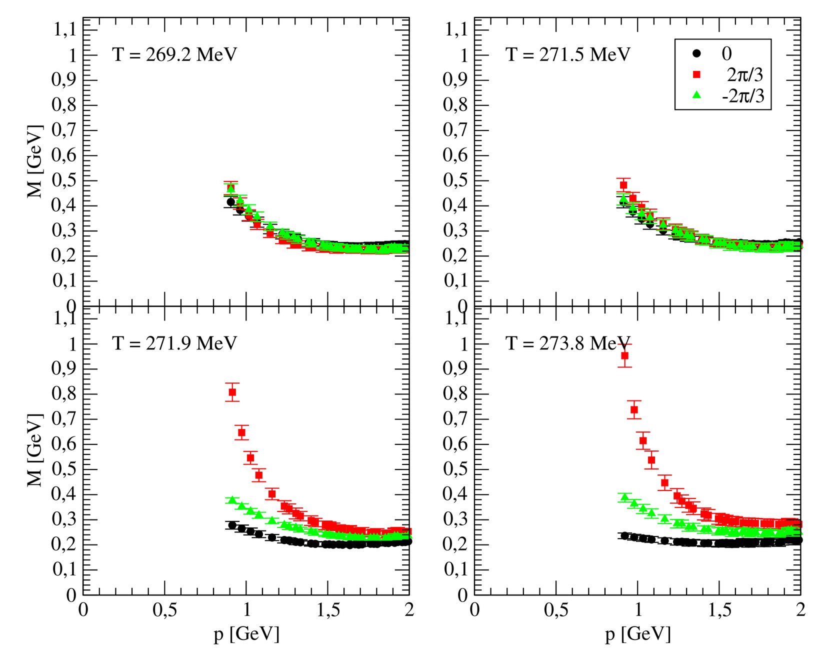


PJS, O. Oliveira, PRD **93** (2016) 114509

Quark wave function



Running quark mass



Conclusions and Outlook

- Landau gauge quark propagator at finite temperature
  - form factors investigated as a function of T for the various Matsubara frequencies
- Quark wave function Z_c and running quark mass have different functional forms above and below T_c
- Running quark mass suppressed for high temperatures
  - IR region: constant above T_c
  - favours a free quasiparticle scenario
- Z_3 dependence — preliminary results
  - quark propagator sensitive to the Z_3 sector
  - decoupling of sectors ± 1 not seen in the gluon case
- Outlook:
  - other temperatures, dynamical simulations

Acknowledgements

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