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

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Outline

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:

$$L(\vec{x}) = \mathrm{Tr} \prod_{t=0}^{N_t-1} \mathcal{U}_4(\vec{x}, t)$$

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

Center symmetry

- Wilson gauge action is 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 $L(\vec{x}) \to zL(\vec{x})$
- $T < T_c$
  - local P_L phase equally distributed among the three sectors

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

- $T > T_c$
  - 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)

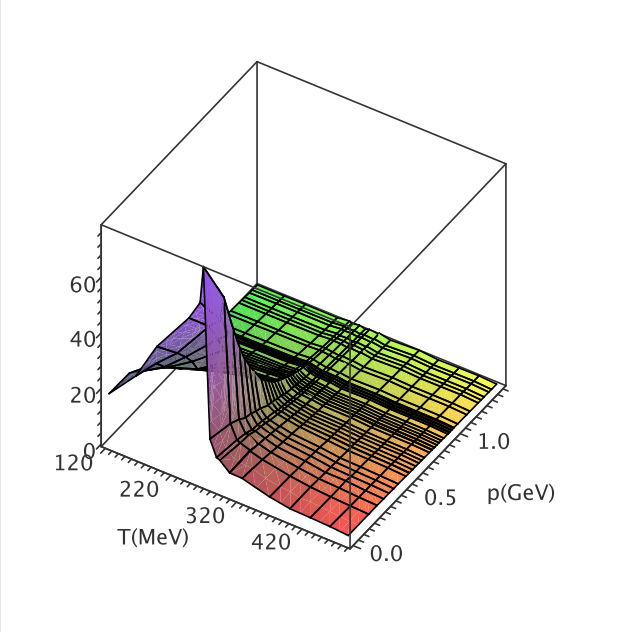
F. M. Stokes, W. Kamleh, D. B. Leinweber, arXiv:1312.0991

Landau gauge gluon propagator

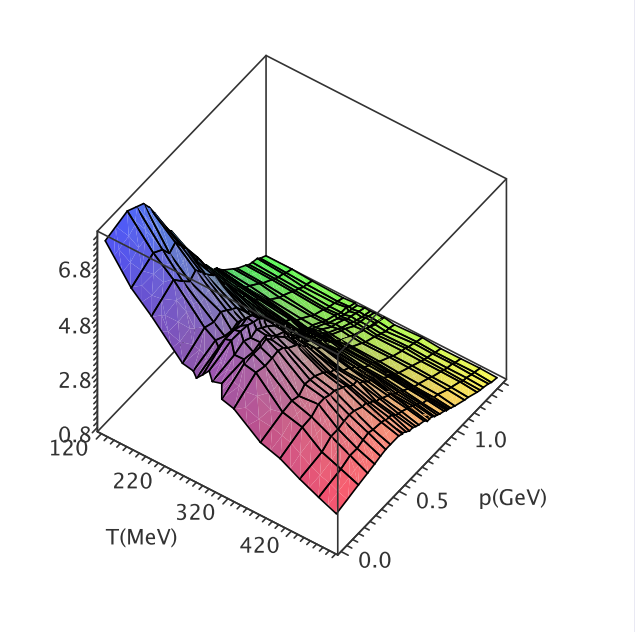
- At finite T: two independent form factors

$$D^{ab}_{\mu\nu}(\hat{q}) = \delta^{ab}\left(P^T_{\mu\nu}D_T(q_4^2,\vec{q}) + P^L_{\mu\nu}D_L(q_4^2,\vec{q})\right)$$

Longitudinal component D_L



Transverse component D_T



PJS, O. Oliveira, P. Bicudo, N. Cardoso, PRD**89** (2014) 074503

Z_3 dependence

- D_L and D_T show quite different behaviours with T
- Usually, the propagator is computed such that $\arg(P_L) < \pi/3$ (Z_3 sector 0)
- what happens in the other sectors?

Lattice setup

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

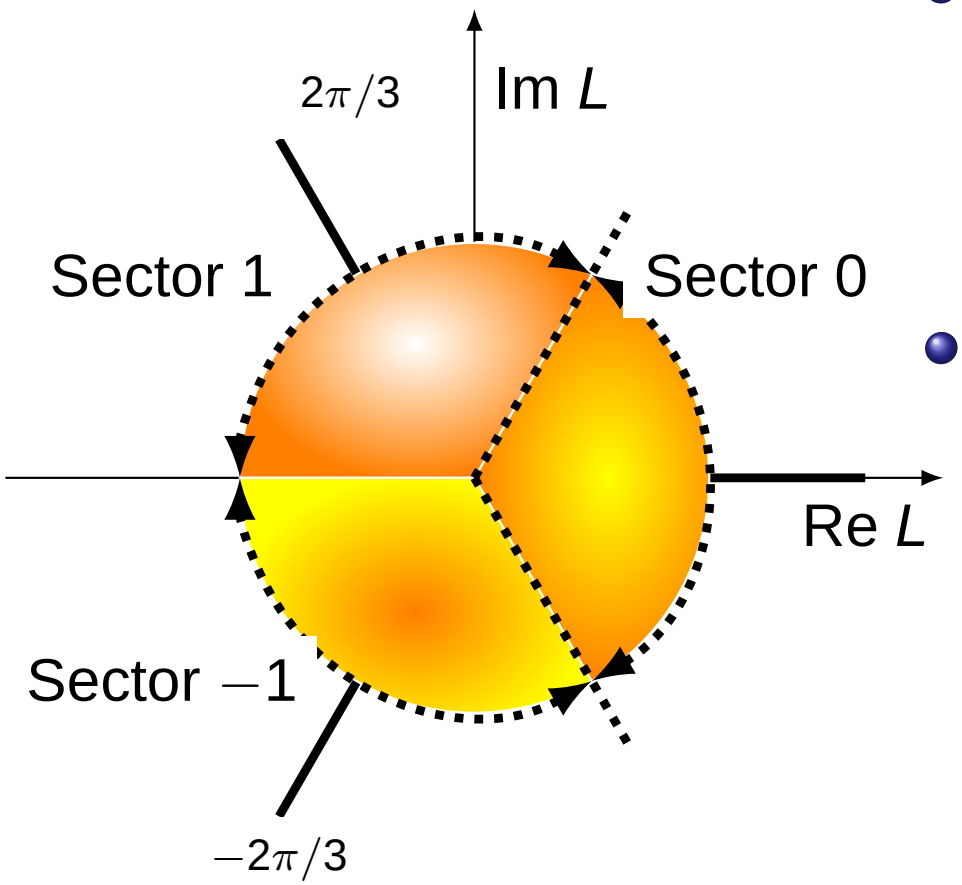
Coarse lattices $a \sim 0.12fm$

Temp. (MeV)	$L_s^3 \times L_t$	β	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 $a \sim 0.09fm$

Temp. (MeV)	$L_s^3 \times L_t$	β	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 $\langle L \rangle = |L| e^{i\theta}$

$$\theta = \begin{cases} -\pi < \theta \leq -\frac{\pi}{3}, & \text{Sector -1,} \\ -\frac{\pi}{3} < \theta \leq \frac{\pi}{3}, & \text{Sector 0,} \\ \frac{\pi}{3} < \theta \leq \pi, & \text{Sector 1} \end{cases}$$

How-to

- Conical cut for momenta above 1GeV; all data below 1GeV

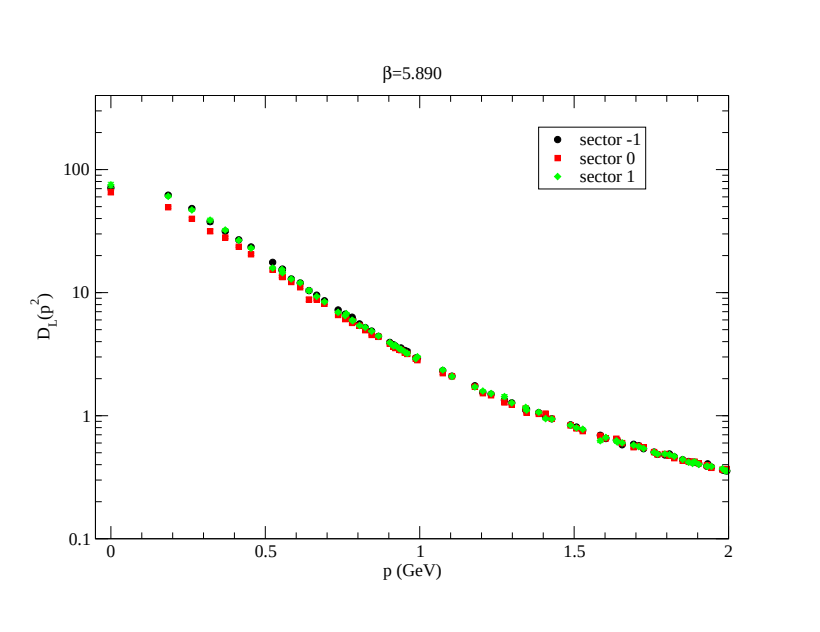
- Renormalization:

$$D_{L,T}(\mu^2) = Z_R D^{Lat}_{L,T}(\mu^2) = 1/\mu^2$$

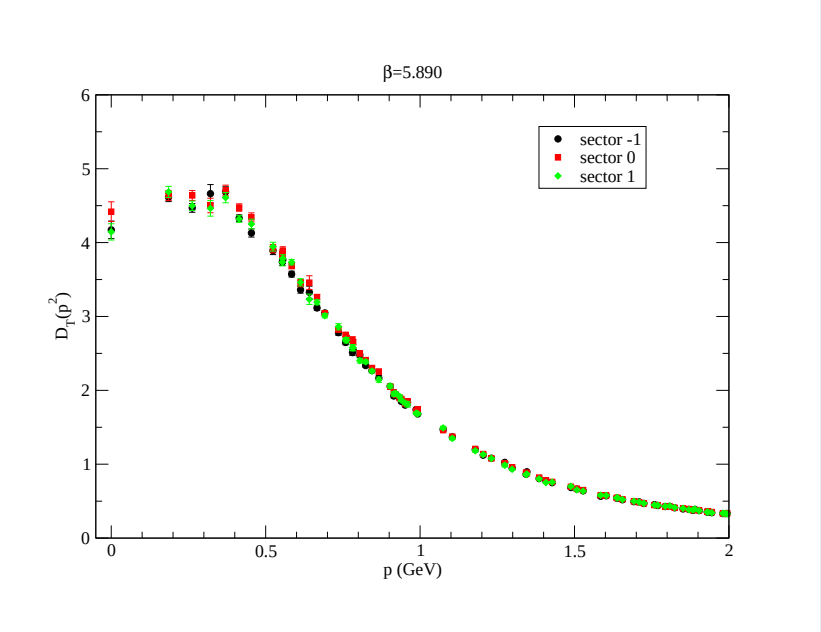
- Renormalization scale: $\mu = 4$ GeV
- D_L and D_T renormalized independently
  - within each $Z(3)$ sector, $Z_R^{(L)}$ and $Z_R^{(T)}$ agree within errors
- each Z_3 sector is renormalized independently
  - Z_R do not differ between the different $Z(3)$ sectors

Coarse lattices, below T_c

Longitudinal component

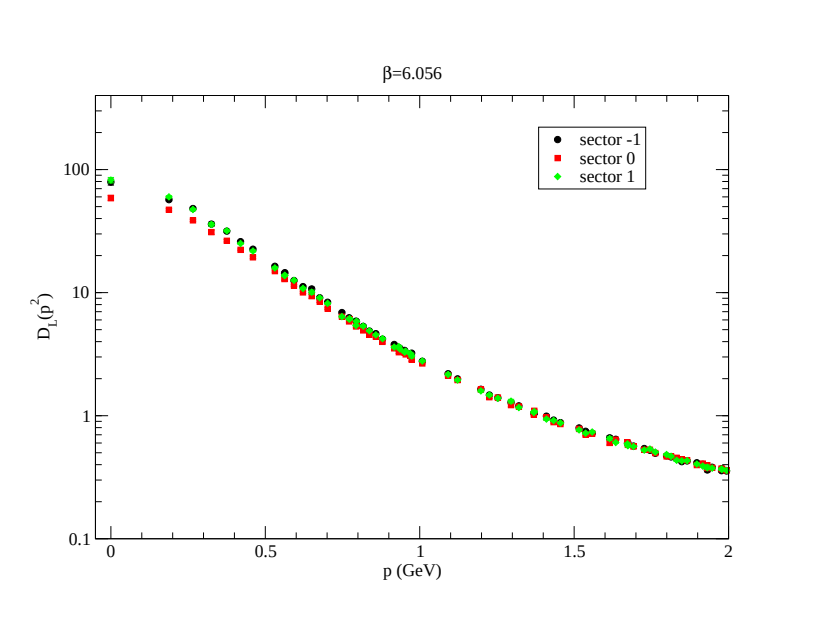


Transverse component

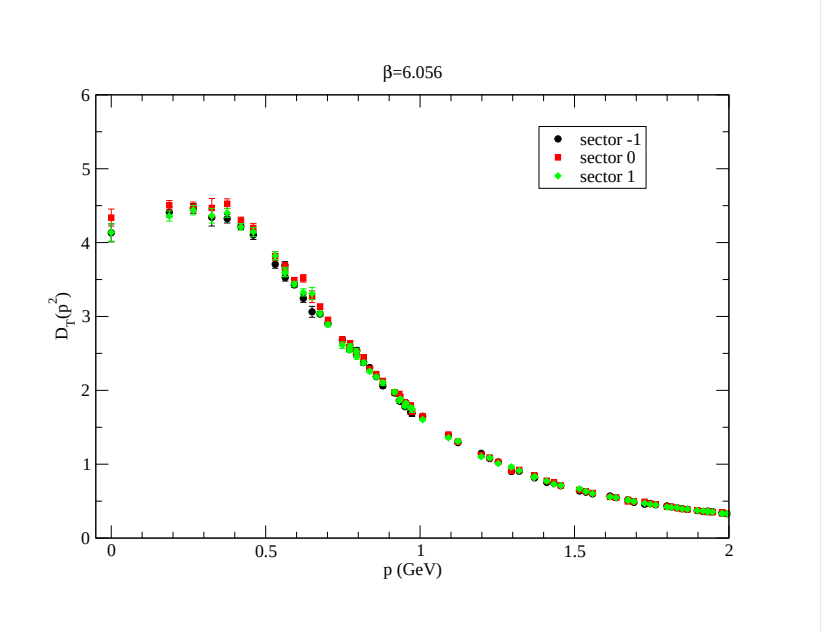


Fine lattices, below T_c

Longitudinal component

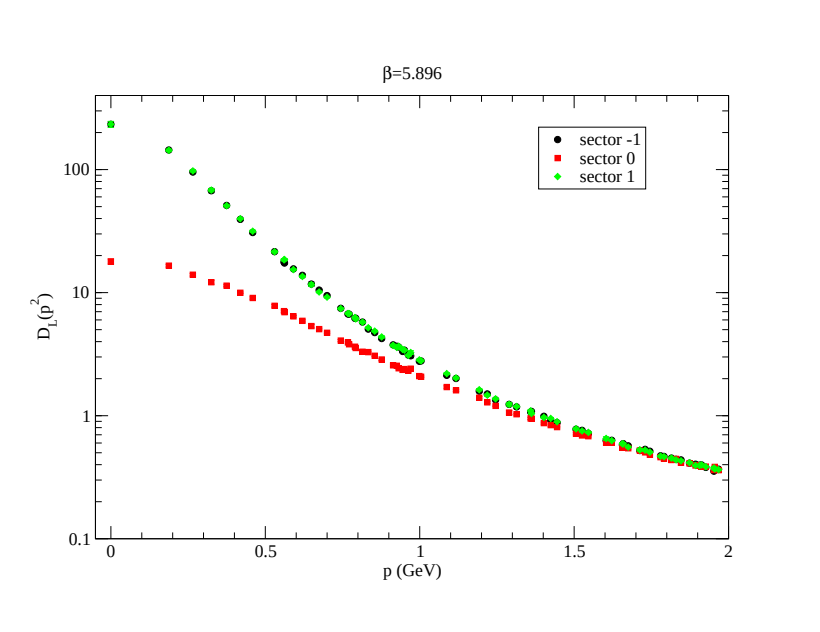


Transverse component

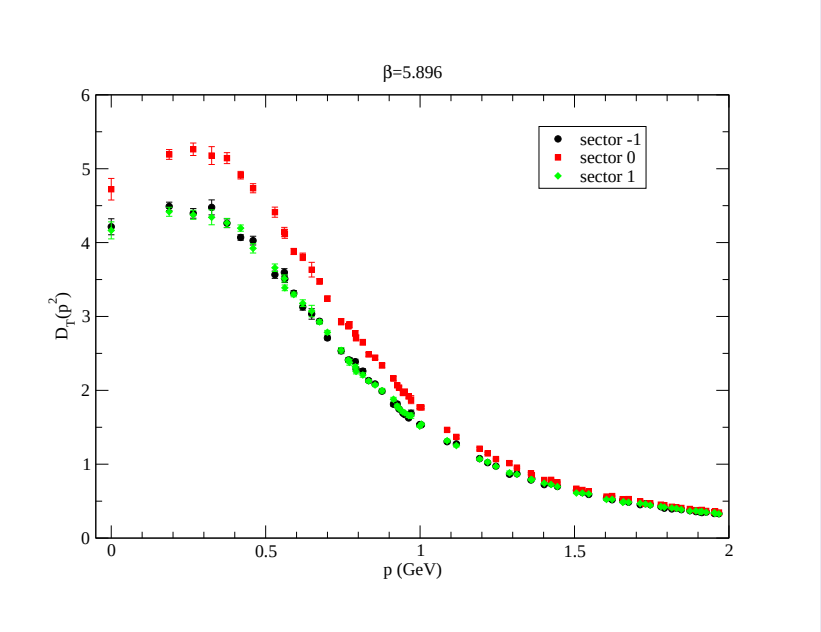


Coarse lattices, above T_c

Longitudinal component

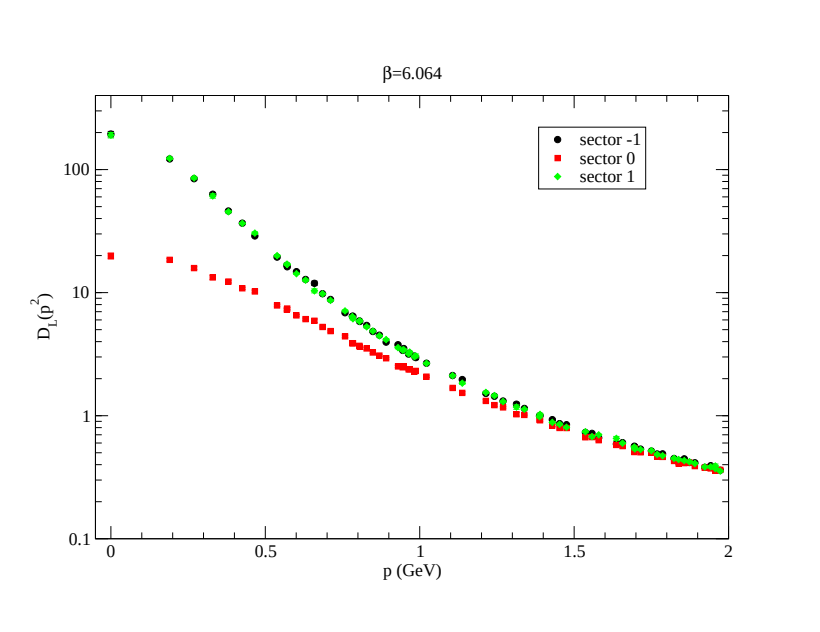


Transverse component

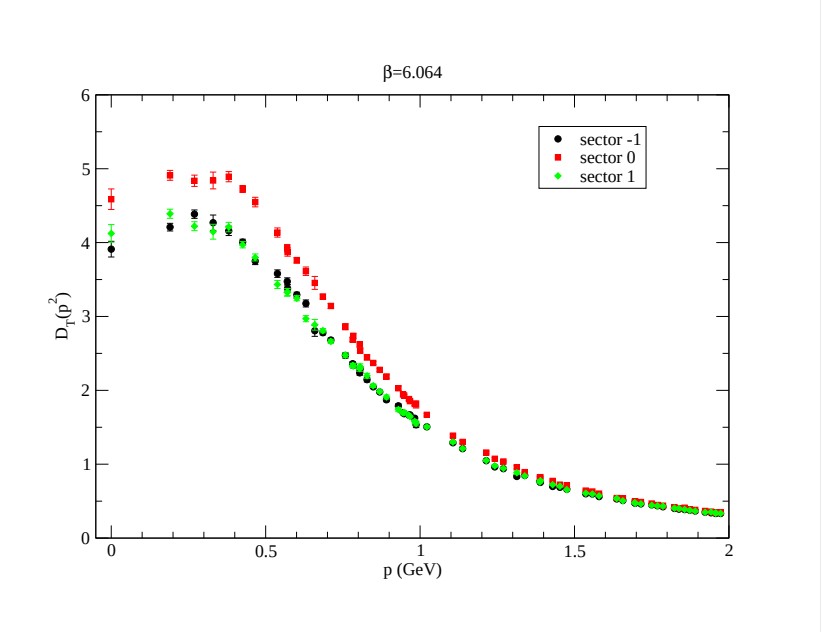


Fine lattices, above T_c

Longitudinal component

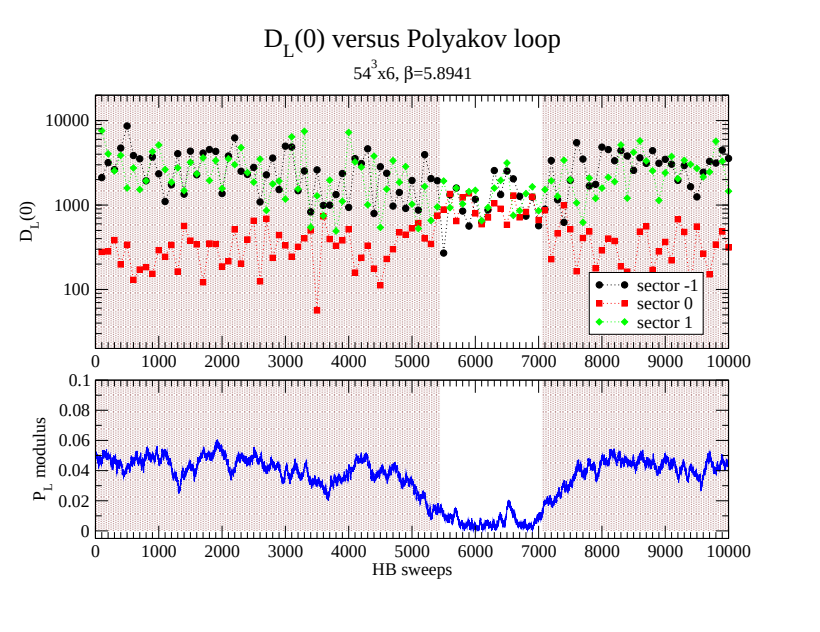


Transverse component

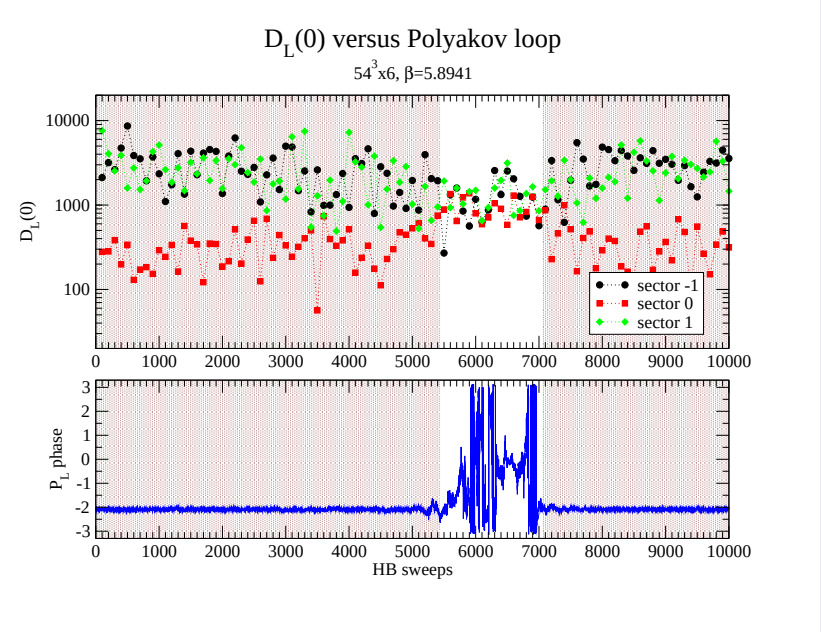


Polyakov loop history

Modulus

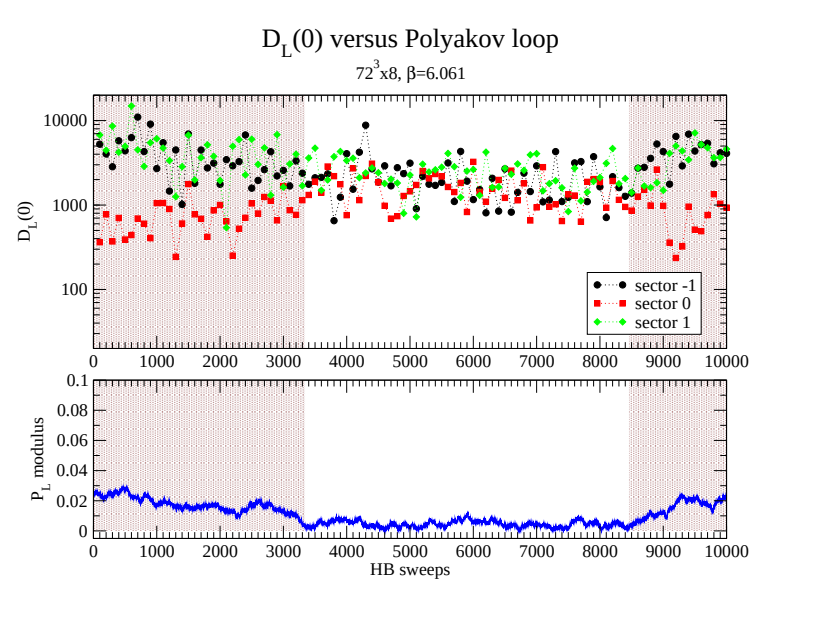


Phase

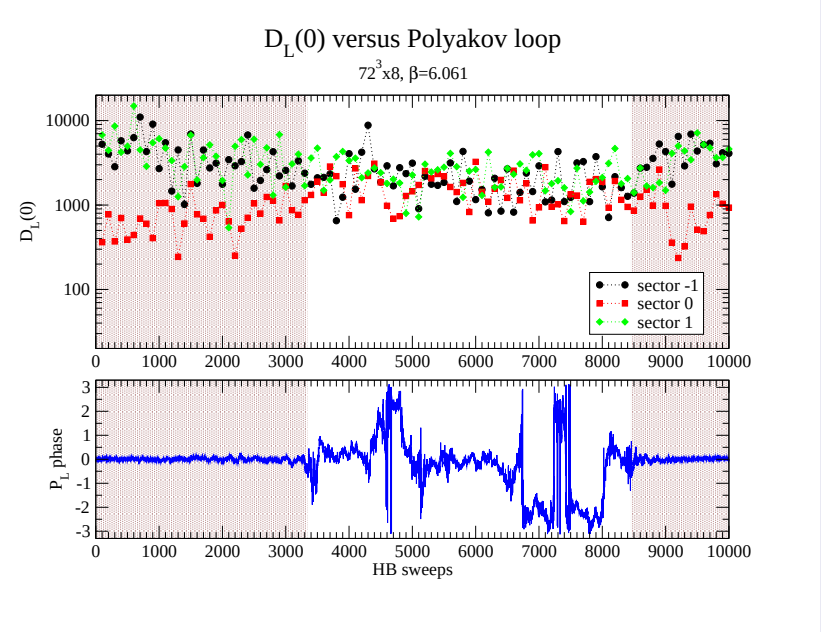


Polyakov loop history

Modulus

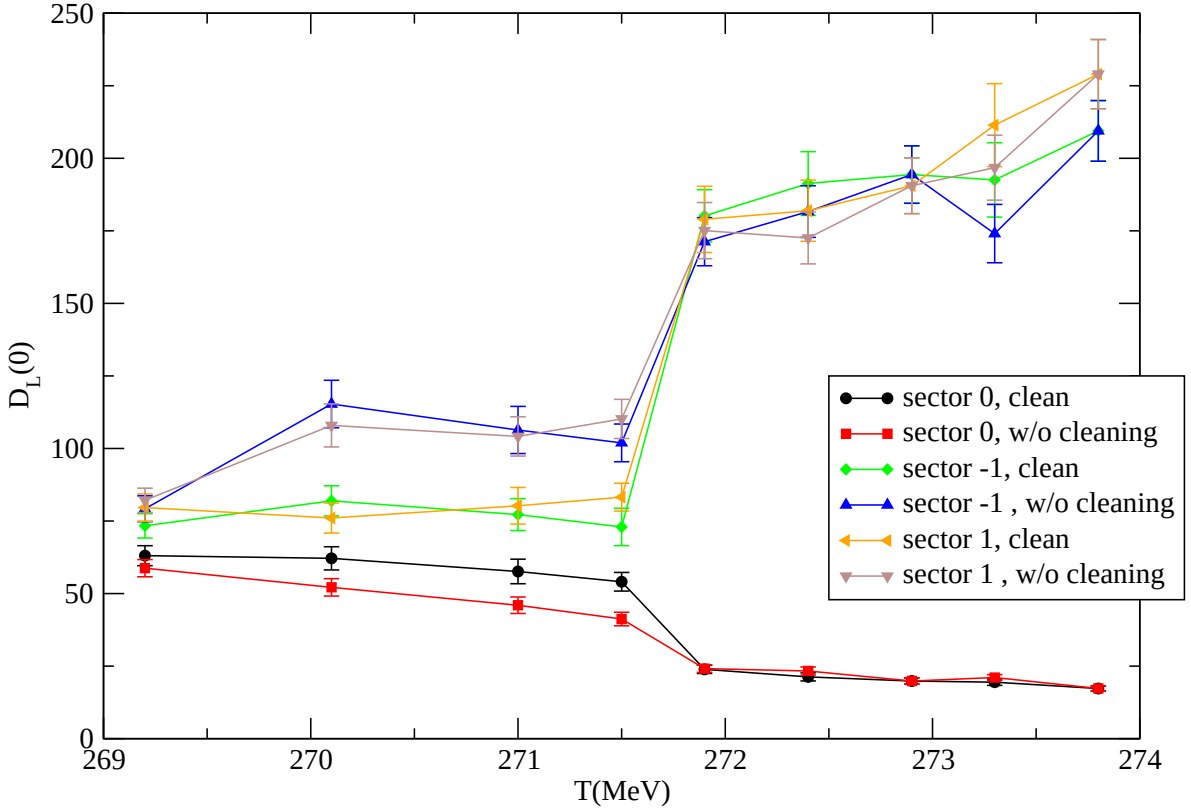


Phase



Removing configurations in wrong phase

Fine lattices



Conclusions and Outlook

- 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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