The Landau gauge gluon propagator on the lattice at zero and finite temperature

Orlando Oliveira [1], Paulo Silva [1],
Nuno Cardoso [2], Pedro Bicudo [2]

[1] Centro de Física Computacional, Universidade de Coimbra, Portugal
[2] CFTP, Instituto Superior Técnico, Portugal

March 19, 2013

Outline

1. Introduction
2. Gluon propagator at zero temperature
3. Gluon propagator at finite temperature
   - Lattice results
   - Gluon mass at finite temperature

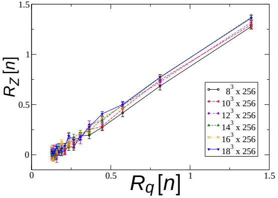
- Study of QCD fundamental propagators
  - allow a complete description of the theory
  - encode non-perturbative physics (e.g. confinement)
- here we address two-point gluon functions
  - $T = 0$
  - $T > 0$

CENTRO DE FÍSICA COMPUTACIONAL

Zero temperature gluon propagator on the lattice

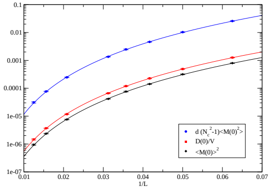
Albeit there are some support for D(0)=0...

- Ratios



O. Oliveira, P. J. Silva, EPJC 62 (2009) 525

- SU(3) Cucchieri-Mendes bounds

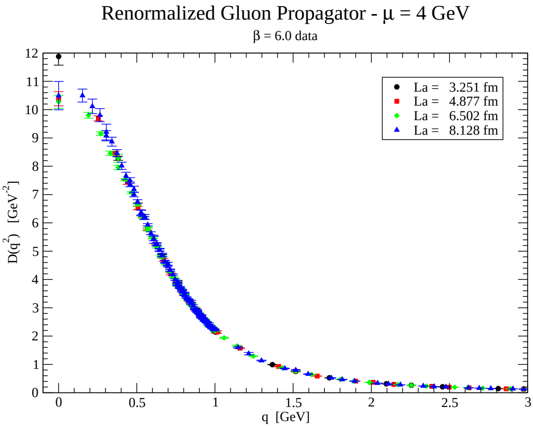


O. Oliveira, P. J. Silva, PRD 79 (2009) 031501(R)

- Also: Sternbeck, Müller-Preussker, arXiv:1211.3057

Gluon propagator on the lattice

... scaling solution is not directly observed in large-volume lattice simulations



Gluon propagator on the lattice

- SU(2): $La = 27\text{fm}\, a \sim 0.22\text{fm}$
  A. Cucchieri, T. Mendes, PoS(LAT2007)297
- SU(3): $La = 17\text{fm}\, a \sim 0.18\text{fm}$
  I. Bogolubsky, E. Ilgenfritz, M. Muller-Preussker, A. Sternbeck, Phys. Lett. B676 (2009) 69

- relative large lattice spacing compared with 1 fm
- does this matter?

O. Oliveira, PJS, Phys.Rev. D86 (2012) 114513, arxiv:1207.3029 [hep-lat]

Gluon propagator on the lattice - technical details

- Landau gauge fixing

$$F_U[g] = C_F \sum_{x,\mu} \mathrm{Re}\{\mathrm{Tr}[g(x)U_\mu(x)g^\dagger(x+\hat{\mu})]\}$$

(Fourier accelerated) Steepest Descent, Overrelaxation

- Gluon propagator

$$D^{ab}_{\mu\nu}(\hat{q}) = \frac{1}{V}\langle A^a_\mu(\hat{q})A^b_\mu(-\hat{q})\rangle = \delta^{ab}\left(\delta_{\mu\nu} - \frac{q_\mu q_\nu}{q^2}\right) D\left(q^2\right)$$

CENTRO DE FÍSICA COMPUTACIONAL

Lattice setup

β	a(fm)	1/a (GeV)	L	La (fm)	#Conf
5.7	0.1838	1.0736	44	8.087	55
5.7	0.1838	1.0736	36	6.617	100
5.7	0.1838	1.0736	26	4.780	132
5.7	0.1838	1.0736	18	3.308	149
6.0	0.1016	1.942	80	8.128	55
6.0	0.1016	1.942	64	6.502	121
6.0	0.1016	1.942	48	4.877	104
6.0	0.1016	1.942	32	3.251	126
6.2	0.07260	2.718	80	5.808	70
6.2	0.07260	2.718	64	4.646	99
6.2	0.07260	2.718	48	3.485	87
6.4	0.05445	3.624	80	4.356	52

O. Oliveira, PJS, Phys.Rev. D86 (2012) 114513, arxiv:1207.3029 [hep-lat]

CENTRO DE FÍSICA COMPUTACIONAL

Lattice setup

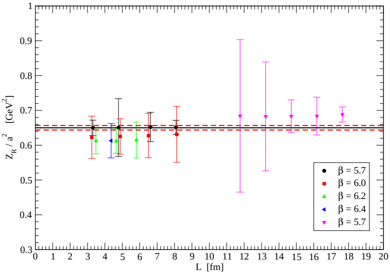
Berlin-Moscow-Adelaide ensembles

β	a(fm)	1/a (GeV)	L	La (fm)
5.7	0.1838	1.0736	64	11.763
5.7	0.1838	1.0736	72	13.234
5.7	0.1838	1.0736	80	14.704
5.7	0.1838	1.0736	88	16.174
5.7	0.1838	1.0736	96	17.645

I. L. Bogolubsky, E. M. Ilgenfritz, M. Muller-Preussker, A. Sternbeck, Phys Lett B676, 69 (2009)

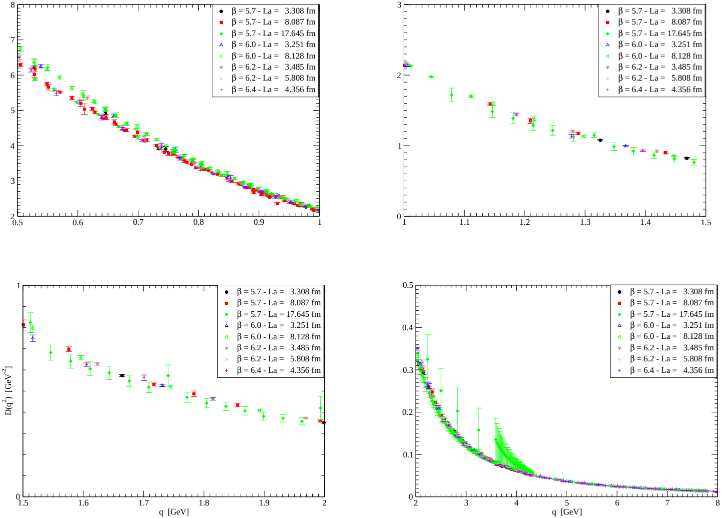
Renormalization

- All lattice data renormalized at $\mu = 4$GeV
- $D(q^2) = Z_R D_{Lat}(q^2)$
  $D(\mu^2) = 1/\mu^2$
- this procedure removes UV lattice artifacts

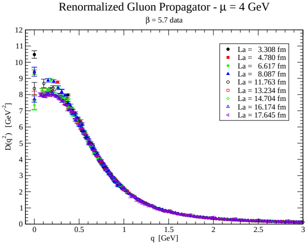


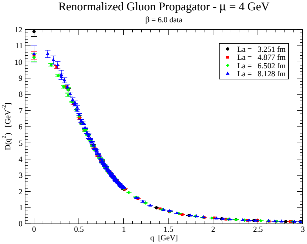
$\frac{Z_R}{a^2}$ = 0.6501(65) GeV^2 is volume independent

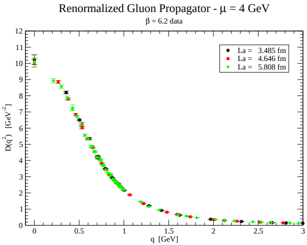
Well defined for momenta above 900 MeV

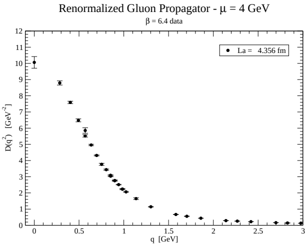


IR propagator decreases with lattice volume



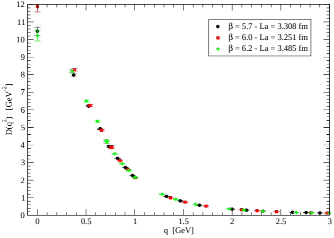


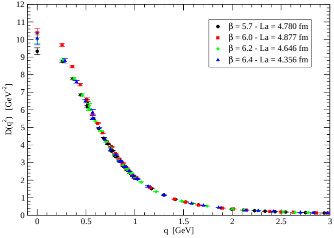


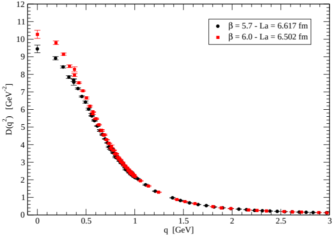


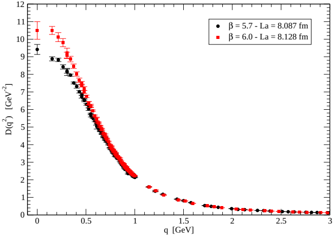
CENTRO DE FÍSICA COMPUTACIONAL

Larger *a* underestimates IR propagator









CENTRO DE FÍSICA COMPUTACIONAL

Summary - Zero temperature

- Good description of the gluon propagator in the UV
- be careful with large lattice spacing simulations
    - finite *a* effects larger than finite *V* effects
    - lower *a* at constant *V* enhances the IR propagator
    - $\beta = 5.7$ results seem to be a lower bound
    - similar results presented in
      I. Bogolubsky, E.-M. Ilgenfritz, M. Müller-Preussker, A. Sternbeck, arXiv:1303.3423

CENTRO DE FÍSICA COMPUTACIONAL

Gluon propagator at finite temperature

Propagator splitted into two components

- transverse D_T
- longitudinal D_L

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

Transverse and longitudinal projectors in the Landau gauge

$$P^T_{\mu\nu} = (1 - \delta_{\mu 4})(1 - \delta_{\nu 4}) \left(\delta_{\mu\nu} - \frac{q_\mu q_\nu}{\vec{q}^2} \right)$$

$$P^L_{\mu\nu} = \left(\delta_{\mu\nu} - \frac{q_\mu q_\nu}{q^2} \right) - P^T_{\mu\nu}$$

Gluon propagator at finite temperature

$$D_T(q^2) = \frac{1}{2V(N_c^2-1)}\left(\langle A_i^a(q)A_i^a(-q)\rangle - \frac{q_4^2}{\vec{q}^2}\langle A_4^a(q)A_4^a(-q)\rangle\right)$$

$$D_L(q^2) = \frac{1}{V(N_c^2-1)}\left(1+\frac{q_4^2}{\vec{q}^2}\right)\langle A_4^a(q)A_4^a(-q)\rangle$$

- Finite temperature on the lattice: $L_t << L_s$

$$T = \frac{1}{aL_t}$$

- Simulations: use of Chroma and PFFT libraries
- keep a constant (spatial) physical volume $\sim (6.5fm)^3$
- all data renormalized at $\mu = 4GeV$

O. Oliveira, PJS, Acta Phys.Polon.Supp. 5 (2012) 1039, PoS(LATTICE2012)216, PoS(Confinement X)045

CENTRO DE FÍSICA COMPUTACIONAL

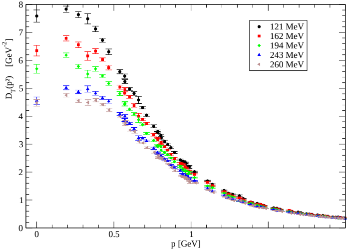
Lattice setup

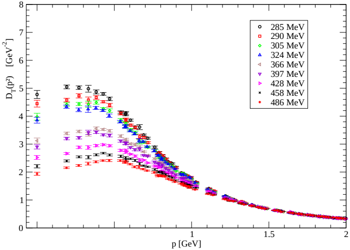
Temp. (MeV)	β	L_s	L_t	a [fm]	1/a (GeV)
121	6.0000	32,64	16	0.1016	1.943
162	6.0000	32,64	12	0.1016	1.943
194	6.0000	32,64	10	0.1016	1.943
243	6.0000	32,64	8	0.1016	1.943
260	6.0347	68	8	0.09502	2.0767
265	5.8876	52	6	0.1243	1.5881
275	6.0684	72	8	0.08974	2.1989
285	5.9266	56	6	0.1154	1.7103
290	6.1009	76	8	0.08502	2.3211
305	5.9640	60	6	0.1077	1.8324
305	6.1326	80	8	0.08077	2.4432
324	6.0000	32,64	6	0.1016	1.943
366	6.0684	72	6	0.08974	2.1989
397	5.8876	52	4	0.1243	1.5881
428	5.9266	56	4	0.1154	1.7103
458	5.9640	60	4	0.1077	1.8324
486	6.0000	32,64	4	0.1016	1.943

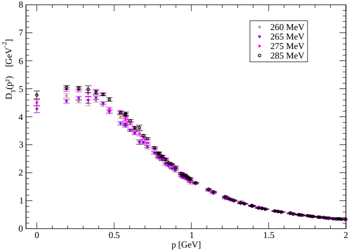
Outline

1. Introduction
2. Gluon propagator at zero temperature
3. Gluon propagator at finite temperature
   - Lattice results
   - Gluon mass at finite temperature

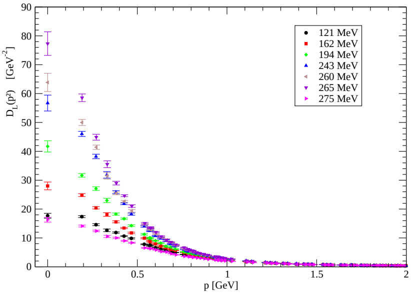
Transverse component

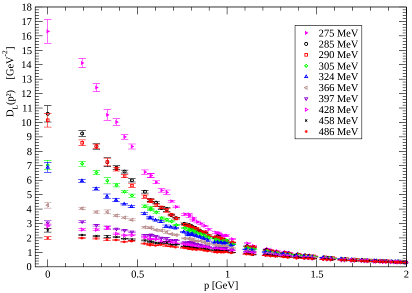






Longitudinal component

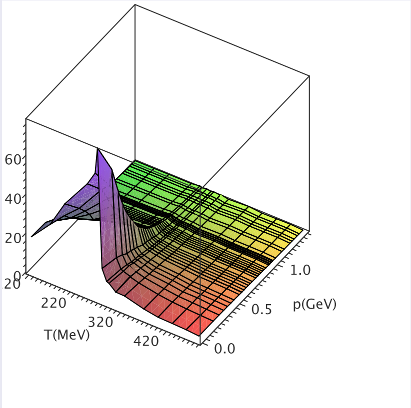




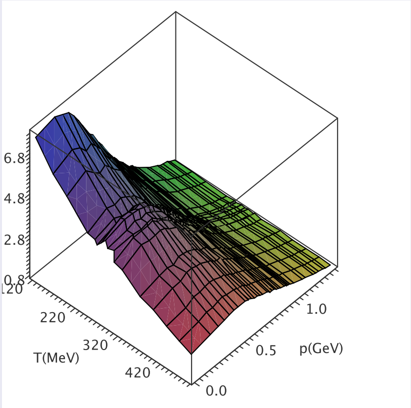
CENTRO DE FÍSICA COMPUTACIONAL

3d plots

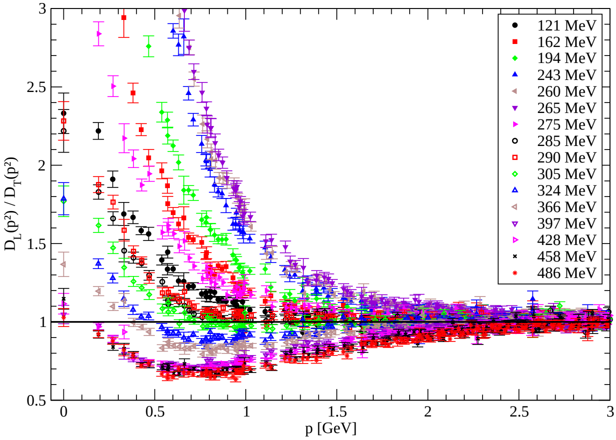
Longitudinal component



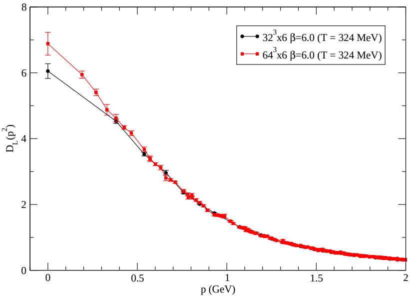
Transverse component

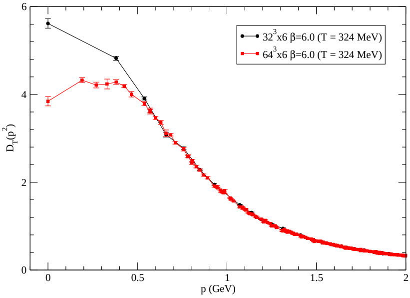


Ratios of the two components

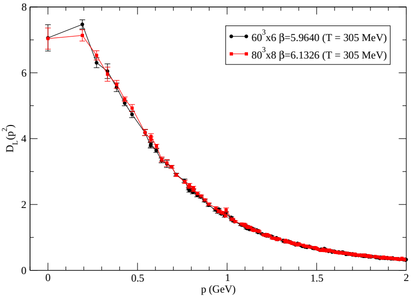


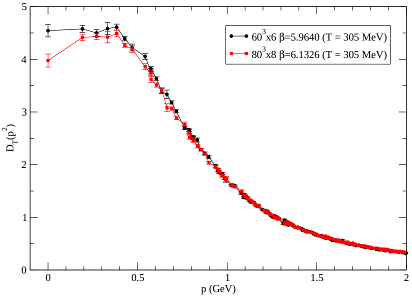
Finite volume effects @ 324 MeV





Finite lattice spacing effects @ 305 MeV



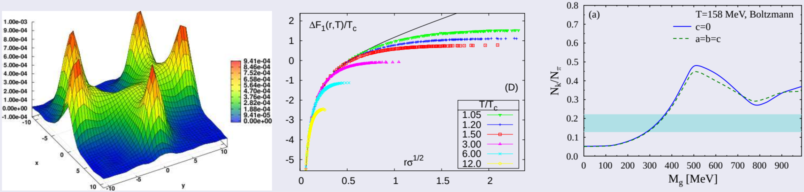


Outline

1. Introduction
2. Gluon propagator at zero temperature
3. Gluon propagator at finite temperature
   - Lattice results
   - Gluon mass at finite temperature

CENTRO DE FÍSICA COMPUTACIONAL

Why gluon mass?



- At $T = 0$ we have colour screening and flux tubes,

  J. M. Cornwall, Phys. Rev. D 26, 1453 (1982)
  N. Cardoso, P. Bicudo, Phys. Rev. D 87, 034504 (2013)
  N. Cardoso, M. Cardoso, P. Bicudo [arXiv:1302.3633 [hep-lat]]

- at large T Debye screening,

  M. Doring, K. Hubner, O. Kaczmarek, and F. Karsch, Phys. Rev. D 75, 054504 (2007)
  M. Bluhm, B. Kampfer and K. Redlich, Phys. Rev. C 84, 025201 (2011)

- at T_c a mass scale in the π and K multiplicities in heavy ions

  P. Bicudo, F. Giacosa, E. Seel Phys.Rev. C86, 034907 (2012)

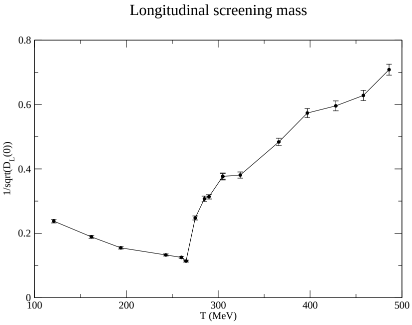
Gluon mass @ finite T

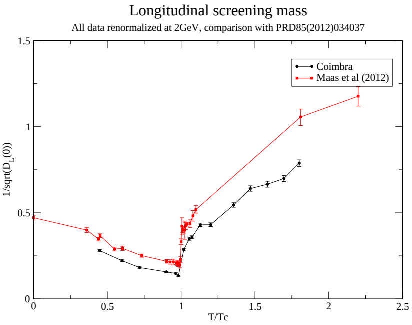
- We consider an infrared gluon mass through a Yukawa fit

$$D_L(p^2) = \frac{Z}{p^2 + m^2}$$

- D_T is not described by a Yukawa in the IR for all T
- we also consider a longitudinal screening mass $1/\sqrt{D_L(0)}$

Longitudinal screening mass





Gluon mass @ finite T

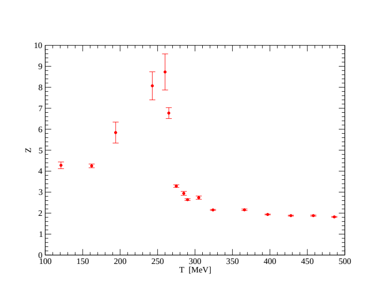
T	p_{max}	Z	M	$\chi^2/d.o.f.$
121	0.467	4.28 ± 0.16	0.468 ± 0.013	1.910
162	0.570	4.252 ± 0.089	0.3695 ± 0.0073	1.657
194	0.330	5.84 ± 0.50	0.381 ± 0.022	0.725
243	0.330	8.07 ± 0.67	0.374 ± 0.021	0.273
260	0.271	8.73 ± 0.86	0.371 ± 0.025	0.030
265	0.383	6.77 ± 0.26	0.2846 ± 0.0097	1.882
275	0.664	3.289 ± 0.063	0.4382 ± 0.0081	1.493
285	0.573	2.941 ± 0.094	0.527 ± 0.013	1.867
290	0.717	2.643 ± 0.042	0.5008 ± 0.0076	1.840
305	0.606	2.737 ± 0.080	0.590 ± 0.013	1.295
324	0.892	2.152 ± 0.023	0.5623 ± 0.0061	1.666
366	0.810	2.159 ± 0.038	0.690 ± 0.010	1.827
397	1.218	1.936 ± 0.019	0.7608 ± 0.0071	1.741
428	1.246	1.882 ± 0.020	0.8073 ± 0.0079	1.767
458	0.993	1.881 ± 0.027	0.878 ± 0.010	1.894
486	1.313	1.820 ± 0.021	0.9184 ± 0.0086	1.606

$$\frac{Z}{p^2 + m^2}$$

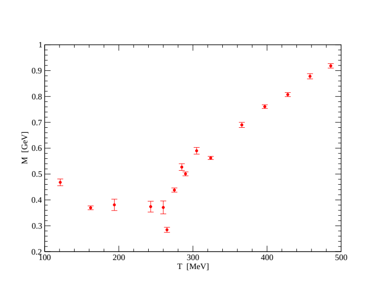
All momenta and masses in GeV

Gluon mass @ finite T

$Z(T)$



$M(T)$



CENTRO DE FÍSICA COMPUTACIONAL

Summary - Finite temperature

- Landau gauge gluon propagator at finite temperature:
  - Lattice effects in the infrared
  - Gluon mass scale versus deconfined phase transition
    - Yukawa mass
    - $1/\sqrt{D_L(0)}$

Work partly funded by FCT contracts CERN/FP/123612/2011, CERN/FP/123620/2011 and PTDC/FIS/100968/2008. Nuno Cardoso and Paulo Silva supported by FCT grants SFRH/BD/44416/2008 and SFRH/BPD/40998/2007 respectively. Work developed under QREN initiative, financed by UE/FEDER through COMPETE - Programa Operacional Factores de Competitividade.