Infrared Propagators and Confinement: a Perspective from Lattice Simulations

Tereza Mendes

University of São Paulo & DESY-Zeuthen

Work in collaboration with Attilio Cucchieri

Summary

- Lattice studies of the infrared behavior of gluon and ghost propagators may offer a crucial test of confinement scenarios in Yang-Mills theories.
- However, finite-volume effects become an important issue as the infrared limit is approached.
- We study the case of Landau gauge and SU(2) gauge group, using data from the largest lattices to date.
- We propose rigorous constraints to gain control over the extrapolation to the infinite-volume limit. At the same time, we gain a better understanding of the propagators in terms of more general quantities.

Pathways to Confinement

- How does linearly rising potential (seen in lattice QCD) come about?
- Theories of quark confinement include: dual superconductivity (electric flux tube connecting magnetic monopoles), condensation of center vortices, but also merons, calorons
- Proposal by Mandelstam (1979) linking linear potential to infrared behavior of gluon propagator as $1/p^4$
- Gribov-Zwanziger (similarly Kugo-Ojima) confinement scenario based on suppressed gluon propagator and enhanced ghost propagator in the infrared

Ghost-enhanced scenario natural in Coulomb gauge, where classical (non-Abelian) Gauss's law is written for color-coulomb potential. In momentum space, IR divergence of ghost propagator as $1/k^4$ leads to linearly rising potential.

Gribov's restriction beyond quantization using Faddeev-Popov (FP) method: take minimal gauge, i.e. FP operator has non-negative eigenvalues. First Gribov horizon approached in infinite-volume limit, implying ghost enhancement.

Note: in principle no obvious connection with Kugo-Ojima scenario; see Kondo, arXiv:09044897.

IR gluon propagator and confinement

- Green's functions carry all information of a QFT's physical and mathematical structure.
- Gluon propagator (two-point function) as the most basic quantity of QCD.
- Confinement given by behavior at large distances (small momenta) $\Rightarrow$ nonperturbative study of IR gluon propagator.

Landau gluon propagator

$$
\begin{aligned}
D^{ab}_{\mu\nu}(p) &= \sum_x e^{-2i\pi k\cdot x} \langle A^a_\mu(x)\, A^b_\nu(0)\rangle \\
&= \delta^{ab} \left(g_{\mu\nu} - \frac{p_\mu\, p_\nu}{p^2} \right) D(p^2)
\end{aligned}
$$

IR ghost propagator and confinement

Ghost fields are introduced as one evaluates functional integrals by the Faddeev-Popov method, which restricts the space of configurations through a gauge-fixing condition. The ghosts are unphysical particles, since they correspond to anti-commuting fields with spin zero.

On the lattice, the (minimal) Landau gauge is imposed as a minimization problem and the ghost propagator is given by

$$G(p) \;=\; \frac{1}{N_c^2 - 1} \sum_{x,\,y,\,a} \frac{e^{-2\pi i \, k \cdot (x-y)}}{V} \,\langle\, \mathcal{M}^{-1}(a, x; a, y) \,\rangle \;,$$

where the Faddeev-Popov (FP) matrix $\mathcal{M}$ is obtained from the second variation of the minimizing functional.

Gribov-Zwanziger Confinement Scenario

- The Gribov-Zwanziger confinement scenario in Landau gauge predicts a gluon propagator $D(p^2)$ suppressed in the IR limit.
- In particular, $D(0) = 0$ implying that reflection positivity is maximally violated.
- This result may be viewed as an indication of gluon confinement.
- Infinite volume favors configurations on the first Gribov horizon, where λ_{min} of $\mathcal{M}$ goes to zero.
- In turn, $G(p)$ should be IR enhanced, introducing long-range effects, related to the color-confinement mechanism.

Tests of Gribov-Zwanziger Scenario

Above results are also obtained by functional methods (e.g. solution of DSEs by Alkofer et al.)

$$D(p^2) \sim (p^2)^{2\kappa-1} , \qquad G(p^2) \sim (p^2)^{-\kappa-1}$$

Note: other solutions by Aguilar et al., Boucaud et al.

Tests of Gribov-Zwanziger Scenario

Above results are also obtained by functional methods (e.g. solution of DSEs by Alkofer et al.)

$$D(p^2) \sim (p^2)^{2\kappa-1} \,, \qquad G(p^2) \sim (p^2)^{-\kappa-1}$$

Note: other solutions by Aguilar et al., Boucaud et al.

What about lattice simulations?

Tests of Gribov-Zwanziger Scenario

Above results are also obtained by functional methods (e.g. solution of DSEs by Alkofer et al.)

$$D(p^2) \sim (p^2)^{2\kappa - 1}\,, \qquad G(p^2) \sim (p^2)^{-\kappa - 1}$$

Note: other solutions by Aguilar et al., Boucaud et al.

What about lattice simulations?

- Gluon propagator is suppressed in the limit $p \to 0$
- On “small” lattices could fit to $D(0) \to 0$
- Studies (with “small” lattices) showed enhancement of $G(p)$.

Tests of Gribov-Zwanziger Scenario

Above results are also obtained by functional methods (e.g. solution of DSEs by Alkofer et al.)

$$D(p^2) \ \sim \ (p^2)^{2\kappa - 1} \, , \qquad G(p^2) \ \sim \ (p^2)^{-\kappa - 1}$$

Note: other solutions by Aguilar et al., Boucaud et al.

What about lattice simulations?

- Gluon propagator is suppressed in the limit $p \to 0$
- On “small” lattices could fit to $D(0) \to 0$
- Studies (with “small” lattices) showed enhancement of $G(p)$.

After 2007:

- From data on very large lattices one sees that $D(0) > 0$
- On very large lattices $G(p)$ shows no enhancement in the IR

References

Studies on very large lattices presented by three groups at the Lattice 2007 Conference (PoS Lat2007)

- Bogolubsky et al. (Berlin): 80^4 lattices (13 fm), SU(3)
- Sternbeck et al. (Adelaide): 112^4 lattices (19 fm), SU(2)
- Cucchieri, T.M.: 128^4 lattices (27 fm), SU(2) plus 3d SU(2) case with 320^3 (85 fm)

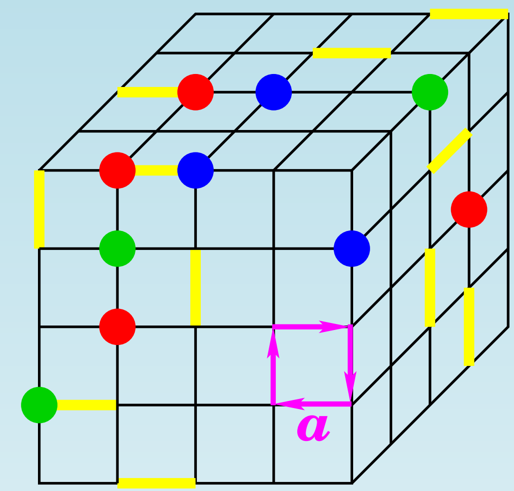
(possibly triggered by Fischer et al., Annals Phys. 2007)

Just before

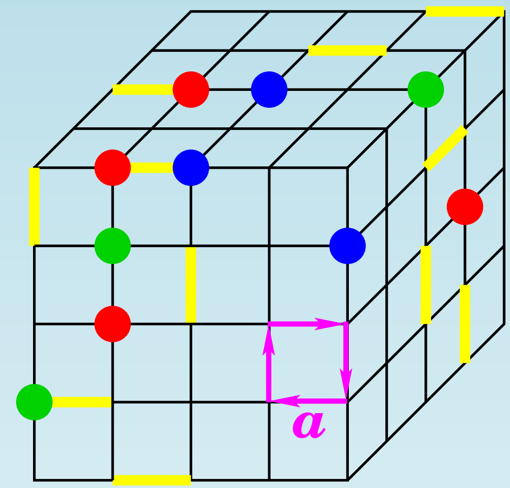
- Scaling behavior seen on 2d lattice (A. Maas, Phys. Rev. D 2007)
- SU(2) & SU(3) are equivalent in the IR (Cucchieri et al., Phys. Rev. D 2007)

Latttice QCD

1. Quantization by path integrals $\Rightarrow$ sum over configurations with "weights" $e^{i\,S/\hbar}$
2. Euclidean formulation (analytic continuation to imaginary time) $\Rightarrow$ weight becomes $e^{-S/\hbar}$
3. Discrete space-time $\Rightarrow$ UV cut at momenta $p \lesssim 1/a \Rightarrow$ regularization



Latttice QCD



1. Quantization by path integrals $\Rightarrow$ sum over configurations with "weights" $e^{i\,S/\hbar}$

2. Euclidean formulation (analytic continuation to imaginary time) $\Rightarrow$ weight becomes $e^{-S/\hbar}$

3. Discrete space-time $\Rightarrow$ UV cut at momenta $p \lesssim 1/a$ $\Rightarrow$ regularization

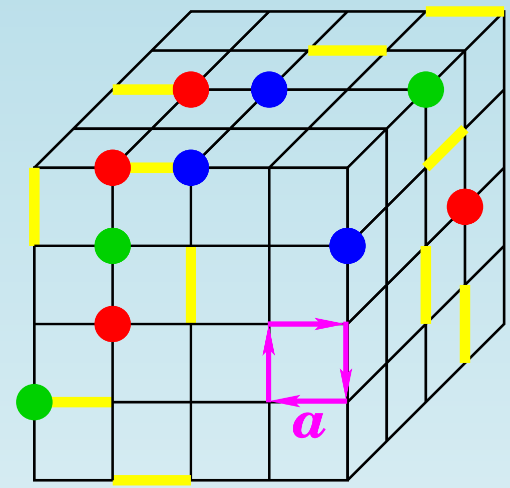
Also: finite-size lattices $\Rightarrow$ IR cut for small momenta $p \approx 1/L$

Latttice QCD

1. Quantization by path integrals $\Rightarrow$ sum over configurations with "weights" $e^{i\,S/\hbar}$

2. Euclidean formulation (analytic continuation to imaginary time) $\Rightarrow$ weight becomes $e^{-S/\hbar}$

3. Discrete space-time $\Rightarrow$ UV cut at momenta $p \lesssim 1/a \Rightarrow$ regularization



Also: finite-size lattices $\Rightarrow$ IR cut for small momenta $p \approx 1/L$

The Wilson action

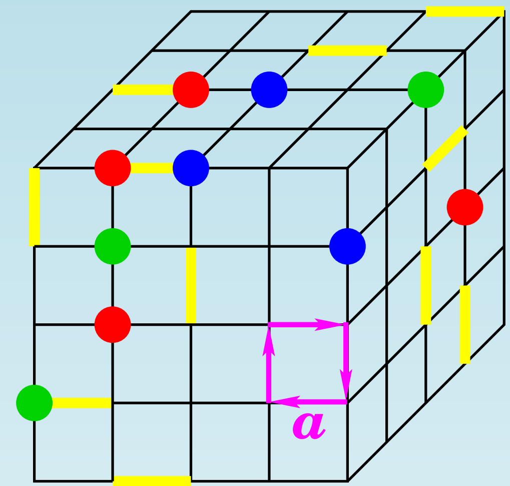
$$S = -\frac{\beta}{3} \sum_{\square} \mathrm{ReTr}\, U_{\square}\,, \quad U_{x,\mu} \equiv e^{i g_0 a A^b_\mu(x) T_b}\,, \quad \beta = 6/{g_0}^2$$

Latttice QCD

1. Quantization by path integrals $\Rightarrow$ sum over configurations with "weights" $e^{i\,S/\hbar}$

2. Euclidean formulation (analytic continuation to imaginary time) $\Rightarrow$ weight becomes $e^{-S/\hbar}$

3. Discrete space-time $\Rightarrow$ UV cut at momenta $p \lesssim 1/a$ $\Rightarrow$ regularization



Also: finite-size lattices $\Rightarrow$ IR cut for small momenta $p \approx 1/L$

The Wilson action

$$S \;=\; -\frac{\beta}{3}\sum_{\Box} \mathrm{ReTr}\, U_{\Box}\,, \quad U_{x,\mu} \;\equiv\; e^{i g_0 a A^b_\mu(x) T_b}\,, \quad \beta \;=\; 6/{g_0}^2$$

$V(R) \sim \sigma R$ from small β expansion

In general: Monte Carlo simulations + ∞-vol limit + $a \to 0$

Lattice Features

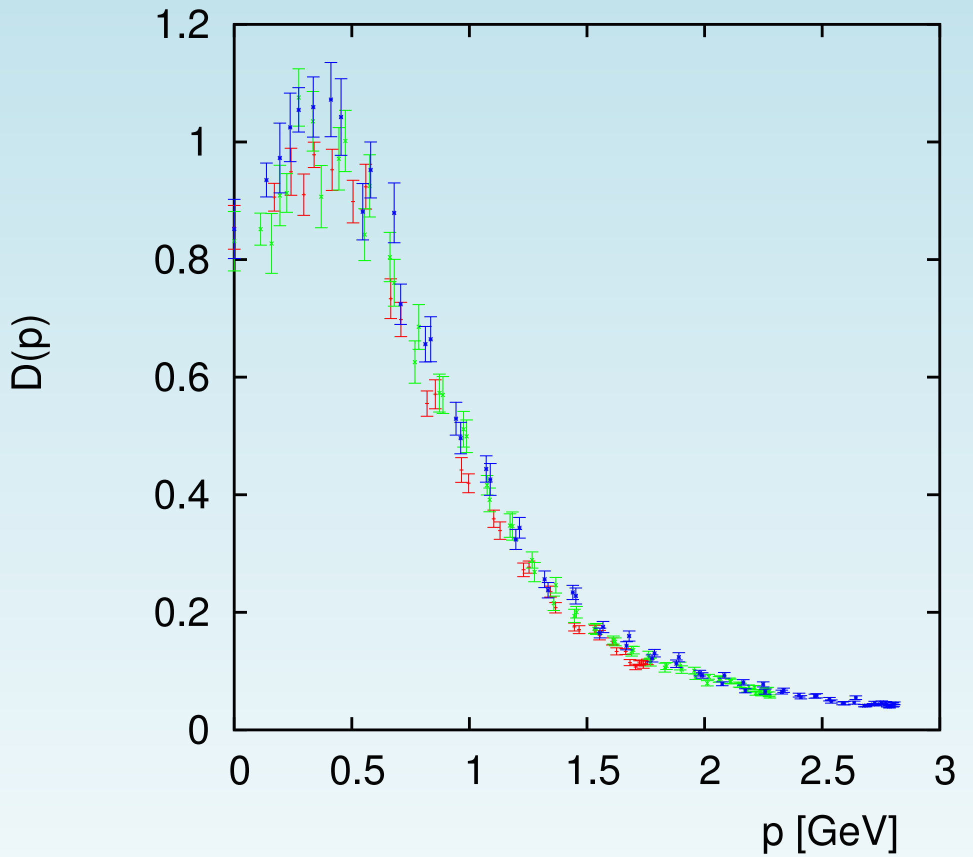
- Gauge action written in terms of oriented plaquettes formed by the link variables $U_{x,\mu}$, which are group elements
- under gauge transformations: $U_{x,\mu} \to g(x)\, U_{x,\mu}\, g^{\dagger}(x+\mu)$, where $g \in SU(3) \Rightarrow$ closed loops are gauge-invariant quantities
- integration volume is finite: no need for gauge-fixing
- when gauge fixing, procedure is incorporated in the simulation, no need to consider FP matrix
- get FP matrix without considering ghost fields explicitly
- Lattice momenta given by $\hat{p}_\mu = 2\,\sin\left(\pi\, n_\mu/N\right)$ with $n_\mu = 0, 1, \ldots, N/2 \;\Leftrightarrow\; p_{min} \sim 2\pi/(a\,N) = 2\pi/L$, $p_{max} = 4/a$ in physical units

Bounds and Results

for the Gluon Propagator

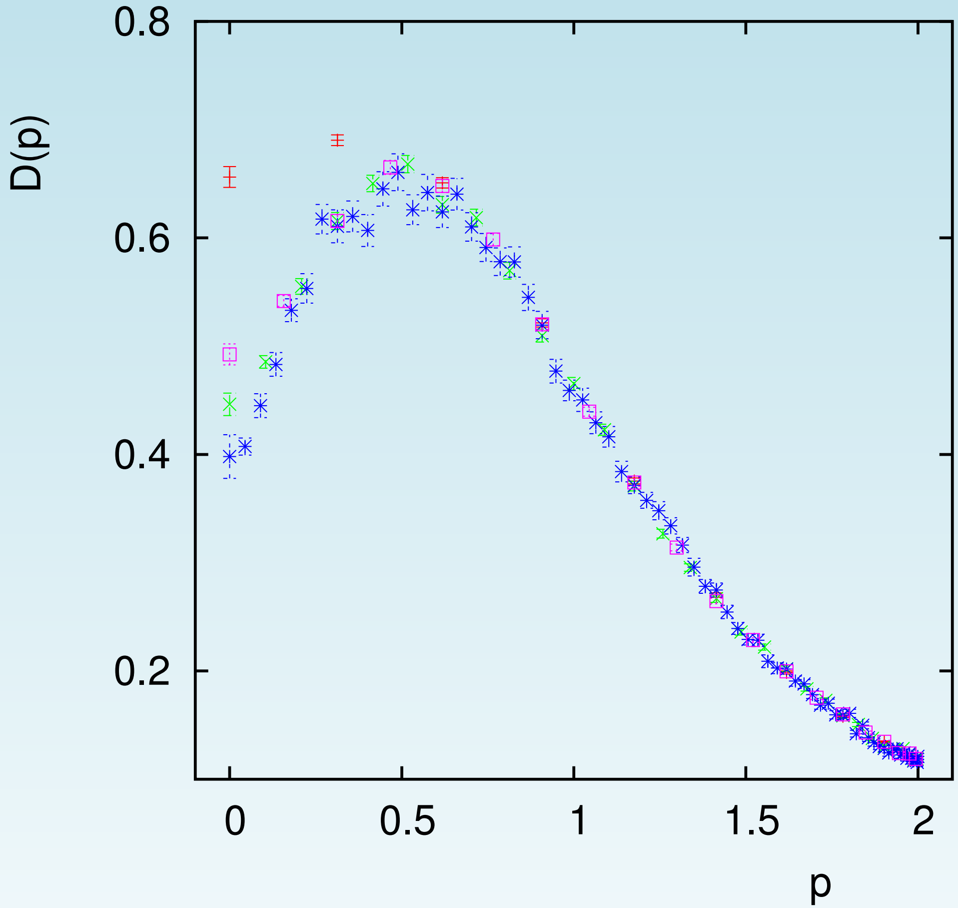
(A. Cucchieri, T.M., PoS LATTICE2007 and Phys. Rev. Lett. 2008)

Infinite-volume limit in 3d (I)



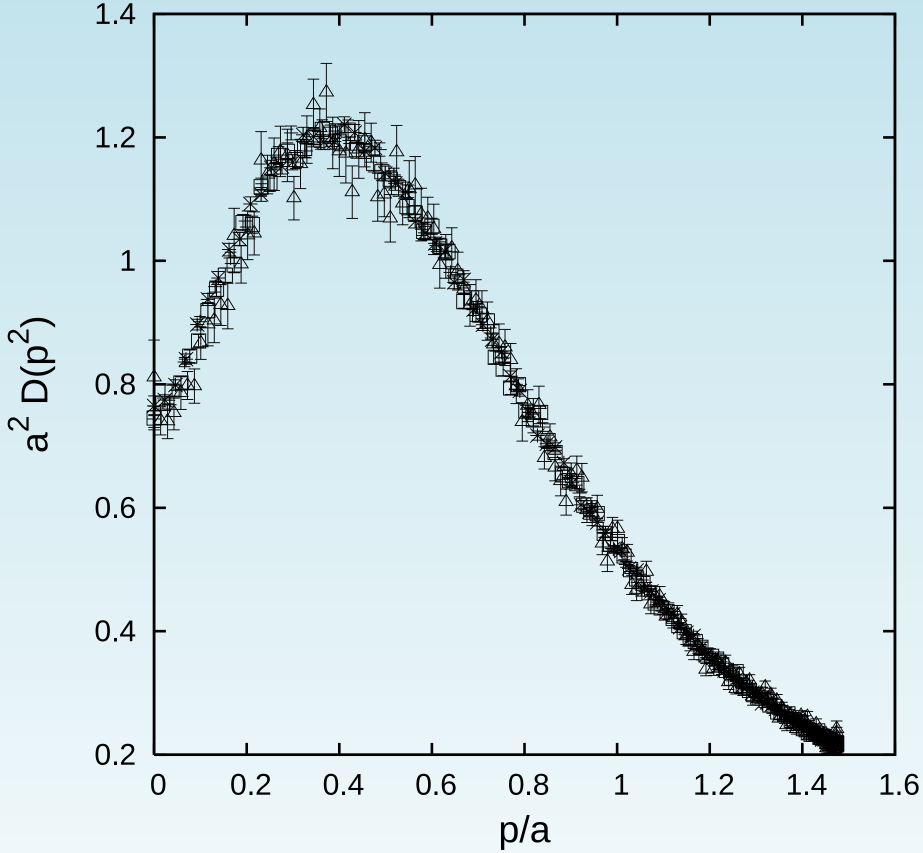
Gluon propagator as a function of the lattice momentum p for $\beta = 3.4$ and 32^3 (+), $\beta = 4.2$ and 64^3 ($\times$), $\beta = 5.0$ and 64^3 ($*$) (A. Cucchieri, Phys. Rev. D60 034508, 1999).

Infinite-volume limit in 3d (II)



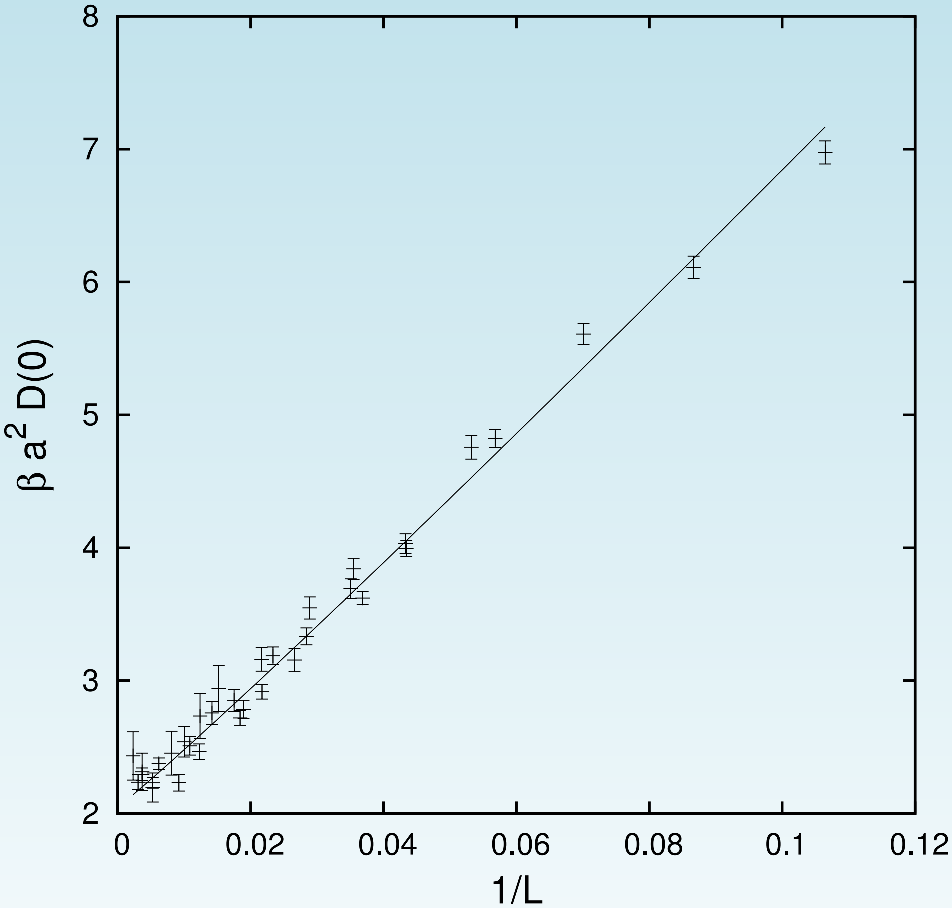
Gluon propagator as a function of the lattice momentum p for lattice volumes $V = 20^3$, 40^3, 60^3 and 140^3 at $\beta = 3.0$ (A. Cucchieri, T. M. and A. Taurines, Phys. Rev. D67 091502, 2003).

Infinite-volume limit in 3d (III)



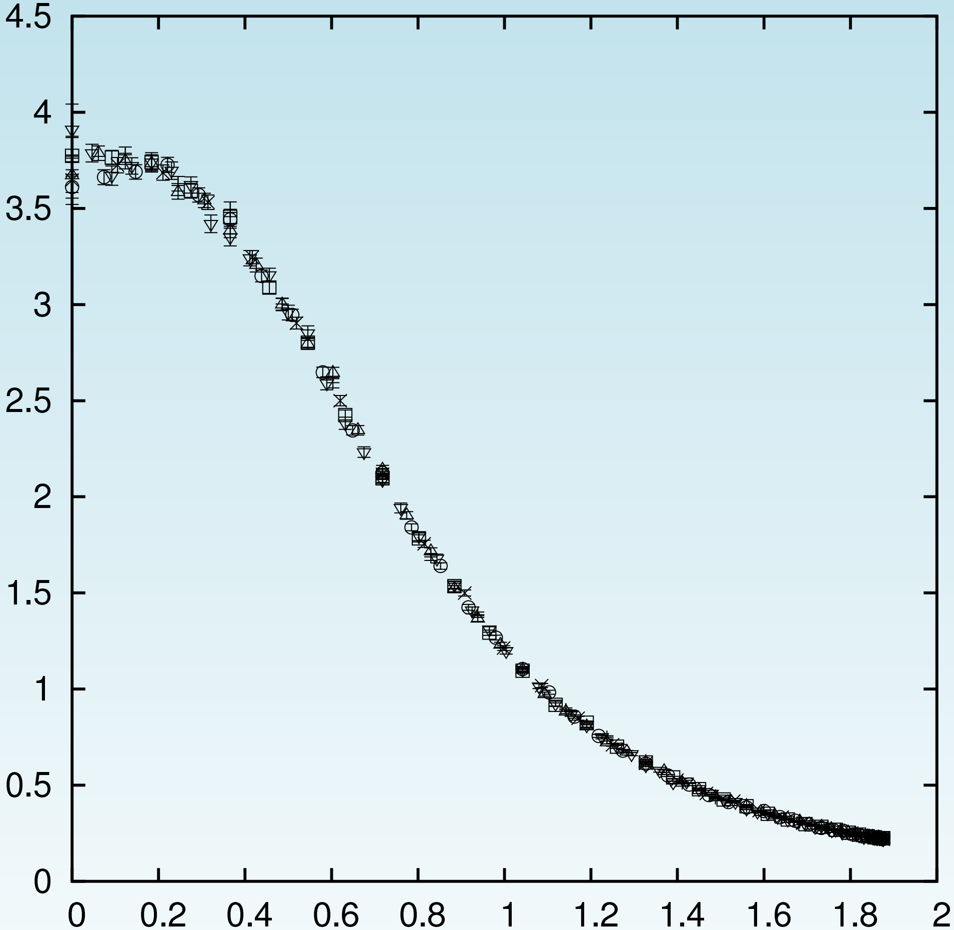
Gluon propagator as a function of the lattice momentum p including lattices up to 320^3 in the scaling region.

Infinite-volume limit in 3d: $D(0)$



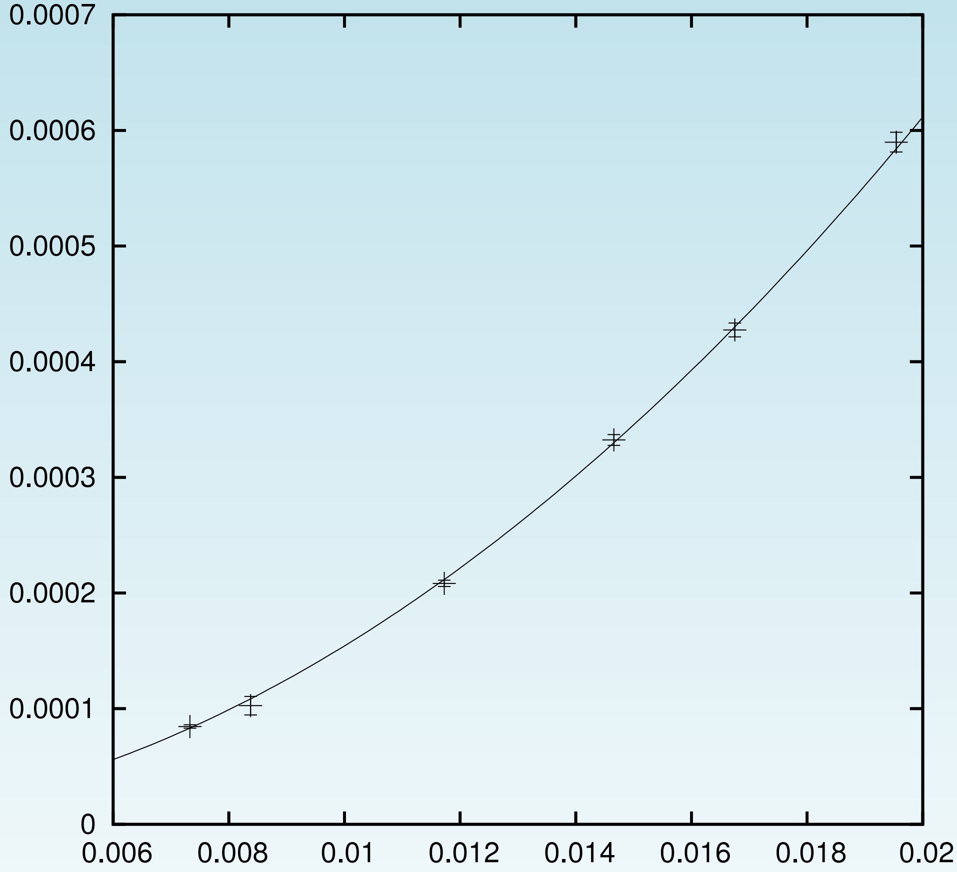
Gluon propagator at zero momentum as a function of the inverse lattice side $1/L$ (in fm^{-1}) and extrapolation to infinite volume. Data for lattice volumes up to 320^3 for $\beta = 3.0$.

Infinite-volume limit in 4d



Gluon propagator as a function of the lattice momentum p for lattice volume up to $V = 128^4$ at $\beta = 2.2$.

Extrapolation to infinite volume: a hint



Average absolute value of the gluon field at zero momentum $|\widetilde{A}^b_\mu(0)|$ (for $\beta = 2.2$) as a function of the inverse lattice side $1/L$ (in fm^{-1}) and extrapolation to infinite volume. Recall that $D(0) \propto V \sum_{\mu,b} |\widetilde{A}^b_\mu(0)|^2$. We also show the fit of the data using the Ansatz b/L^c (with $c = 1.99 \pm 0.02$).

Zwanziger proved that in Landau gauge this quantity should go to zero at least as fast as $1/L$.

Lower bound for $D(0)$

We can obtain a lower bound for the gluon propagator at zero momentum $D(0)$ by considering the quantity

$$\overline{M}(0) \;=\; \frac{1}{d(N_c^2-1)} \sum_{b,\mu} |\widetilde{A}^b_\mu(0)| \;.$$

Consider the Schwarz inequality $|\vec{X}\cdot\vec{Y}|^2 \leq \|\vec{X}\|^2 \|\vec{Y}\|^2$, a vector $\vec{Y}$ with all components equal to 1 and a vector $\vec{X}$ with components X_i, we find

$$\left(\frac{1}{m}\sum_{i=1}^{m} X_i\right)^2 \;\leq\; \frac{1}{m}\sum_{i=1}^{m} X_i^2 \;,$$

where m is the number of components of the vectors $\vec{X}$ and $\vec{Y}$.

Lower bound for $D(0)$ (II)

We can now apply this inequality first to the vector with $m = d(N_c^2 - 1)$ components $\langle|\widetilde{A}_\mu^b(0)|\rangle$, where

$$\widetilde{A}_\mu^b(0) \; = \; \frac{1}{V} \sum_x A_\mu^b(x)$$

is the gluon field at zero momentum. This yields

$$\langle \overline{M}(0) \rangle^2 \; \leq \; \frac{1}{d(N_c^2 - 1)} \sum_{b,\mu} \langle |\widetilde{A}_\mu^b(0)| \rangle^2 \; .$$

Then, we can apply the same inequality to the Monte Carlo estimate of the average value

$$\langle|\widetilde{A}_\mu^b(0)|\rangle \; = \; \frac{1}{n} \sum_c |\widetilde{A}_{\mu,c}^b(0)| \; ,$$

where n is the number of configurations. In this case we obtain

$$\langle|\widetilde{A}_\mu^b(0)|\rangle^2 \; \leq \; \langle|\widetilde{A}_\mu^b(0)|^2\rangle \; .$$

Lower bound for $D(0)$ (III)

Thus, by recalling that

$$D(0) \; = \; \frac{V}{d(N_c^2 - 1)} \sum_{b,\mu} \langle |\widetilde{A}_\mu^b(0)|^2 \rangle \; ,$$

we find

$$\left[V^{1/2} \langle \overline{M}(0) \rangle \right]^2 \; \leq \; D(0) \; .$$

We obtain that $\langle \overline{M}(0) \rangle$ goes to zero exactly as $1/V^{1/2}$!

This gives

- $D(0) \geq 0.5(1)$ (GeV^{-2}) in 3d
- $D(0) \geq 2.5(3)$ (GeV^{-2}) in 4d

Upper bound for $D(0)$

We can now consider the inequality

$$\langle \sum_{\mu,b} |\widetilde{A}^b_\mu(0)|^2 \rangle \;\leq\; \langle \Big\{ \sum_{\mu,b} |\widetilde{A}^b_\mu(0)| \Big\}^2 \rangle \;.$$

This implies

$$D(0) \;\leq\; V d (N_c^2 - 1) \, \langle \overline{M}(0)^2 \rangle \;.$$

Thus

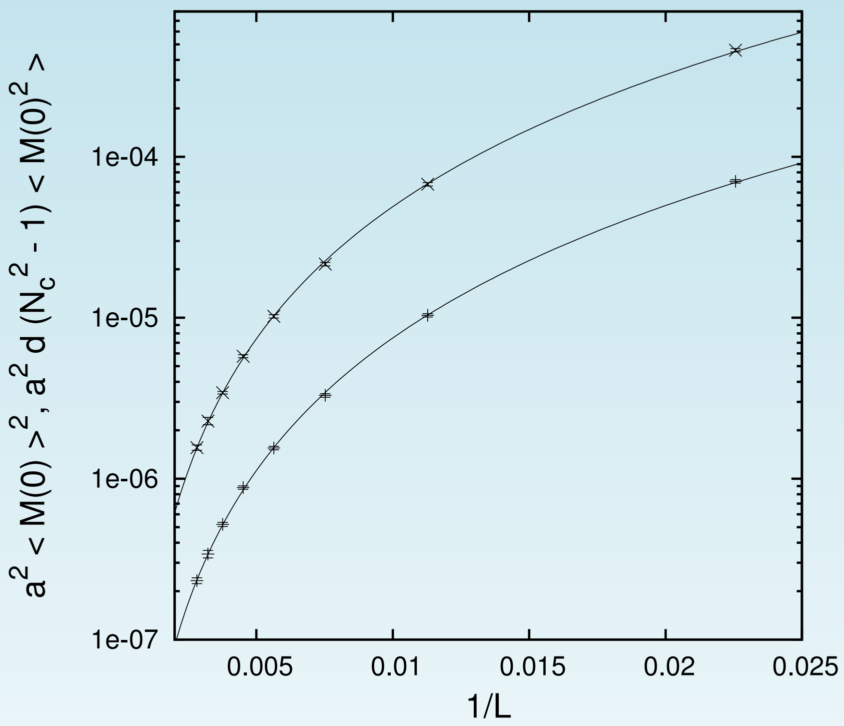
$$V \, \langle \overline{M}(0) \rangle^2 \;\leq\; D(0) \;\leq\; V d (N_c^2 - 1) \, \langle \overline{M}(0)^2 \rangle \;.$$

In summary, if $\overline{M}(0)$ goes to zero as $V^{-\alpha}$ we find that

$D(0) \to 0$, $\quad 0 < D(0) < +\infty \quad$ or $\quad D(0) \to +\infty$

respectively if α is larger than, equal to or smaller than 1/2.

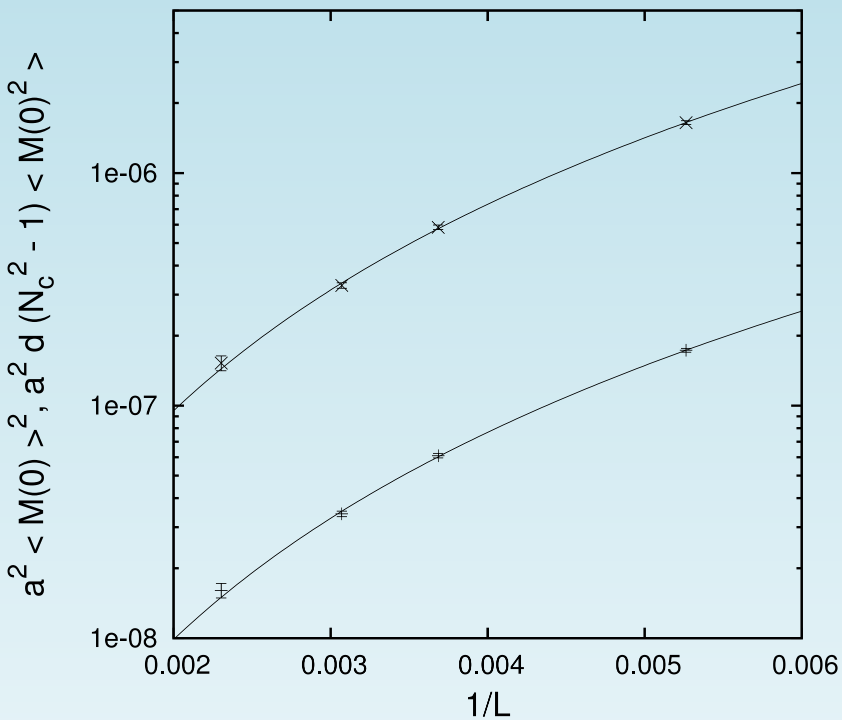
Upper and lower bounds for $D(0)$

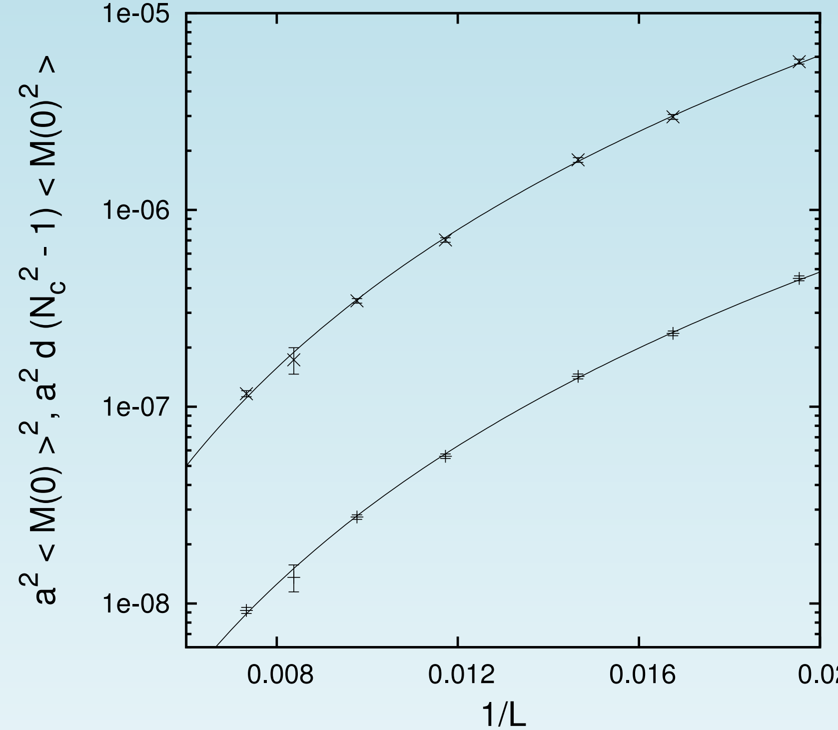


Two-dimensional case: B_l/L^l (for $a\langle \overline{M}(0)\rangle$) and the Ansatz B_u/L^u (for $a^2\langle\, \overline{M}(0)^2\,\rangle$), with $B_l = 1.48(6)$, $l = 1.367(8)$ and $\chi/d.o.f. = 1.00$ and $B_u = 2.3(2)$, $u = 2.72(1)$ and $\chi/d.o.f. = 1.02$.

Upper and lower bounds extrapolate to zero faster than $1/V$, implying $D(0) = 0$.

Upper and lower bounds for $D(0)$ (II)



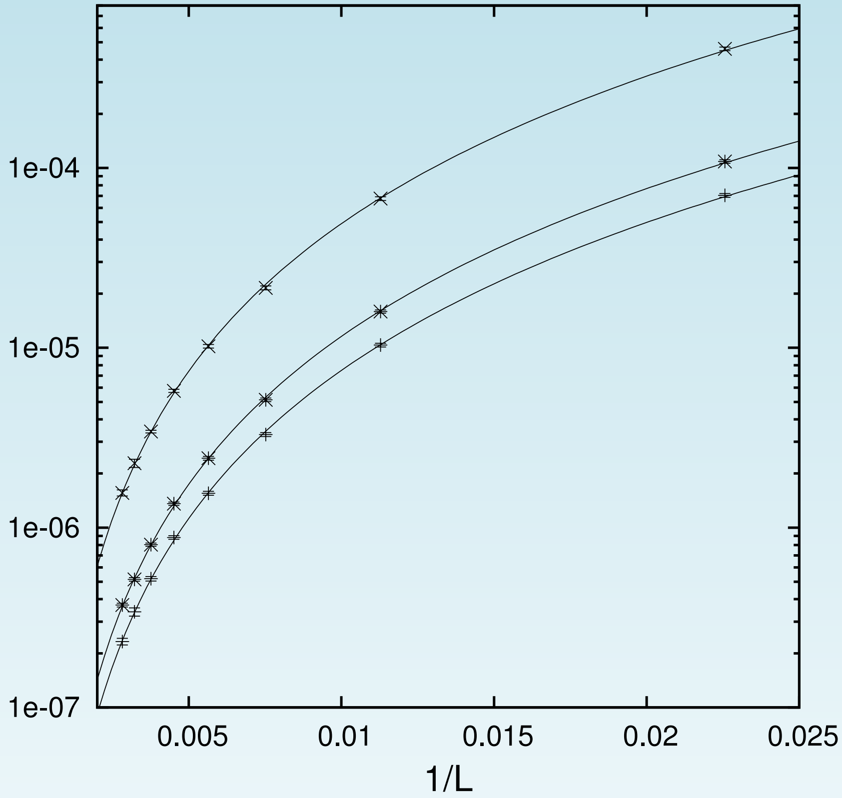


Similarly for 3d: $l = 1.48(3)$; $B_u = 1.0(3)$, $u = 2.95(5)$ and $\chi/d.o.f. = 0.95$.

Similarly for 4d: $l = 1.99(2)$; $B_u = 3.1(5)$, $u = 3.99(4)$ and $\chi/d.o.f. = 0.96$.

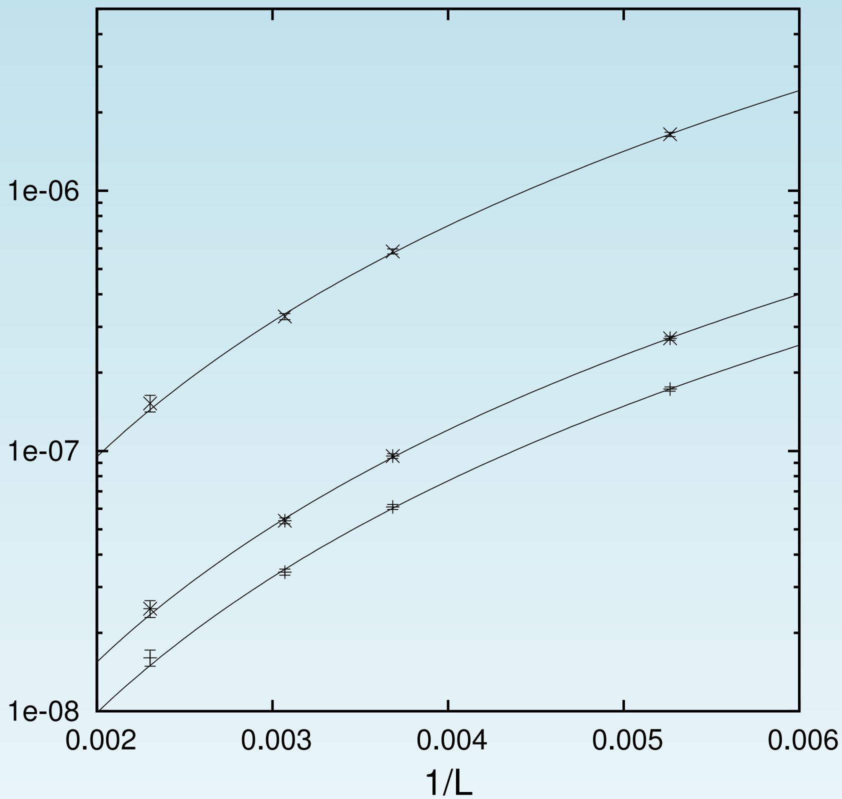
Upper / lower bounds extrapolate to zero as $1/V$, implying $D(0) > 0$.

Upper and lower bounds plus $D(0)/V$

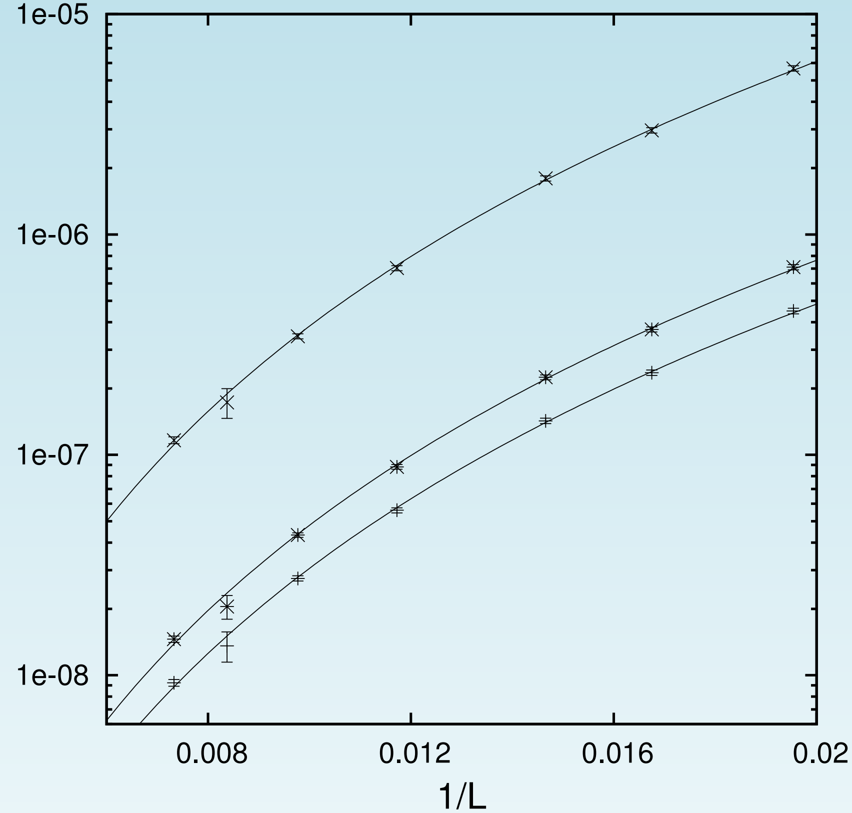


2d case

Upper and lower bounds plus $D(0)/V$ (II)



3d case



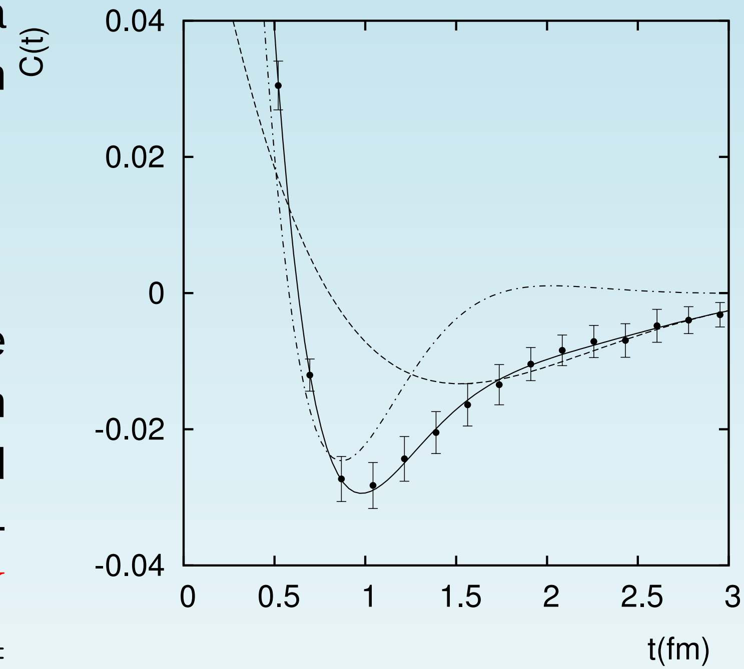
4d case

Gluon Propagator at Infinite Volume

- Gluon propagator in Landau gauge IR finite in 3d and 4d, as a consequence of "self-averaging" of a magnetization-like quantity [i.e. $M(0)$, without the absolute value].
- May think of $D(0)$ as a response function (susceptibility) of this observable ("magnetization"). In this case it is natural to expect $D(0) \sim const$ in the infinite-volume limit.
- 2d case is different, the magnetization is "over self-averaging", the susceptibility is zero.
- Question: why is the 2d case different? Possible solution from S. Sorella and collaborators.
- Note: violation of reflection positivity in 2d, 3d and in 4d.

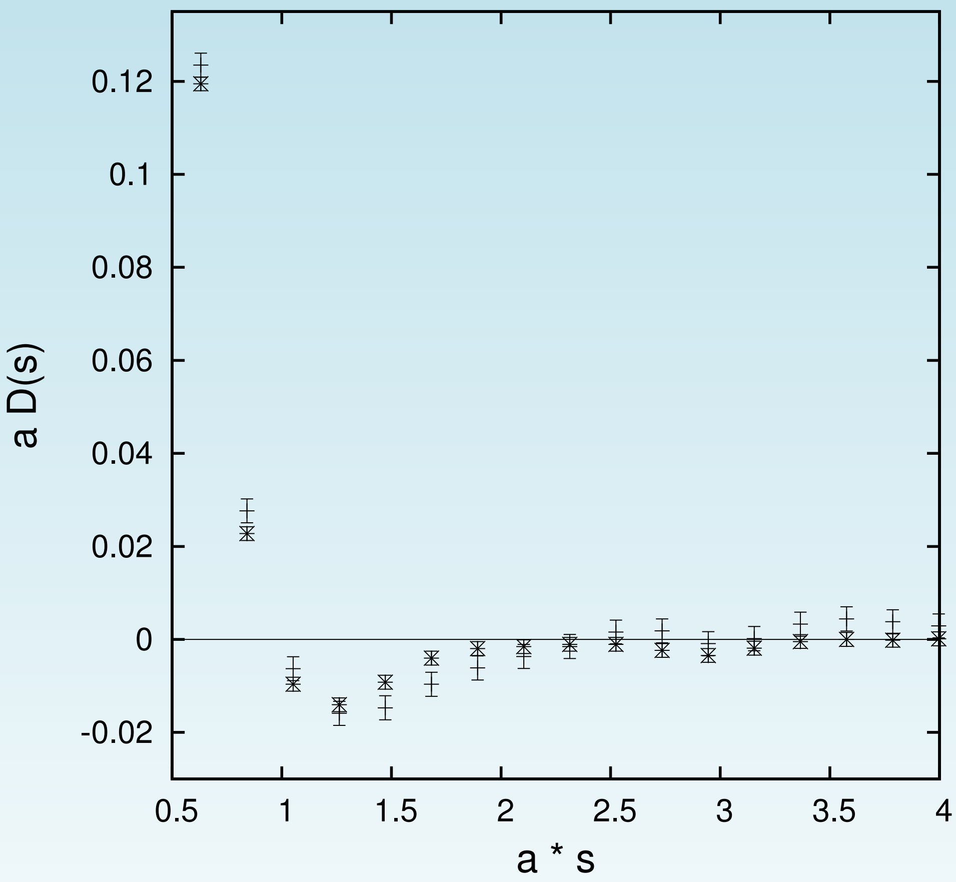
Violation of reflection positivity in 3d

- The transverse gluon propagator decreases in the IR limit for momenta smaller than p_{dec}, which corresponds to the mass scale λ in a Gribov-like propagator $p^2/(p^4 + \lambda^4)$. We can estimate $p_{dec} = 350^{+100}_{-50}$ MeV.



- Clear violation of reflection positivity: this is one of the manifestations of gluon confinement. In the scaling region, the data are well described by a sum of Gribov-like formulas, with a light-mass scale $M_1 \approx 0.74(1)\sqrt{\sigma} = 325(6)\,MeV$ and a second mass scale $M_2 \approx 1.69(1)\sqrt{\sigma} = 745(5)\,MeV$.

Violation of reflection positivity in 4d



Clear violation of reflection positivity for lattice volume $V = 128^4$ at $\beta = 2.2$.

Bounds and Results

for the Ghost Propagator

(A. Cucchieri, T.M., PoS LATTICE2007 and Phys. Rev. D 2008)

Upper and Lower Bounds for $G(p)$

Consider eigenvectors $\psi_i(a,x)$ and associated eigenvalues λ_i of the FP matrix $\mathcal{M}(a,x;b,y)$. The ψ's form a complete orthonormal set

$$\sum_{i=1}^{(N_c^2-1)V} \psi_i(a,x)\,\psi_i(b,y)^* \;=\; \delta_{ab}\delta_{xy} \quad \text{and} \quad \sum_{a,x} \psi_i(a,x)\,\psi_j(a,x)^* \;=\; \delta_{ij}\;.$$

If we now write

$$\mathcal{M}^{-1}(a,x;b,y) \;=\; \sum_{i,\lambda_i\neq 0} \frac{1}{\lambda_i} \psi_i(a,x)\,\psi_i(b,y)^*\;,$$

we get for $G(p)$ the expression

$$G(p) \;=\; \frac{1}{N_c^2-1} \sum_{i,\lambda_i\neq 0} \frac{1}{\lambda_i} \sum_a |\widetilde{\psi}_i(a,p)|^2 \;,$$

where

$$\widetilde{\psi}_i(a,p) \;=\; \frac{1}{\sqrt{V}} \sum_x \psi_i(a,x)\, e^{-2\pi i k\cdot x}\;.$$

Upper and Lower Bounds for $G(p)$ (II)

From the above expression we immediately get for $G(p)$ the lower bound

$$\frac{1}{N_c^2 - 1} \, \frac{1}{\lambda_{min}} \sum_a |\widetilde{\psi}_{min}(a,p)|^2 \, \leq \, G(p)$$

and the upper bound

$$G(p) \, \leq \, \frac{1}{N_c^2 - 1} \, \frac{1}{\lambda_{min}} \sum_{i,\lambda_i \neq 0} \sum_a |\widetilde{\psi}_i(a,p)\,|^2 \, .$$

Now by adding and subtracting the contribution from the null eigenvalue and using the completeness relation, the upper bound may be rewritten as

$$G(p) \, \leq \, \frac{1}{\lambda_{min}} \left[1 - \frac{1}{N_c^2 - 1} \sum_{j,\lambda_j = 0} \sum_a |\widetilde{\psi}_j(a,p)\,|^2 \right] \, .$$

Upper and Lower Bounds for $G(p)$ (III)

In Landau gauge the eigenvectors corresponding to null λ are constant modes. Thus for any nonzero p we have

$$\frac{1}{N_c^2 - 1} \frac{1}{\lambda_{min}} \sum_a |\widetilde{\psi}_{min}(a,p)|^2 \leq G(p) \leq \frac{1}{\lambda_{min}} \, .$$

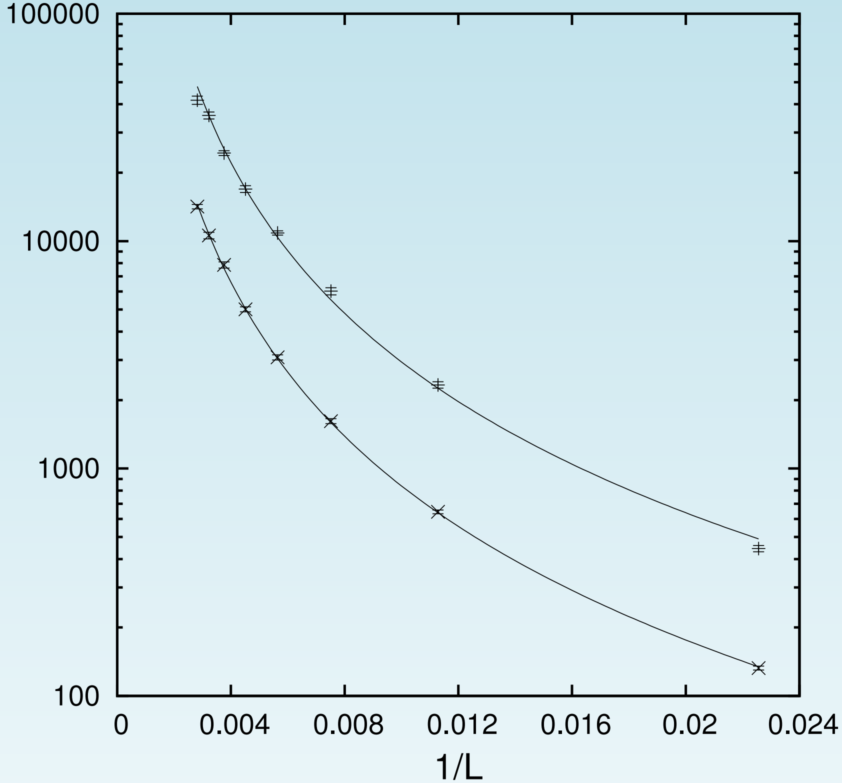
Now, assuming $\lambda_{min} \sim N^{-\alpha}$ and the power-law behavior $p^{-2-2\kappa}$ for the IR ghost propagator, we expect to have

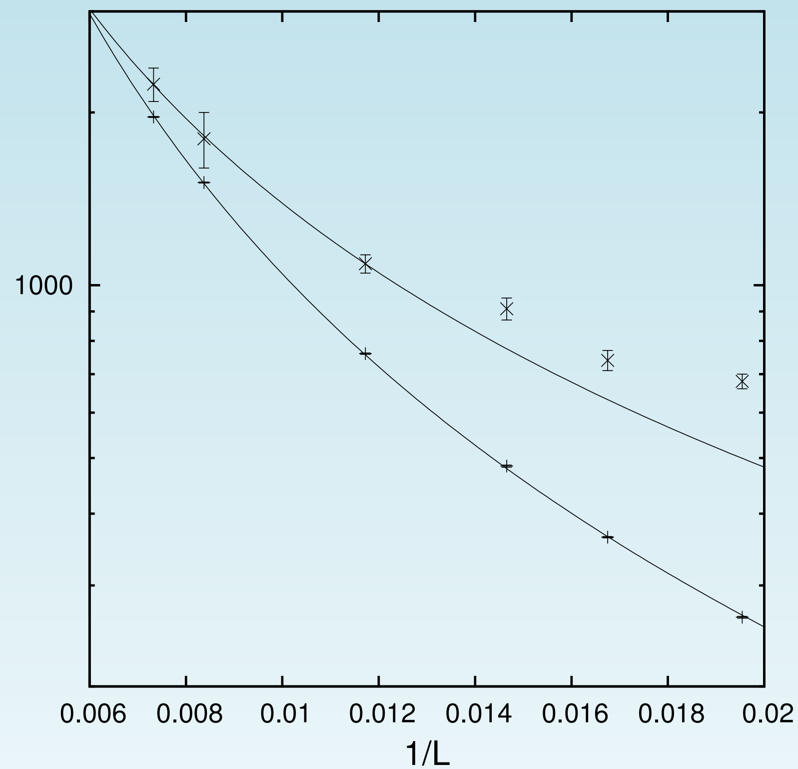
$$2 + 2\kappa \leq \alpha$$

and a necessary condition for IR enhancement of $G(p)$ is

$$\alpha > 2 \, .$$

Upper bound for $G(p_{min})$



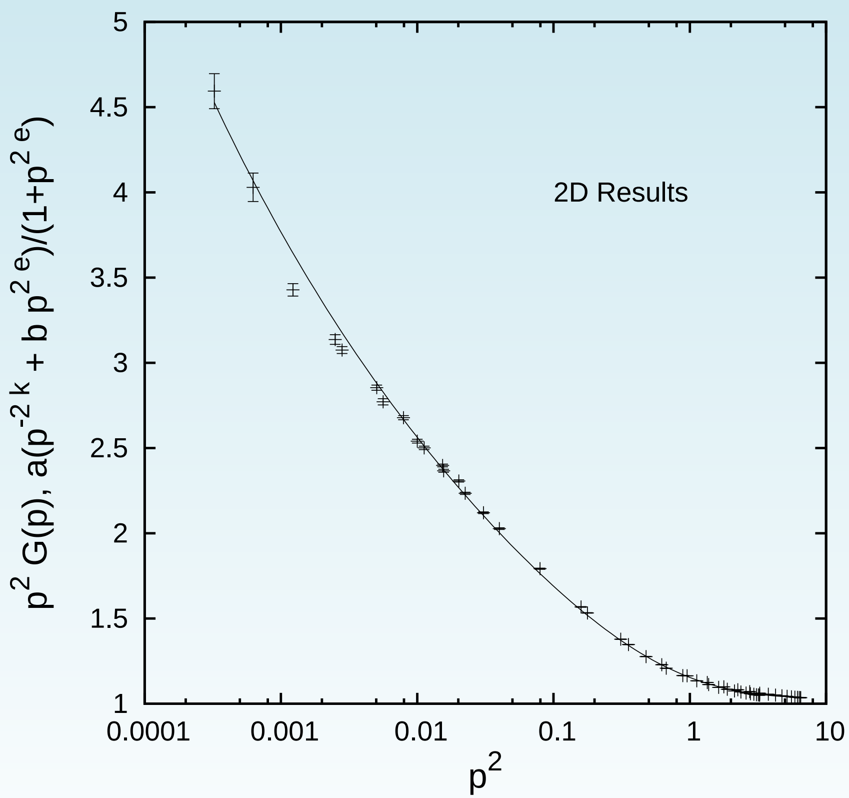


For 2d: $2\kappa = 0.251(9)$, $\alpha = 2.20(4)$.

For 4d: $2\kappa = 0.043(8)$, $\alpha = 1.53(2)$.

Ghost fits (I)

Fit of the ghost dressing function $p^2G(p^2)$ as a function of p^2 (in GeV) for the 2d case ($\beta = 10$ with volume 320^2). We find that $p^2G(p^2)$ is best fitted by the form $p^2G(p^2) = a(p^{-2k} + bp^{2e})/(1 + p^{2e})$, with

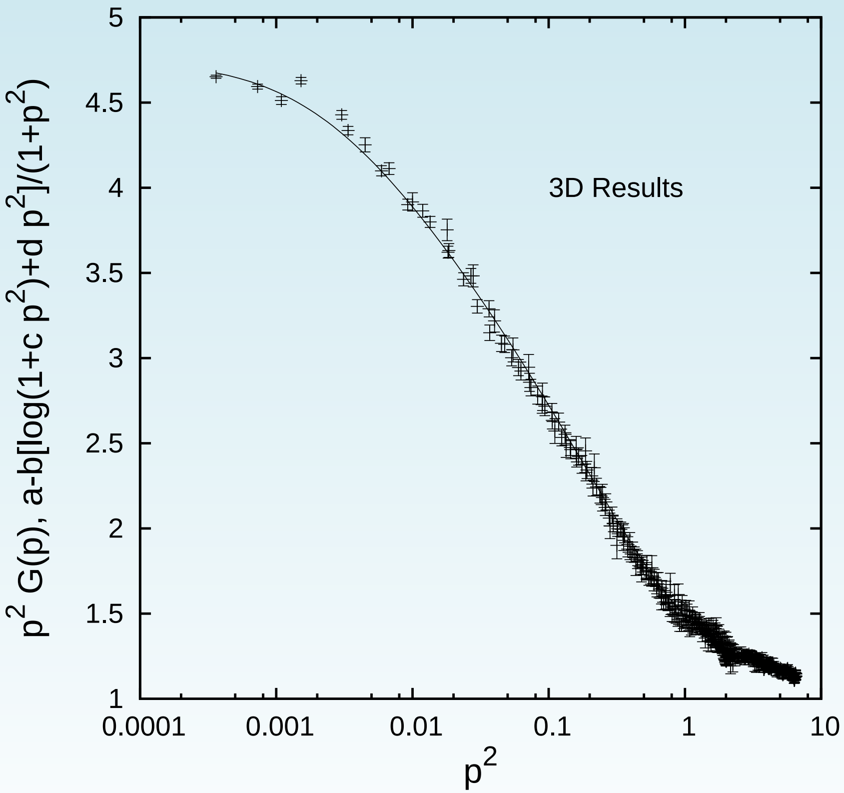


$a = 1.24(3)\, GeV^{2(e+\kappa)}$,
$\kappa = 0.16(2)$,
$b = 0.86(3)\, GeV^{-2(e+\kappa)}$,
$e = 0.75(15)$.

In the infrared limit $p^2G(p^2) \sim p^{-2k}$.

Ghost fits (II)

Fit of the ghost dressing function $p^2 G(p^2)$ as a function of p^2 (in GeV) for the 3d case ($\beta = 3$ with volume 240^3). We find that $p^2 G(p^2)$ is best fitted by the form $p^2 G(p^2) = a - b[\log(1 + cp^2) + dp^2]/(1 + p^2)$, with

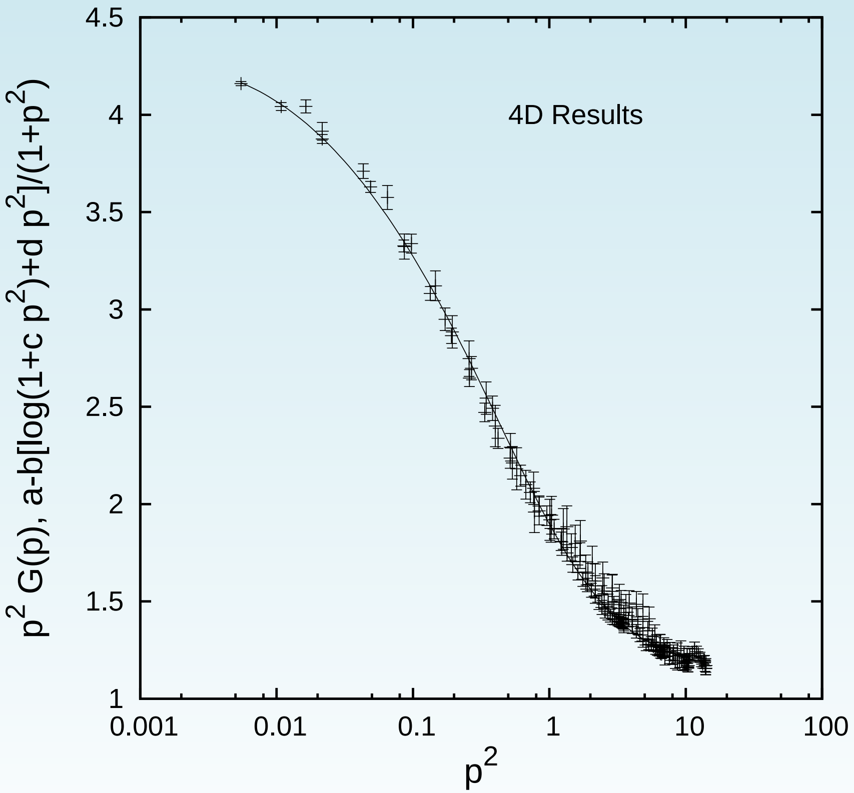


$$a = 4.75(1),$$
$$b = 0.491(5)\, GeV^2,$$
$$c = 450(30)\, GeV^{-2},$$
$$d = 7.1(1)\, GeV^{-2}.$$

In the infrared limit $p^2 G(p^2) \sim a$.

Ghost fits (III)

Fit of the ghost dressing function $p^2G(p^2)$ as a function of p^2 (in GeV) for the 4d case ($\beta = 2.2$ with volume 80^4). We find that $p^2G(p^2)$ is best fitted by the form $p^2G(p^2) = a - b[\log(1 + cp^2) + dp^2]/(1 + p^2)$, with



$a = 4.32(2)$,
$b = 0.38(1)\, GeV^2$,
$c = 80(10)\, GeV^{-2}$,
$d = 8.2(3)\, GeV^{-2}$.

In the infrared limit $p^2G(p^2) \sim a$.

Ghost Propagator at Infinite Volume

- From present fits we have $\alpha > 2$ in 2d [implying IR enhancement of $G(p)$], but $\alpha < 2$ in 4d.
- On the other hand the expected relation $2 + 2\kappa \leq \alpha$ is not satisfied, although the upper bound is.
- Of course, we should get better data for λ_{min} in 2d, 3d and 4d.
- From fits of the ghost dressing function we find $p^2 G(p^2) \sim p^{-2k}$ in 2d and $p^2 G(p^2) \sim a$ in 3d and in 4d.

Propagators at $\beta = 0$

In agreement with the simulations at $\beta > 0$ we find (arXiv:0904.4033[hep-lat]) that

- the gluon propagator $D(p)$ violates reflection positivity,
- the gluon propagator at zero momentum $D(0)$ seems to be finite and nonzero,
- the ghost propagator $G(p)$ is not infrared enhanced in the deep infrared limit, but it is enhanced at larger momenta,
- a very good fit for the ghost propagator $G(p)$ in given by $f(x) = \left[a - b \log\left(p^2 + c^2\right)\right] / p^2$,
- see also recent work by A. Sternbeck and L. von Smekal.

Conclusions

- Simple properties of gluon and ghost propagators constrain (by upper and lower bounds) their IR behavior. For the gluon case we define a magnetization-like quantity, while for the ghost case we relate the propagator to λ_{min} of the FP matrix. These quantities are studied as a function of the lattice volume, to gain better control of the infinite-volume limit of IR propagators.
- For the gluon propagator, data & extrapolation (plus explanation as response function) support a finite value in the IR
- For the ghost case, enhancement seems unlikely...
- Questions: just considering large volumes is not enough? is the behavior of the propagators at $p = 0$ so crucial for confinement?
- Interesting to consider other gauges: MAG, λ-gauges, linear covariant gauge (collaboration with A. Maas, A. Mihara, E. Santos)