Gluon Propagators at Finite Temperature and Density

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- Motivation
  - Why the propagators are of interest?
  - QC_2D as a “testing ground” for the computations at $\mu_B \neq 0$
  - Phases and transitions in QC_2D
  - The concept of screening mass and propagators
- Pure $SU(2)$ propagators at finite temperatures
  - Gribov-Stingl fit function
  - Propagators and transition from electric to magnetic dominance
- Gluon propagators in QC_2D at $\mu_B \neq 0$
- Gluon propagators in QC_3D at $\mu_B \neq 0$
- Conclusions

$$D_{\mu\nu}(p) = D_L(p) P^L_{\mu\nu} + D_T(p) P^T_{\mu\nu} + \alpha \frac{p_\mu p_\nu}{p^4}$$

We consider propagators only for *soft modes* $p_4 = 0$, where

$$P^T_{\mu\nu} = \begin{pmatrix} 0 & 0 \\ 0 & \delta_{ij} - \frac{p_i p_j}{|\vec{p}|^2} \end{pmatrix} \qquad P^L_{\mu\nu} = \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix}$$

$$D_L(p) = \frac{1}{p^2 + F(p)}, \qquad D_T(p) = \frac{1}{p^2 + G(p)}$$

$D_L(0) \simeq \frac{1}{m_e^2} \simeq r_e^2$ — chromoelectric forces

$D_T(0) \simeq \frac{1}{m_m^2} \simeq r_m^2$ — chromomagnetic forces

Wilson action and standard definition of the lattice gauge vector potential $\mathcal{A}_{x+\hat{\mu}/2,\mu}$ (Mandula, 1987):

$$\mathcal{A}_{x+\hat{\mu}/2,\mu} = \frac{1}{2i}\left(U_{x\mu} - U^{\dagger}_{x\mu}\right) \equiv A^{a}_{x+\hat{\mu}/2,\mu}\frac{\sigma_a}{2} \ . \quad (1)$$

Landau gauge fixing condition is

$$(\partial\mathcal{A})_x = \sum_{\mu=1}^{4}\left(\mathcal{A}_{x+\hat{\mu}/2;\mu} - \mathcal{A}_{x-\hat{\mu}/2;\mu}\right) = 0 \ , \quad (2)$$

which is equivalent to finding an extremum of the gauge functional

$$F_U(g) = \frac{1}{4V}\sum_{x\mu}\frac{1}{2}\ \mathrm{Tr}\ U^{g}_{x\mu} \ , \quad (3)$$

with respect to gauge transformations g_x .

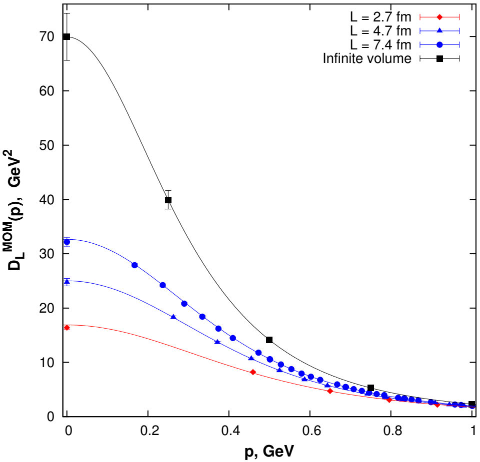
We adopt the strategy of finding gauge copies being as close as possible to the global maximum of the gauge fixing functional - so called **absolute Landau gauge**.

Features of our approach are as follows:

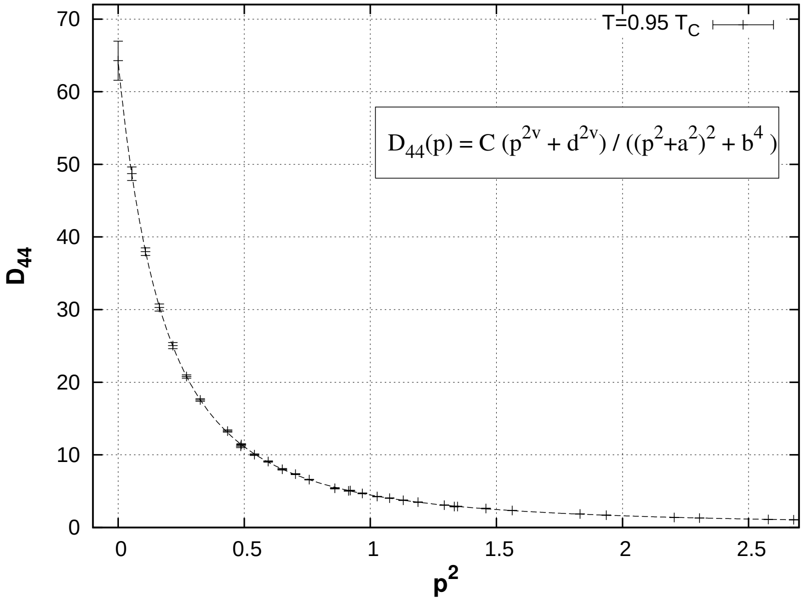
- efficient optimization algorithm - simulated annealing.
- many gauge copies per MC configuration with the choice of the one with maximal F_U - *best copy*.
- In pure gauge theories Z_N flips to use full gauge freedom (with pbc).

Landau-gauge Propagators in Pure Gluodynamics

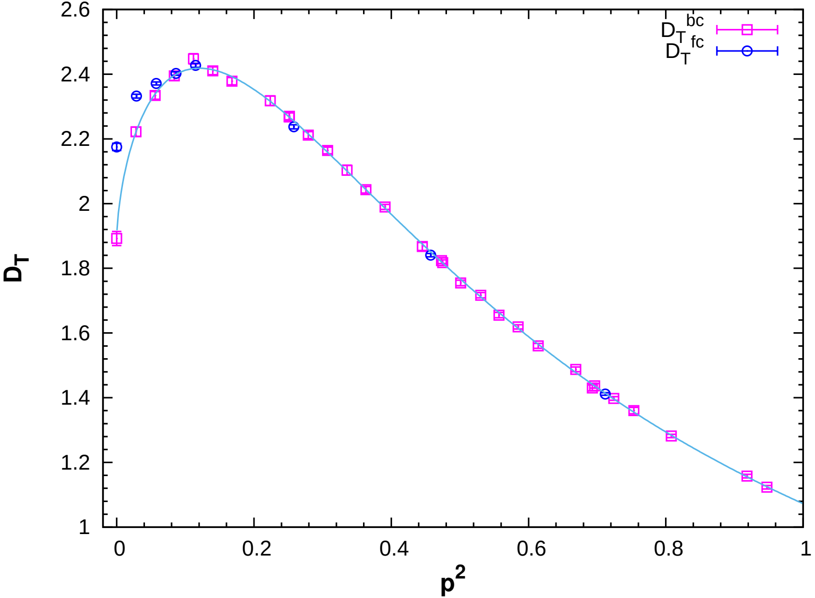
- Momentum dependndence
- Effects of Gribov copies
- Temperature dependence
- Volume dependence
- Renormalization, or lattice-spacing dependence



$SU(2)$ gluon propagator at $T \sim T_c$



T=0.95 T_C
D_44(p) = C (p^2v + d^2v) / ((p^2+a^2)^2 + b^4)
D_44
p^2
0
10
20
30
40
50
60
70
0
0.5
1
1.5
2
2.5

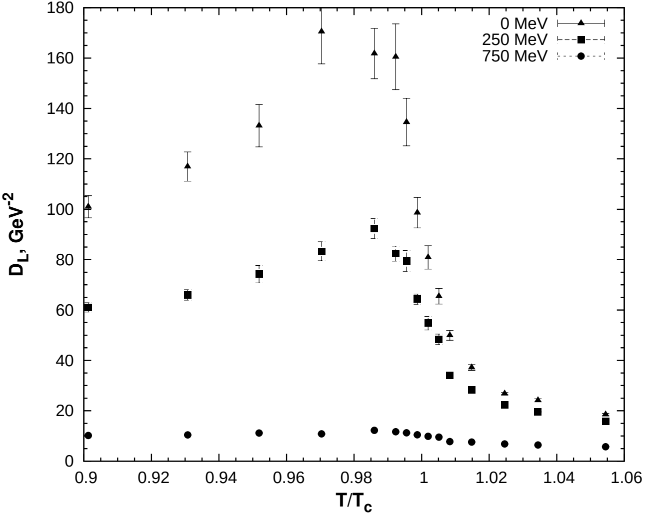


D_T^{bc}
D_T^{fc}
D_T
p^2
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0
0.2
0.4
0.6
0.8
1

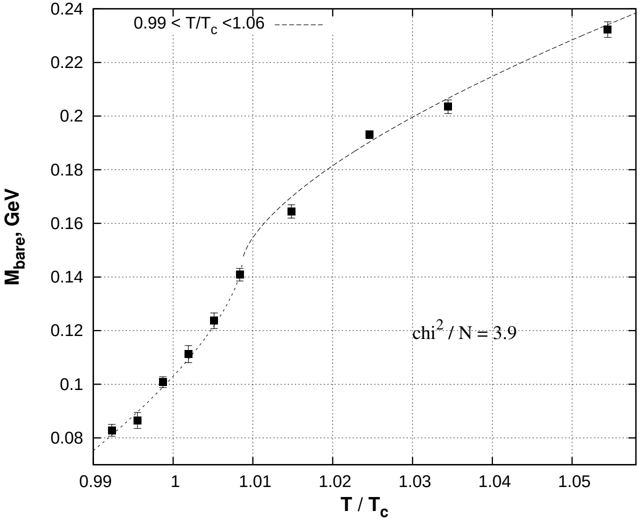
Magnetic screening mass:

$$m_M^2 = G^{-1}(0, \vec{p} \to 0)$$

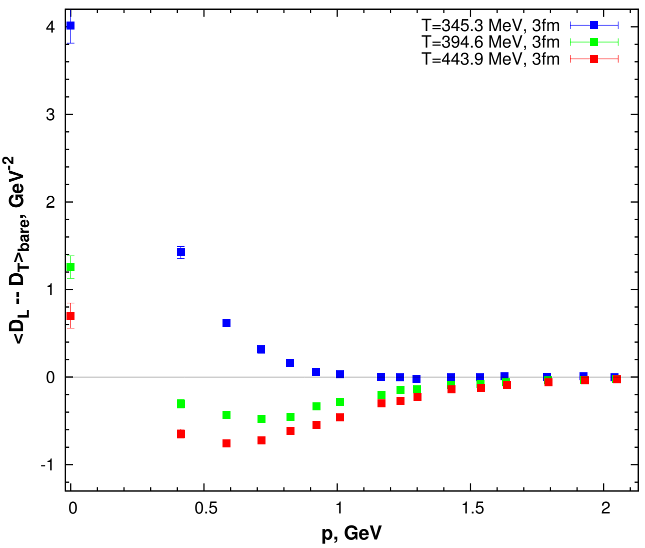
- Perturbation theory: $m_M = 0$
- Linde proposal: $m_M \simeq g^2 T$
  (to provide perturbative calculability of various quantities)
- Our assumption: $D_T(|\vec{p}|) \sim c_0 + c_1 |\vec{p}|^{2/3}$;
  therefore, $D_T(|\vec{x}|) \sim \dfrac{1}{|\vec{x}|^b}$,
  NOT $D_T(|\vec{x}|) \sim \exp(-m_M|\vec{x}|)$
- When the effects of Gribov copies are properly taken into account, the concept of magnetic screening mass is inconsistent with the behavior of the gluon propagator ,
  see Fig. above



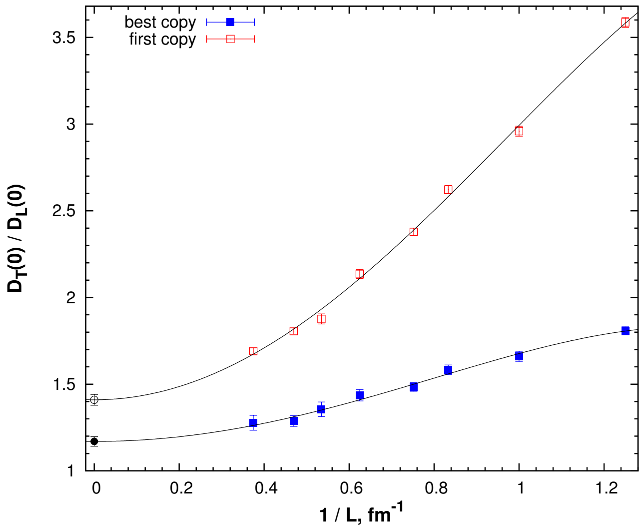
0 MeV
250 MeV
750 MeV
D_L, GeV^{-2}
T/T_c
0
20
40
60
80
100
120
140
160
180
0.9
0.92
0.94
0.96
0.98
1
1.02
1.04
1.06



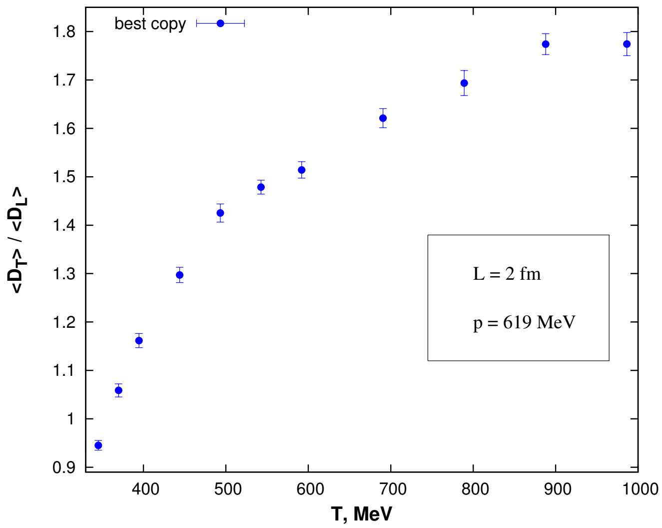
$SU(2)$, infinite-volume limit



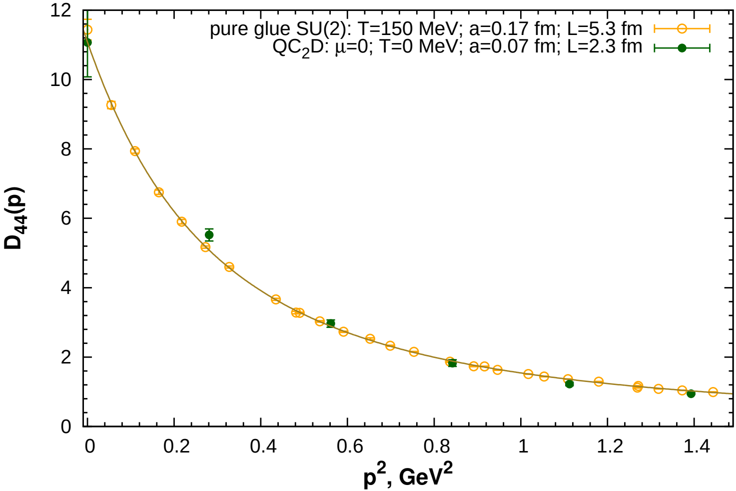
T=345.3 MeV, 3fm
T=394.6 MeV, 3fm
T=443.9 MeV, 3fm
$<D_L - D_T>_{bare}$, GeV^{-2}
p, GeV
4
3
2
1
0
-1
0
0.5
1
1.5
2



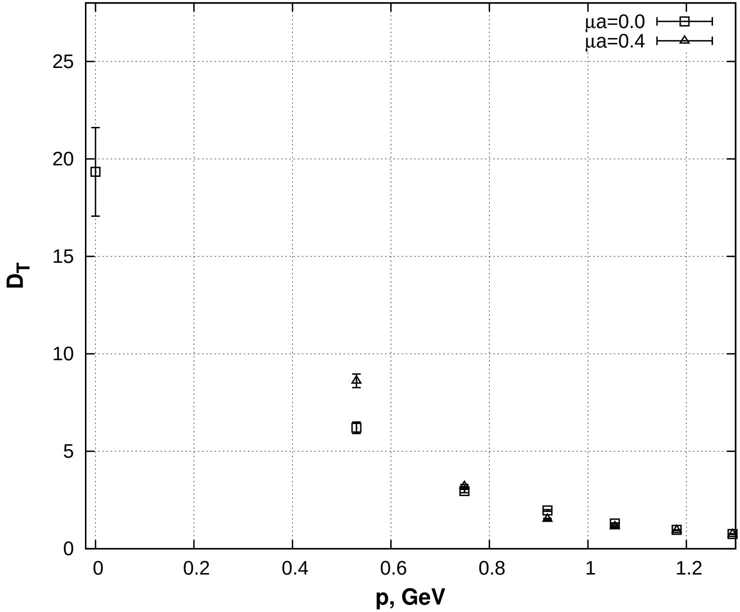
best copy
first copy
3.5
3
2.5
2
1.5
1
0
0.2
0.4
0.6
0.8
1
1.2
$D_T(0) / D_L(0)$
1 / L, fm^{-1}



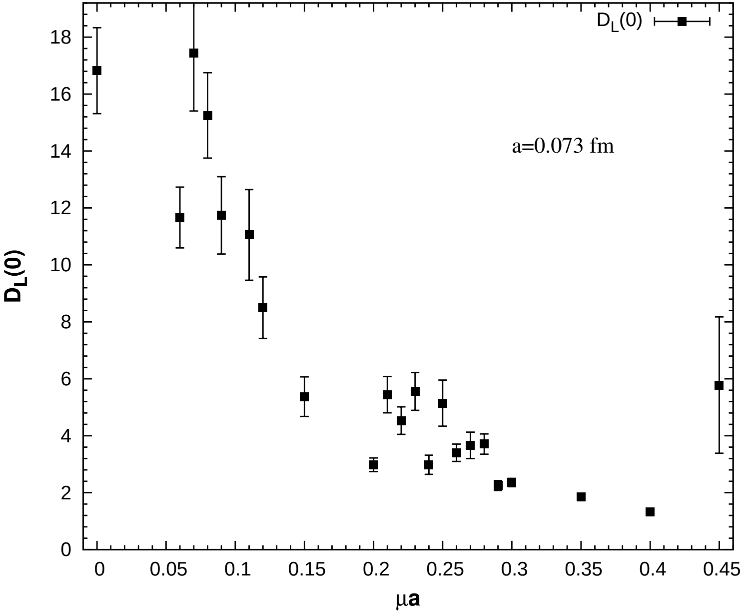
best copy
L = 2 fm
p = 619 MeV
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
400
500
600
700
800
900
1000
T, MeV
<D_T> / <D_L>



32^4 lattice; configurations were discussed in Braguta's talk

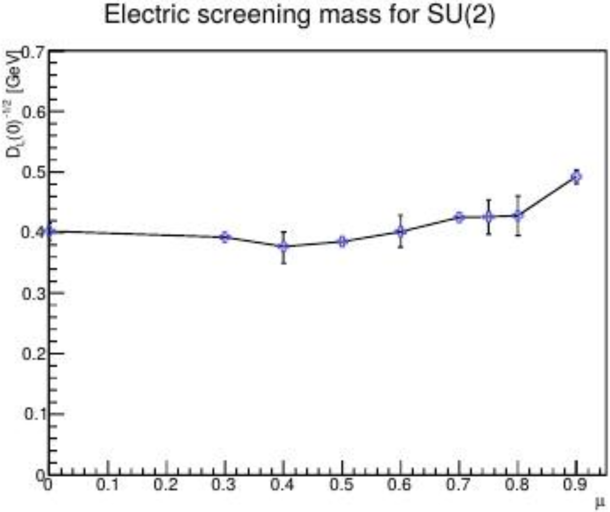


QC_2D; 32^4



$D_L(0)$
a=0.073 fm
$D_L(0)$
0
2
4
6
8
10
12
14
16
18
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
μa

QC_2D; 32^4



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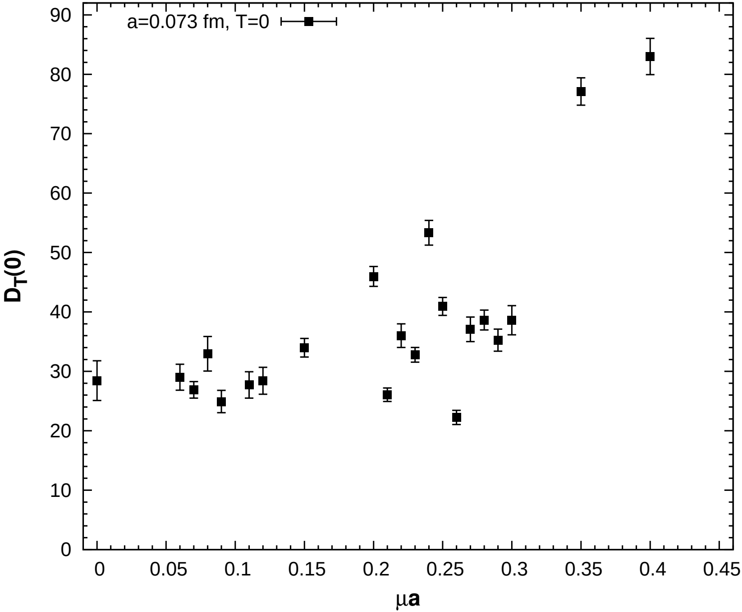
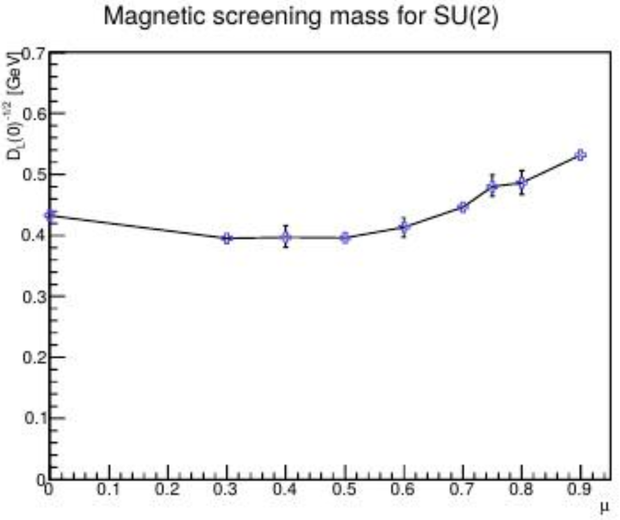


a=0.073 fm, T=0
D_T(0)
μa
0
10
20
30
40
50
60
70
80
90
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45

QC_2D; 32^4



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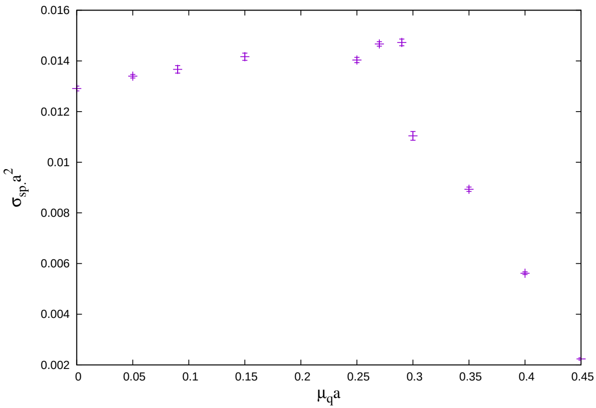
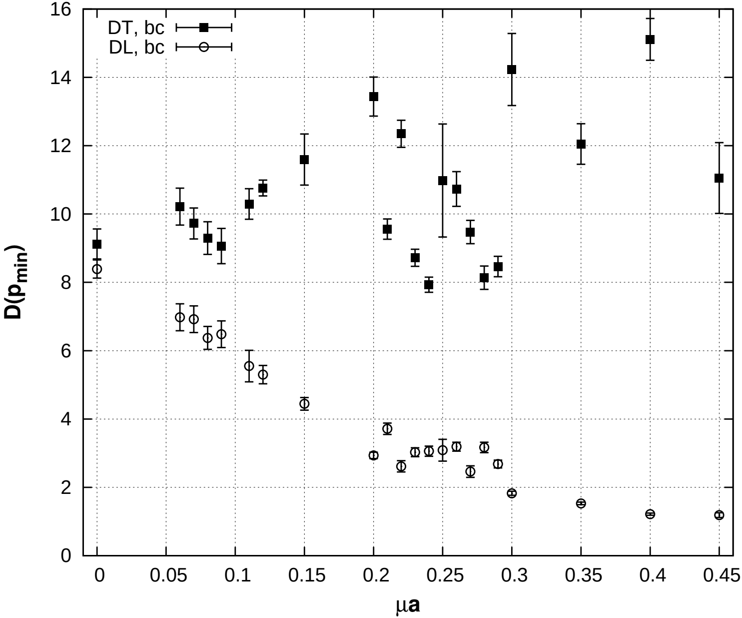
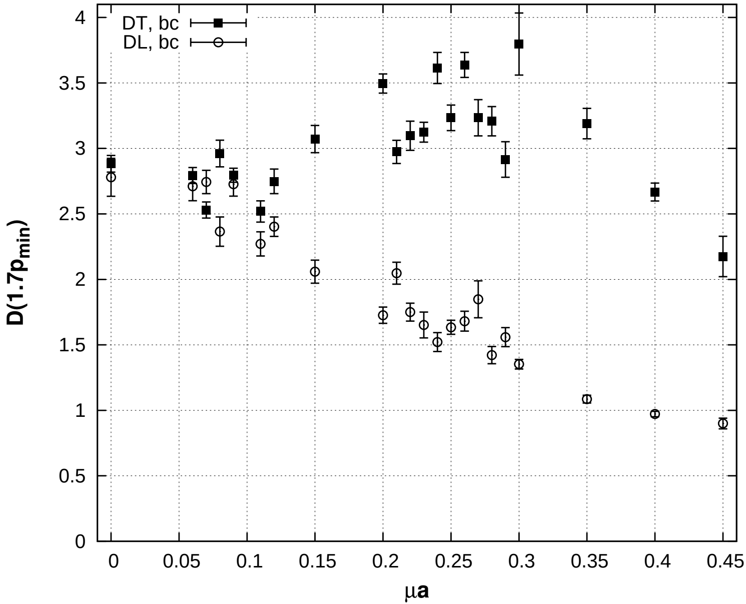
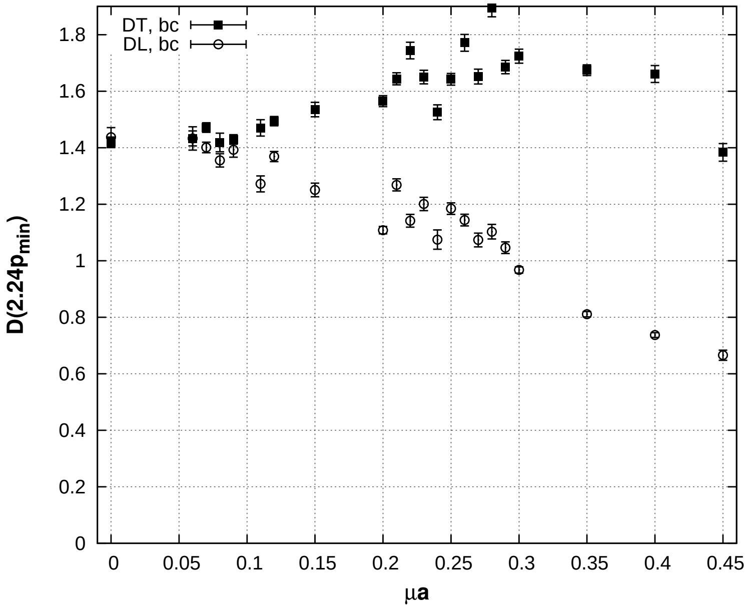
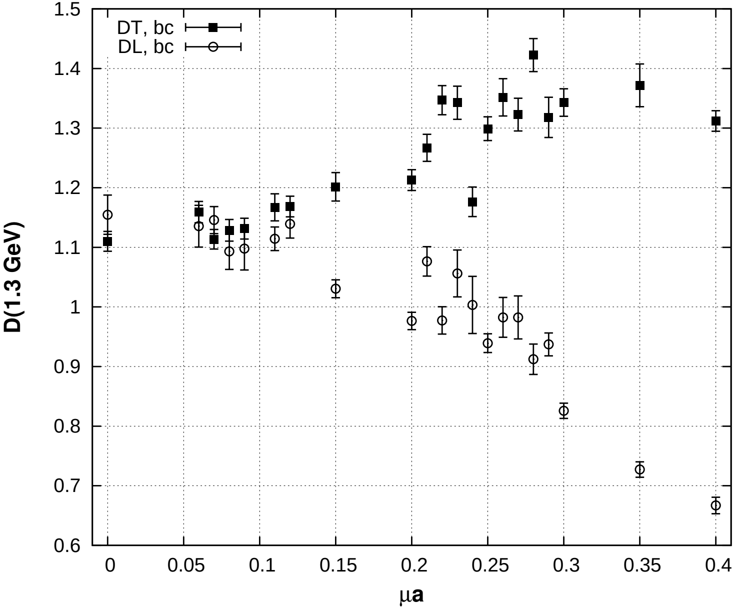


spatial string tension QC_2D; 32^4 (Braguta's talk)
steep decreasing at 800 MeV

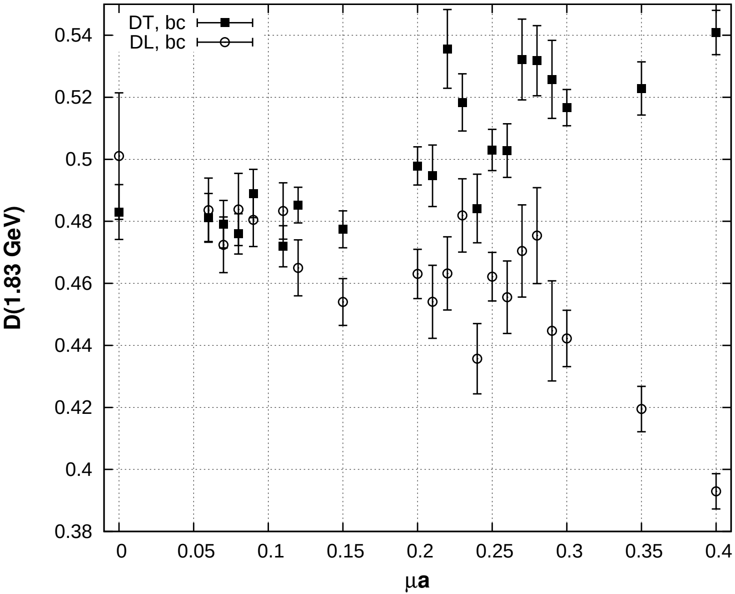

DT, bc
DL, bc
D(p_min)
μa
0
2
4
6
8
10
12
14
16
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45

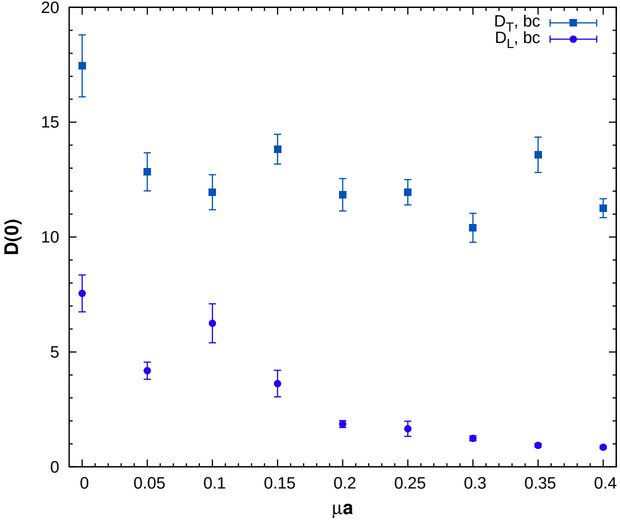

DT, bc
DL, bc
D(1.7p_min)
μa
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
1
1.5
2
2.5
3
3.5
4


DT, bc
DL, bc
D(2.24p_min)
μa
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45

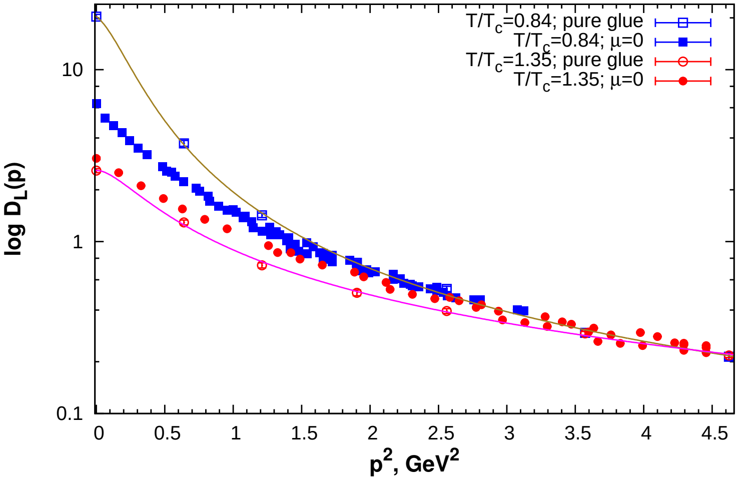


DT, bc
DL, bc
D(1.3 GeV)
μa
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4

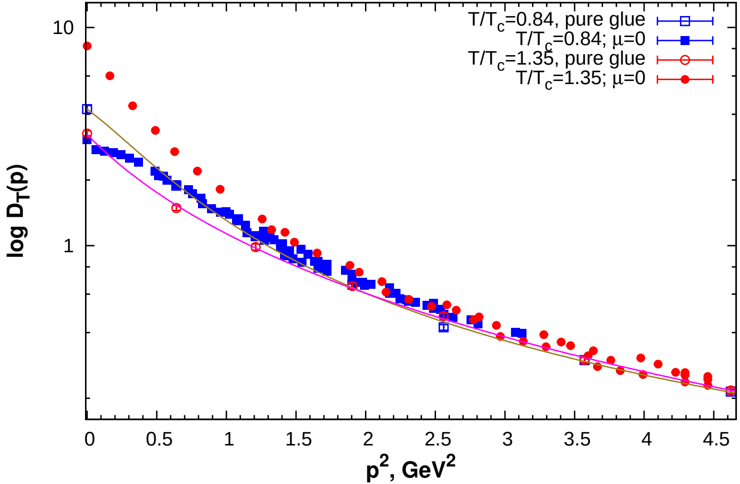

DT, bc
DL, bc
0.54
0.52
0.5
0.48
0.46
0.44
0.42
0.4
0.38
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
D(1.83 GeV)
μa



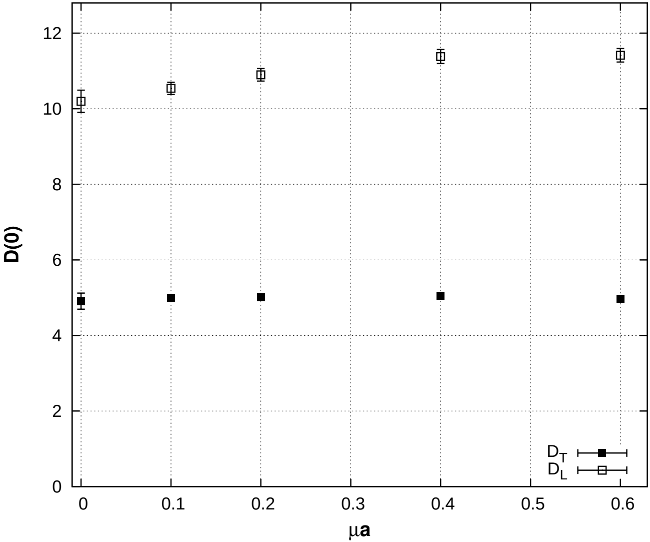
Zero-momentum propagators (normalized at 2 GeV);
$T = 170$ MeV, a=0.073 fm; $L = 2.3$ fm



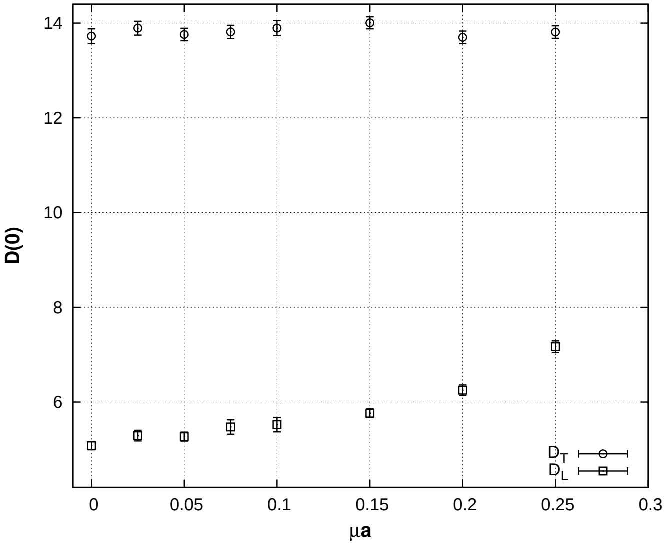
$SU(3)$ longitudinal propagator; p_μ^4 terms are neglected



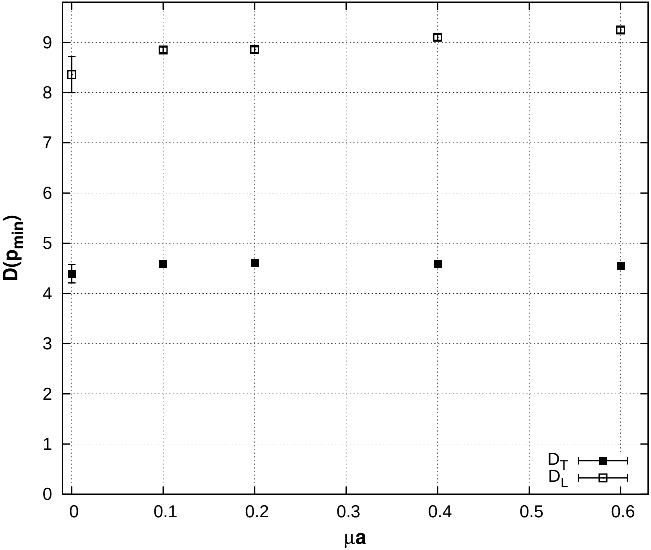
SU(3) transverse propagator;



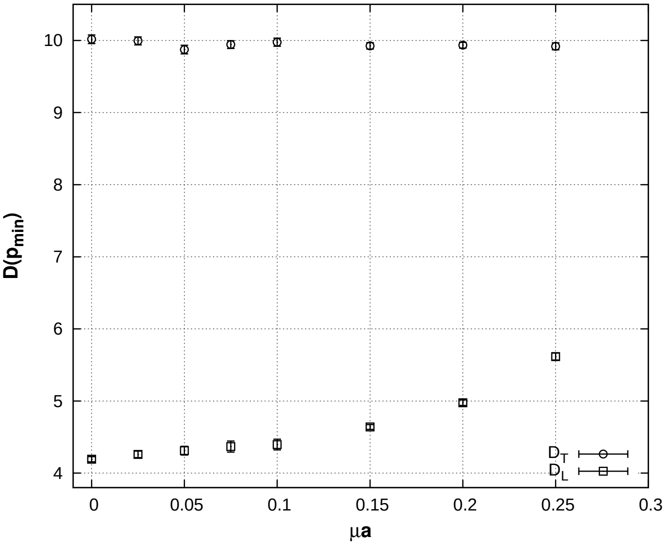
QCD $T/T_c = 0.84; 16^3 \times 4; \quad \frac{m_p i}{m_\rho} = 0.8$



$T/T_c = 1.35$



$T/T_c = 0.84$



$T/T_c = 1.35$

Conclusions

- Over a vast domain of temperatures and baryon densities gluon propagators at $0 < p < 4$ GeV can well be described by the Gribov-Stingl fit functions.
- A sharp growth of $D_T(0)$ in QC_2D is seen at $\mu \simeq 800$ MeV which is correlated with a rapid change in the behavior of the $\bar{q}q$ potential as μ varies.
- At finite temperatures the QCD gluon propagators depend only weakly on μ
- A question arises in the pure $SU(2)$ theory: does $D_T(0, |\vec{x}|)$ decrease exponentially as $|\vec{x}| \to \infty$?

The work is in progress