Lattice calculation of medium effects at short and long distances.

P. Petreczky

UNIVERSITÄT Bielefeld

Naive perturbation theory breaks down at $T \neq 0$.
Different length scales are generated at $T \neq 0$. For gauge theories $g \ll 1$ for $T \gg \Lambda_{\overline{MS}}$

$$\frac{1}{T} \ll \frac{1}{gT} \ll \frac{1}{g^2T}$$

$\uparrow$	$\uparrow$	$\uparrow$
Naive PT	HTL resummed PT	Non-perturbative methods

For interesting temperature range $g \gtrsim 1$.

For short distances $r \ll T$ no temperature dependence (medium effects) should be observed.

Open questions:

- Up to which length (momentum) scale perturabtion theory is applicable ?
- At which scale medium effects (e.g. screening) becomes important ?

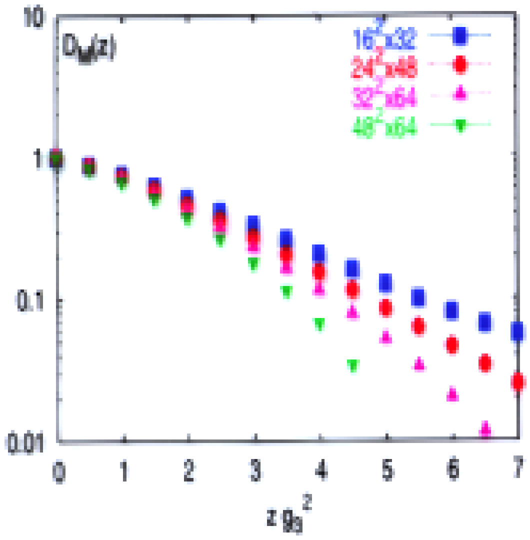
- Static magnetic propagators in SU(2) gauge theory
  A. Cucchieri, F. Karsch and P.P., Phys. Lett. **497** (2001) 80
- Heavy quark potential in SU(3) gauge theory
  F. Karsch, F. Zantow and P.P
- Temporal quark and gluon propagators in quenched QCD
  F. Karsch, E. Laermann, S. Stikan, I. Wetzorke and P.P
- Conclusion and outlook

Magnetic propagators in SU(2) gauge theory at finite temperature

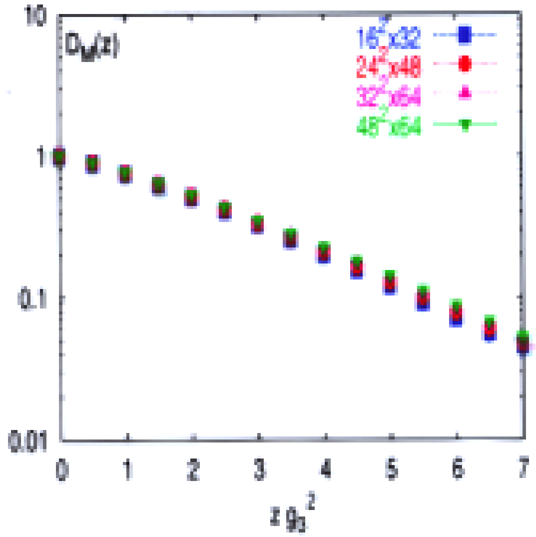
- Generation of a magnetic mass of order g^2T in non-Abelian gauge theories at $T \neq 0$ was postulated to avoid IR divergencies in PT. colorgreen (Linde)
- Self consistent resummation of PT :
  for SU(2) $m_M = (0.28 - 0.38)g^2T$
  (Buchmüller and Philipsen, Alexanian and Nair, Eberlein)
- Lattice calculation of the Landau gauge propagators:
  $m_M = 0.46(3)g^2T$ (Heller, Karsch and Rank, Karsch, Oevers, Petreczky)

Magnetic propagators were studied in the dimensionally reduced 3d effective theory.
Dimensionfull coupling : $g_3^2 = g^2(T)T$.

λ -gauges : $\partial_1 A_1 + \partial_2 A_2 + \lambda \partial_3 A_3 = 0$
$\lambda = 1$ is the Landau gauge
Maximally Abelian Gauge (MAG)



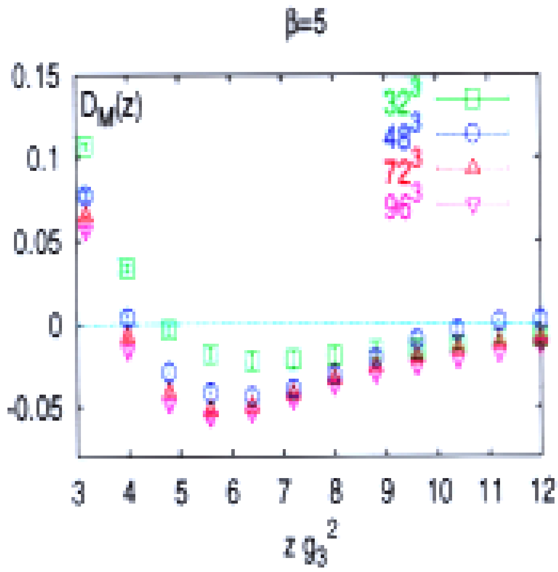
Landau



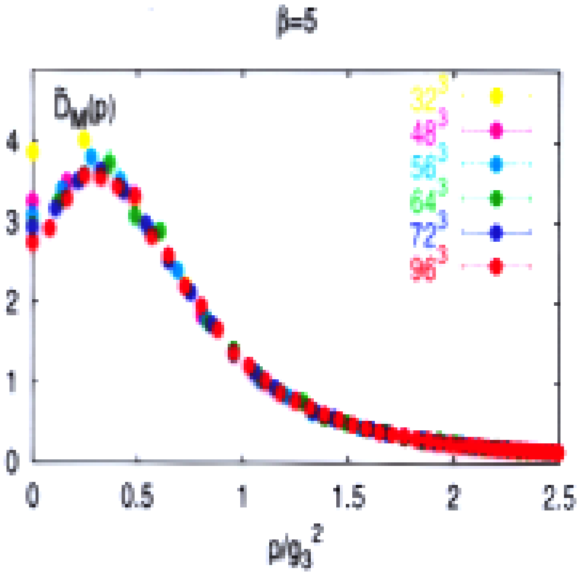
MAG

$$\beta = 4/g_3^2 a$$

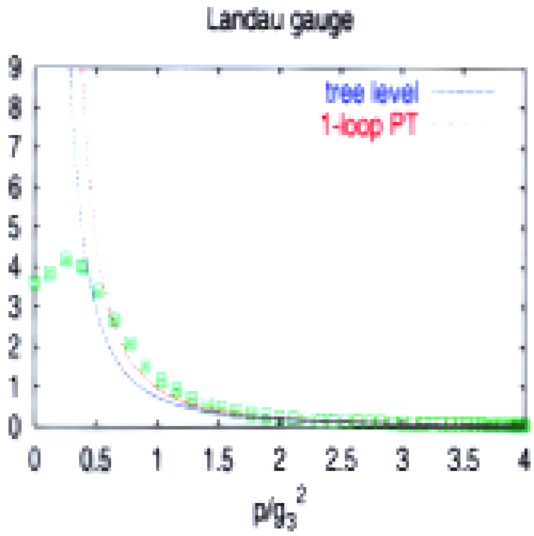
In λ-gauges the propagators become negative at large distances.

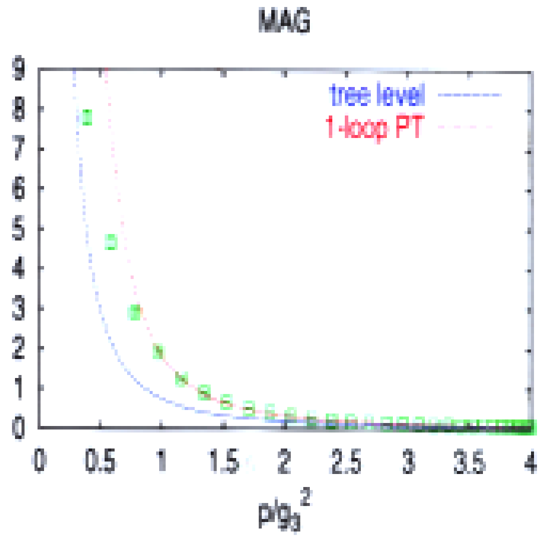


Momentum space magnetic propagators are infrared suppressed.



Comparison with perturbation theory





Perturbation theory works well for $p/g_3^2 > 1$ and breaks down completely at $p/g_3^2 \sim 0.7g_3^2$.

The heavy quark potential in SU(3) gauge theory

- $$V(R) = -\log \frac{< L(R) L^\dagger(0) >}{| < L > |^2}$$

  $L(R)$ is the Polyakov loop

- Most of studies concentarte on long distance behaviour of the heavy quark-potebtial $RT > 1$. For physics of heavy quarkonia, J/ψ, Υ etc. it is important to know the potential for $RT < 1$.

- At leading order in perturabtion theory

  $$\frac{V(R)}{T} = \frac{\alpha^2}{9} \frac{1}{(RT)^2}$$

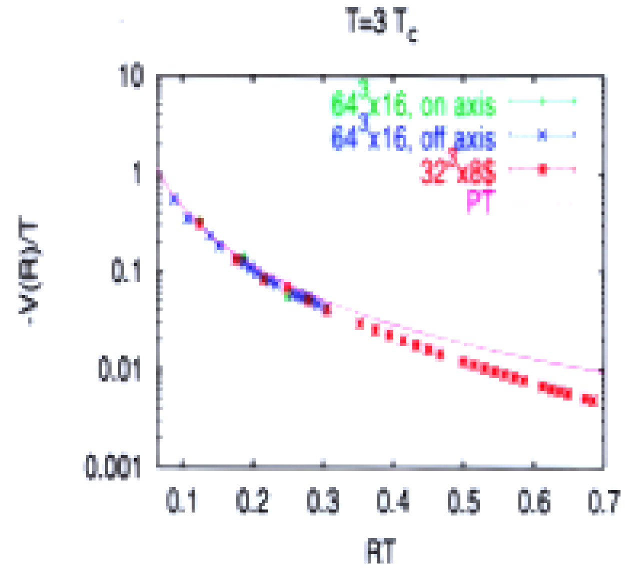
  $\alpha = g^2/(4\pi)$ At large distances perturbation theory needs to be resummed leading to

  $$\frac{V(R)}{T} = \frac{\alpha^2}{9} \frac{1}{(RT)^2} e^{-m_D R}, \quad RT \gg 1$$

  $m_D = gT \cdot 2$

- Simulation with the Wilson action on $48^3 \times 12$ and $64^3 \times 16$ at $T = 1.5 T_c$ and $3 T_c$. Simulation with (2×1) improved action on $32^3 \times 8$ at $T/T_c = 1, 1.05, 1.14, 1.23, 1.50, 1.68, 3.0, 6.0, 12.0$

- Comparison of lattice data with PT.

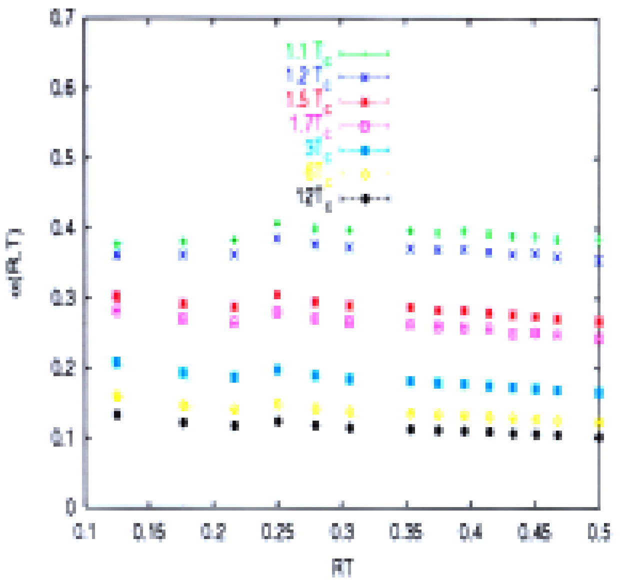


$g(3T_c) = 1.6$

$g(1.5T_c) = 2.1$

at $RT = 0.125$

- The running coupling constant Define $\alpha(R,T) = -9R^2TV(R,T)$



Temperature dependence of coupling:

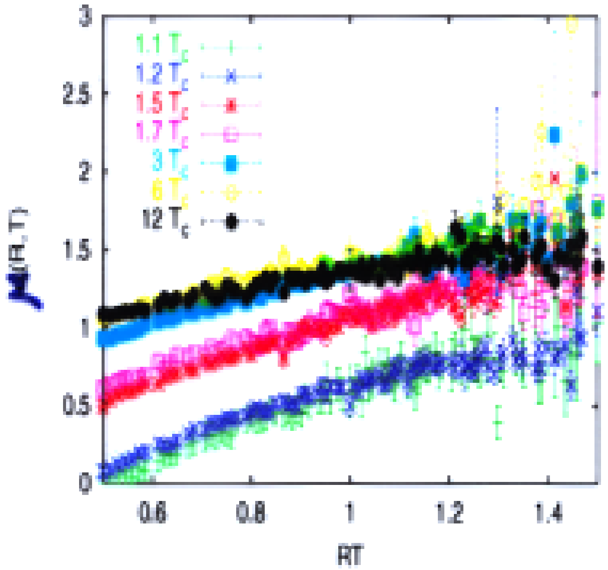
$$(4\pi\alpha)^{-1} = \frac{11}{8\pi^2}\log(T/\Lambda_V) + \frac{51}{(88\pi^2)}\log(2\log(T/\Lambda_V)$$

$\Lambda_V \sim 0.4T_c$
Expected: $\alpha(R,T)$ is only function of R for $RT \ll 1$

- Effective screening mass:

$$\mu(R) = -\frac{1}{R}\log\left(\frac{9R^2TV(R,T)}{-\alpha^2}\right)$$

with α defined at $RT = 0.125$



The effective screening masses are smaller then the perturbative value $2gT$.

Reason: The momentum dependence of the gluon self-energy cannot be neglected for $RT < 1.5$.

J. C. Gale and J. Kapusta, Phys. Lett. B 198 (1987) 89

Temporal quark and gluon propagator at finite temperature in quenched QCD

- Temporal propagators carry information about the quasiparticle in the medium.
- Simulation were done on $64^3 \times 16$ lattice at $\beta = 7.457$ and $\kappa = 0.1339$ corresponding to $T = 3T_c$ and the quark mass $m_q \sim 30MeV$.
- Wilson action for the gauge sector, O(a)-improved Wilson fermions
- Calculating the propagator in the mixed (τ, p) representation one can extract the spectral function $\rho(\omega)$ with the help of the Maximal Entropy Method (MEM)

$$G(\tau,p) = \int_{-\infty}^{\infty} d\omega \rho(\omega,p) K(\tau,\omega)$$

$$K(\tau,\omega) = \frac{e^{-\omega\tau}}{1 \pm e^{-\omega\tau}}$$

- MEM works only for positive $\rho(\omega,p) \Rightarrow$ Coulomb gauge
- The position of peaks in the spectral function $\rho(\omega,p)$ gives the dispersion relation $\omega_p = \omega(p)$ of quasiparticles.
- The minimal spatial momementum available on our lattice is $p_{min} = 1.5T$.

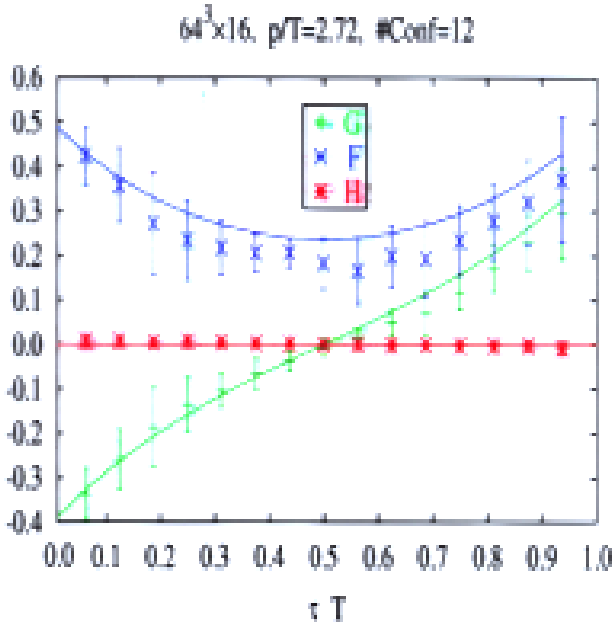
Quark propagators

$$S(\tau, p) = \gamma_0 F(\tau, p) + \vec{\gamma} \cdot \vec{p} G(\tau, p) + H(\tau, p)$$

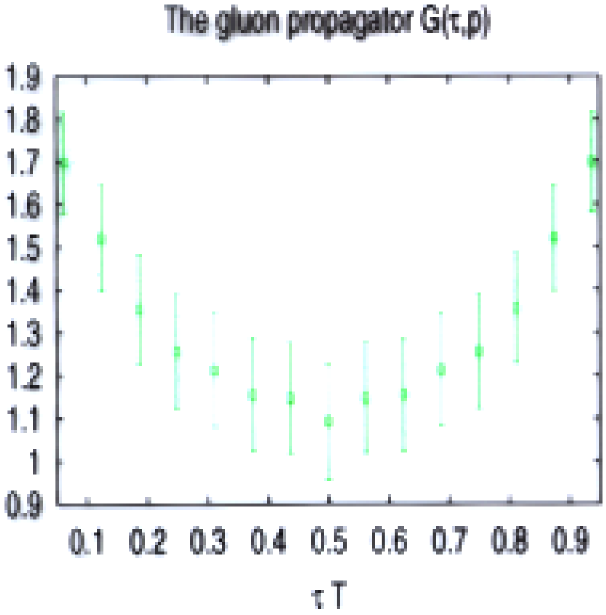
H is present due to breaking of the chiral symmetry on lattice.

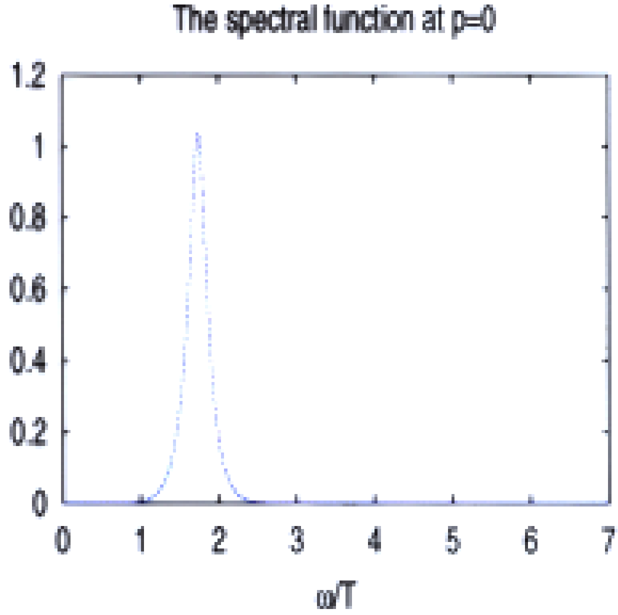
Analysis was done for $p = 0$ and for $p = 2.72T$:

- At $p = 0$ only $\gamma_0 F(\tau, p)$ contributes. Results are compatible with HTL predistions.
- p=2.72 T



Gluon propagators at $p = 0$





$$\Downarrow$$

$$\omega_p \sim 1.65T$$

HTL prediction : $\omega_p = 0.96$ using $g = 1.65$ from the heavy quark protential.

Conclusions and outlook

- Static magnetic propagators show quite different behaviour in different gauges. In Landau type gauges the data do not support the existence of a simple pole mass. PT breaks down at $p/g_3^2 \sim 0.7$ in all gauges considered.

- The short distance behaviour of the heavy quark potential ($RT \lesssim 0.4$) is described by the leading order formula. Its temperature dependence can be viewed as temperature dependence of the coupling constant.

- Screening effects become important at $RT > 0.5$ $\Rightarrow$ 0.2 fm for $1.5\,T_c$
  0.1 fm for $3\,T_c$

- Temporal quark propagator are compatible with HTL resuts for zero and non-zero spatial momenta

- Temporal gluon propagator at zero momenta shows considerable deviation from the HTL results.

- More statistics for temporal correlators is needed

- Complete 1-loop calculation of the heavy quark potential.