Towards the Phase Diagram of QCD in Landau Gauge

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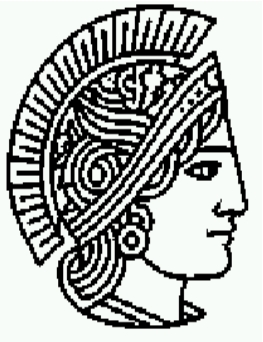


Overview

- Method: Equations of Motion
- Ghost-Gluon-Vertex
  - Wolfgang Schleifenbaum, Axel Maas, Jochen Wambach, Reinhard Alkofer
- Quarks at finite Chemical Potential
  - Dominik Nickel, Jochen Wambach, Reinhard Alkofer
- Gluons at finite Temperature [Grüter et al.,hep-ph/0401164,Maas et al.,hep-ph/0210178]
  - Axel Maas, Jochen Wambach, Burghard Grüter, Reinhard Alkofer
- Conclusions

Darmstadt University of Technology, Tübingen University

QCD

- **QCD in Landau gauge**

$$L = \frac{1}{4} F^a_{\mu\nu} F^{\mu\nu,a} - \bar{c}^a \partial^\mu D^{ab}_\mu c^b - \bar{\psi}^a \left(\gamma_\mu D_\mu - m \right) \psi^a$$

$$F^a_{\mu\nu} = \partial_\mu A^a_\nu - \partial_\nu A^a_\mu + g f^{abc} A^b_\mu A^c_\nu$$

$$D^{ab}_\mu = \delta^{ab} \partial_\mu - g f^{abc} A^c_\mu \qquad D_\mu = \partial_\mu + igt^a A^a_\mu$$

- **Degrees of freedom:**
  - $\psi^a, \bar{\psi}^a$ **Quarks**
  - A^a_μ **Gluons**
  - $c^a, \bar{c}^a$ **Ghosts (Pure quantum fluctuations)**

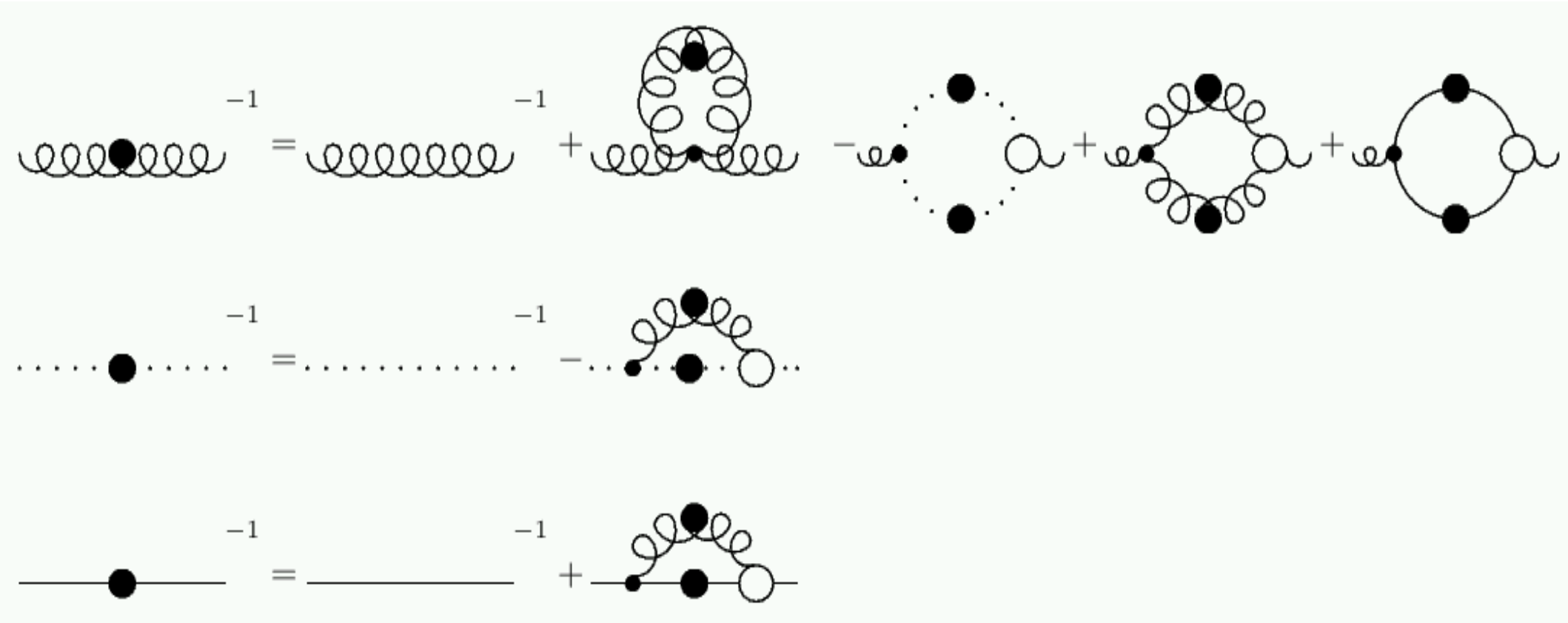
Green's Functions [Alkofer et al., Phys. Rept. 353, p281]

- Green's functions encode complete theory
- 2-point functions are the propagators

- Sufficient Confinement Criterion from propagators: $D(0)=0$

- Determined by equations of motions
  - Dyson-Schwinger equations (DSE)

(Truncated) Dyson Schwinger Equations

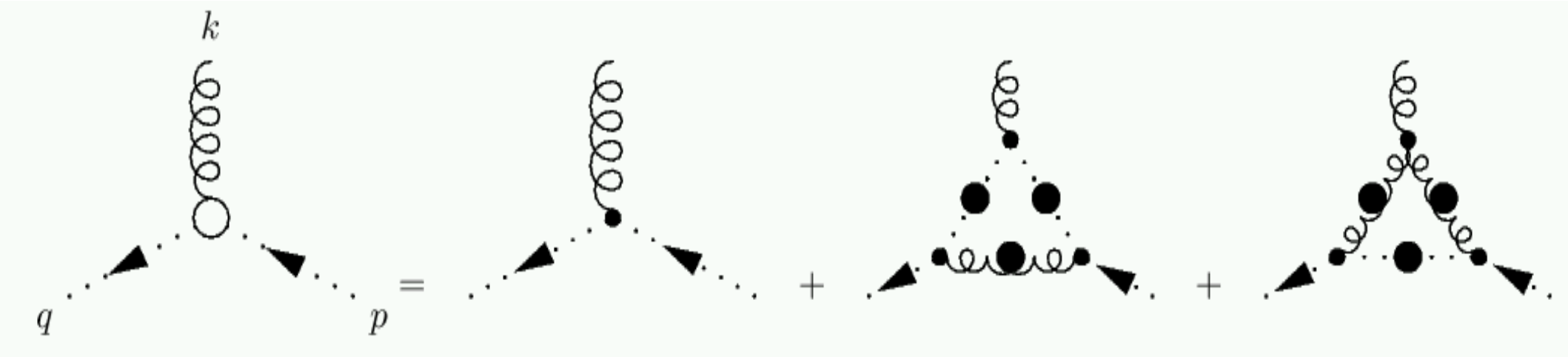


- Infinite set of coupled equations
- Truncation necessary
- Induces severd problems: Under control

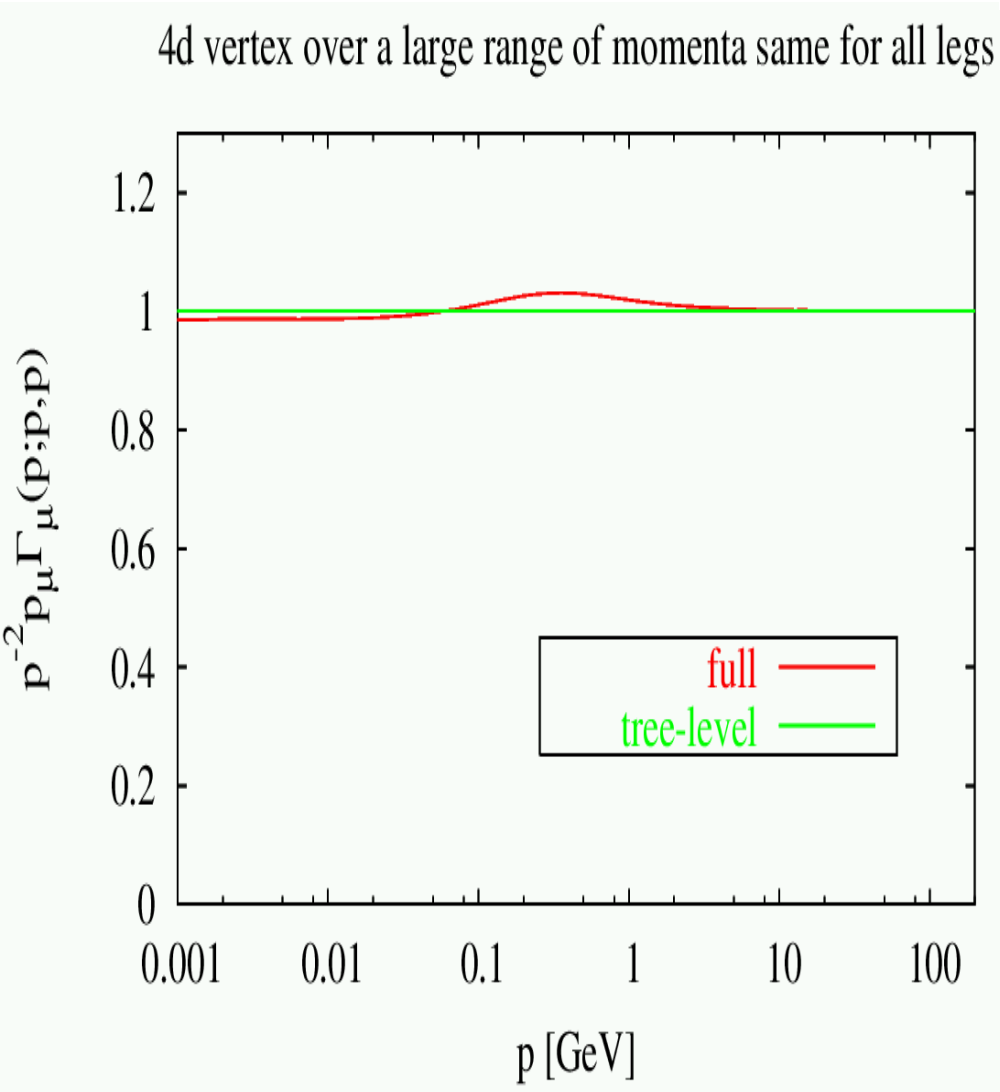
Ghost-Gluon Vertex

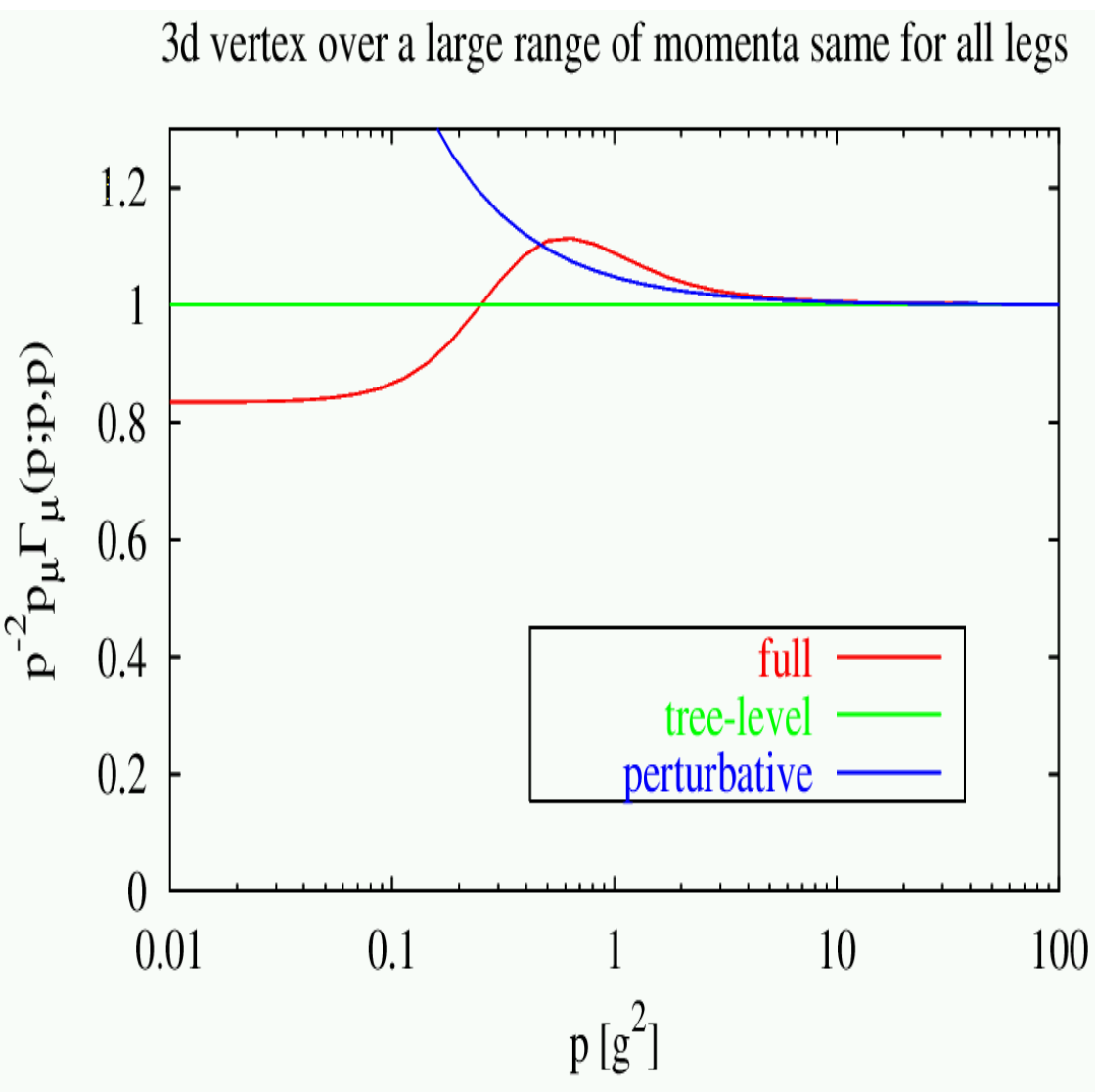
- Vertex reconstruction ambiguous
  - Validation by explicit calculation
- Ghost-Gluon vertex possibly connected to Confinement
- Calculate first non-perturbative correction

$$\Gamma_\mu^{abc} = g f^{abc} \left(q_\mu \left(1 + A(k,q,p) \right) + k_\mu B(k,q,p) \right)$$



Results





- **Satisfies** IR-Slavnov-Taylor Identity and asymptotic freedom
- Nearly undressed in IR: Link to **Confinement**

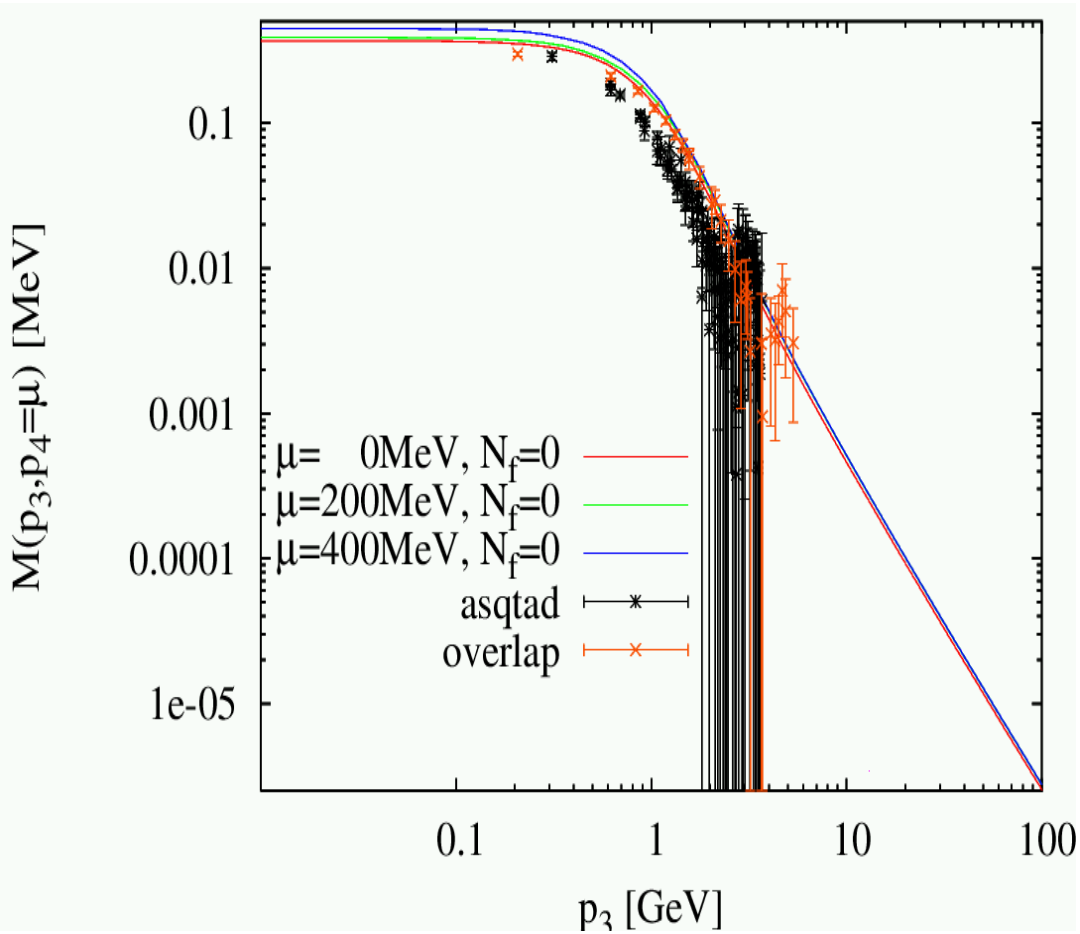
Quark propagator [Roberts et al., Prog. Part. Nucl. Phys. 45, 1]

- **Unquenched** solutions in the vacuum
- **Quenched** solutions at finite chemical potential
- Chiral symmetry breaking present
- **Sensitive** to vertex construction
  - Here: Modified Curtis-Pennington vertex
- Propagator:

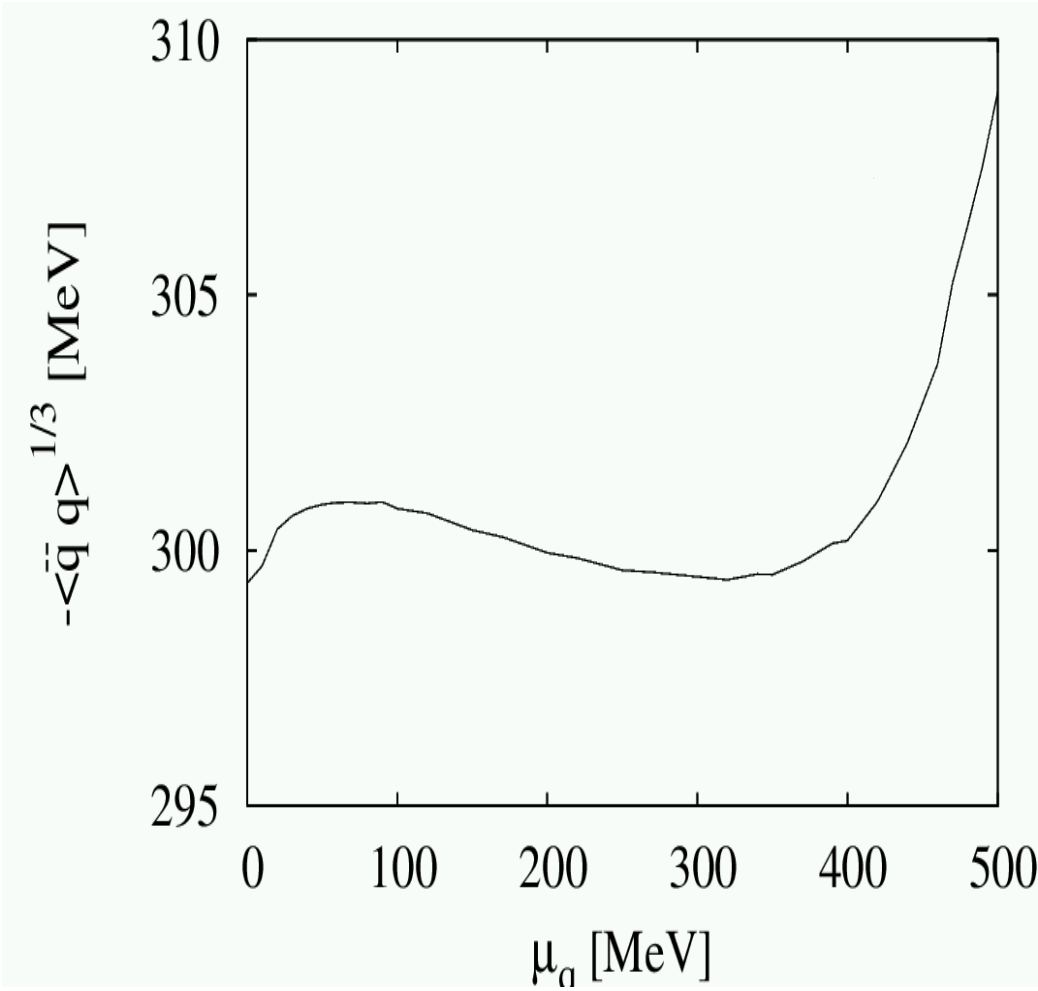
$$S(p_4,\vec{p}) = \frac{Z(p^2)}{-i\gamma_\mu p_\mu + M(p^2)} \overset{\mu\neq 0}{=} \frac{Z(p_4,\vec{p})}{-i(p_4+i\mu)\gamma_4 - i\vec{p}\vec{\gamma}\,\tilde{A}(p_4,\vec{p}) + \tilde{B}(p_4,\vec{p})}$$

Results

Mass function



Chiral condensate



- Quark properties extractable
- Handle on order parameter

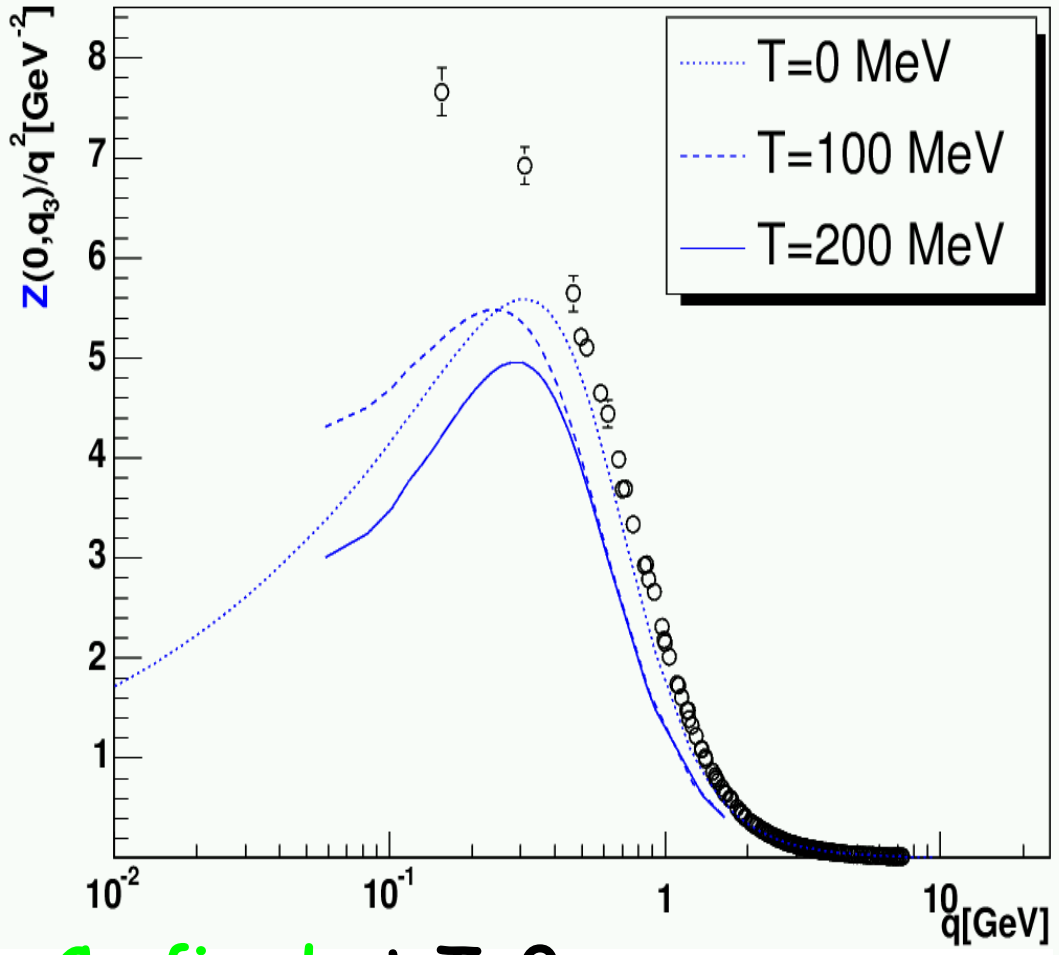
[Vaccum DSE: Fischer et al., Phys. Rev. D67, 094020
Vacuum Lattice: Overlap: Bonnet et al., Phys. Rev. D65, 114503, Zhang et al., hep-lat/0208037, hep-lat/0301018
Asqtad: Bowman et al., Phys. Rev. D66, 014505]

Ghost- and Gluon-Propagators

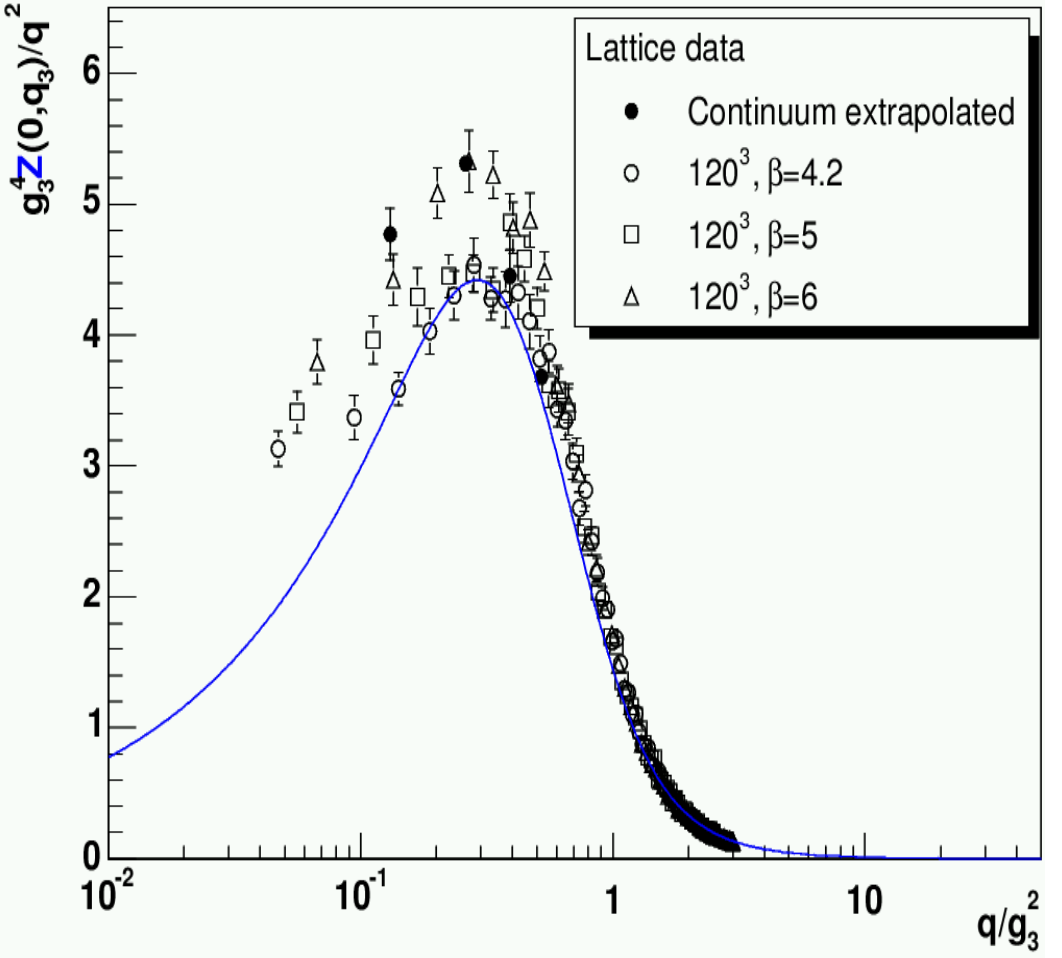
- Pure glue at finite temperature: No quarks
- Equilibrium properties only: Matsubara formalism
- Ghosts $$D_G(q_0^2,\vec{q}^2)=\frac{-G(q_0^2,\vec{q}^2)}{q^2}$$
- Gluons $$D_{\mu\nu}(q_0^2,\vec{q}^2)=P^T_{\mu\nu}\frac{Z(q_0^2,\vec{q}^2)}{q^2}+P^L_{\mu\nu}\frac{H(q_0^2,\vec{q}^2)}{q^2}$$
  - T=0: $Z=H$
  - High T: H: Chromoelectric and Z: Chromomagnetic

Chromomagnetic gluon

Z part of the gluon propagator $T < T_c$



Chromomagnetic gluon propagator $T \to \infty$



- Confined at T=0
- Still confined at high T!
- Non-trivial phase: s(Q)GP at all T

[T=0 DSE: Fischer et al., Phys. Lett. B536, p201
small T lattice: Bowman et al., hep-lat/0402032
high T lattice: Cucchieri et al., Phys. Rev. D64, p036001, D67, p091502]

Summary

- First principle calculations possible...
- ...albeit complicated, many problems...
- ...but seems to be consistent
- Phase diagram under investigation
- First steps at finite chemical potential
- Pure glue at finite temperature in good shape
- Non-trivial high T phase
- Long-range correlations and far from perturbative
- Worth the effort...

Outlook

- Under investigation
  - Unquenched finite chemical potential
  - Phase transition in Yang-Mills Theory
  - Vertex structure and feedback
- Other topics under investigations
  - Vacuum and analytic structure; Quark confinement
- Later on
  - Quarks at finite temperature
  - Finite temperature and chemical potential
  - Hadrons?