Chiral phase transition at finite temperature with Dyson-Schwinger equations

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In collaboration with Christian S. Fischer

QCD Chiral Phase Transition

- early universe $\rightarrow$ dramatic change of physics
- experiments (RHIC,FAIR) may cool through the chiral phase transition

The chiral phase transition is connected to

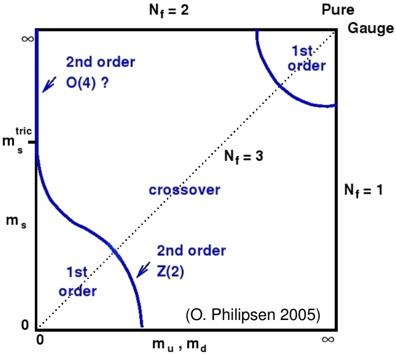
- DχSB
- critical phenomena

$\Longrightarrow$ Nonperturbative methods are needed

Finite Temperature

We investigate

- ⋆ finite temperature $T \neq 0$
- ⋆ zero chemical potential $\mu = 0$



[F. R. Brown et al, PRL 65 (1990)]

Nonperturbative methods:

- Lattice calculations
- Effective model studies, e.g. linear sigma model

Functional methods:

- Functional renormalization group (fRG)
- Dyson-Schwinger equations (DSE's)

Basic Objects are the Propagators

- Quark propagator

$$S(p_{\omega_n}) = (i\,\vec{\gamma}\cdot\vec{p}\;A(p_{\omega_n}) + i\,\gamma_4\omega_n\;C(p_{\omega_n}) + B(p_{\omega_n}))^{-1}$$

- Landau gauge gluon propagator

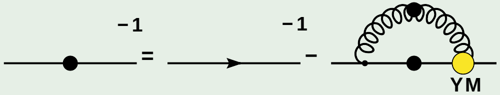
$$D_{\mu\nu}(p_{\Omega_n}) \quad = \quad \Delta^T_{\mu\nu}(p_{\Omega_n})\frac{Z(p_{\Omega_n})}{p^2} + \Delta^L_{\mu\nu}(p_{\Omega_n})\frac{H(p_{\Omega_n})}{p^2}$$

$\Delta^T_{\mu\nu}$, $\Delta^L_{\mu\nu}$ are transverse and longitudinal projectors wrt the heat bath

Dyson-Schwinger Equations

Infinite tower of coupled integral equations $\Longrightarrow$ truncation needed

Quark DSE



We use:

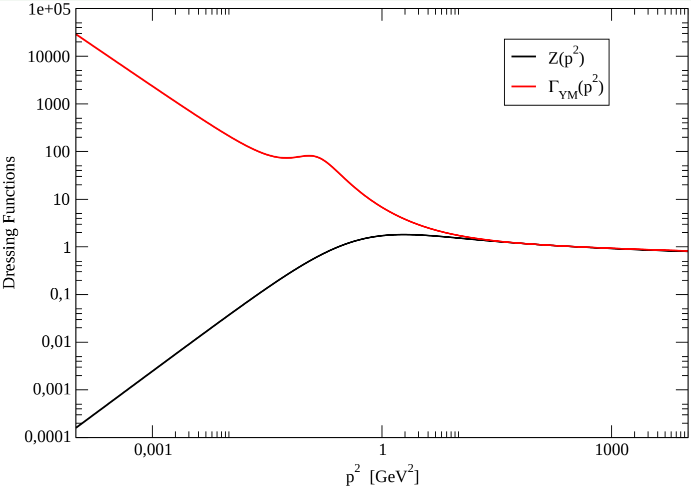
- Gluon propagator: $Z(p_{\Omega_n}) = H(p_{\Omega_n}) \overset{T \to 0}{=} Z(p)$ ($\leftarrow$ fit function)
- YM part of quark-gluon vertex: $\Gamma_\mu = \Gamma_{\mathrm{YM}}\, \gamma_\mu$ ($\leftarrow$ rainbow truncation)

[C. Fischer, R. Williams, arXiv:0808.3372, [hep-ph]]

correct asymptotics of Γ_{YM} and so for both when $T \to 0$

Quark-Gluon vertex -YM part

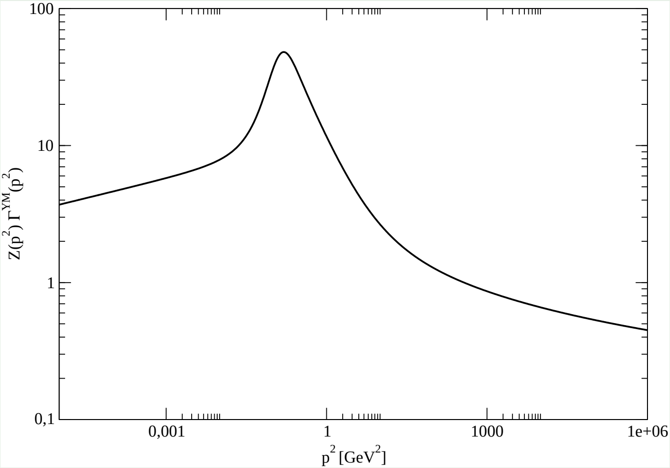
Gluon and vertex dressing functions



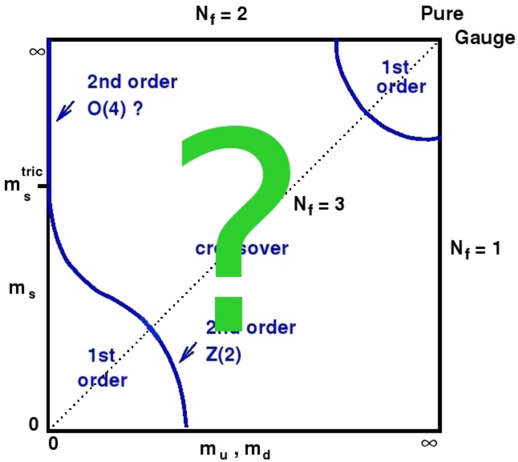
Quark-Gluon vertex -YM part

- For large momenta: $Z(p^2)\Gamma_{\mathrm{YM}} \sim \alpha(p^2)$

Gluon and vertex dressing functions



Where are we located



So far

- no flavor dependence
- no meson contributions
- mean-field critical behavior

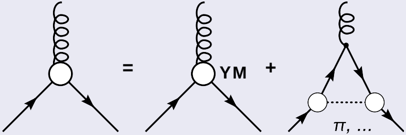
Clear:

- To go beyond mean-field one has to
  - study the mesonic contributions to the quark-gluon vertex
  - but take care of axWTI $\rightarrow$ Pion as Goldstone boson
    Goldberger-Treiman rel
    Gellman-Oaks-Renner rel.

Quark-Gluon vertex

By investigating the DSE of the quark-gluon vertex one can motivate the vertex

Approximated quark-gluon vertex



- The dotted lines describe meson contributions

  [C. Fischer, D. Nickel, J. Wambach, PRD 76 (2007) 094009]

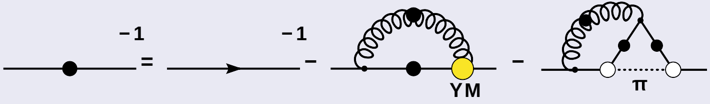
  [C. Fischer, D. Nickel, R. Williams, arXiv:0807.3486, [hep-ph]]

  $\Rightarrow$ flavor dependence
  $\Rightarrow$ mesonic contributions

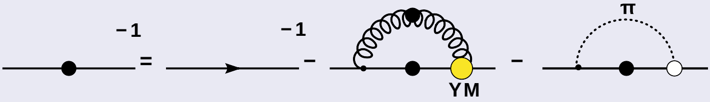
Truncation

Up to now only pion exchange is taken into account in our studies

Truncation



Approximated DSE:



AxWTI can be satisfied!

Order parameters

Order parameters:

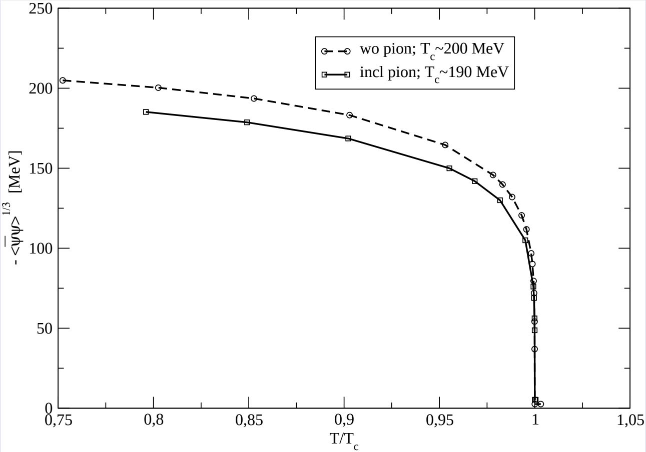
- $\langle\bar{\psi}\psi\rangle_\mu = -Z_m(\mu)\sum_{p_\omega}^{\Lambda} \mathrm{Tr}_{c,f,D}(S(p_\omega;\mu)Z_2(\mu))$
- $\chi_B := B(\omega_0, \vec{p}^2 = 0)$

At $T = 0$:

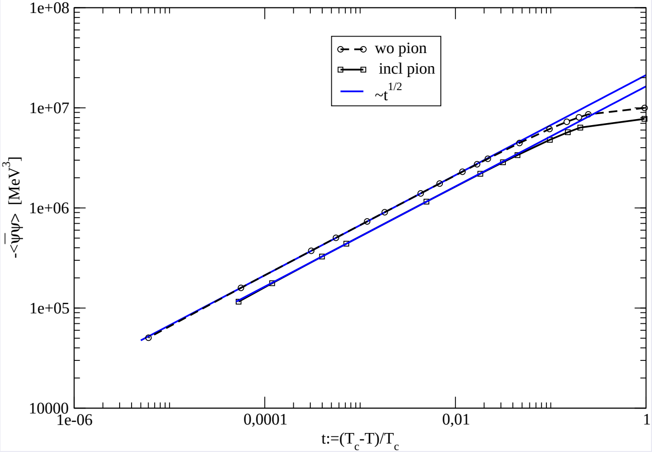
- without pion: $f_\pi = 80$ MeV; -$\langle\overline{\psi}\psi\rangle_{\sqrt{300}\,\mathrm{GeV}} = (0.22\,\mathrm{GeV})^3$
- inclusion of pion: $f_\pi = 64$ MeV; -$\langle\overline{\psi}\psi\rangle_{\sqrt{300}\,\mathrm{GeV}} = (0.20\,\mathrm{MeV})^3$

Results: chiral condensate

Chiral condensate

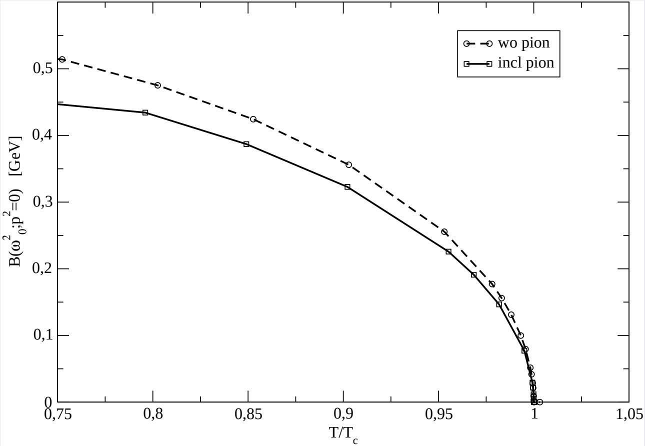


Chiral condensate



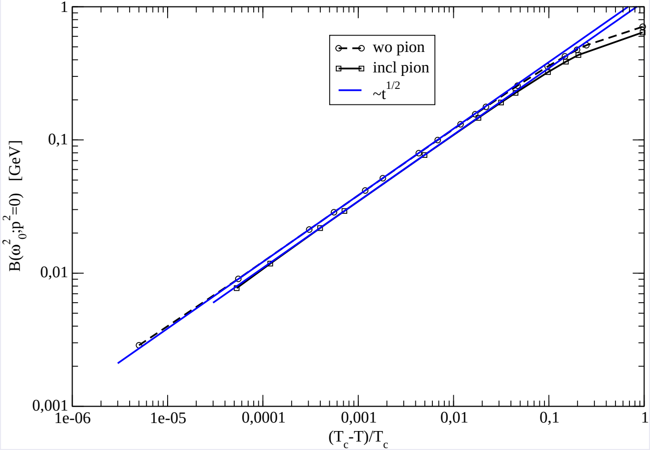
Results: χ_B

χ_B



Results: χ_B

χB



Conclusions

Summary

- Rainbow ladder truncation cannot describe transitions
- Proposal how to incorporate mesonic dof in DSE's
- Despite pion backreaction mean-field critical exponents

$\Longrightarrow$
- Take into account other mesonic dof
- Try other points than $\mathrm{m}_{u,d} = 0, \mathrm{m}_s = \infty$

Future plans

In collaboration with D. Nickel

Quark spectral functions above T_c

- QGP near phase transition $\rightarrow$ strongly interacting system
- Explore quasi-particle properties
  - Is the quasi-particle picture valid in this regime
  - How do bosonic modes affect the quark spectrum

    [M. Kitazawa, T. Kunihiro, K. Mitsutani, PRD 77 (2008)]
    [M. Harada, Y. Nemoto, PRD 78 (2008)]

    [F. Karsch, M. Kitazawa, PRL B 658 (2007)]
- Extraction of spectral functions from DSE's via MEM is possible

  [D. Nickel, Annals Phys. 322 (2006)]