On the Influence of the Infrared on the Chiral Transition Temperature

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University of Graz

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- People involved:
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  D. Horvatić, D. Klabučar (University of Zagreb)
- In association with
  Doctoral College Graz 'Hadrons in Vacuum, Nuclei and Stars'
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Outline

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Introduction

- Use Dyson-Schwinger equations (DSE) and Bethe-Salpeter equation (BSE) to calculate physical observables from QCD

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- DSE: Obtain full Green's functions
- BSE: Description of bound states (e.g. meson masses)
- Focus here: DSE for quark propagator at zero and finite temperature (T)

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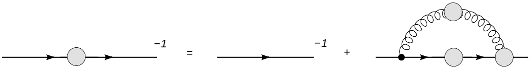
QCD Gap Equation

- Structure:



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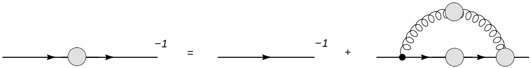

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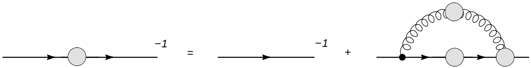

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  In principle: obtain them from their DSE
- For numerical study (e.g. mesons): Use truncation

QCD Gap Equation

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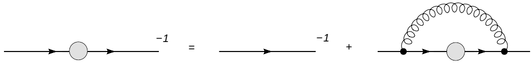

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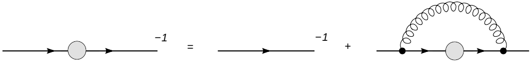

  - Full vertex times full gluon propagator $\longrightarrow$ bare vertex times bare propagator times some function $\gamma_\mu G_{\mu\nu}(p_\alpha)\mathcal{D}(p^2)$ [Landau gauge]

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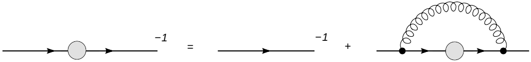

  - Full vertex times full gluon propagator → bare vertex times bare propagator times some function $\gamma_\mu G_{\mu\nu}(p_\alpha)\mathcal{D}(p^2)$ [Landau gauge]
- Model for interaction: Choice of $\mathcal{D}(p^2)$

(Some) Interaction Models

MN - Model [Munczek, Nemirovsky 1983]:

- $\mathcal{D} = \frac{D}{2}\,(2\pi)^4\delta^4(p_\mu)$

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- In gap equation: Quark mass as additional parameter!

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(Some) Interaction Models

Gaussian Model [Alkofer, Watson, Weigel 2002]:

- $$\mathcal{D}(p^2) = \frac{D}{2}\,\frac{(2\pi)^2}{\omega^6}p^2 e^{-p^2/\omega^2}$$

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- Width of Gaussian ω
- Original definition: $\frac{D}{\omega^2}$ instead of $\frac{D}{\omega^6}$

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- $$\mathcal{D}(p^2) = \frac{D}{2} \left((2\pi)^4 \delta^4(p_\mu) + \frac{(2\pi)^2}{\omega^6} p^2 e^{-p^2/\omega^2} \right) + \mathcal{F}_{UV}(p^2)$$

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- Infrared: $\delta^4(p)$ and Gaussian term
- Parameters: D, ω
- $\mathcal{F}_{UV}(p^2)$: Proportional to $\alpha(p^2)/p^2$ for large p^2 (preserves one-loop RG behaviour of QCD)

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$$I.S. = \int \frac{d^4p}{(2\pi)^4} \mathcal{D}^{IR}$$

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- Other models (MN, MT, Gaussian): $\frac{D}{2}$

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- Insert one of the models into the Gap Equation to get the quark propagator for any current quark mass m_q

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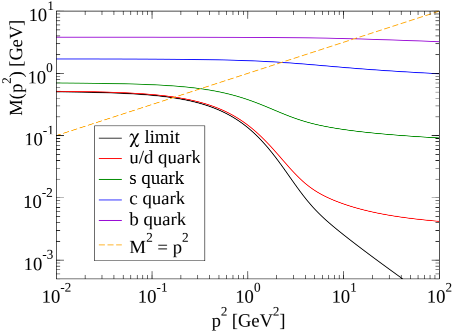
- 

Even at $m_q = 0$ (chiral limit), $M(p^2) \neq 0 \rightarrow$ Dynamical chiral symmetry breaking

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- E.g., choose parameters such that $m_\pi = 140\text{MeV}$

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- Example: MT - Model: ω - dependence of meson masses (while keeping $D \cdot \omega$ constant)

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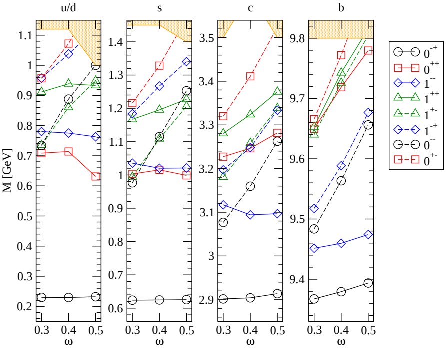
- 

[Krassnigg] Ground states are (almost) not sensitive to ω (pointwise behaviour in the IR).

Recipe for Finite Temperature Calculations

- Extend formalism to finite temperature

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- Inverse Quark propagator:

$$S^{-1} = i\gamma \cdot \mathbf{p}\ A(\mathbf{p}, \omega_k) + i\gamma_4\omega_k\ C(\mathbf{p}, \omega_k) + B(\mathbf{p}, \omega_k)$$

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- m_g Debye screening mass

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- Functions: $\mathcal{D}(\mathbf{p}, \Omega_k; m_g)$
- Substitutions in the formulas:

$$p_\alpha p_\alpha \to \mathbf{p}^2 + \omega_k^2 + m_g^2$$

$$\int \frac{d^4 p}{(2\pi)^4} \to T \sum_{k=-\infty}^{+\infty} \int \frac{d^3 p}{(2\pi)^3}$$

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(Some) Interaction Models at Finite T

- Apply the recipe to all discussed models

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- Taken from $T = 0$ studies

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Limit T $\to$ 0

- Consistency check: Recover the $T = 0$ results

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Limit T $\rightarrow$ 0

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- The Lorentz symmetry has to be restored

Limit T $\longrightarrow$ 0

- Consistency check: Recover the $T = 0$ results
- The Lorentz symmetry has to be restored
- $A(\mathbf{p}, \omega_k)$ and $C(\mathbf{p}, \omega_k)$ become identical as T $\longrightarrow$ 0

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Limit T $\longrightarrow$ 0

- $\mathrm{MT}^{[\mathrm{T}]}$ - Model, $D = 0.465$, $\omega = 0.4$

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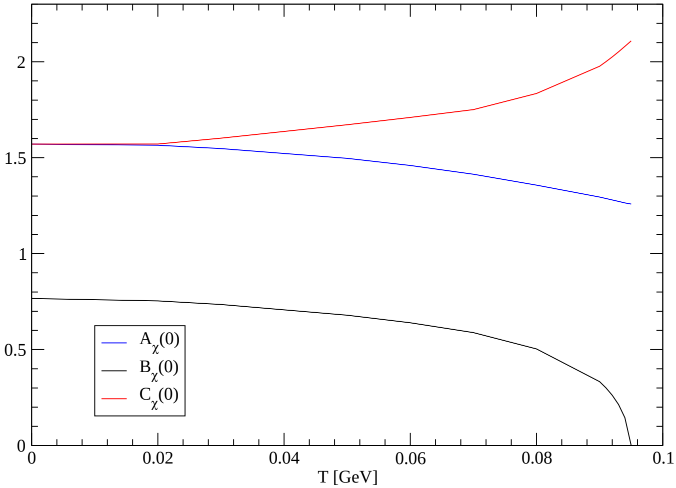

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Chiral Phase Transition

- Order parameter: $B(0, \pi T)$

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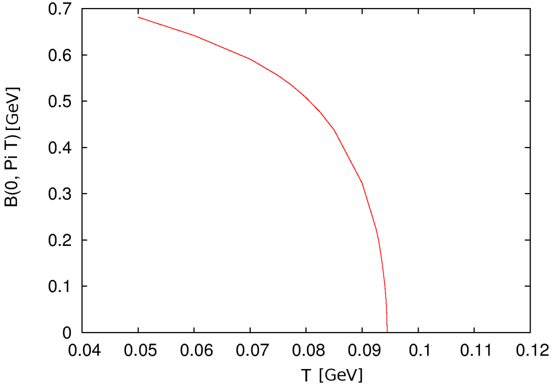
- Example: $\mathrm{MT}^{[\mathrm{T}]}$ - Model, $D = 0.465$, $\omega = 0.4$



$T_c = 0.094$ GeV

Comparison of Transition Temperatures

- Compare T_c for all discussed models:

[1] [Blaschke, Roberts, Schmidt 1998]
[2] [Höll, Maris, Roberts 1999]
[3] [Maris, Tandy 1999]
[4] [Alkofer, Watson, Weigel 2002]

Comparison of Transition Temperatures

- Compare T_c for all discussed models:

Model	$I.S.$	T_c [MeV]	ω	D
MN[T]	0.2809	169 [1]		0.5618
MR[T]	0.78	120 [2]	0.3	0.78
	0.78	152 [2]	0.4	0.78
MT[T]	0.62	82	0.3	1.24 [3]
	0.465	94	0.4	0.93 [3]
	0.372	96	0.5	0.744 [3]
Gaussian[T]	0.76835	83	0.3	1.5367
	0.57625	95	0.4	1.1525 [4]
	0.461	97	0.5	0.922 [4]

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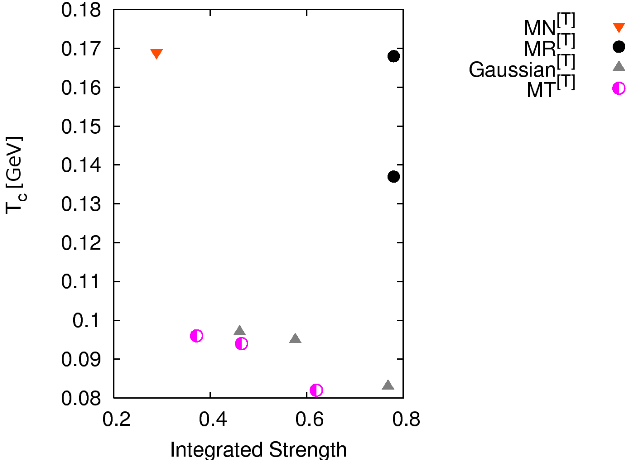
Comparison of Transition Temperatures

There is no simple relation between T_c and integrated strength!



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- The integrated strength is no model independent measure for T_c.

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- T_c depends strongly on the pointwise infrared behaviour of the model.
- The integrated strength is no model independent measure for T_c.
- Possibility to test models!

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Outlook: Critical Exponents

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- Models including δ-term: Mean field behaviour $\beta = 0.5$ [Höll, Maris, Roberts 1999]

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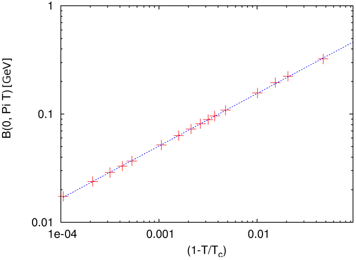
- Preliminary: Critical exponents for non-δ-Models, e.g. $\mathrm{MT}^{[\mathrm{T}]}$:



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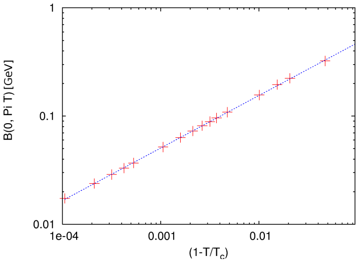
- Investigation of critical exponents
- Models including δ-term: Mean field behaviour $\beta = 0.5$ [Höll, Maris, Roberts 1999]
- Preliminary: Critical exponents for non-δ-Models, e.g. $\mathrm{MT}^{[\mathrm{T}]}$:



- $\beta = 0.486 \pm 0.002$ (fit of power law $B(0) \sim (1 - \frac{T}{T_c})^{\beta}$)

FWF Der Wissenschaftsfonds.