# Polyakov-loop potential from functional methods

Jan Lücker

Collaborators: Christian S. Fischer, Leonard Fister (Talk on Tuesday), Tina K. Herbst (Talk on Wednesday), Jan M. Pawlowski (Talk on Tuesday)

Uni Heidelberg

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# Layout

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# The Polyakov-loop potential

- Effective glue sector $\rightarrow$ used in effective models
- Order parameter for confinement (center symmetry)

## With functional methods

- Study confinement from QCD degrees of freedom
- Providing input for effective models

## Background-field potential

$$\mathcal{L} = \bar{\psi} \left( \partial_0 + igA_0 + ig\bar{A}_0 - \mu \right) \gamma_0 \psi + \dots$$

Constant background field $\bar{A}$

$\Rightarrow$ potential $V(\bar{A})$

## Polyakov loop

$$L[A_0] = \frac{1}{N_c}\mathrm{Tr}_c\left[\mathcal{P}e^{i\,g\,\int_0^\beta dx_0\,A_0(x_0,\vec{x})}\right]$$

## Connecting b.f. and Polyakov loop

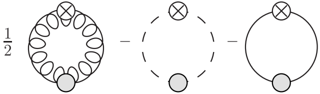
$$L[\bar{A}_0] \geq \langle L[A_0]\rangle \quad \text{and} \quad \langle L[A_0]\rangle = 0 \rightarrow L[\bar{A}_0] = 0\,,$$

$$V(\bar{A}) = V(L[\bar{A}])$$

- $\langle L[A_0]\rangle$ measured on the lattice
- $L[\bar{A}_0]$ used here, in effective models

## From the FRG

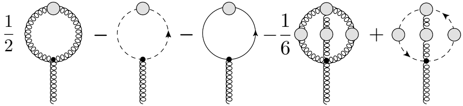
$$\partial_t \Gamma_k[\bar{A}] =$$




- One-loop exact

## From the DSE

$$\frac{\delta(\Gamma - S)}{\delta A_0} =$$



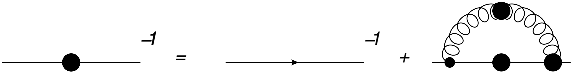

- Gives $V'$
- Neglect two-loop terms

See: *Fister, Pawlowski, PRD88, arXiv:1301.4163*

# Propagators

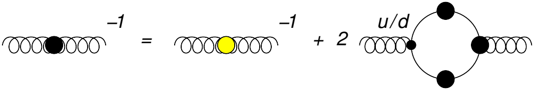


## Quark



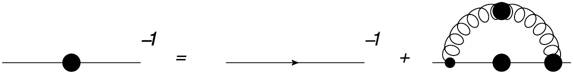

## Ghost and gluon

- Quenched *k*-dependent props by Leo Fister
  *Fister, Pawlowski, arXiv:1112:5440*
- Quenched gluon as input, unquenching via DSE



# Propagators

## Quark

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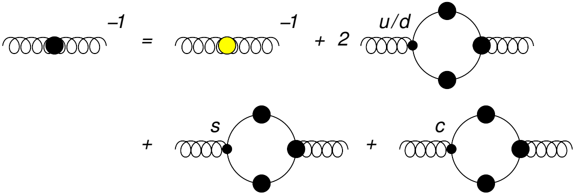

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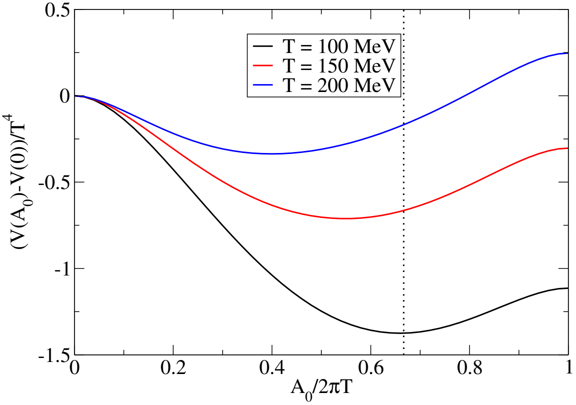
## Potential at $\mu = 0$

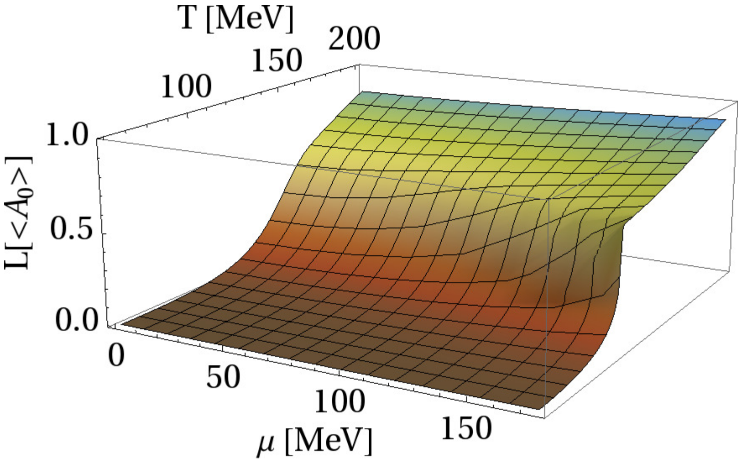



*Fischer, Fister, JL, Pawlowski, PLB732, arXiv:1306:6022*

$$\bar{A}_0 = 2\pi T \varphi_3 \frac{\lambda_3}{2}$$

# Full physical QCD (from DSE)

## Order parameter at all $\mu$




*Fischer, Fister, JL, Pawlowski, PLB732, arXiv:1306:6022*

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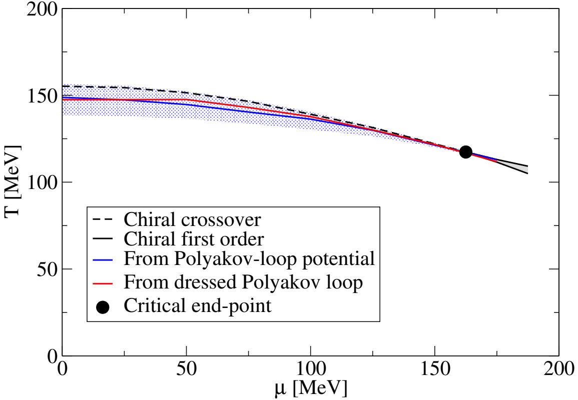
## Phase diagram




*Fischer, Fister, JL, Pawlowski, PLB732, arXiv:1306.6022*

See also: *Fischer, JL, Welzbacher PRD90, arXiv:1405.4762* for $N_f = 4$

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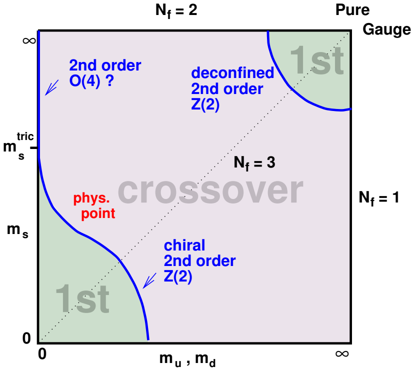


de Forcrand, Philipsen, PRL105, arXiv:1004.3144

- Upper-right hand corner
- $1^{st}$ order area bounded by critical quark mass $m_c$

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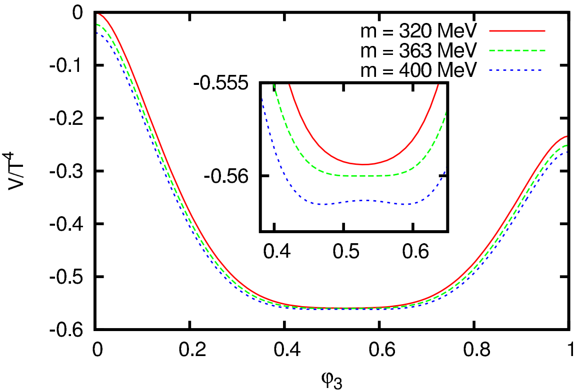
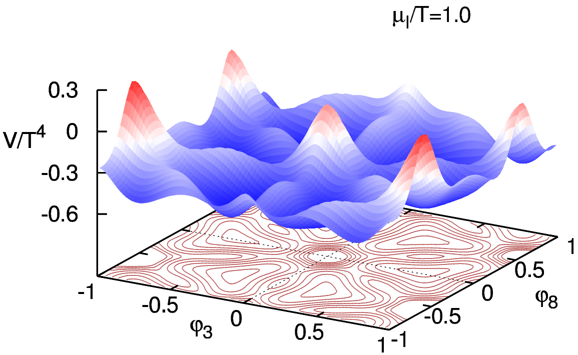
## Potential at $T_c$




*Fischer, JL, Pawlowski, in preparation*

- Number of minima → order of phase transition

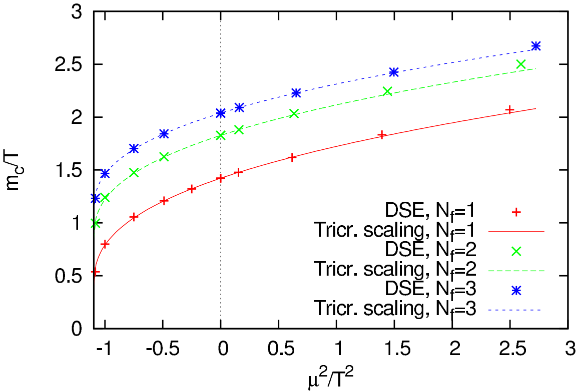
# Finding $m_c$ at imaginary $\mu$




*Fischer, JL, Pawlowski, in preparation*

$$\bar{A}_0 = 2\pi T \left( \varphi_3 \frac{\lambda_3}{2} + \varphi_8 \frac{\lambda_8}{2} \right)$$

- Potential of $\varphi_3, \varphi_8 \Rightarrow$ complex Polyakov loop
- Roberge-Weiss symmetry realized

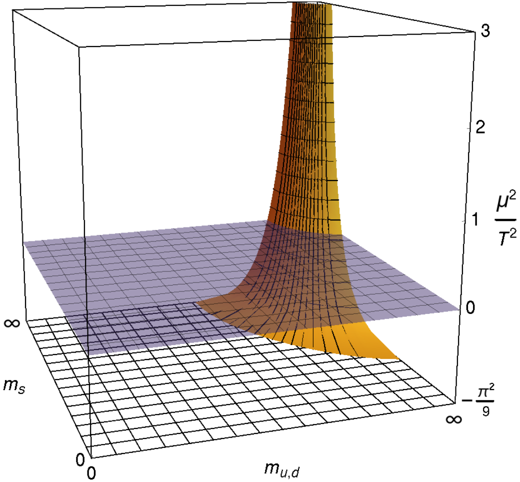



*Fischer, JL, Pawlowski in preparation*

- From Roberge-Weiss critical surface up to all real chemical potentials
- Good agreement with tricritical scaling
- Agreement with lattice *Fromm et al, JHEP 1201, arXiv:1111.4953*

# $m_c$ for all $\mu^2$

## 3D Columbia plot




*Fischer, JL, Pawlowski in preparation*

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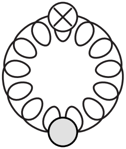
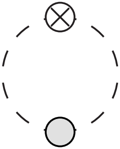
# Potential for models

## Model ansätze

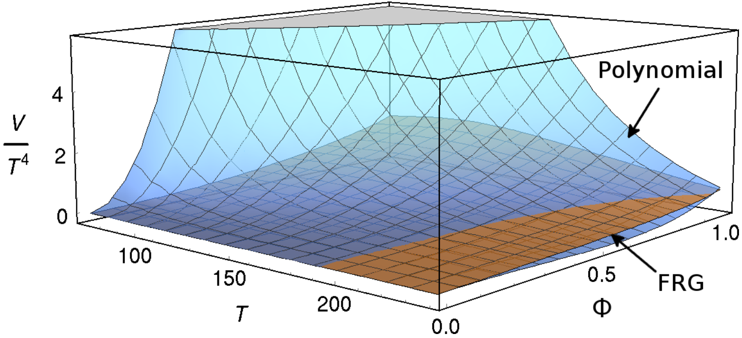
- Constructed along symmetries
- Constrains from $\langle L[A] \rangle$, thermodynamics in YM
- $\Rightarrow$ low temperatures not constrained
- $\Rightarrow$ no unquenching effects included, no finite $\mu$

## Calculate from FRG

$\partial_t \Gamma_k[\bar{A}] = \frac{1}{2}$  $-$ 

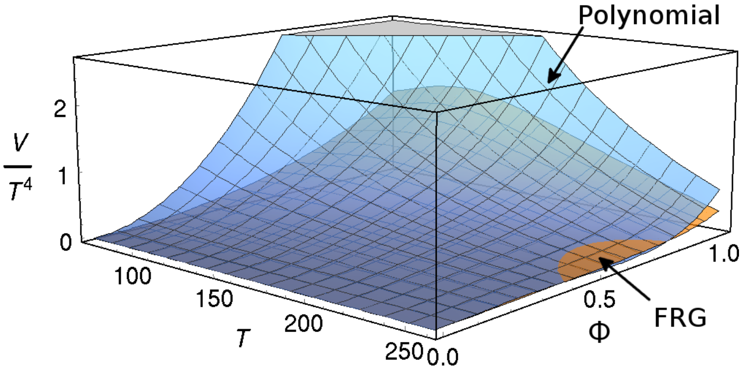
Preliminary!

## Compared to polynomial *ansatz* I



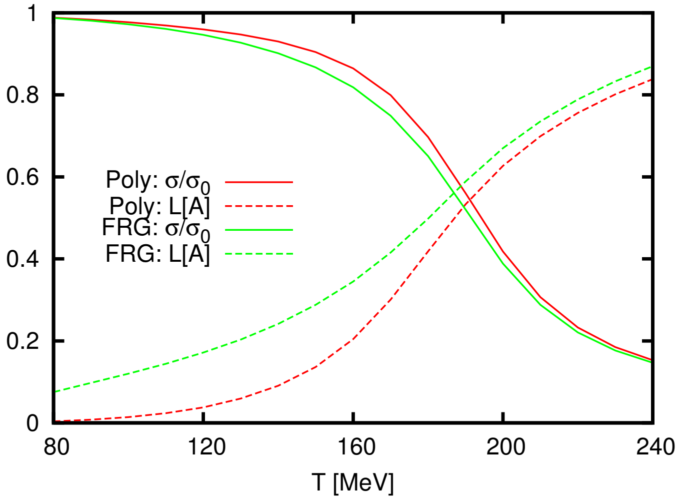

- Polynomial potential by *Ratti, Weise, PRD D70, hep-ph/0406159*

## Compared to polynomial *ansatz* II




- Modified polynomial potential by *Haas, Stiele, Braun, Pawlowski, PRD87, arXiv:1302.1993*

# $N_f = 2$ PQM results




*Herbst, JL, Pawlowski, in preparation*

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- Phase diagram with physical quark masses
- Heavy quark limit $\rightarrow$ Columbia plot
- Application in effective models
- $\Rightarrow$ $\mu$-dependent potential

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**Thank you for your attention!**