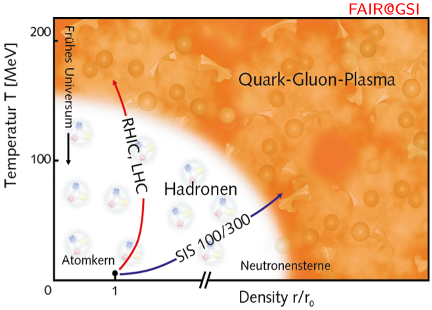
Dynamical Locking of the Chiral and the Deconfinement Phase Transition in QCD at Finite Chemical Potential

Paul Springer
Jens Braun, Marc Leonhardt, Stefan Rechenberger

7th International ERG Conference
Lefkada, Greece

September 22, 2014

Motivation



- Confinement ⇔ **gauge degrees of freedom**
- χSB ⇔ **quark self-interactions**

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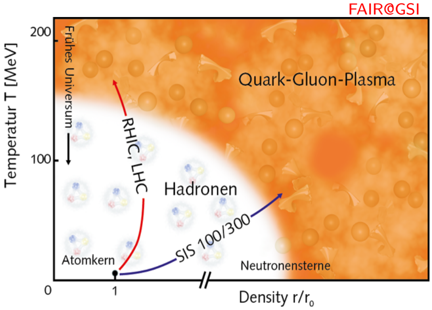

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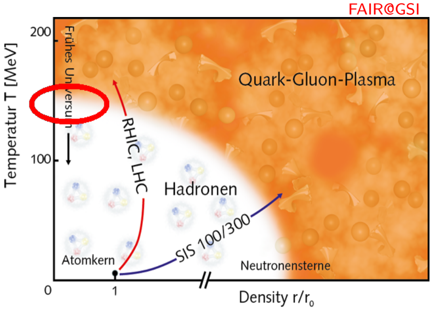

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$$\Downarrow$$

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Lattice QCD:

At $\mu = 0$ pseudo-critical temperatures are very similar for both crossovers
e.g. [Karsch et al., 2003], [Endrodi et al., 2006], [Aoki et al., 2009] etc.

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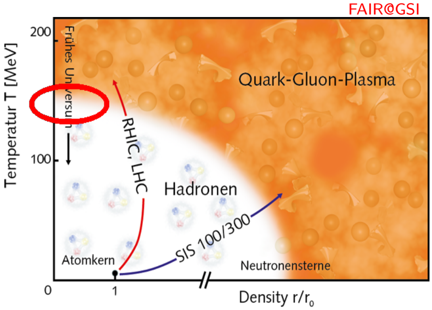

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Deeper relation between chiral and confining dynamics???

λ_ψ-deformed QCD

We investigate λ_ψ-deformed QCD (model) without gluons (basically PNJL model) with two massless flavors, N_c colors and finite chemical potential:

$$\mathcal{L} = \bar{\psi}(\mathrm{i}\partial\!\!\!/ + \gamma_0 \bar{\mathrm{g}}\langle A_0 \rangle + \mathrm{i}\gamma_0\mu)\psi + \frac{\bar{\lambda}_\psi}{2}[(\bar{\psi}\psi)^2 - (\bar{\psi}\vec{\tau}\gamma_5\psi)^2)]$$

- **two** parameters: $\lambda_\psi(\Lambda)$, $\langle A_0 \rangle$
- large λ_ψ triggers χSB
- deconfinement order parameter:

$$\mathrm{Tr}_F\, L[\langle A_0 \rangle] = \frac{1}{N_c}\,\mathrm{Tr}_F[\mathcal{P}\mathrm{e}^{i\beta\bar{g}\langle A_0 \rangle}] \overset{\text{PNJL}}{=} \frac{1}{N_c}\langle \mathrm{Tr}_F[\mathcal{P}\mathrm{e}^{i\bar{g}\int_0^\beta A_0}]\rangle$$

e.g. [Meisinger, Ogilvie, 1996]

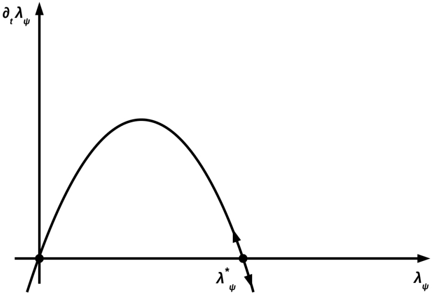
- Tool: **Wetterich flow equation** [C. Wetterich, 1993]

λ_ψ-deformed QCD: RG fixed-point analysis

$$\mathcal{L} = \bar{\psi}(\mathrm{i}\partial\!\!\!/ + \qquad\qquad)\psi + \frac{\bar{\lambda}_\psi}{2}[(\bar{\psi}\psi)^2 - (\bar{\psi}\vec{\tau}\gamma_5\psi)^2)]$$

RG-flow equation:
$T = 0,\ \mu = 0,\ \langle A_0 \rangle = 0$
(k is momentum scale)

$$k\partial_k\lambda_\psi = 2\lambda_\psi - C\lambda_\psi^2$$



$$\boxed{\lambda_\psi(\Lambda) > \lambda^*_\psi \Rightarrow \chi SB}$$

λ_ψ-deformed QCD: RG fixed-point analysis

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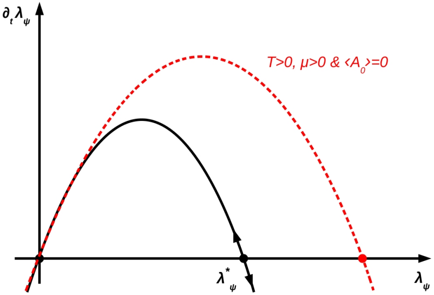
RG-flow equation:
$T \neq 0$, $\mu \neq 0$, $\langle A_0 \rangle = 0$
(k is momentum scale)

$$k\partial_k \lambda_\psi = 2\lambda_\psi - C(\tfrac{T}{k}, \tfrac{\mu}{k})\lambda_\psi^2$$



$\lambda_\psi(\Lambda) > \lambda^*_\psi$, T or (and) μ increase $\Rightarrow$ restoration of χ-Symmetry

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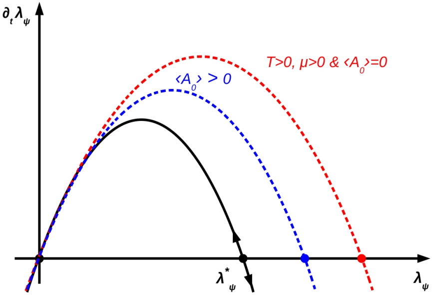
RG-flow equation:
$T \neq 0,\ \mu \neq 0,\ \langle A_0\rangle \neq 0$
(color-confined regime)

$$k\partial_k \lambda_\psi = 2\lambda_\psi - C\left(\frac{T}{k}, \frac{\mu}{k}, \langle A_0\rangle\right)\lambda_\psi^2$$



Finite $\langle A_0\rangle \Rightarrow$ fixed point "moves" to the left

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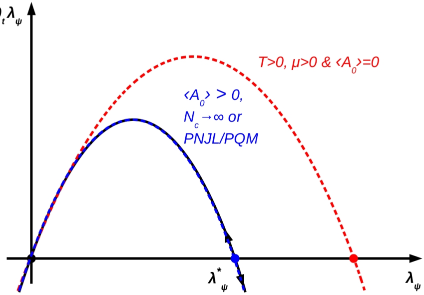
Analytical result:
as long

- $N_c \to \infty$, **or**
- $\mathrm{Tr}_F\, L[\langle A_0\rangle] \approx \langle \mathrm{Tr}_F\, L[A_0]\rangle$ (PNJL/PQM-models)

$$\Rightarrow \boxed{\lambda^*(T,\mu,\langle A_0\rangle) = \lambda^*(0,0,0)}$$



$$\boxed{T_\chi \gtrsim T_d}$$

Conclusion

- **PNJL/PQM-models $\Longleftrightarrow$ Large-N_c in the coupling of the matter and gauge sector** (should not be confused with the standard large-N_c approximation, such as neglecting pion fluctuations etc.)
- $T_\chi \geq T_d$ in the phase diagram of PNJL/PQM-models
  - $\Rightarrow$ existence of quarkyonic phase in PNJL/PQM-models under debate
  - $\Rightarrow$ **Constraint on parametrization of Polyakov potential**

Thank you for your attention!

Numerical Results

- We use the data for $\langle A_0 \rangle$ for pure $SU(N_c)$ gauge theory, i. e., we drop the back coupling of fermions to the gauge sector: T_d **is fixed!**
  [Braun, Gies, Pawlowski, 2010], [Braun, Eichhorn, Gies, Pawlowski, 2010]
- Back coupling $\rightarrow$ corrections, but the main results should be the same on the qualitative level

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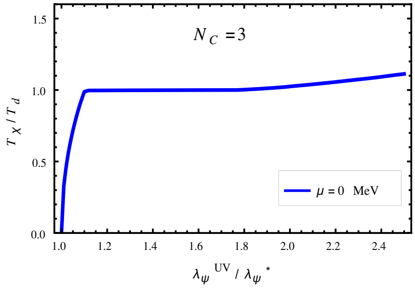

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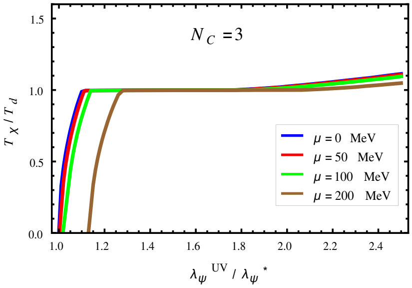

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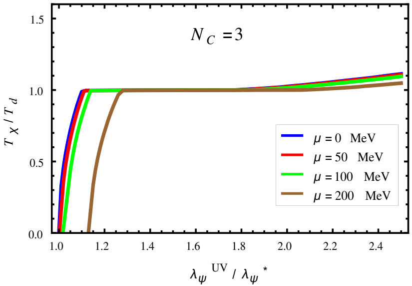

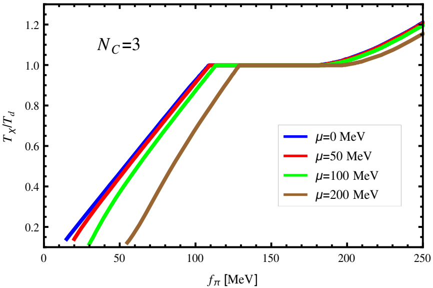

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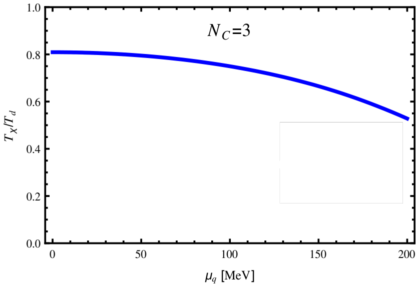

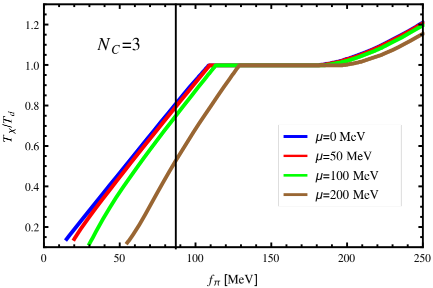

$$\kappa = -T_\chi \frac{dT_\chi(\mu^2)}{d(\mu^2)} \Big|_{\mu=0} = 0.385(5)$$