Phase structure of strongly-interacting matter: Thermodynamics and chiral anomaly

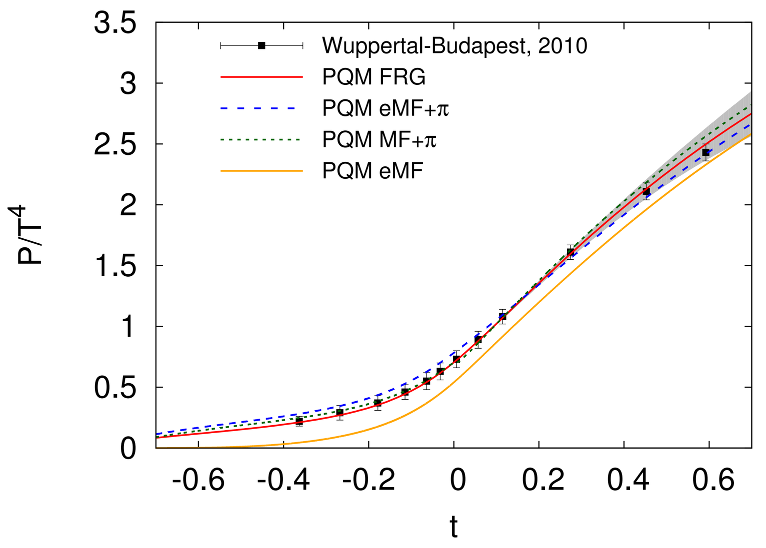
M. Mitter[1], T. K. Herbst[1], J. M. Pawlowski[1], B.-J. Schaefer[2], R. Stiele[1,2]

1 Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, Germany
2 Institut für Theoretische Physik, Justus-Liebig-Universität Gießen, Germany

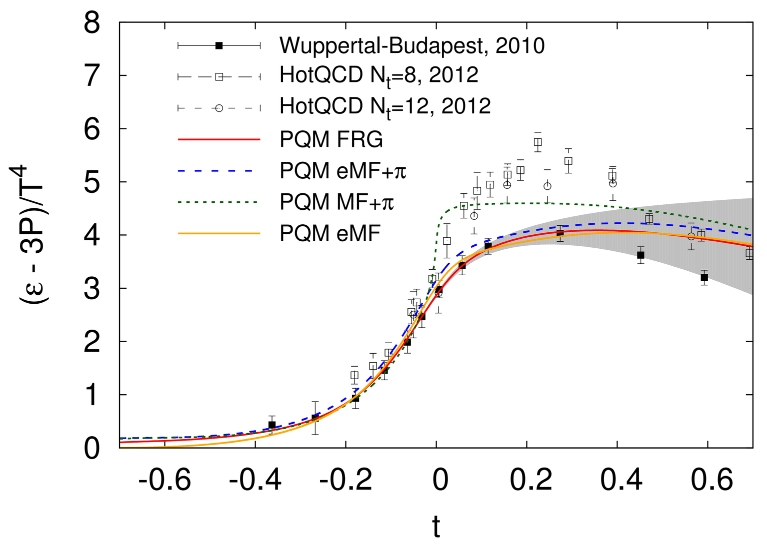
UNIVERSITÄT HEIDELBERG ZUKUNFT SEIT 1386

Thermodynamics [1]

Pressure

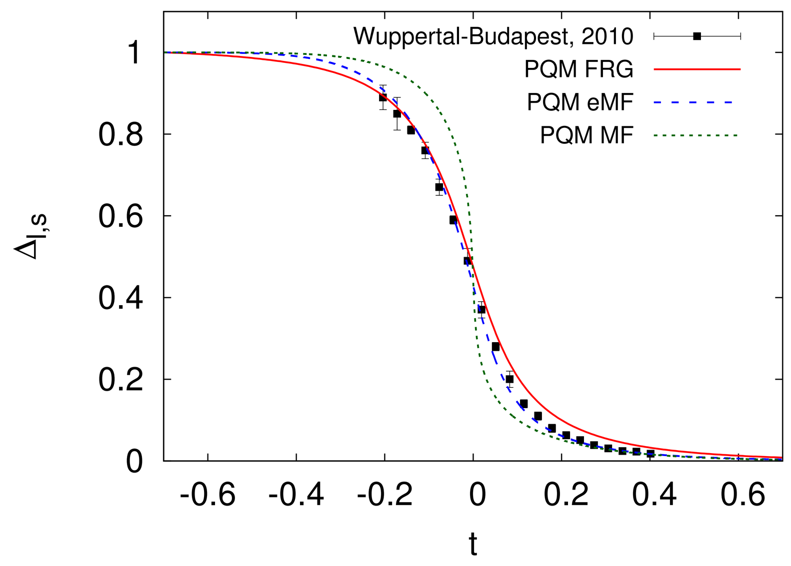


Trace anomaly



- perfect agreement of pressure and trace anomaly with lattice QCD data
- larger temperatures: need additional unquenching effects and meson suppression

QCD crossover [1]

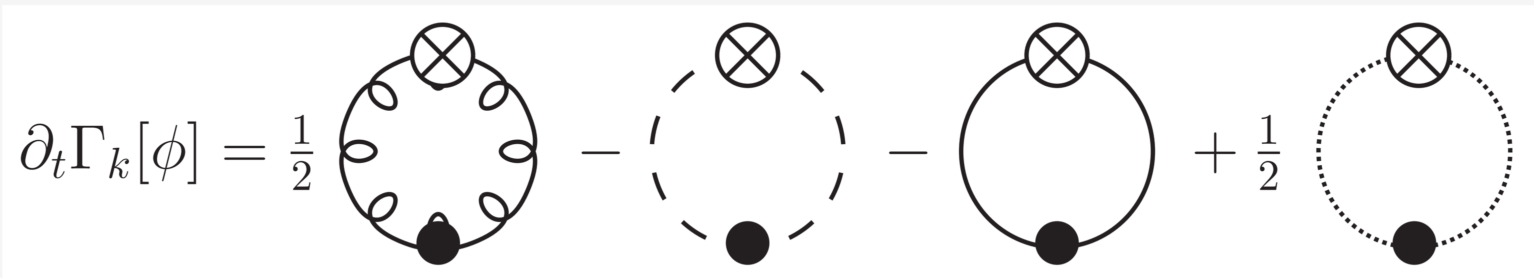


- perfect agreement with data from lattice QCD simulations
- subtracted condensate:

$$\Delta_{l,s} = \frac{\left(\langle\sigma_l\rangle - \frac{c_l}{c_s}\langle\sigma_s\rangle\right)_T}{\left(\langle\sigma_l\rangle - \frac{c_l}{c_s}\langle\sigma_s\rangle\right)_{T=0}}$$

- reduced temperature $t = (T - T_c)/T_c$

Fluctuations and nonperturbative dynamics: Functional Renormalization Group Equation (FRG)

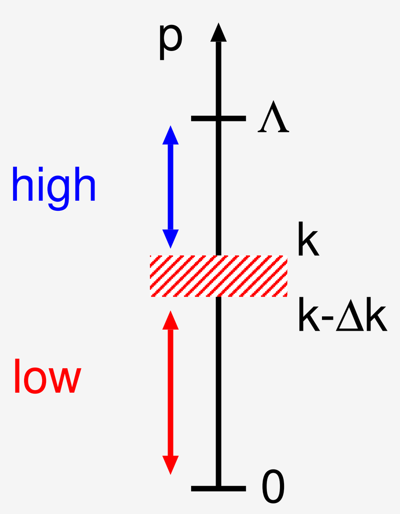


- connects bare action $\Gamma_\Lambda[\phi] = S[\phi]$ with full effective action

$$\Gamma[\phi] = \lim_{k\to 0}\Gamma_k[\phi]$$

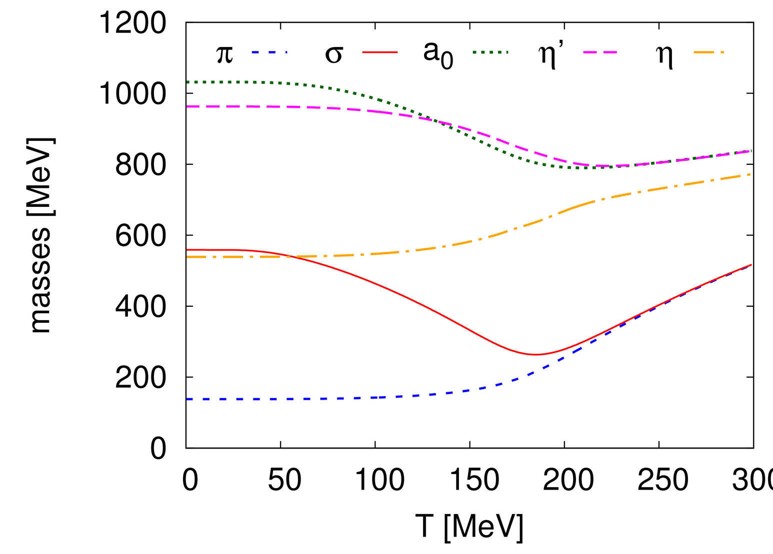
via momentum-shell integration.

- nonperturbative equation: full field-dependent propagators
- integrates thermal as well as quantum fluctuations
- comparison with (extended) mean-field results: (e)MF

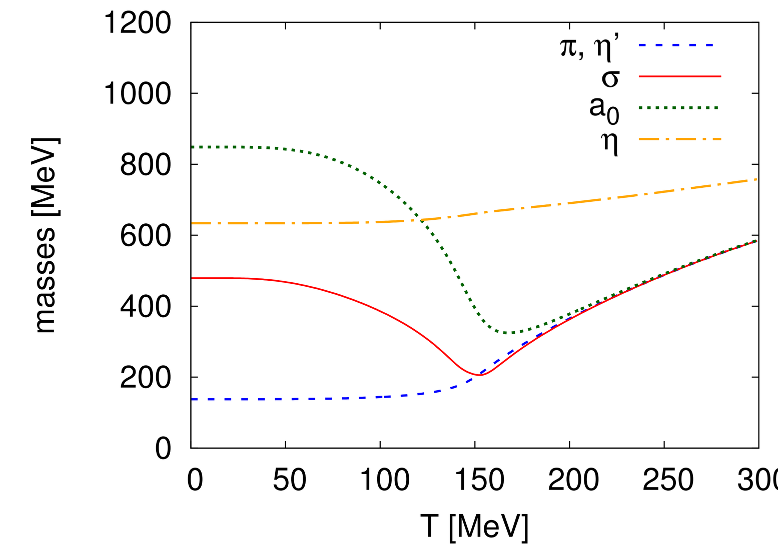


η'-meson mass at chiral transition [2]

without $U(1)_A$-symmetry



with $U(1)_A$-symmetry



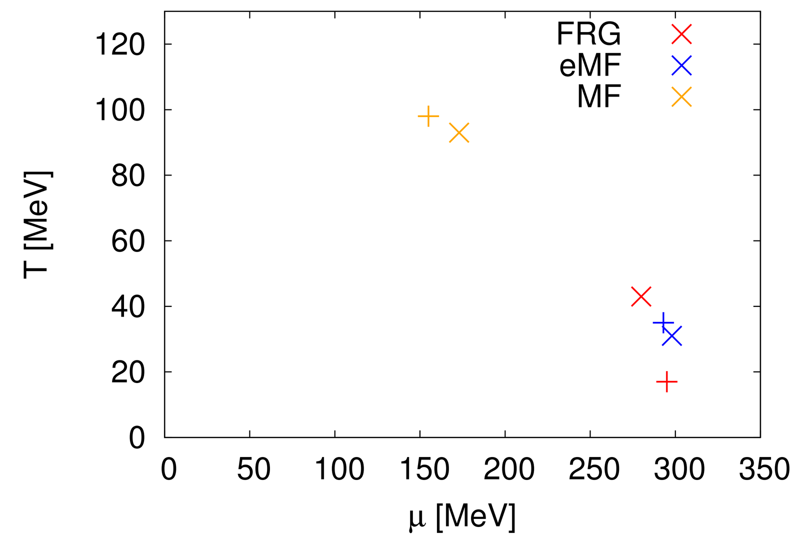
- drop in (screening) mass of η' meson due to melting of light condensate
- consistent with indirect measurements [3]

Critical point: fluctuations and chiral anomaly [2]

- chiral anomaly with full fluctuations: stronger effect on critical point location
- with anomaly: effect of fluctuations as in two-flavor QM-model with $\sigma, \vec{\pi}$ mesons

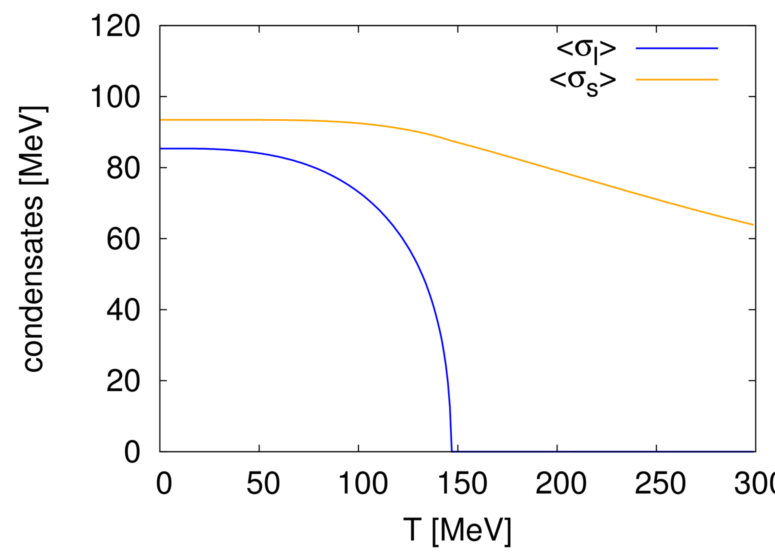
× without $U(1)_A$ symmetry

+ with $U(1)_A$ symmetry

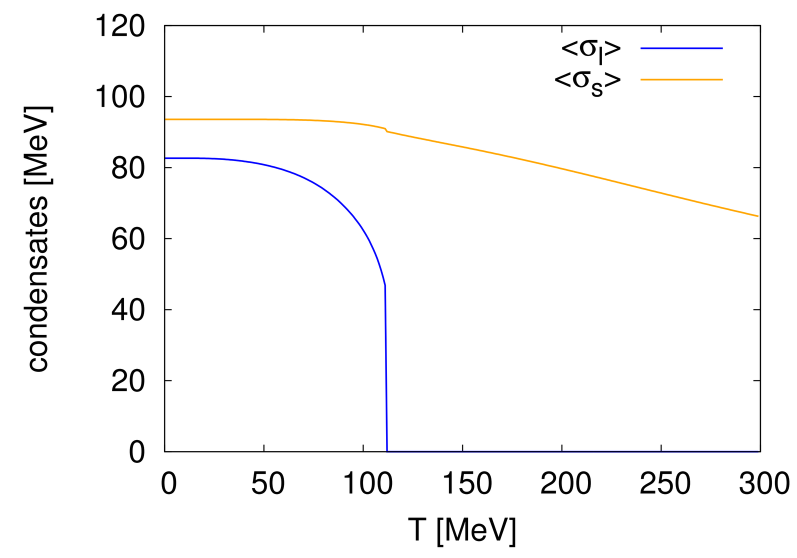


Order of transition for $m_l \to 0$ [2]

without $U(1)_A$-symmetry



with $U(1)_A$-symmetry



- second-order transition in $O(4)$ universality class without $U(1)_A$ symmetry
- first-order transition with $U(1)_A$ symmetry
- consistent with two-flavor dominated dynamics [4]
- inclusion of mesonic fluctuations (FRG) crucial

Low-energy effective description: quarks and mesons with $2+1$ flavors

(De-)Confinement dynamics (PQM):

- effective Polyakov Loop potential $\mathcal{U}(\Phi)$ with

$$\Phi = \langle \mathrm{tr}\mathcal{P}\exp[ig\int_0^\beta A_0]\rangle / N_c$$

- dynamical quark effects parametrized with linear rescaling $t_{YM}(t_{QCD})$ [5, 6]

$$\mathcal{U}_{QCD}(t_{QCD}) \equiv \mathcal{U}_{YM}(t_{YM}(t_{QCD}))$$

- very good approximation close to T_c, [cf. poster R. Stiele]

Quark-Meson Model (QM):

$$\mathcal{L}_{QM} = \bar{q}\left(\partial_\mu\gamma_\mu + h\left(\sigma^a + \mathrm{i}\gamma_5\pi^a\right)\frac{\lambda_a}{2}\right)q + \mathrm{tr}\left[\partial_\mu\Sigma^\dagger\partial_\mu\Sigma\right] + U\left(\Sigma,\xi\right) + (\text{expl. symmetry breaking})$$

- Σ: $SU(3)$ mesonic field matrix, λ_a: Gell-Mann matrices
- Yukawa type interaction h between quarks and mesons
- $U(1)_A$-symmetry breaking via Kobayashi-Maskawa-'t Hooft determinant [7], [8]

$$\xi = \det(\Sigma) + \det(\Sigma^\dagger)$$

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Acknowledgments

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FWF Der Wissenschaftsfonds.

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