Materie bei endlicher Temperatur und Dichte

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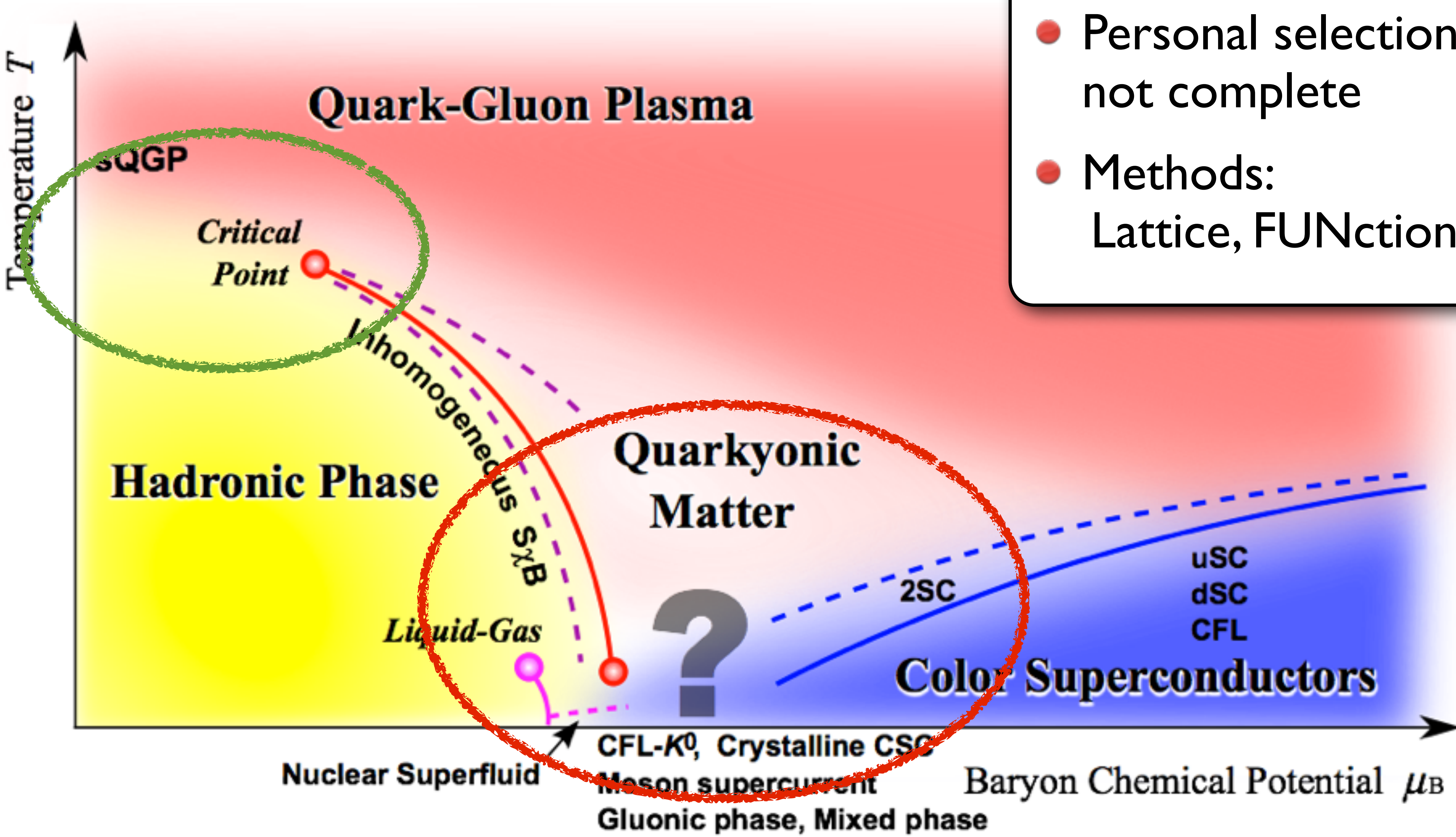
Justus Liebig Universität Gießen

5th of December 2016

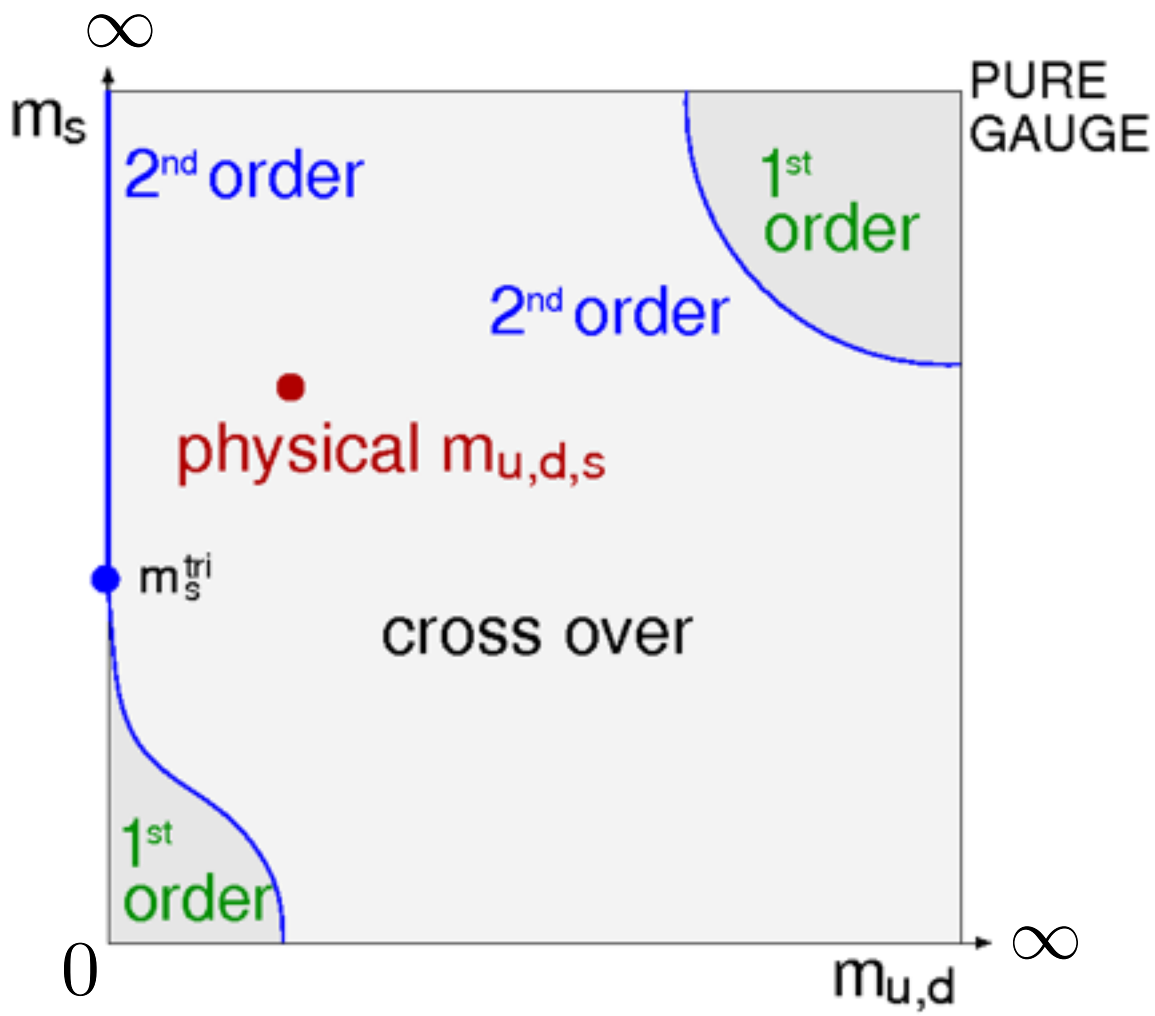
QCD phase transitions I

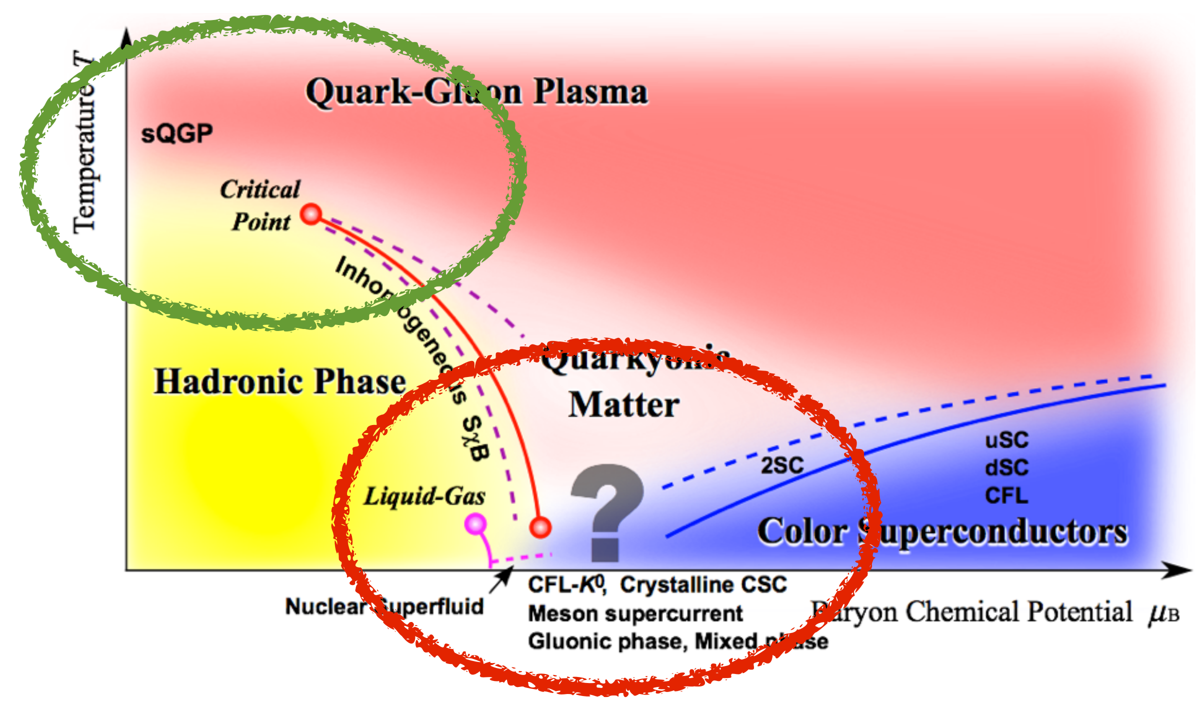


- Overview on progress in 2015
- Personal selection, not complete
- Methods: Lattice, FUNctional

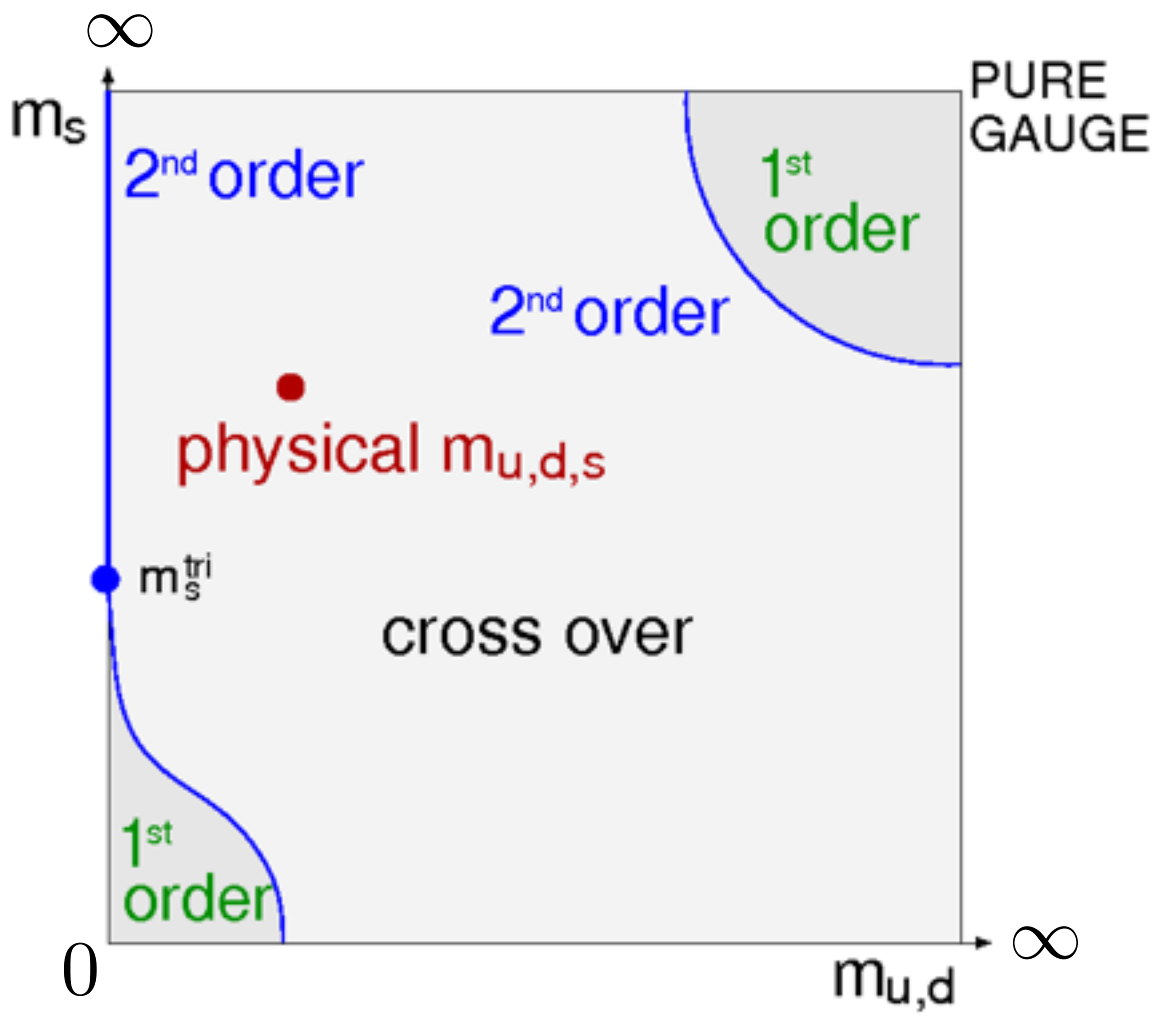
Fukushima, Hatsuda, Rept. Prog. Phys. 74 (2011) 014001

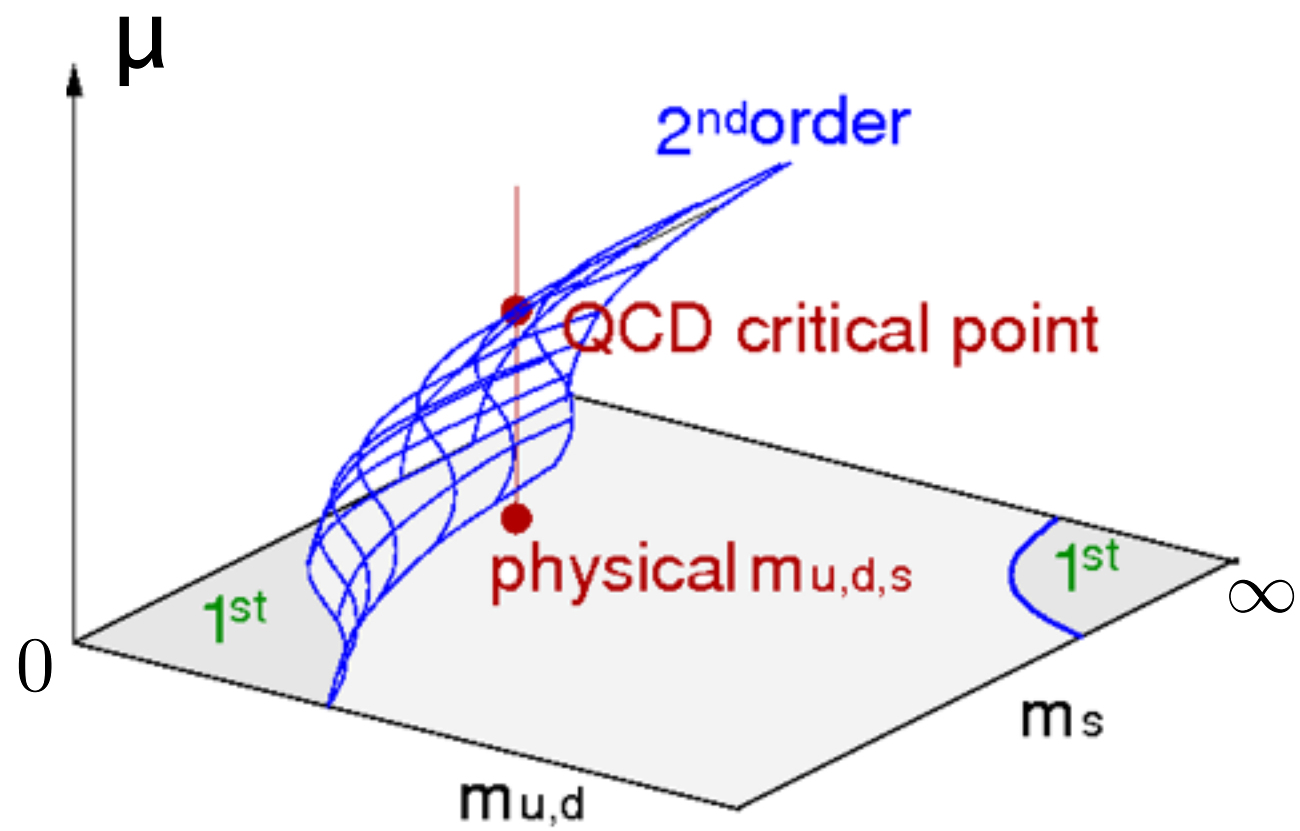
Existence and properties of critical end point (CEP)

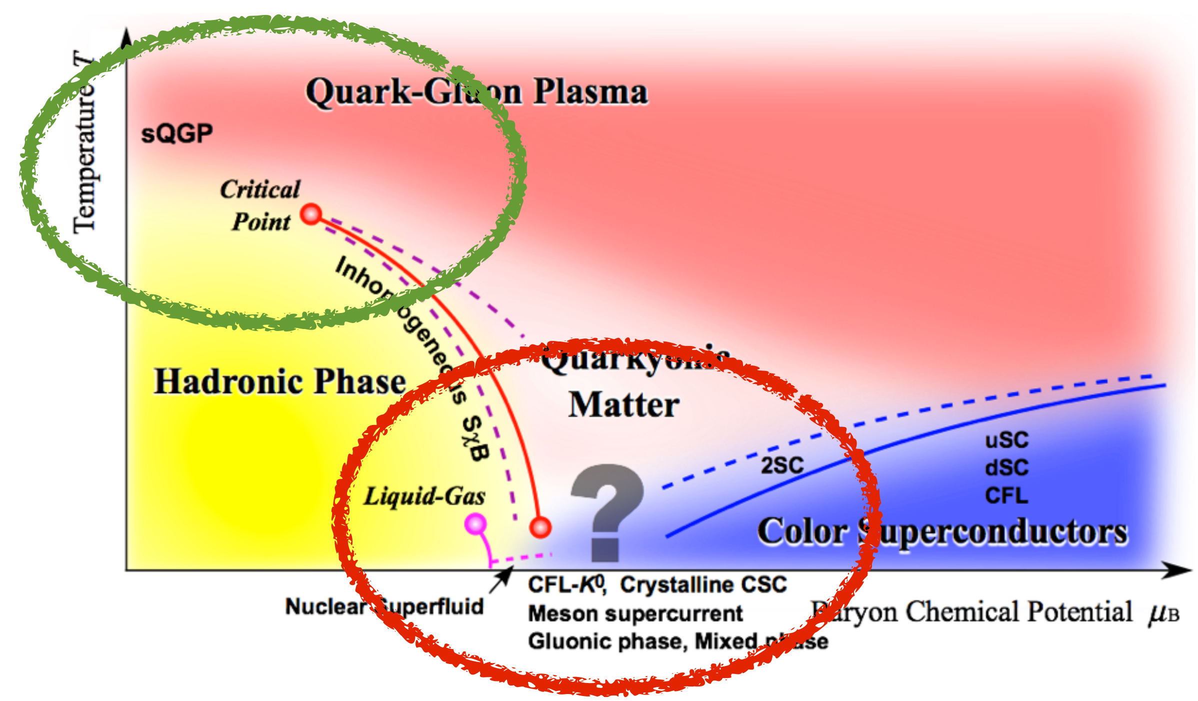


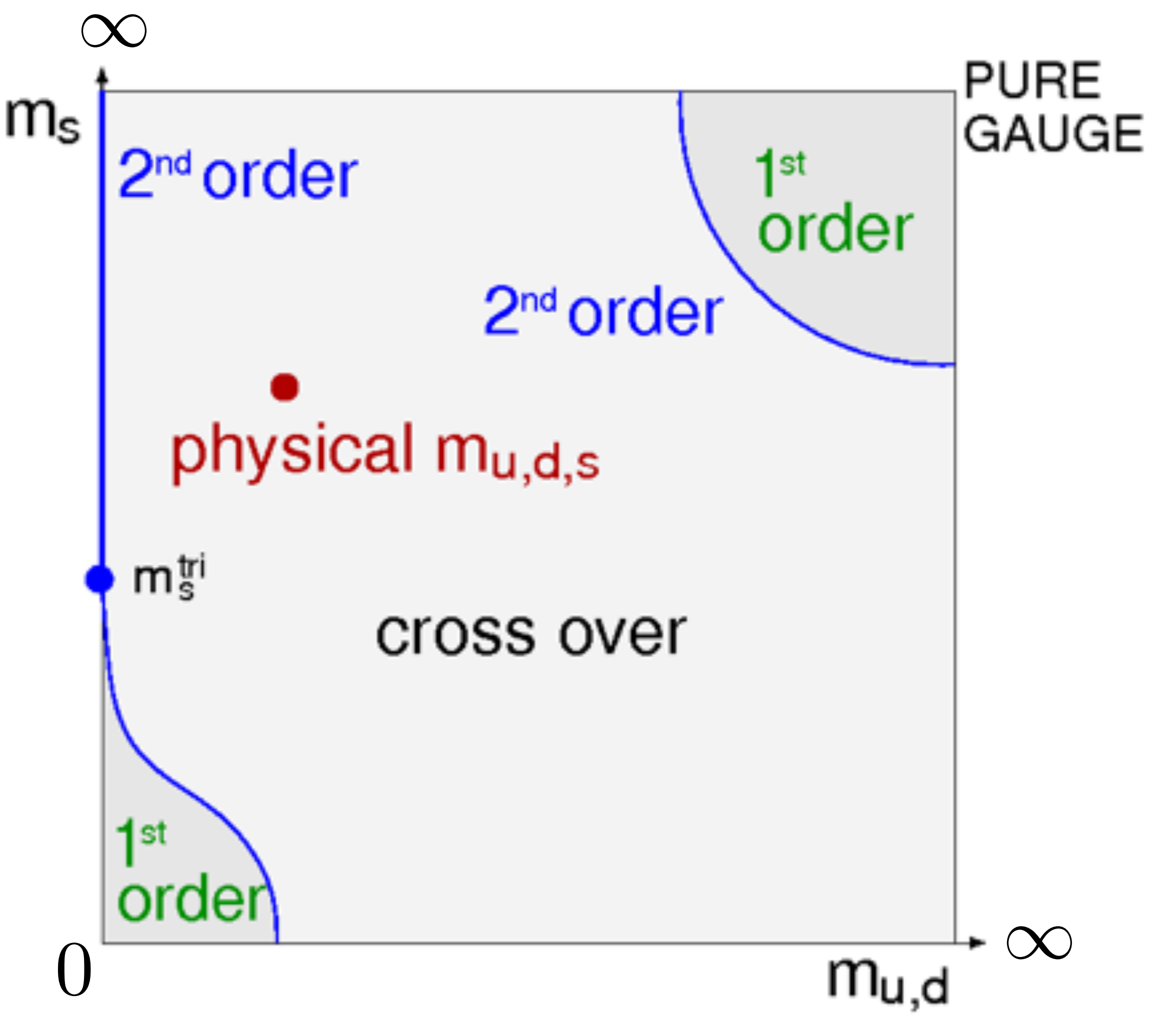


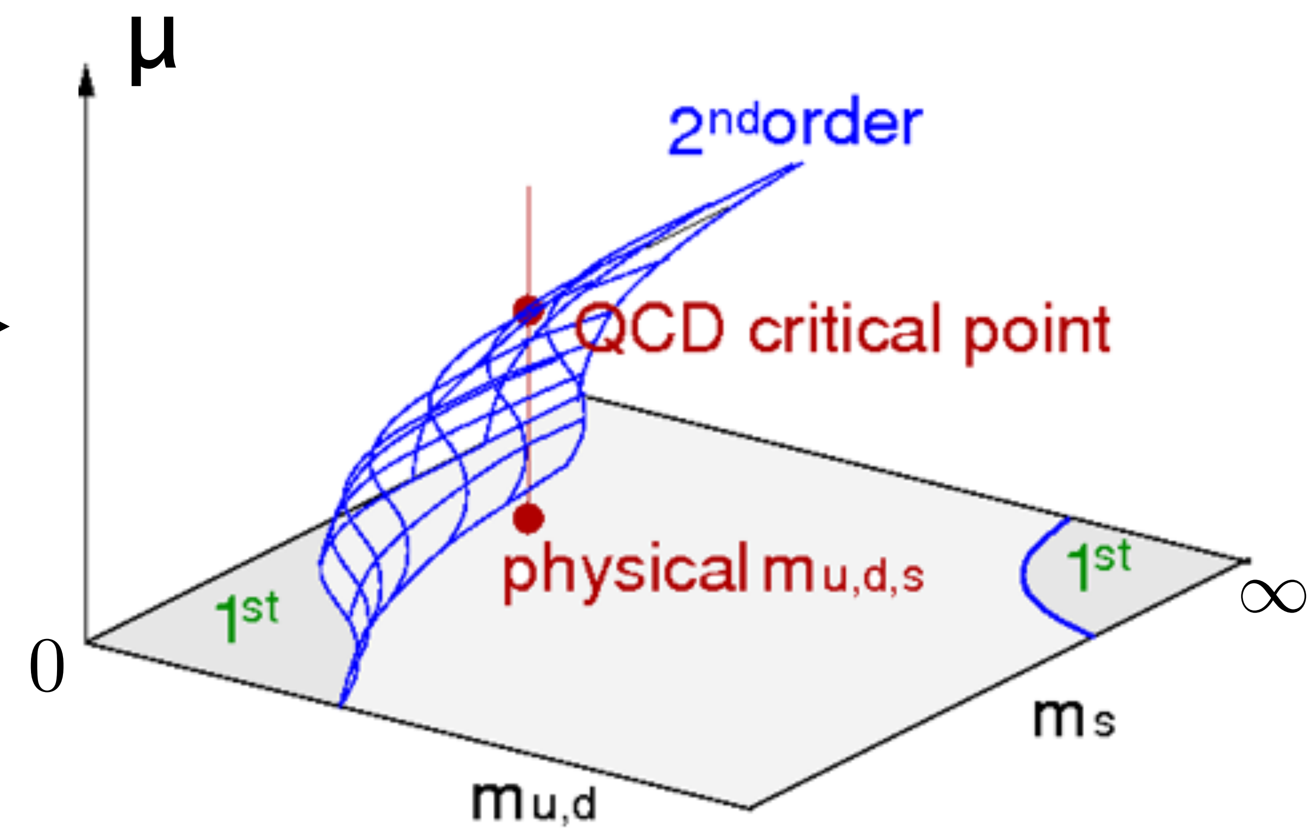
Existence and properties of critical end point (CEP)





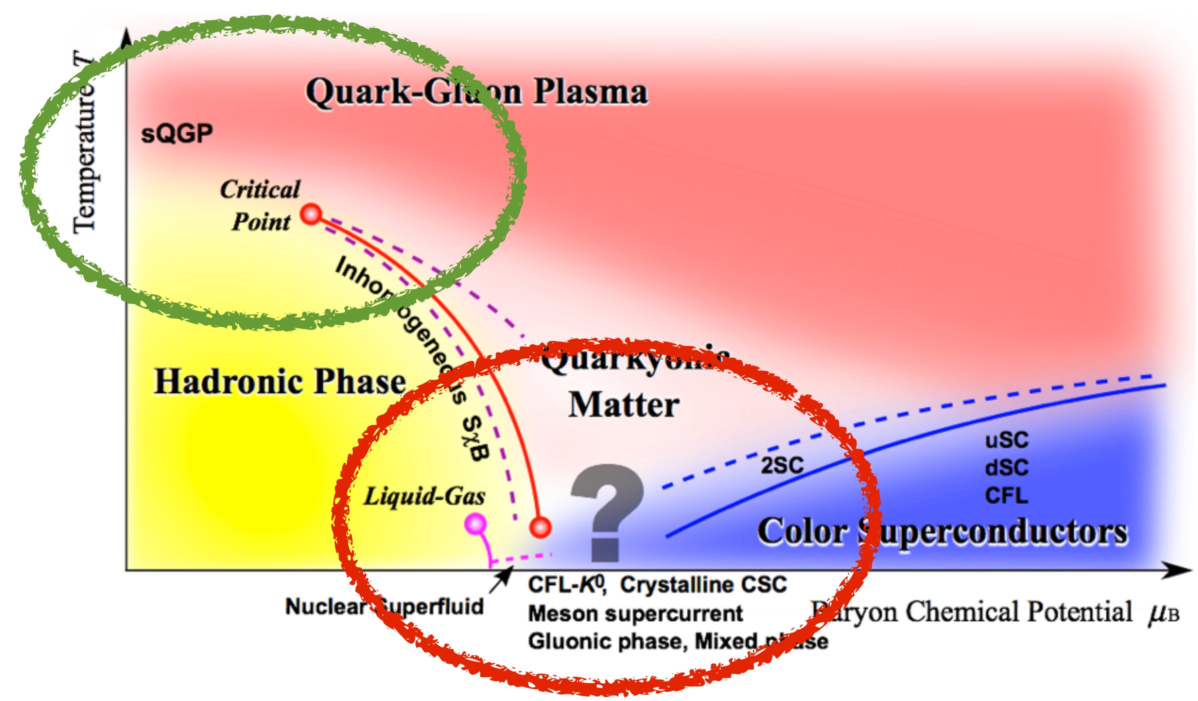




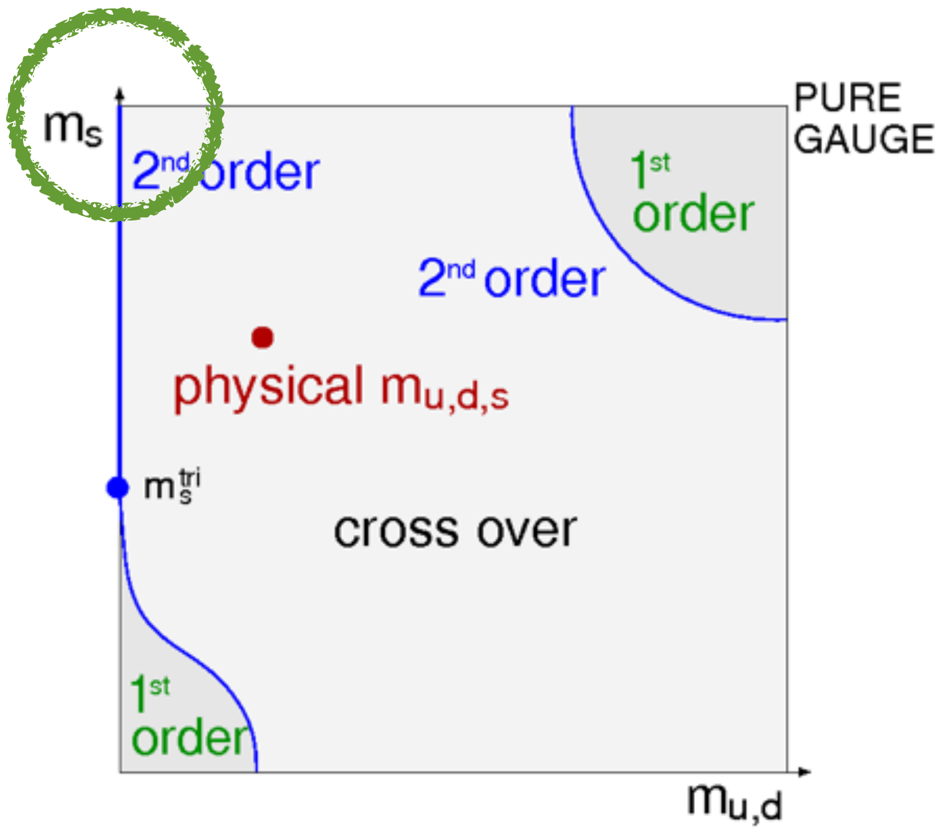


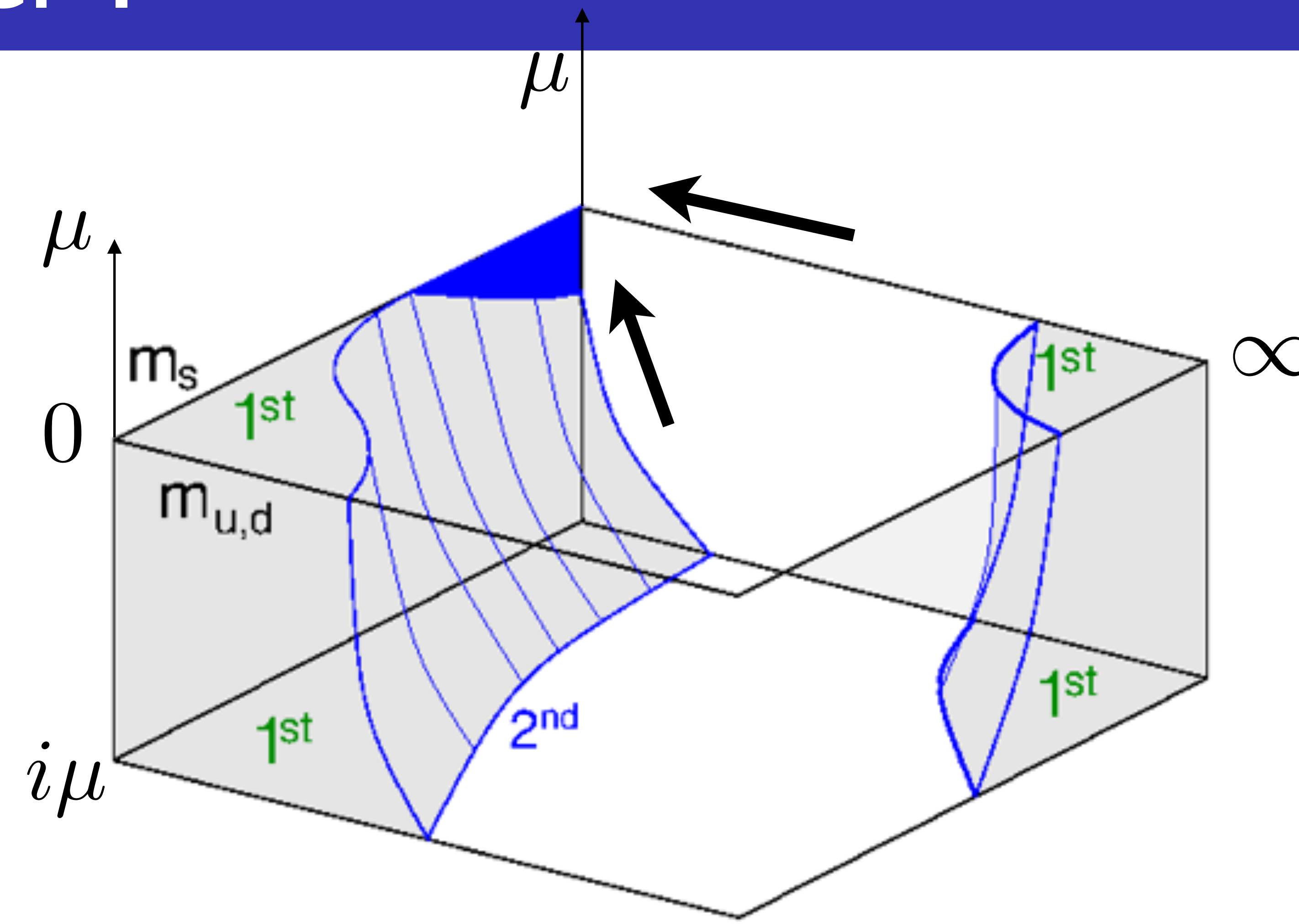
Open questions:

- existence and location of CEP
- inhomogeneous phases
- observables: η/s



The chiral N_f=2 - corner I





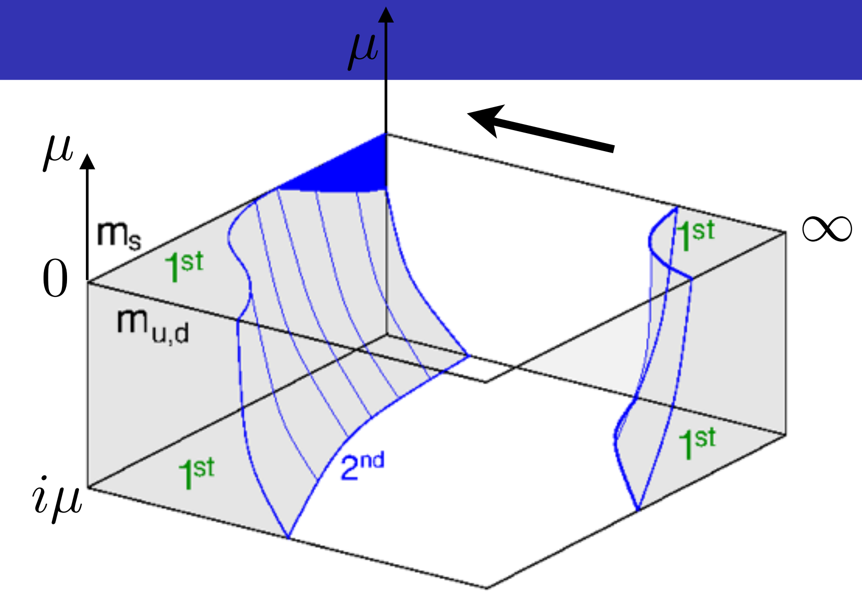
- N_f=2: QCD chiral symmetries: 1st or 2nd order
- connected to axial $U_A(1)$-symmetry

  not restored at $T \approx T_c$: 2nd order O(4)

  restored at $T \approx T_c$: 1st or 2nd order U(2)xU(2)

The chiral N_f=2 - corner II

Dick, Karsch, Laermann, Mukherjee and Sharma, PRD 91 (2015) 9, 094504



Lattice method:

- restoration of $U_A(1)$ makes π and δ degenerate

$$\chi_\pi - \chi_\delta \overset{V\to\infty}{\longrightarrow} \int_0^\infty d\lambda \frac{4m^2\rho(\lambda,m)}{(\lambda^2+m^2)^2} \qquad \text{for} \;\; m_{u,d} \to 0$$

ρ : eigenvalue density of overlap quark operator

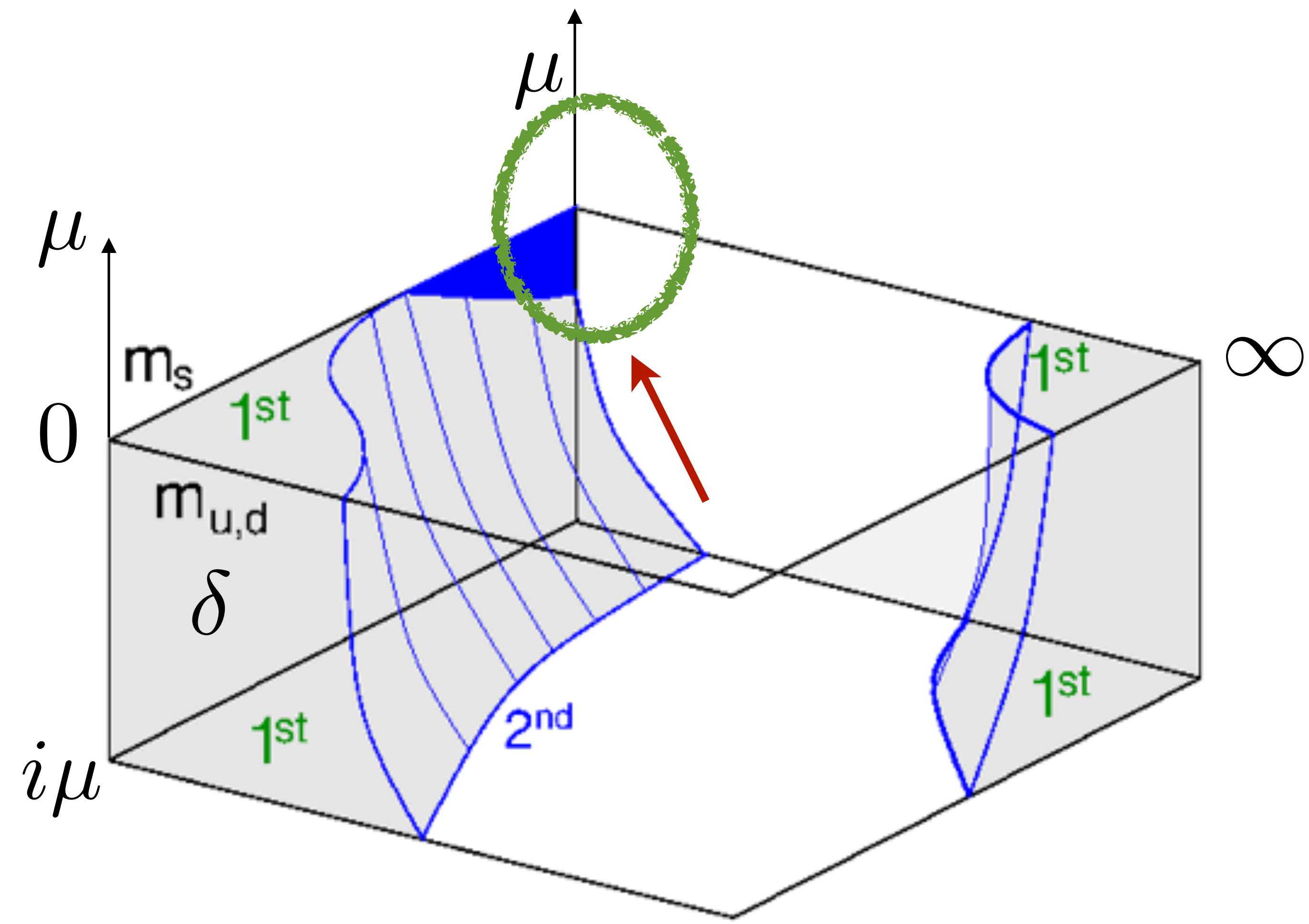
Result:

- $\rho(0,0) \neq 0$ up to $T = 1.5T_c$
- axial $U_A(1)$-symmetry is not restored: 2nd order O(4)

The chiral N_f=2 - corner III

Lattice method:

- staggered or Wilson fermions
- map out critical line →

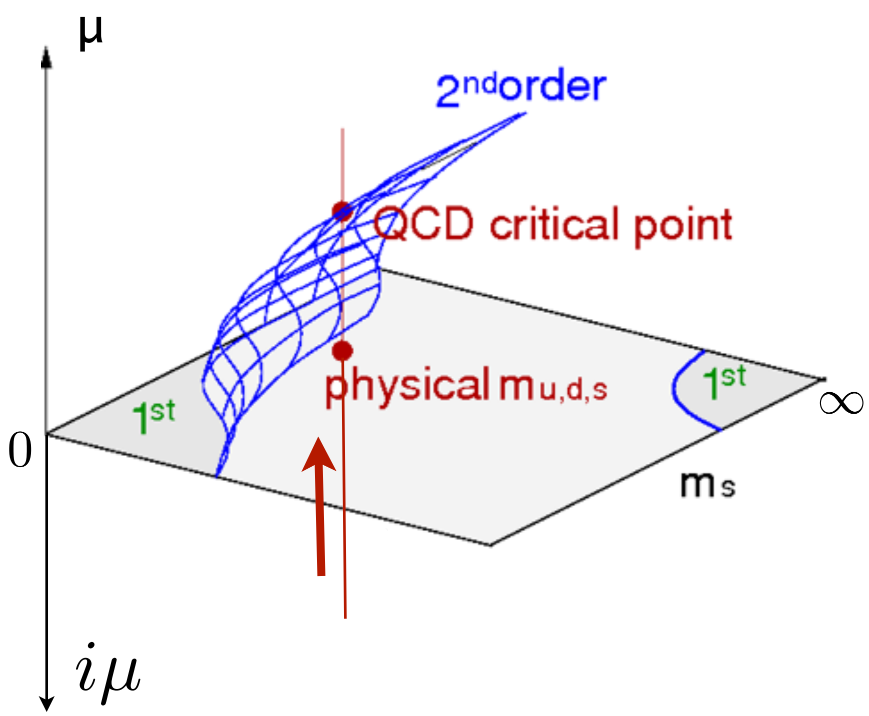


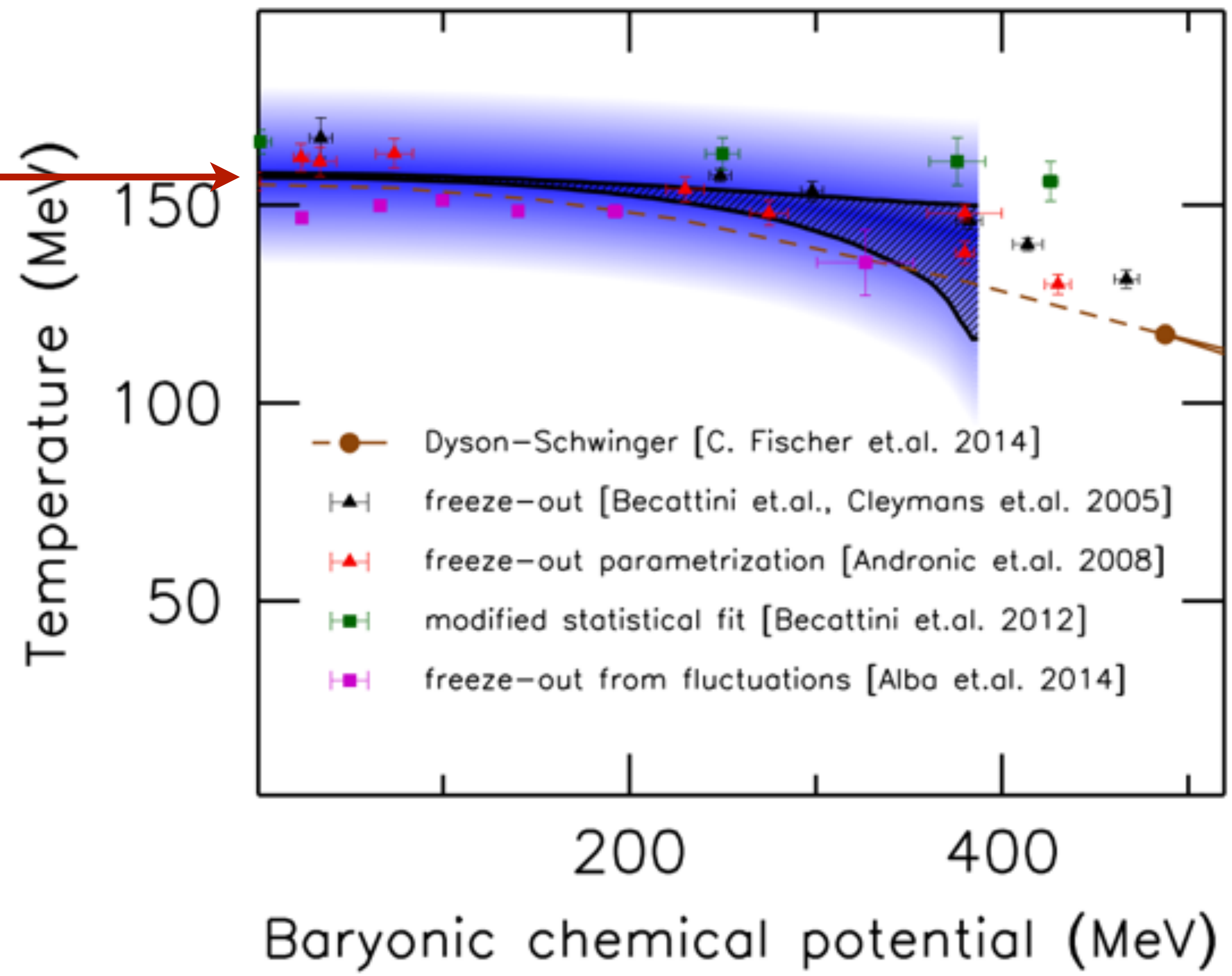
Results:

- N_T=4: tricritical point at real μ, i.e. chiral N_f=2 is 1st order
- N_T=6: chiral 1st order region shrinks...

Bonati, de Forcrand, D'Elia, Philipsen and Sanfilippo,PRD 90 (2014) 7
Cuteri, Czaban, Philipsen and Pinke, arXiv:1511.03105 [hep-lat]

Chiral transition line from analytic continuation





Bellwied, Borsanyi, Fodor, Günther, Katz, Ratti and Szabo, PLB B 751 (2015) 559

Lattice method:

- Calc. boundary at imaginary and extrapolate to real μ
- Control systematics

Results:

- Larger curvature than previous results (but: different definitions and error budget)

Freeze out line from lattice QCD

Basic idea:

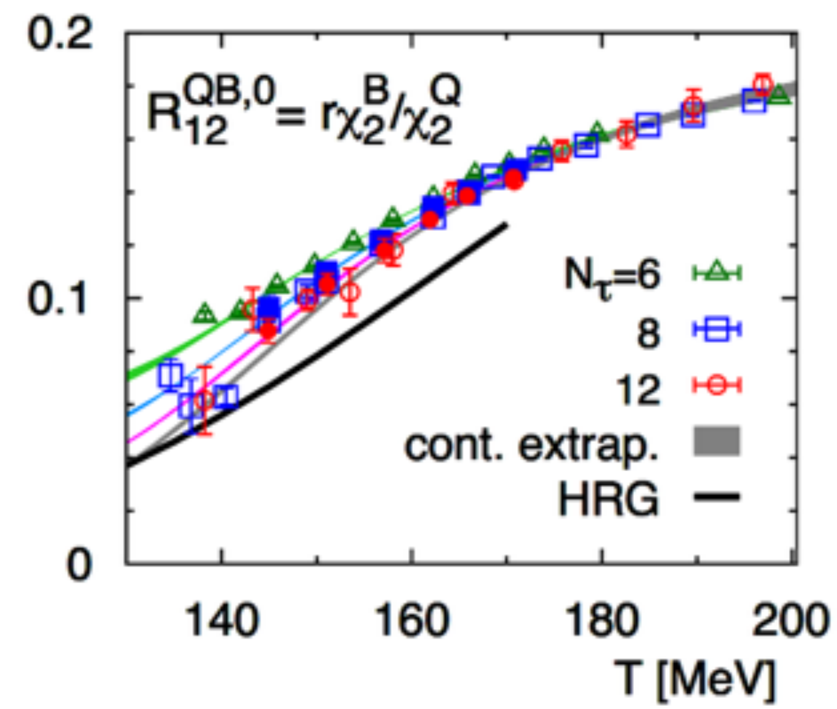
- Constrain freeze-out line by baryon number and electric charge fluctuations

$$T_f(\mu_B) = T_{f,0}\left(1 - \kappa_2^f \left(\frac{\mu_B}{T_{f,0}}\right)^2 - \cdots\right)$$

$$R_{12}^{QB} = R_{12}^{QB,0} + \left(R_{12}^{QB,2} - \kappa_2^f\, T_{f,0} \frac{dR_{12}^{QB,0}}{dT_{|T_{f,0}}}\right)\hat{\mu}_B^2$$

$$with\;\; R_{12}^{QB}(T,\mu) = \frac{\chi_1^Q}{\chi_1^B}\frac{\chi_2^B}{\chi_2^Q}$$

extract κ_2^f from lattice QCD and/or experiment

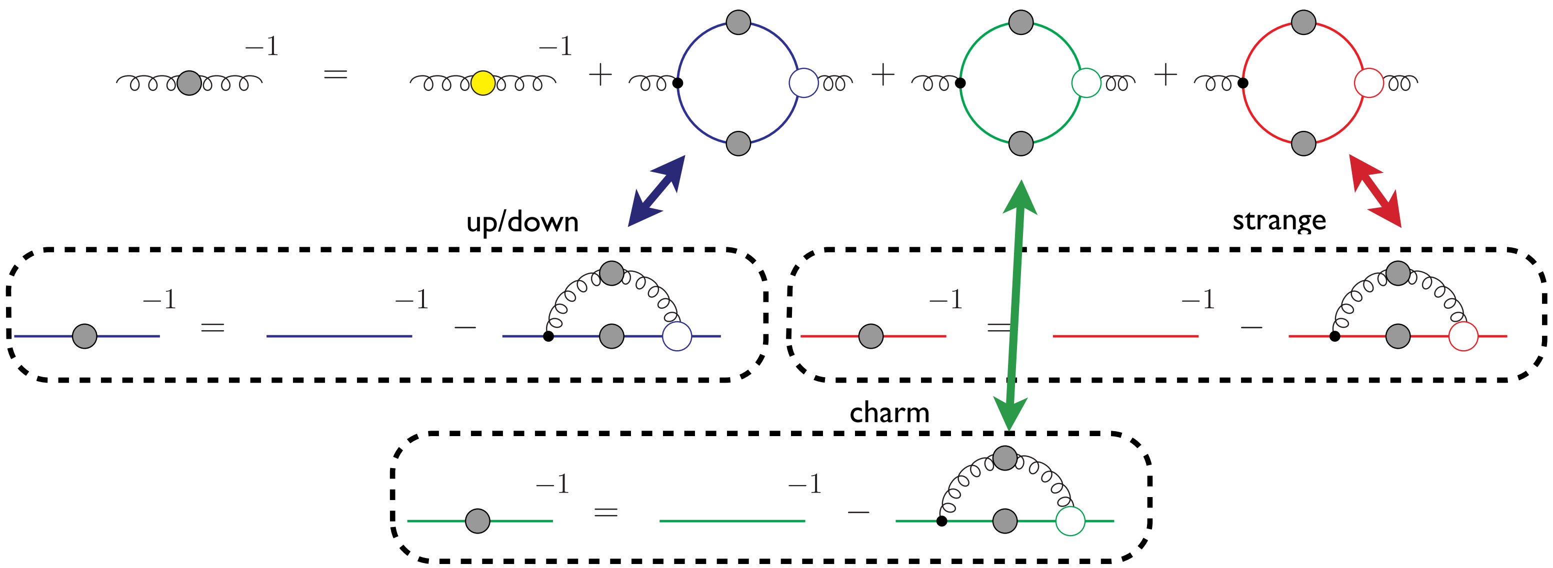


Results:

- Small curvature up to $\sqrt{s_{NN}} \geq 27\text{GeV}\;\; i.e.\;\; \mu_B \leq 150\text{MeV}$

Bazavov, Ding, Hegde, Kaczmarek, Karsch, Laermann {\it et al.}, arXiv:1509.05786 [hep-lat]

Chiral transition line from functional methods

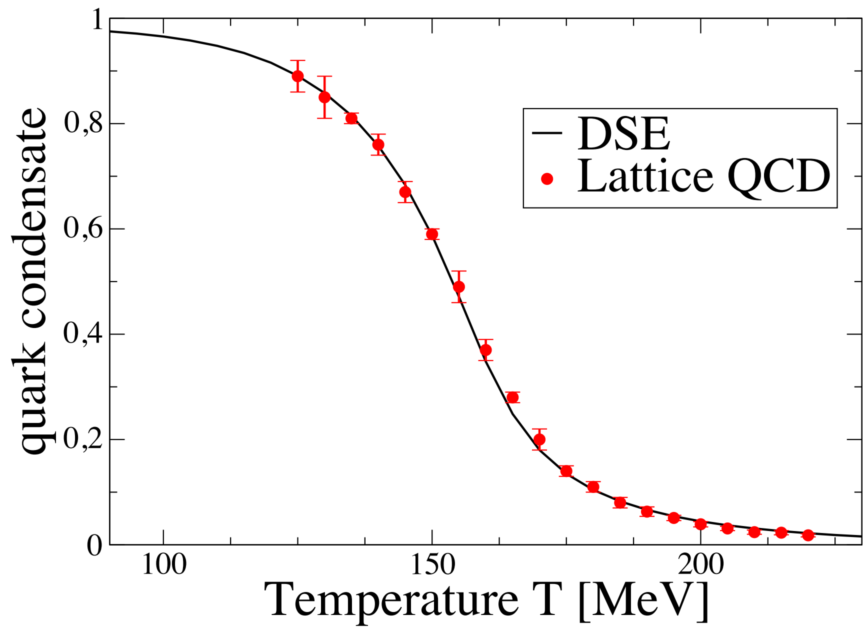


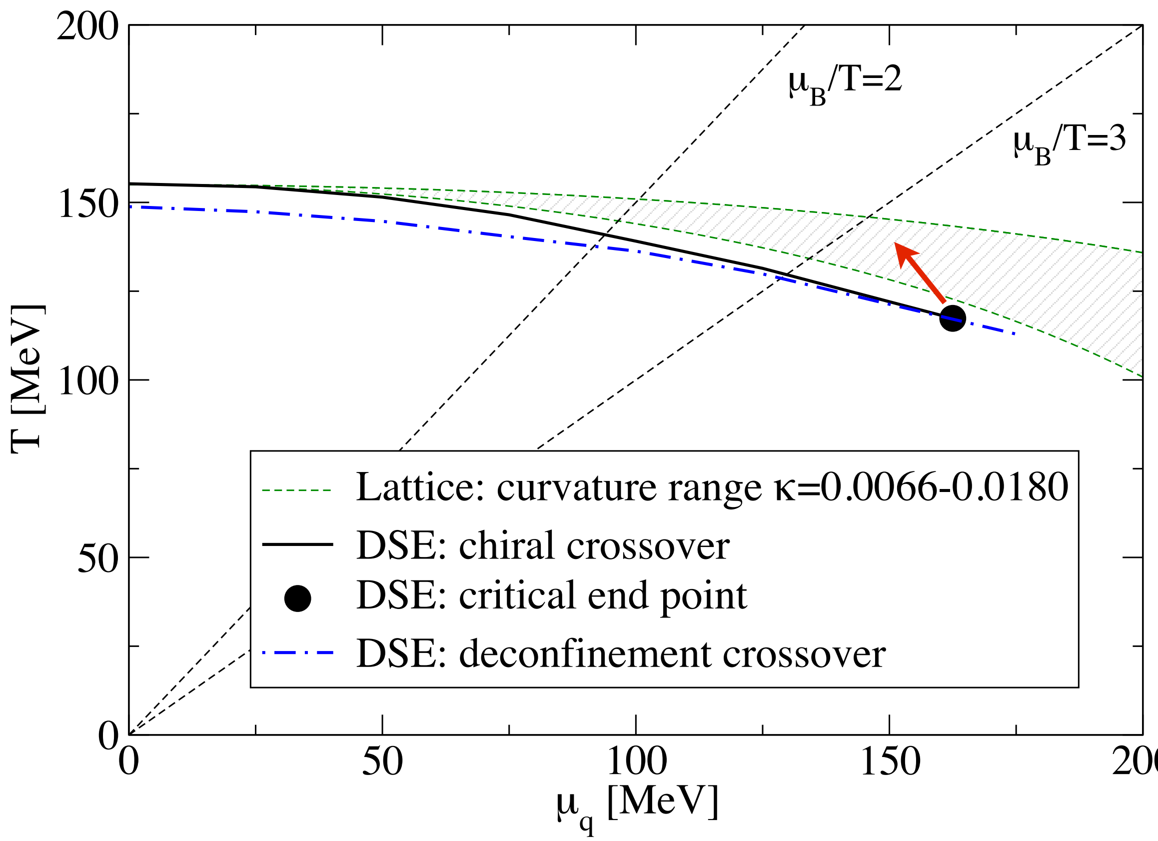
Functional method: DSEs

- Use lattice results at μ=0 as input (quenched glue) and crosscheck (chiral condensate)

Fischer, Luecker and Welzbacher, PRD 90 (2014) 3,034022
Eichmann, Fischer and Welzbacher, arXiv:1509.02082 [hep-ph]

Chiral transition line from functional methods





Functional method: DSEs

- Use lattice results at μ=0 as input (quenched glue) and crosscheck (chiral condensate)

Results:

- CEP at large chemical potential
- Baryon effects: curvature may decrease (exploratory calc.)

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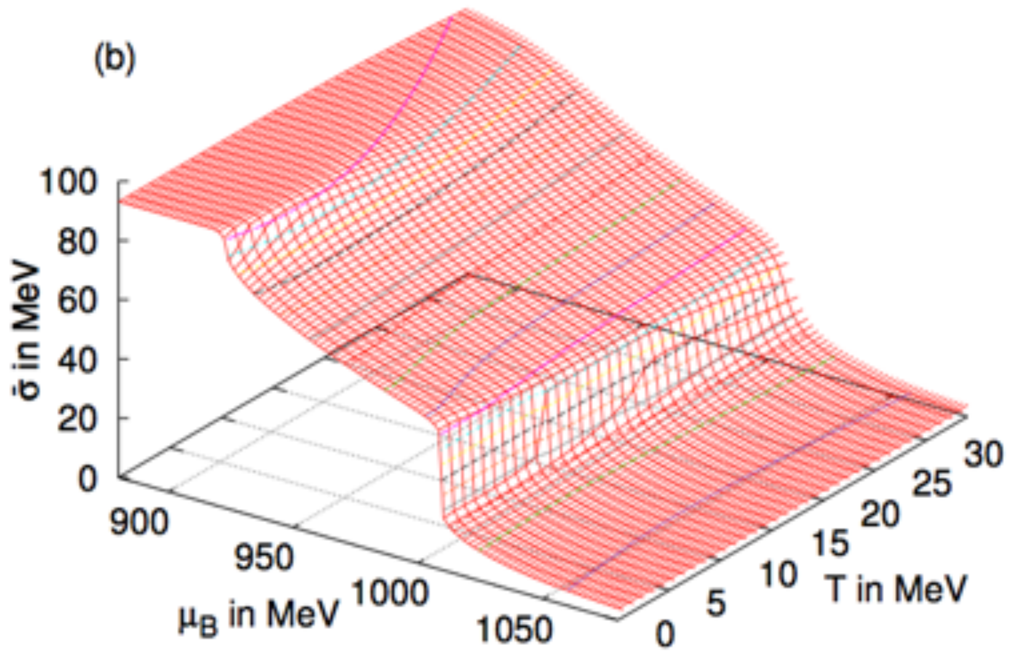
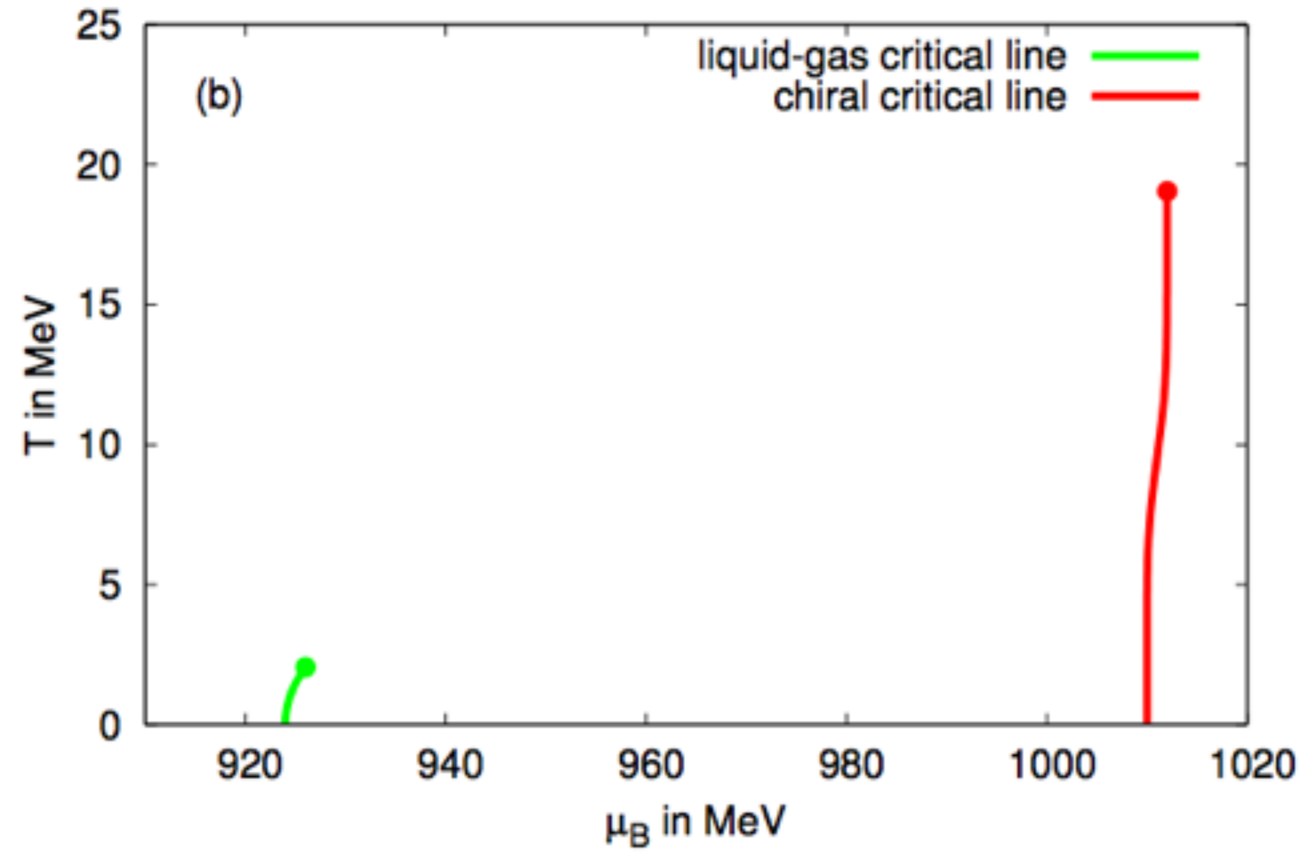
Nuclear matter beyond mean field





FRG-treatment of 'Mirror model':

- Baryons multiplets together with parity partners: finite baryon masses in chiral limit
- Interaction via meson exchanges

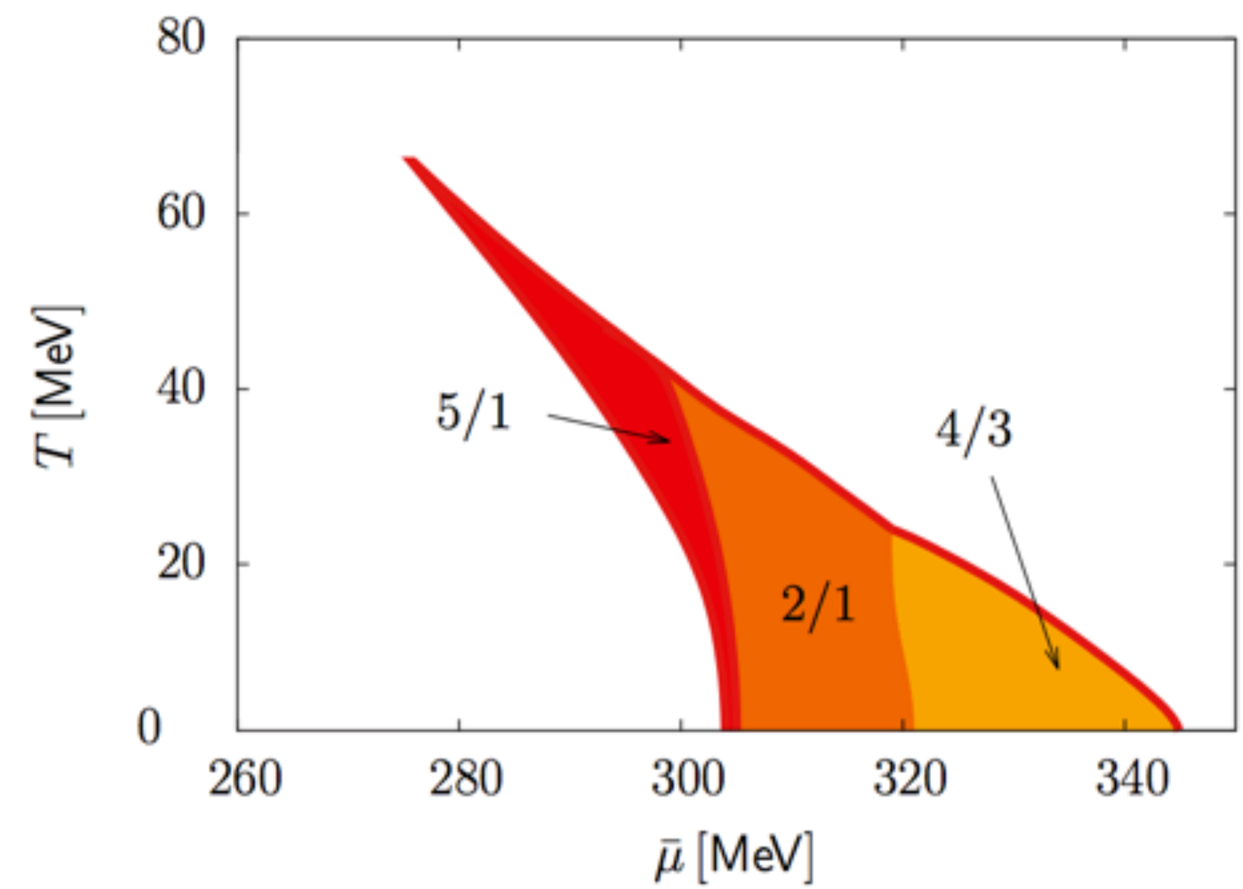
Results:

- See both, liquid-gas and chiral transition
- Qualitatively stable wrt. fluctuations

Weyrich, Strodthoff and von Smekal, PRC 92 (2015) 1, 015214

Basic idea:

- allow for spatially varying chiral condensates
- potential impact on transport and cooling in compact stars



Mean field NJL-model:

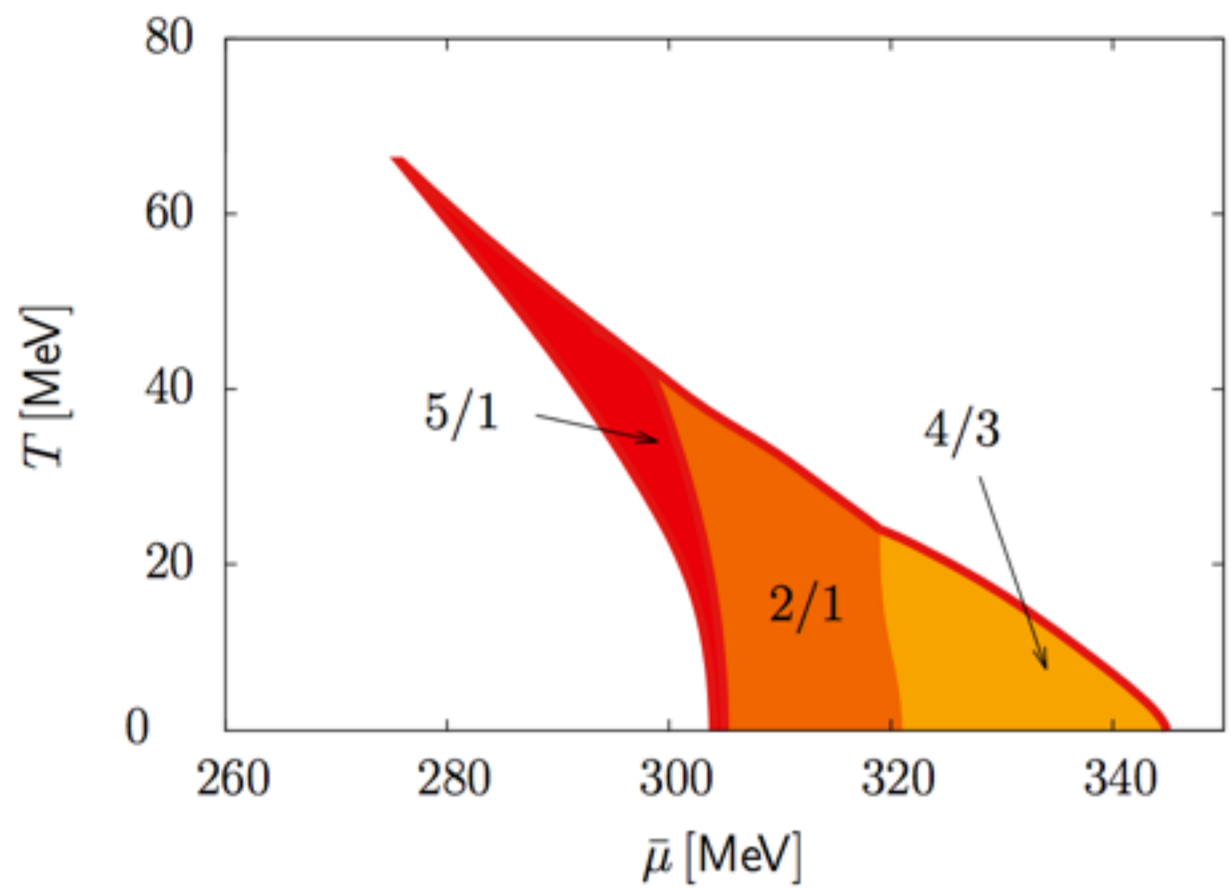
- Compact stars: charge neutrality and beta-equilibrium implies isospin imbalance

Nowakowski, Buballa, Carignano and Wambach, arXiv:1506.04260 [hep-ph]Buballa and Carignano, Prog. Part. Nucl. Phys. 81 (2015) 39

Inhomogenuous phases

Basic idea:

- allow for spatially varying chiral condensates
- potential impact on transport and cooling in compact stars



Mean field NJL-model:

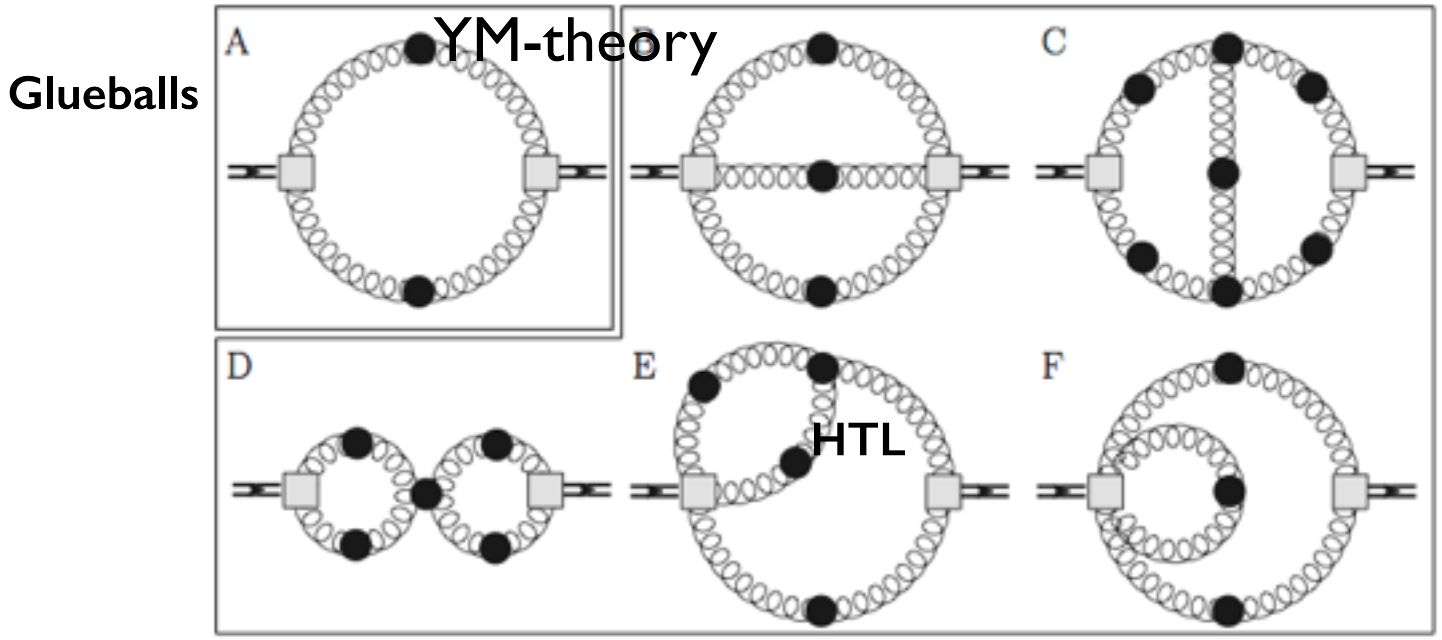
- Compact stars: charge neutrality and beta-equilibrium implies isospin imbalance

Results:

- Stable inhomogeneous regime

Nowakowski, Buballa, Carignano and Wambach, arXiv:1506.04260 [hep-ph]Buballa and Carignano, Prog. Part. Nucl. Phys. 81 (2015) 39

Transport coefficients: η/s



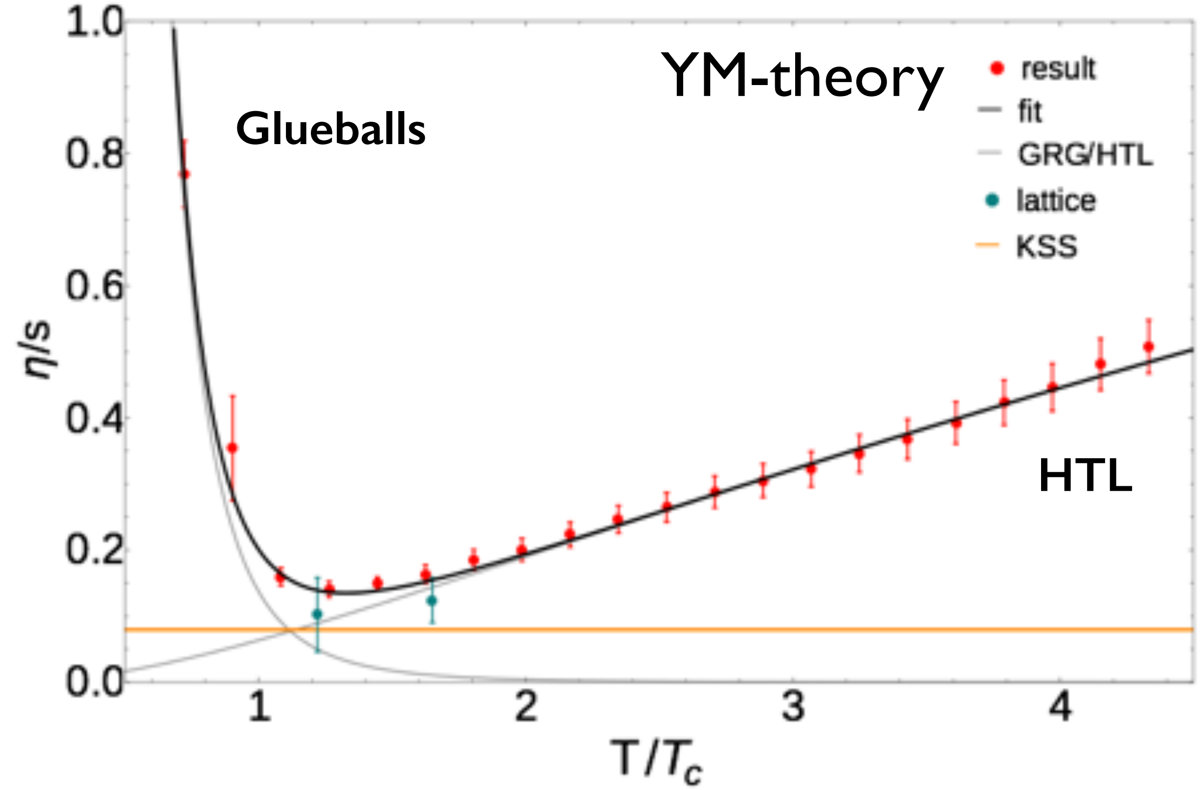
Functional method:

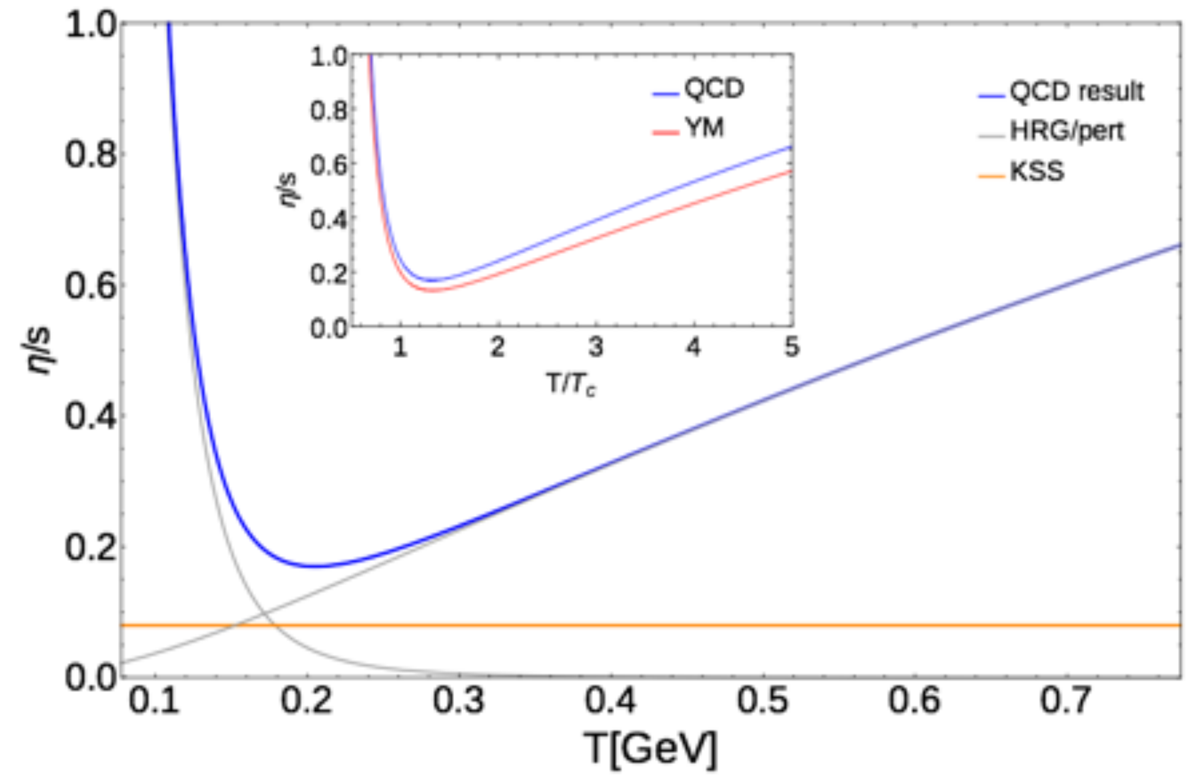
- Calc. gluon spectral function and running coupling
- Kubo formula to determine η/s

Results:

- Good agreement DSE vs lattice at pure YM
- First estimate for QCD using perturbative quark corrections

Christiansen, Haas, Pawlowski and Strodthoff, PRL 115 (2015) 11, 112002





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