Chiral restoration and deconfinement in two-color QCD with two flavors of staggered quarks

David Scheffler[1], Christian Schmidt[2], Philipp Scior[1], Dominik Smith[1], and Lorenz von Smekal[1,3]
[1]TU Darmstadt, [2]Uni Bielefeld, [3]Uni Gießen

Motivation

- understand phases of strong-interaction matter under extreme conditions in temperature and density
- develop reliable methods for finite baryon density where fermion sign problem prevents direct lattice Monte-Carlo simulations
- detour: QCD-like theories without fermion sign problem

This project: chiral properties

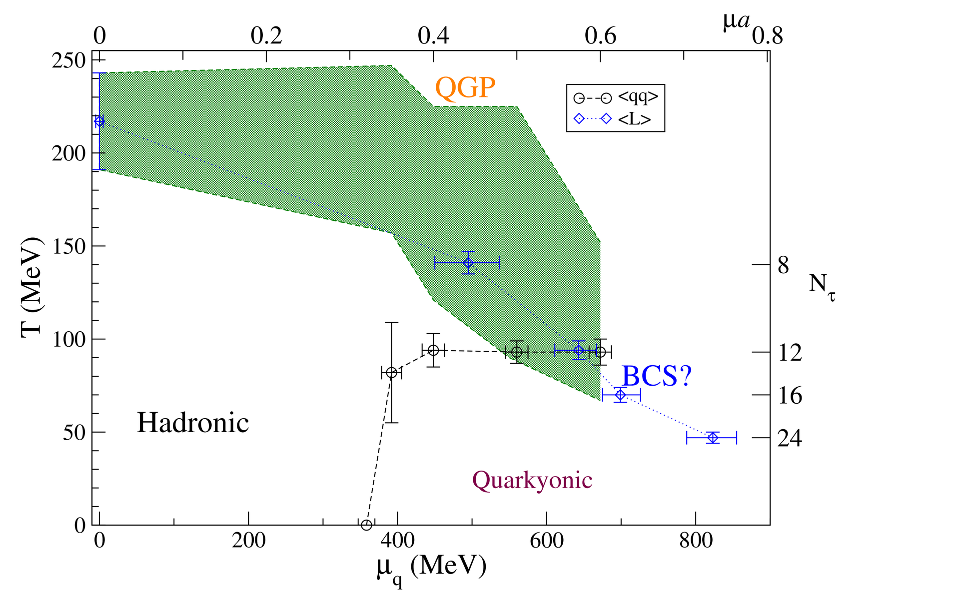
- preparations for finite density
- setting of (relative) temperature scale
- determine (unusual) chiral scaling behavior

Two-Color QCD

- Dirac operator has antiunitary symmetry
  → no fermion sign problem
  → extended flavor symmetry
- color-singlet diquarks: bosonic baryons
- would-be Goldstone bosons: pions and diquarks
- BEC-BCS crossover in diquark condensation phase

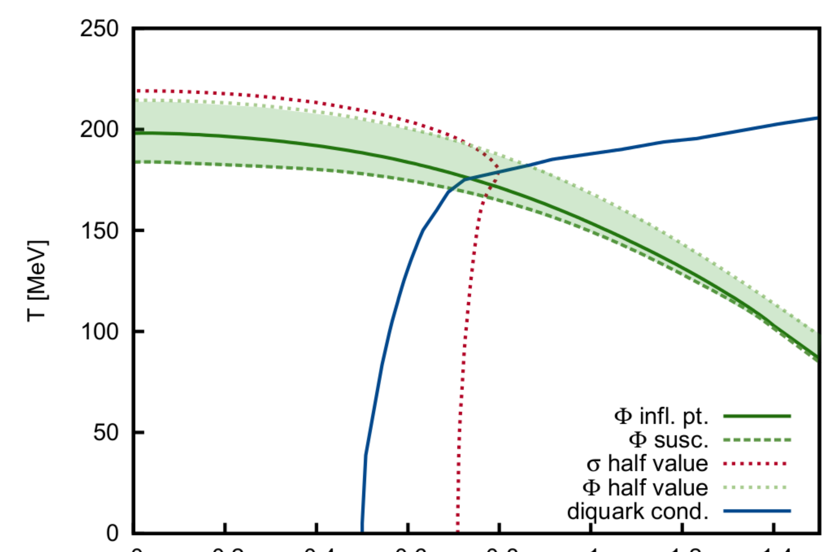
Chiral Symmetry Breaking Pattern

- continuum: $SU(2N_f) \to Sp(N_f)$
- staggered: $SU(2N_f) \to O(2N_f)$, here: $SU(4) \simeq O(6) \to O(4)$



Two-Color Lattice QCD ($N_f = 2$ Wilson fermions)

Boz, Cotter, Fister, Mehta, Skullerud, Eur. Phys. J. A49 (2013) 87 [arXiv:1303.3223]

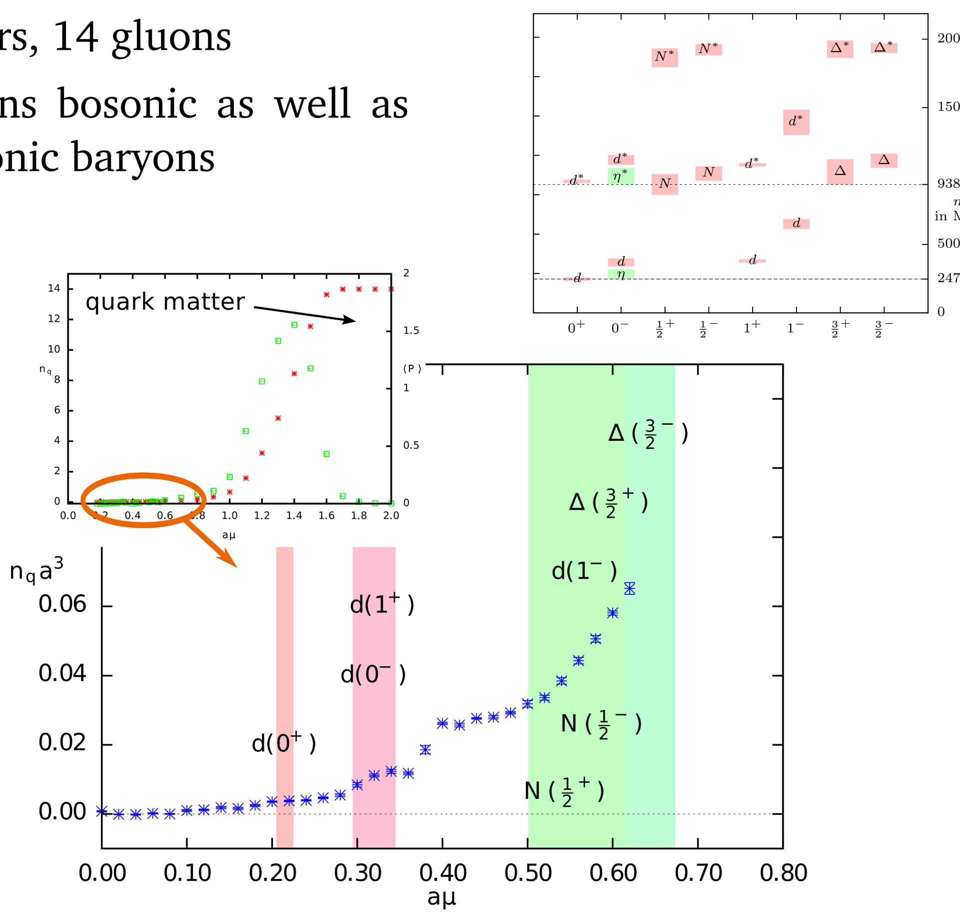


Two-Color Polyakov-Quark-Meson-Diquark model

Strodthoff, von Smekal, Phys. Lett. B731 (2014) 350 [arXiv:1306.2897]

G_2-QCD

- gauge group of QCD replaced by exceptional Lie group G_2
- contains SU(3) as subgroup
- no fermion sign problem → can be simulated at finite baryon density using standard lattice techniques
- without quarks: first order deconfinement transition
- 7 colors, 14 gluons
- contains bosonic as well as fermionic baryons



G_2-mass spectrum and possible G_2-nuclear-matter transition

Maas, von Smekal, Wellegehausen, Wipf, Phys. Rev. D 86, 111901(R) (2012) [arXiv:1203.5653]

Wellegehausen, Maas, Wipf, von Smekal, Phys. Rev. D 89, 056007 [arXiv:1312.5579]

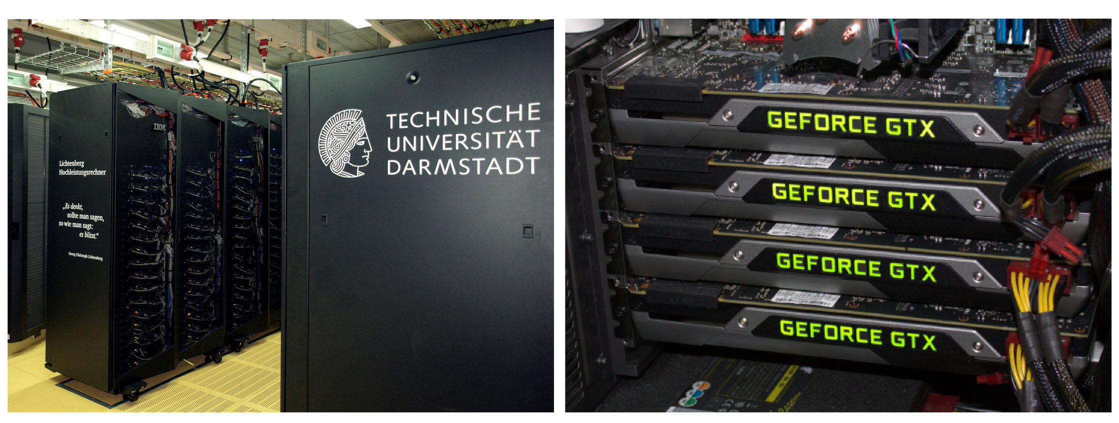
Simulation Details

- $N_f = 2$ staggered quarks

$$\mathscr{D} = \frac{1}{2a}\sum_\mu \eta_\mu(x)\left(U_\mu(x)\delta_{y,x+\hat\mu} - U_{-\mu}(x)\delta_{y,x-\hat\mu}\right) + m\,\delta_{x,y}$$

with *staggered phases* $\eta_\mu(x) = (-1)^{x_0+\ldots+x_{\mu-1}}$

- $N_t = 4, 6, 8$ with aspect ratio $N_s/N_t = 4$
- finite temperature: vary coupling β
- various masses for chiral extrapolation



Lichtenberg Cluster and local machines @ TU Darmstadt

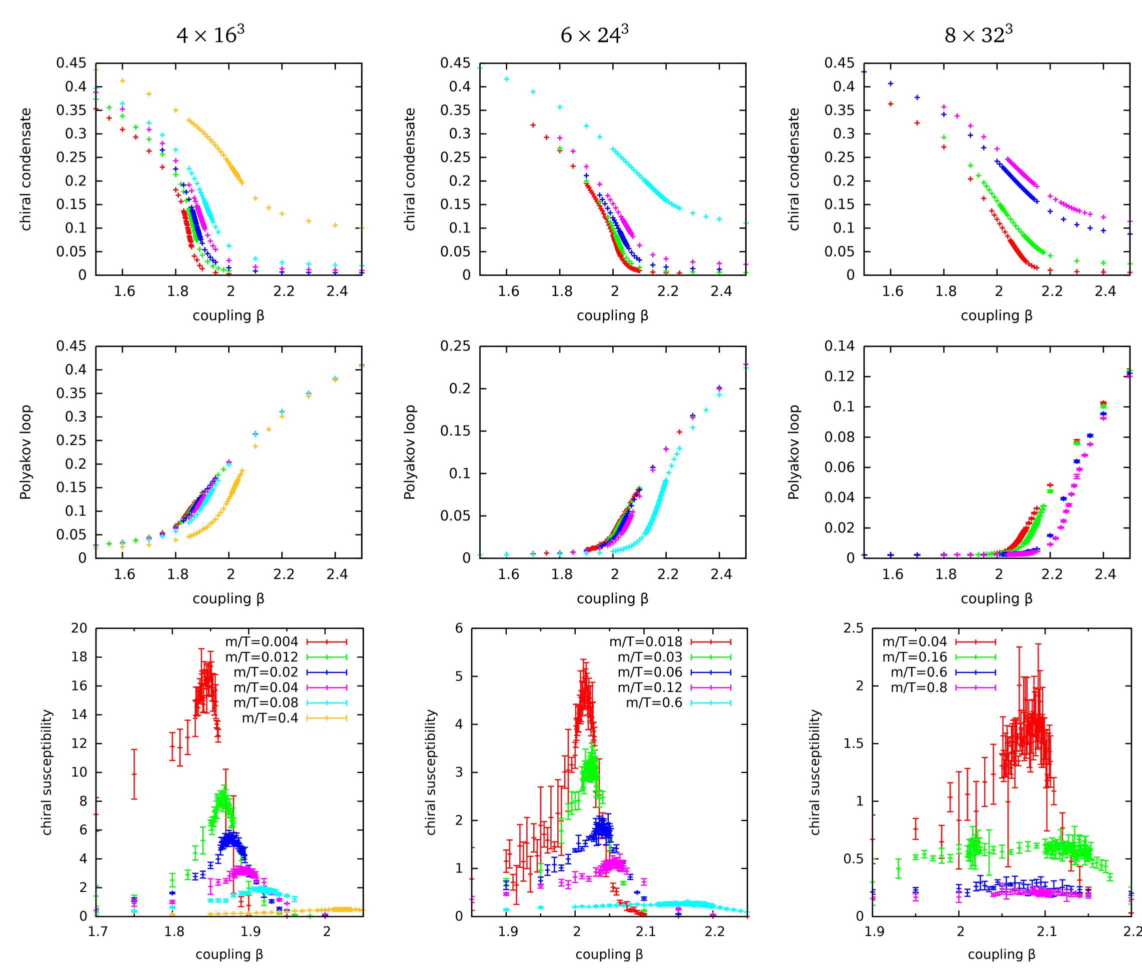
- generation of gauge configurations via Rational Hybrid Monte-Carlo (RHMC) algorithm
- implemented with CUDA
- running on NVIDIA Tesla K20X (up to 1.3 TFlops in DP), GTX Titan or GTX 780
- inversion of fermion matrix is numerically expensive
- exemplary runtime:
  $N_t = 8$, $N_s = 32$, $m/T = 0.04$ data: ≈ 80 GPU months

Support

GEFÖRDERT VOM
HIC for FAIR Helmholtz International Center
Bundesministerium für Bildung und Forschung

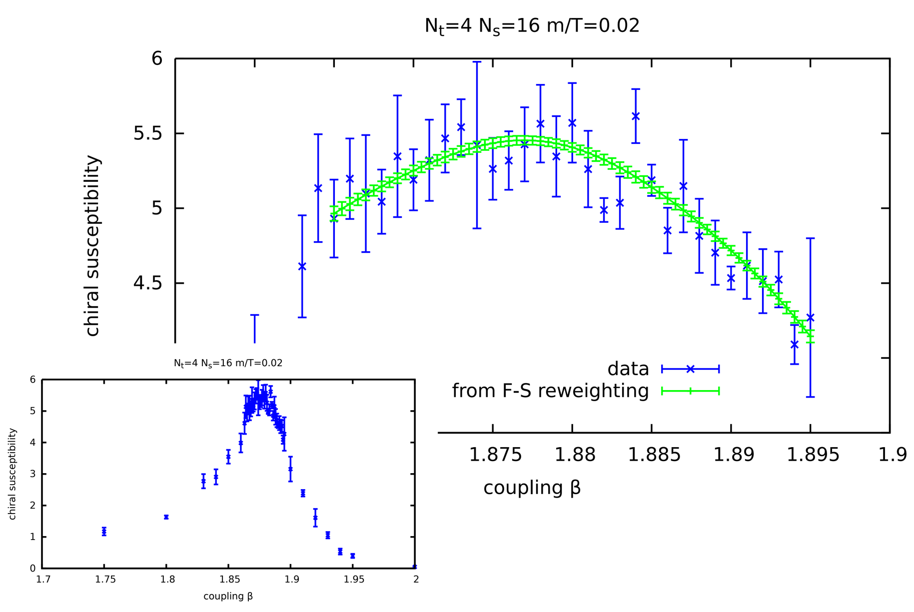
Results

Order Parameters



Ferrenberg-Swendsen Reweighting

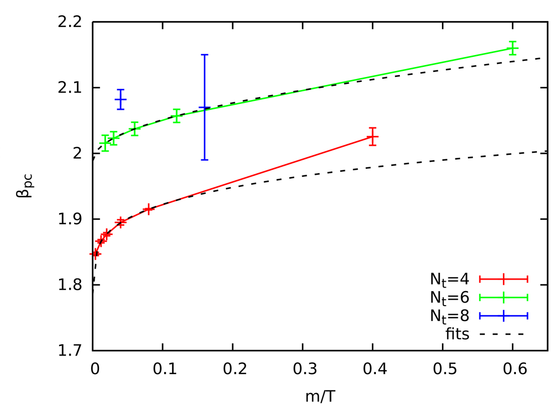
- combination of several ensembles at different values of the coupling β (multi-histogram method)
- enables precise peak determination of chiral susceptibility
- needs overlapping histograms
- successful at $N_t = 4$ and 6, still problematic at $N_t = 8$



Temperature Scale

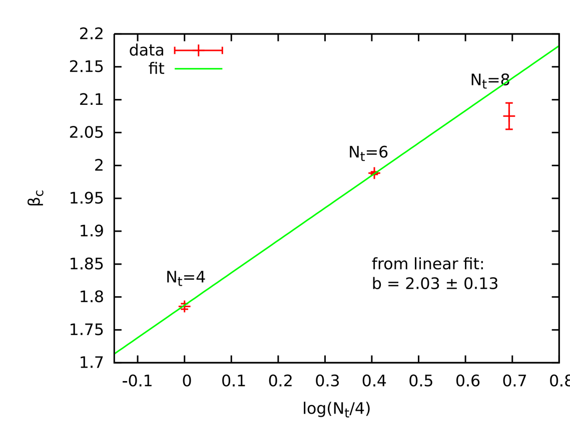
- chiral extrapolation:

$$\beta_{pc}(m, N_t) = \beta_c(N_t) + d \cdot am^c$$



- leading scaling behavior:

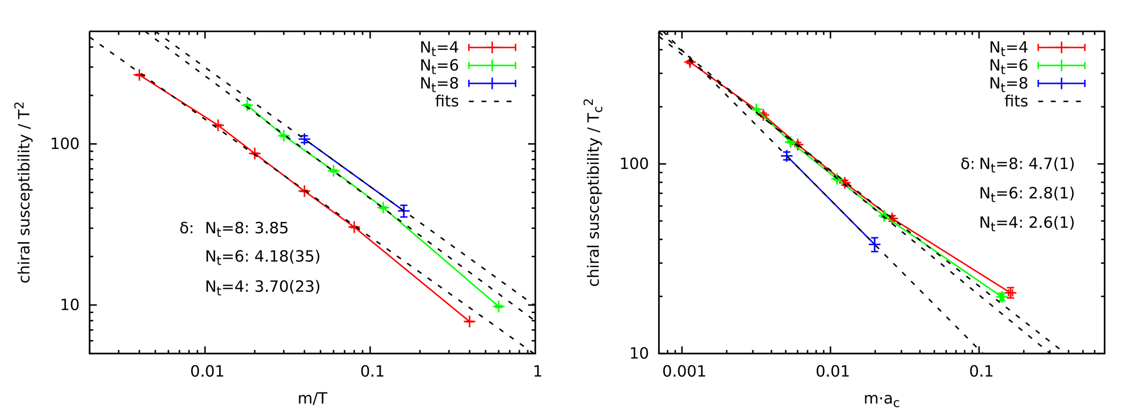
$$\frac{T}{T_c} = \exp\{b(\beta - \beta_c)\}$$



Magnetic Scaling

- determination of a critical exponent via susceptibility peak height:

$$\chi_{max} \sim m^{1/\delta - 1}$$



Outlook

- main goal: Polyakov loop potentials at finite density
- longer runs necessary at $N_t = 8$
- lines of constant physics, scale setting