The Roberge-Weiss transition from $N_f = 2$ QCD with Wilson fermions

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Outline

QCD phase diagram

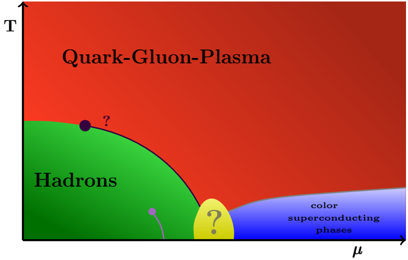
QCD at imaginary μ

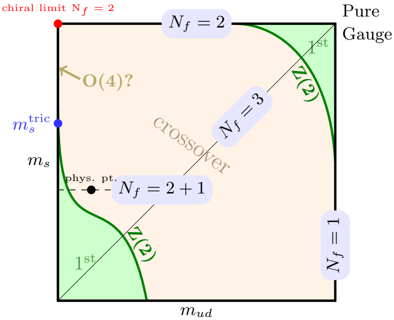
- Roberge-Weiss symmetry

Endpoint of Roberge-Weiss transition for $N_f = 2$ QCD

Summary & Perspectives

QCD phase diagram





Sign-Problem:

$$\det(D+\mu)^* = \det(D-\mu^*)$$

Solutions: Reweighting, Taylor-Series, Complex Langevin...

Imaginary μ

Roberge-Weiss symmetry

Roberge & Weiss, Nucl. Phys. B 275, 734 (1986)

At imaginary μ, QCD has the symmetries:

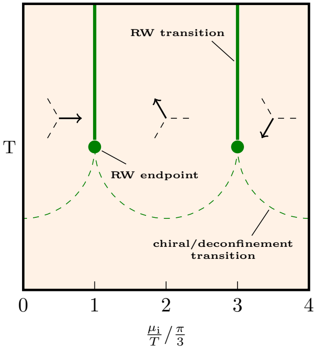
$$Z(\mu) = Z(-\mu)$$

$$Z(\mu/T) = Z(\mu/T + \mathrm{i}\frac{2\pi n}{N_c}), n \in \mathbb{N}$$

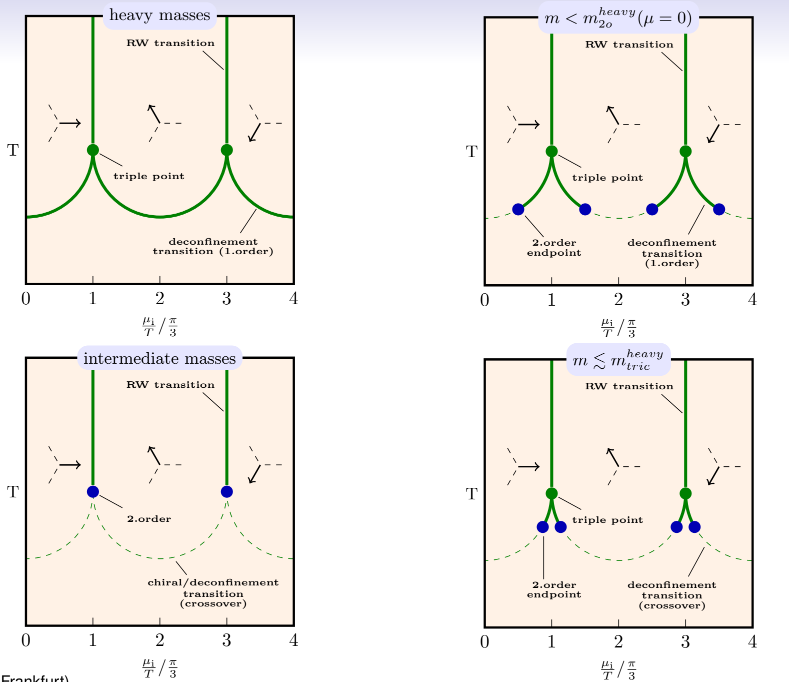
Phases of Polyakov-Loop cycle through different $\mathbb{Z}(N_c)$ sectors:

$$L(x) = \frac{1}{N_c} \mathrm{Tr} \prod_{\tau=1}^{N_\tau} U_0(x) = |L| \mathrm{e}^{-\mathrm{i}\varphi}$$

$$\langle\varphi\rangle = n\,(2\pi/N_c), n = 0, 1..., N_c - 1$$



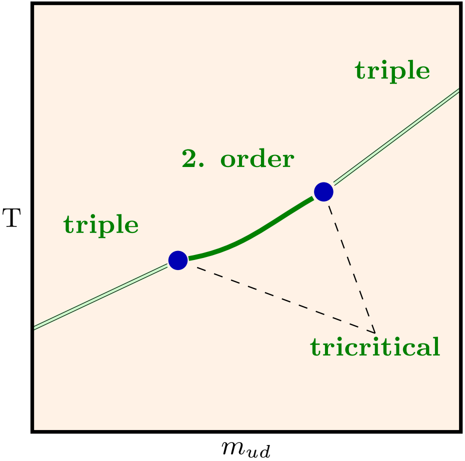
de Forcrand & Philipsen, PRL 105 152001 (2010), D'Elia & Sanfilippo, PRD 80 (2009)


heavy masses
RW transition
triple point
deconfinement transition (1.order)
T
0 1 2 3 4
$\frac{\mu_i}{T} / \frac{\pi}{3}$
$m < m_{2o}^{heavy}(\mu = 0)$
RW transition
triple point
2.order endpoint
deconfinement transition (1.order)
T
0 1 2 3 4
$\frac{\mu_i}{T} / \frac{\pi}{3}$
intermediate masses
RW transition
2.order
chiral/deconfinement transition (crossover)
T
0 1 2 3 4
$\frac{\mu_i}{T} / \frac{\pi}{3}$
$m \lesssim m_{tric}^{heavy}$
RW transition
triple point
2.order endpoint
deconfinement transition (crossover)
T
0 1 2 3 4
$\frac{\mu_i}{T} / \frac{\pi}{3}$

Nature of RW endpoint at $\mu = \mathrm{i}\pi T$

based on staggered studies, $N_\tau = 4$

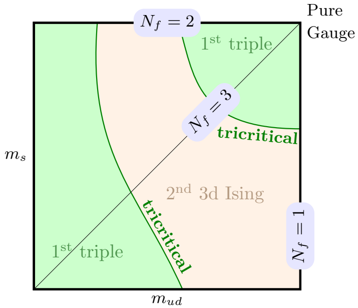
de Forcrand & Philipsen, PRL 105 152001 (2010), D'Elia & Sanfilippo, PRD 80 (2009)

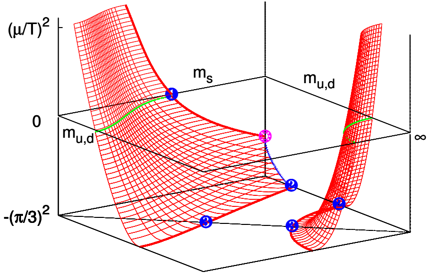


Extended Columbia Plot

based on staggered studies, $N_\tau = 4$

de Forcrand & Philipsen, PRL 105 152001 (2010), D'Elia & Sanfilippo, PRD80 (2009)





Rich phase structure
Constraints on QCD phase diagram

→ Talk by O. Philipsen (8A) ($N_f = 2$)

RW endpoint with Wilson fermions

- Studies done at $\mu = \mathrm{i}\pi T$ and $N_\tau = 4$ for various κ and N_σ
- $\mathcal{O}(10)$ β for each (κ, N_σ)
- Employ reweighting Ferrenberg & Swendsen, PRL 63, 1195 (1989)
- Simulations carried out with OpenCL-based CL^{2}QCD

  Bach, Lindenstruth, Philipsen & Pinke [arXiv:1209.5942]

  $\rightarrow$ talk by M. Bach (4G)

Related work:

- Heavy-Quark effective lattice theory predicts:

  Fromm, Langelage, Lottini & Philipsen [arXiv:1111.4953]

  $$\kappa_{tric}^{heavy} = 0.1048 \pm 0.0008$$

  $\rightarrow$ Talks by J. Langelage & M. Neuman (7A)

- Study by Wu & Meng [arXiv:1303.0336]: Triple points for $\kappa \geq 0.155$

RW endpoint with Wilson fermions

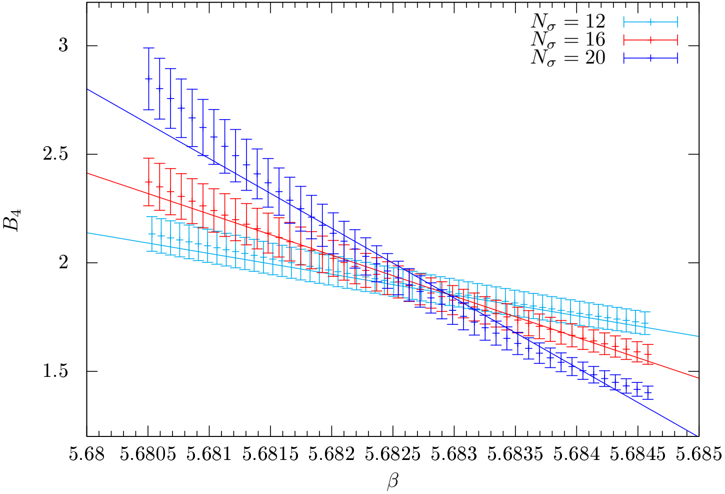
Binder-Cumulant:

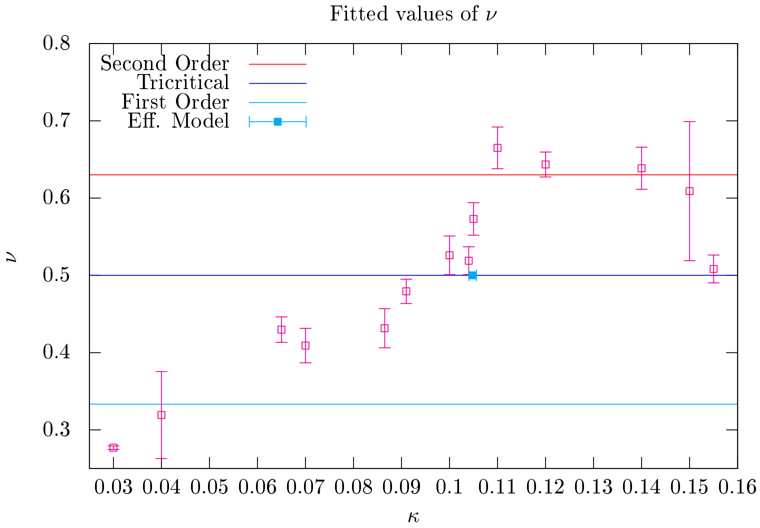
$$B_4(\text{L.Im}) = \frac{\langle(\text{L.Im} - \langle\text{L.Im}\rangle)^4\rangle}{\langle(\text{L.Im} - \langle\text{L.Im}\rangle)^2\rangle^2} \xrightarrow{V \to \infty} \begin{cases} 1.5 & \text{1. order triple} \\ 1.604 & \text{2. order (3D Ising)} \\ 2 & \text{tricritical} \\ 3 & \text{crossover} \end{cases}$$

Finite Size scaling:
Close to the RW-endpoint, B_4 scales with critical exponent ν:

$$B_4(\beta, N_\sigma) = B_4(\beta, \infty) + a_1(\beta - \beta_c)N_\sigma^{1/\nu} + a_2((\beta - \beta_c)N_\sigma^{1/\nu})^2 + \ldots$$

Finite size scaling analysis




Fitted values of ν
Second Order
Tricritical
First Order
Eff. Model
ν
κ
0.8
0.7
0.6
0.5
0.4
0.3
0.03 0.04 0.05 0.06 0.07 0.08 0.09 0.1 0.11 0.12 0.13 0.14 0.15 0.16

Summary

- No sign problem at imaginary μ, HMC applicable
- QCD phase diagram constrained by imaginary μ region
- Started studies to map out $N_f = 2$ phase diagram at Roberge-Weiss value of μ using Wilson fermions
- Qualitative agreement with staggered results
- Quantitative agreement of κ_{tric}^{heavy} with effective theory

Perspectives

- Simulate at smaller masses
- Aoki phase at imaginary μ?