Fractional Charge and Confinement of Quarks

TECHNISCHE UNIVERSITÄT DARMSTADT

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Outline

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Introduction

- Motivation, hidden global symmetry, toy model

Fractional Electric Charge

- SU(2) x U(1): simulations
- SU(3) x U(1): character expansion of fermion determinant
- Implications for the sign problem?

Summary and conclusions

Motivation

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- In QCD with dynamical quarks:

  deconfinement transition, Z_3 connected to SSB of global center symmetry, explicitly broken

- Standard Model exhibits Z_6 center-like symmetry with fermions due to charge quantization $\longrightarrow$ Grand Unified Theories

- Introduce EM interactions with fractional charge to restore center-like symmetry

Center Symmetry and Fractional Charge

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- Toy model: $SU(2) \times U(1)/Z_2$ $\qquad q = \frac{1}{2}$

$$S = -\sum_p \left(\frac{\beta}{2} \mathrm{ReTr}[U_p] + \beta_{\mathrm{em}} \cos 2\varphi_p \right) + \ln \det[D(\varphi_\mu, U_\mu)]$$

- Weak EM coupling limit: gauge action orders links:

$$e^{i\varphi_\mu} \simeq \pm 1 \qquad U(1) \xrightarrow{\beta_{em} \to \infty} Z_2$$

- New Z_2 links: centerlike sym. But: no continuum limit

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Center Symmetry and Grand Unified Theories

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- Toy model: $SU(3) \to SU(2) \times U(1)/Z_2$ $\qquad q = \frac{1}{2}$
- Continuum limit exists
- Different action:

$$S = -\frac{\beta}{3} \sum_p \left(\cos(\varphi_p) \mathrm{Tr}[U_p] + \cos(2\varphi_p) \right) + \ln \det[D(\varphi_\mu, U_\mu)]$$

- After breaking and $\beta_{\mathrm{em}} \to \infty$:

$$\left(SU(2) \times Z_2 \right) / Z_2 \cong SU(2)$$

SU(2) x U(1) Simulations

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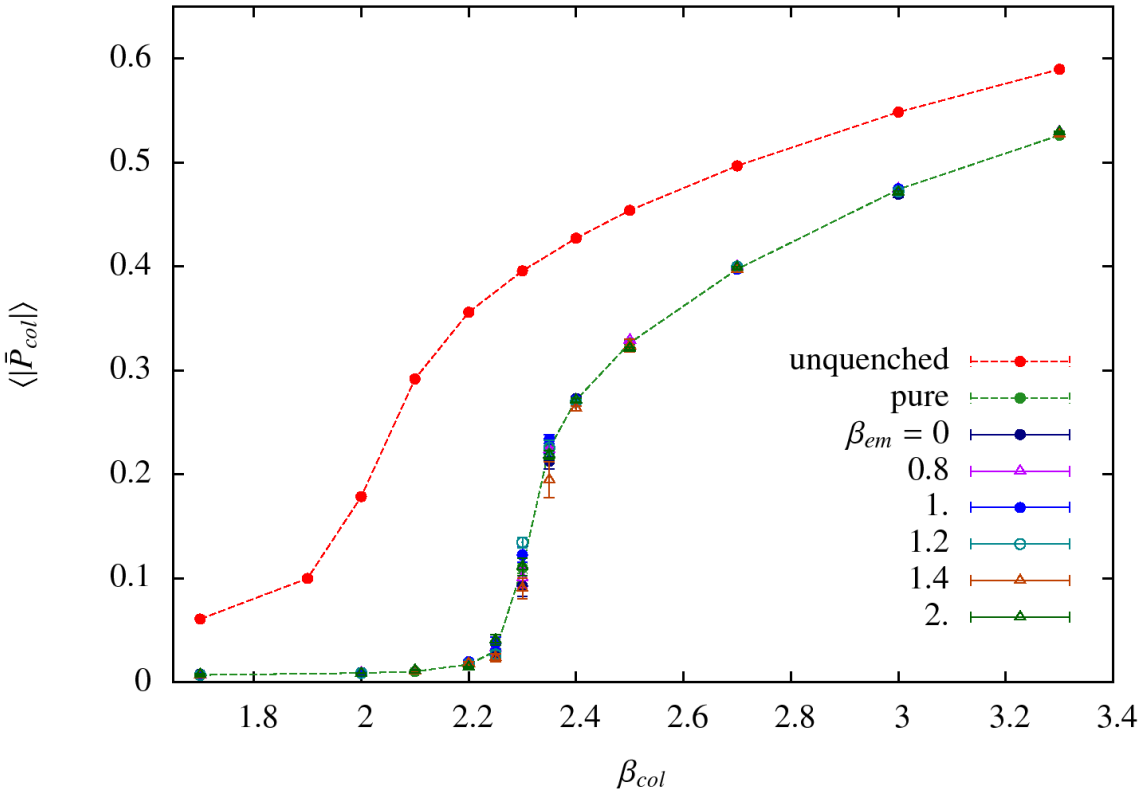
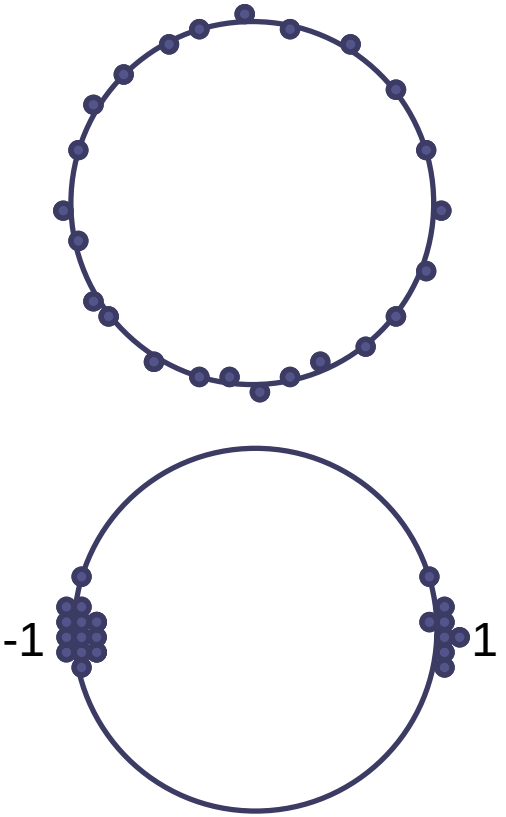
Simulations on 4×16^3 lattices:





Sam Edwards, PhD thesis (2013)

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SU(2) x U(1) Simulations

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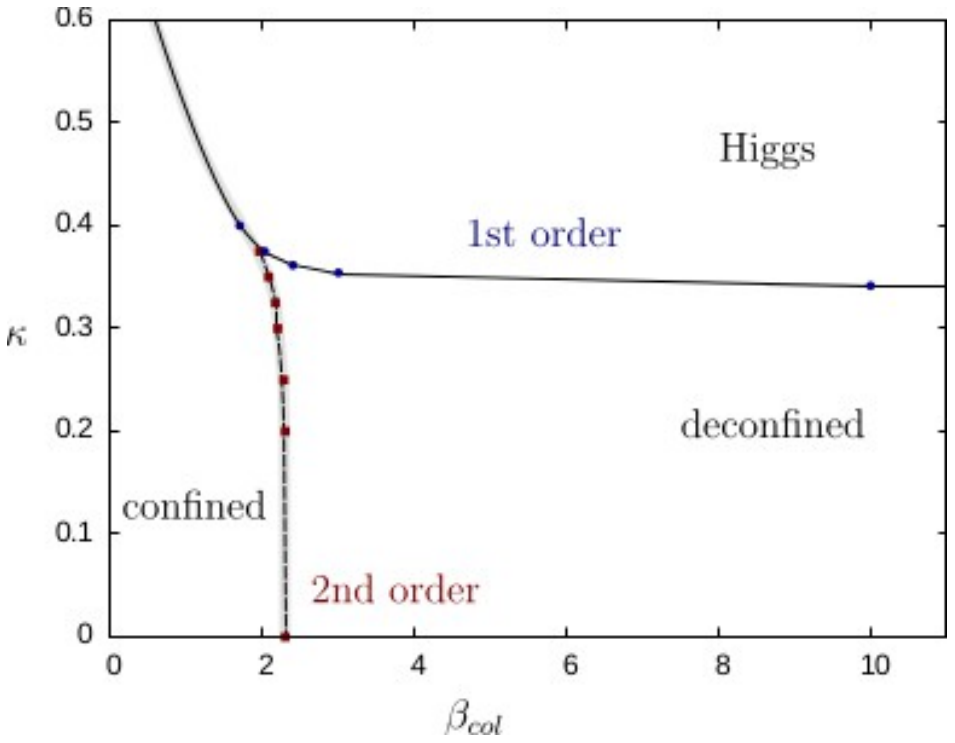
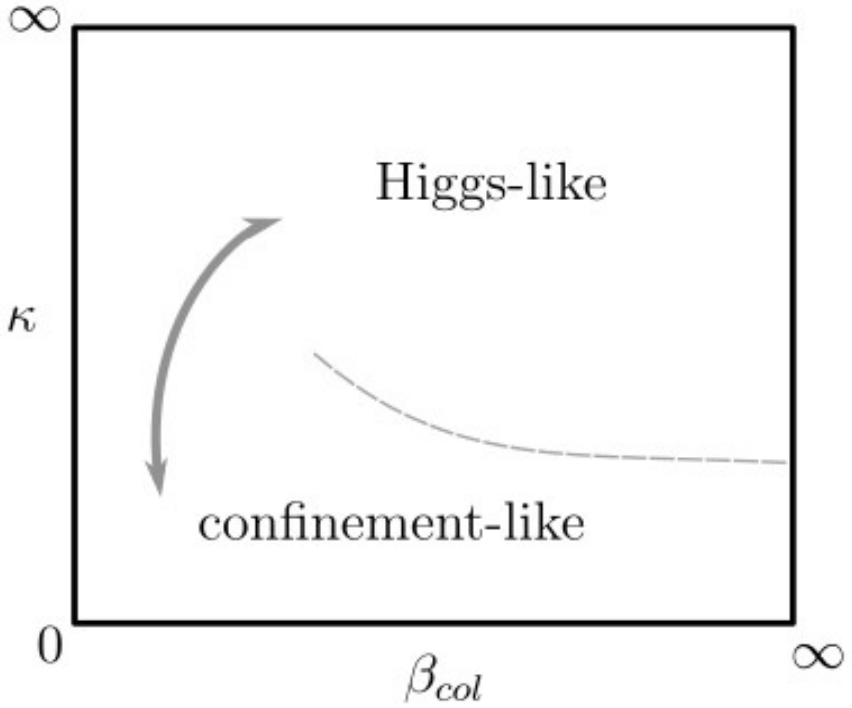
Simulations with $N_t = 4$ in $\mathcal{O}(\kappa^4)$ Hopping expansion:





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Character Analysis of the SU(3) Fermion Determinant

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- Expansion of the Z_3 averaged fermionic weight in group characters (separately for every link):

$$\sum_{z \in Z_3} \exp[-S_f(z_\nu U_\nu)] = \sum_{\lambda,\mu} f^{\lambda\mu} \chi^{\mu\lambda}(U_\nu)$$

$$f^{\lambda\mu} = \int dU_\nu \; \chi^{\mu\lambda}(U_\nu) \sum_{z \in Z_3} \exp[-S_f(z_\nu U_\nu)]$$

- For center symmetry breaking representations: $f^{\lambda\mu} = 0$

partition function is center symmetric

Implications for the Fermion Sign Problem

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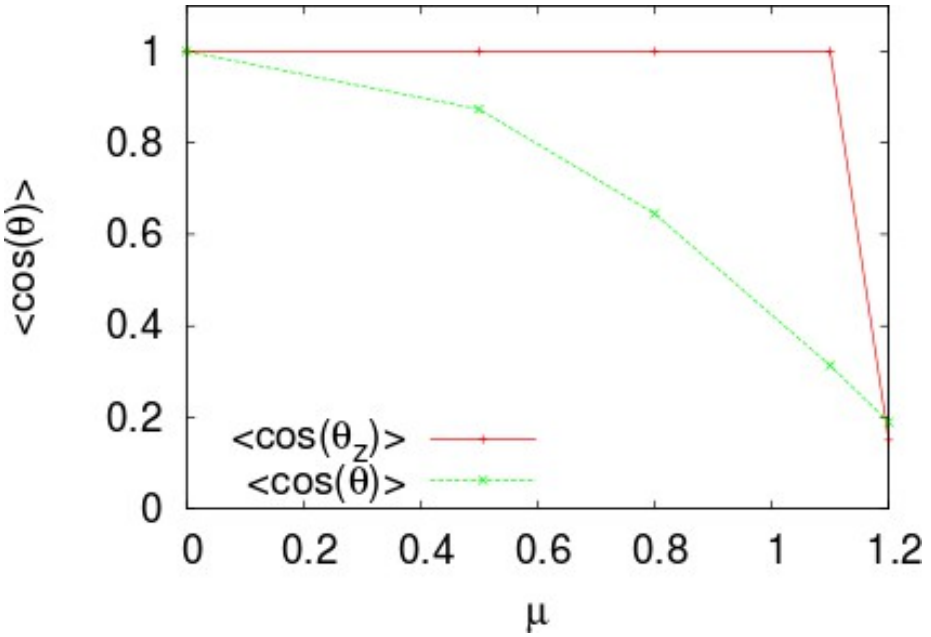
- No sign problem in G2, SU(2) or SU(3) with adjoint quarks theories without explicit breaking of center symmetry
- Does Z_3 averaging remove the sign problem from QCD?
- Not quite, some complex representations remain, i.e. (3,0) representation
- However, sign problem seems less severe in center averaged one link model simulations

Compare to: Bringoltz (2010)



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Summary and Conclusions

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Fractional electric charge and confinement

- Restoration of center symmetry due to additional Z_n fields
- Problems: change of mass scale, no continuum limit
- No suitable GUT candidate yet

Implications for the sign problem

- Z_3 average removes many complex representations from fermion determiant
- One link model shows milder sign problem
- Further simulations with Z_3 averaged fermion contribution