Indications for infrared conformal behaviour of SU(2) gauge theory with $N_f = 3/2$ flavours of adjoint fermions

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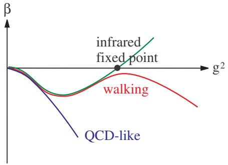
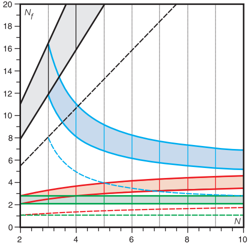
Motivation

- Exploration of the conformal window for adjoint fermions
- $N_f = 1/2$: Super YM, "QCD-like"
- $N_f = 1$: conformal? walking?

  [Athenodorou et. al: 1412.5994]
- $N_f = 2$: conformal fixed point
- Here: $N_f = 3/2$

  [Bergner, Guidice, Münster, Montway, Piemonte, PS: 1712.04692]





[Dietrich, Sannino hep-ph/0611341]

Setup

- tree-level Symanzik-improved gauge action
- Wilson-fermions

$$D_w(x,y) = \delta_{xy} - \kappa \sum_{\mu=\pm 1}^{\pm 4} (1-\gamma_\mu) V_\mu(x) \delta_{x+\mu,y}$$

- adjoint links

$$V_\mu(x)^{ab} = 2\mathrm{Tr}[U_\mu^\dagger(x) T^a U_\mu(x) T^b]$$

- 3 flavours of Majorana fermions with 3 levels of Stout smearing

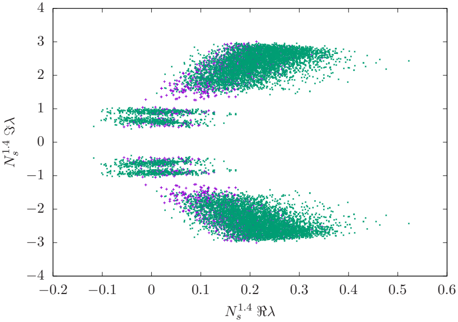
$$\bar{\psi} = \psi^T C$$

- possible sign problem

$$\int [d\psi] e^{-\bar{\psi} D_w \psi} = Pf(CD_w)^3 = \pm(\mathrm{Det} D_w)^{3/2}$$

Simulation

- two-step Polynomial HMC algorithm
- ensembles for $\beta = 1.5$ and 1.7 with several values for κ/am_{PCAC}
- sign problem can be cured by reweighting, however not necessary



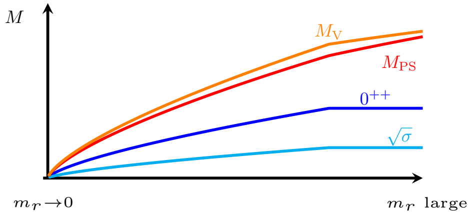
Particle Spectrum and Scaling

- mesons: m_{PS}, m_S, m_V, m_{PV}
- glueballs, e.g. 0^{++}
- spin-1/2 mixed fermion-gluon state

$$\sum_{\mu,\nu} \sigma_{\mu\nu} \mathrm{Tr}[F_{\mu\nu}\psi]$$

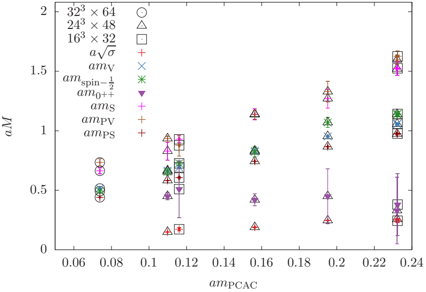
Expected behaviour of a (near) conformal theory:

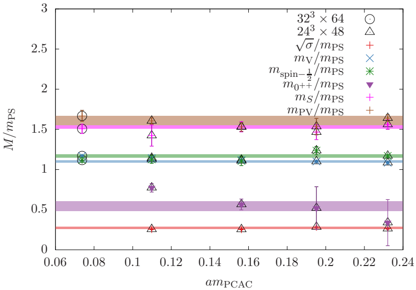
- no light Goldstone boson
- scaling law: $M \propto m_r^{1/1+\gamma^*}$
- constant mass ratios



Particle Spectrum and Scaling

$\beta = 1.5$



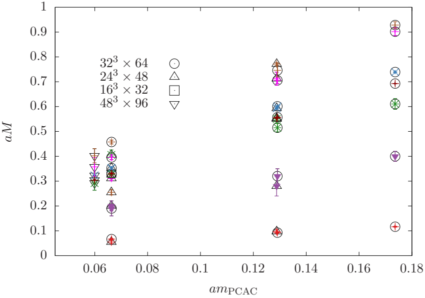


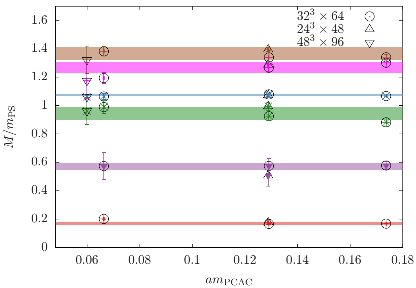
[1712.04692]

mass anomalous dimension: $\gamma^* = 0.499(12)$

Particle Spectrum and Scaling

$\beta = 1.7$





[1712.04692]

mass anomalous dimension: $\gamma^* = 0.33(13)$

Mode Number

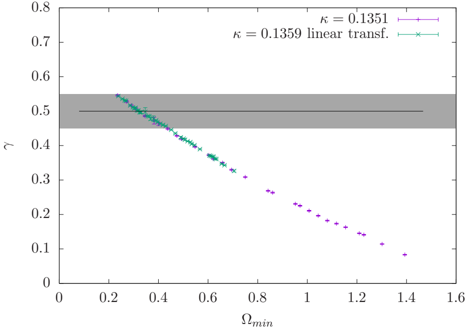
alternative method to determine the mass anomalous dimension:

$$\nu(\Omega) = \nu_0 + a_1(\Omega^2 - a_2^2)^{2/(1+\gamma^*)}$$

- determine $\gamma(\Omega)$ by a fit of ν in some interval $[\Omega_{\mathrm{min}}, \Omega_{\mathrm{max}}]$
- $\Omega \to \infty$: $\gamma(\Omega) \to 0$, gaussian fixed point value
- $\Omega \to 0$: scaling violations from finite size and finite m_{PCAC}
- carefully choose some intermediate $[\Omega_{\mathrm{min}}, \Omega_{\mathrm{max}}]$ for fitting
- conformal: slow change in $\gamma(\Omega) \to$ plateau at γ^*

Mode Number

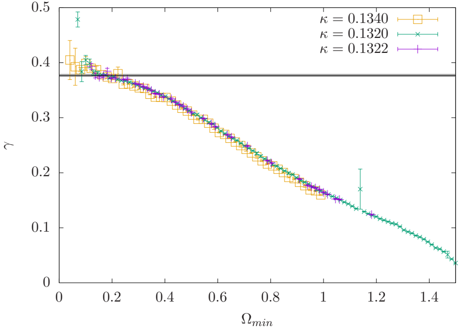
$\beta = 1.5$ with $\kappa = 0.1351$ and $\kappa = 0.1359$



- no plateau visible
- grey band: best χ^2 for both ensembles
- $\gamma^* \approx 0.50(5)$

Mode Number

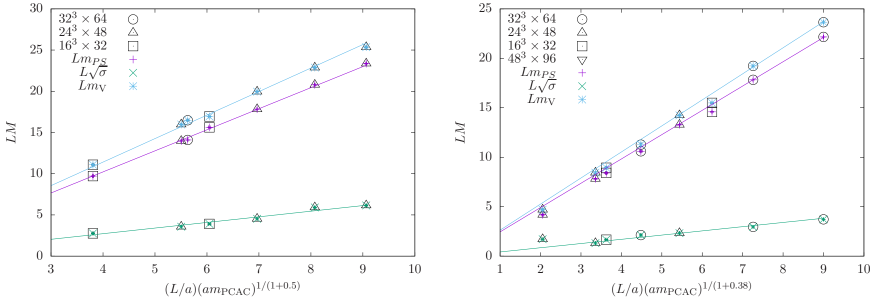
$\beta = 1.7$ with $\kappa = 0.13540$, $\kappa = 0.1320$ and $\kappa = 0.1322$



- plateau forming in the infrared
- $\gamma^* \approx 0.38(2)$

Crosscheck

$\beta = 1.5$ $\beta = 1.7$



[1712.04692]

- γ^* from the mode number together with the hyperscaling of the mass spectrum

Running Coupling

[Bergner, Piemonte: 1709.074510]

- Landau gauge:

$$\alpha(p^2) = \alpha(\mu) Z(p^2) J^2(p^2)$$

MiniMOM scheme:

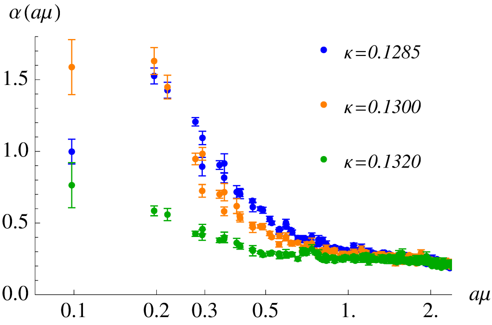
[von Smekal, Maltman, Sternbeck: 0903.1696]

- gluon dressing: $Z(\mu) = 1$
- ghost dressing: $J(\mu) = 1$

$$\alpha(p^2) = \frac{g_{\text{lat}}^2}{4\pi} Z(p^2) J^2(p^2)$$

Running Coupling

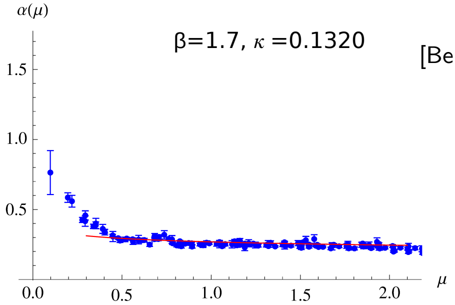
- determine $Z(p^2)$, $J(p^2)$ from gluon-, ghost-propagators in Landau gauge



$$\beta = 1.7,\ N_s = 32,\ N_t = 64$$

- κ is relevant parameter $\rightarrow$ significant running for low p^2
- largest κ: α running slowly over a large momentum range

Running Coupling



[Bergner, Piemonte: 1709.074510]

$$a\Lambda(\beta = 1.5) = 0.0051(8)\,,$$

$$a\Lambda(\beta = 1.6) = 0.0055(4)\,,$$

$$a\Lambda(\beta = 1.7) = 0.0054(5)\,.$$

- determine Λ^{MiniMOM} parameter by fitting to perturbation theory
- unlike QCD: $a\Lambda \ll aM \approx 0.3$
- Λ almost independent of $\beta_{\text{lat}} \to$ slowly running β-function

Summary & Conclusion

- bound state spectrum indicates infrared conformality
- mass anomalous dimension obtained from mode number of the Dirac operator

  $\gamma^*(\beta = 1.5) \approx 0.5, \quad \gamma^*(\beta = 1.7) \approx 0.38$
- cross check of γ^* with hyperscaling of the mass spectrum also points towards conformal behaviour
- running coupling in MiniMOM scheme: scaling violations from finite quark mass.
- determined Λ parameter
- slowly running coupling also indicates theory is close to or inside conformal window

Ensembles

	β	N_s	κ	am_{pcac}
A	1.5	16	0.137	0.02270(18)
B	1.5	16	0.135	0.11604(44)
C	1.5	16	0.132	0.23236(83)
D	1.5	24	0.1351	0.10986(12)
E	1.5	24	0.134	0.15632(15)
F	1.5	24	0.133	0.19515(20)
G	1.5	24	0.132	0.23207(22)
H	1.5	32	0.1359	0.07380(07)
J	1.7	16	0.130	0.12890(77)
K	1.7	24	0.133	0.03360(30)
L	1.7	24	0.132	0.06628(08)
M	1.7	24	0.130	0.12882(15)
N	1.7	32	0.132	0.06635(12)
O	1.7	32	0.130	0.12910(04)
P	1.7	32	0.1285	0.17366(04)
Q	1.7	48	0.1322	0.05990(05)
R1	1.7	24	0.134	-0.00097(22)
R3	1.7	32	0.134	-0.00052(11)