Non-perturbative investigations of gauge theories with adjoint and fundamental matter related to composite Higgs and supersymmetric gauge theories

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Gauge theories with adjoint-fundamental matter

Motivations:

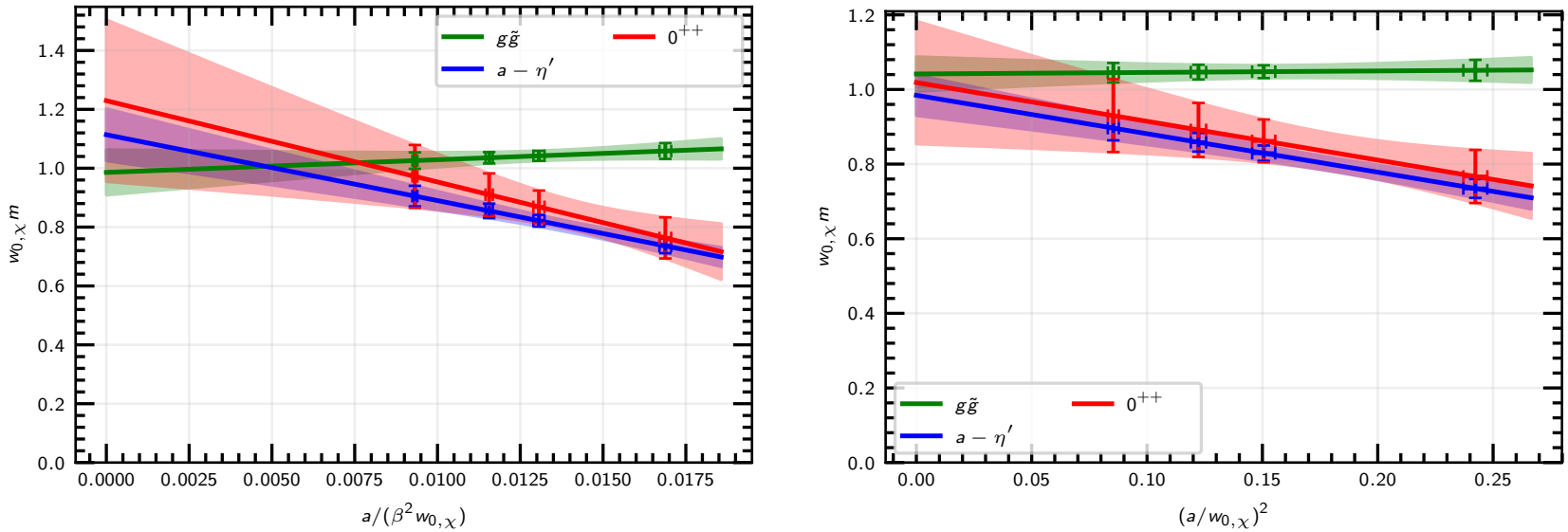
- supersymmetric theories
- composite Higgs scenarios
- quantum distillation and color-flavor center symmetry

$$\mathcal{S}_L = S_G + \sum_{x,y} \sum_{n_f=1}^{N_f^{(F)}} \bar{\psi}_x^{n_f} (D_w^{(F)})_{xy} \psi_y^{n_f} + \sum_{x,y} \sum_{n_f=1}^{N_f^{(A)}} \bar{\psi}_x^{n_f} (D_w^{(A)})_{xy} \psi_y^{n_f}$$

Supersymmetric gauge theories

- pure gauge sector, A_μ + SUSY partner:
  gluino (Majorana fermion in adjoint representation)
- $\mathcal{N} = 1$ supersymmetric QCD: coupling to quark, squark fields
- heavy squark field limit: $(N_f^{(A)} = 1/2) + N_f^{(F)}$ gauge theory
- similarly $\mathcal{N} = 2$ SQCD connected to $N_f^{(A)} = 1$

Supersymmetric gauge theories on the lattice



[S. Ali, GB, H. Gerber, I. Montvay, G. Münster, arXiv:1902.11127]

- SUSY broken by lattice regularization: fine tuning problem
- pure gauge sector: tuning problem solved
- complicated tuning squark fields add $O(10)$ additional counterterms

Composite Higgs scenarios

SU(2) with ($N_f^{(F)} = 2$) fundamental + ($N_f^{(A)} = 1$) adjoint matter:

- $N_f^{(A)} = 1$ adjoint: (near) conformal, large mass anomalous dimension

$\rightarrow$ coupled to standard model by 2 fundamental flavors

- $N_f^{(F)} = 2$ fundamental: composite Higgs scenario

$\rightarrow$ extended towards (near) conformality by $N_f^{(A)}$ adjoint flavors

Ultra minimal walking technicolor

[T. A. Ryttov, F. Sannino,Phys. Rev. D, arXiv:0809.0713]

SU(2) with $N_f^{(A)} = 1$ adjoint Dirac fermion

Motivations

- check alternative IR scenarios:
  1. chiral symmetry breaking
     QCD-like scenario with mesonic pNGb particles
  2. conformal IRFP
     mass scaling according to mass anomalous dimension
  3. light baryon scenario

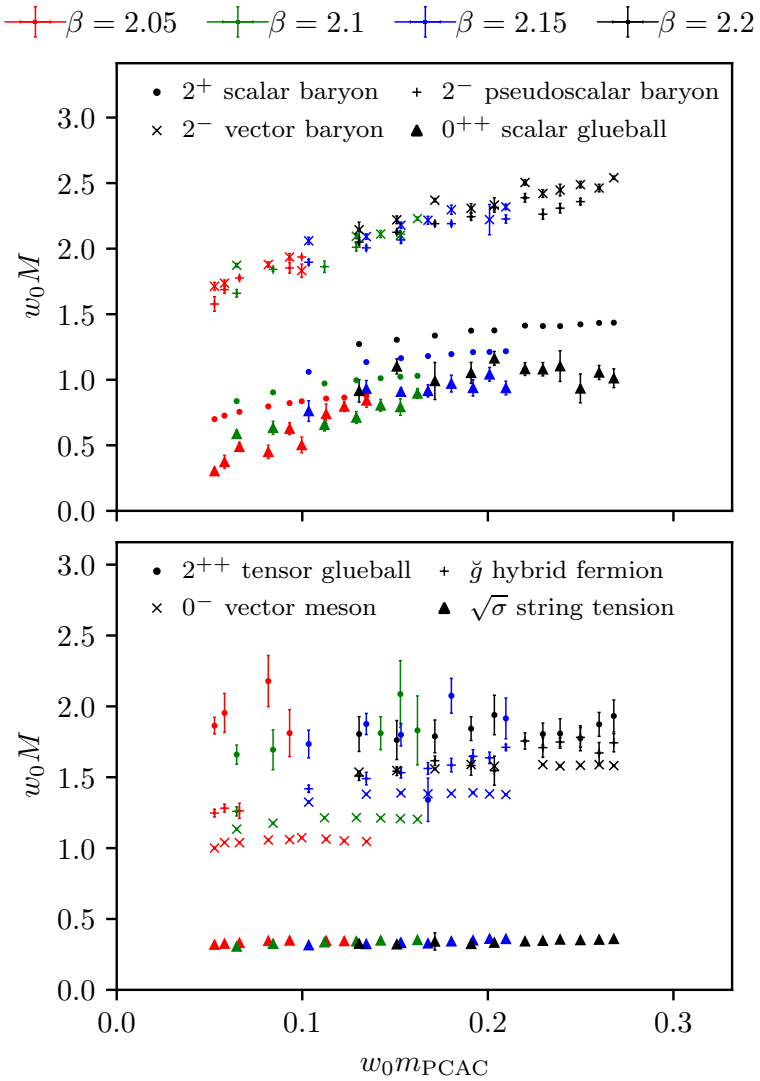
     [M. M. Anber, E. Poppitz, arXiv:1805.12290]
- in conformal case: possible large mass anomalous dimension at lower bound of conformal window

[A. Athenodorou, E. Bennett, GB, B. Lucini, arXiv:1412.5994]

[Z. Bi, A. Grebe, G. Kanwar, P. Ledwith, D. Murphy, M. L. Wagman, arXiv:1912.11723]

[A. Athenodorou, E. Bennett, GB, B. Lucini, arXiv:2103.10485]

Lattice results for the pure adjoint limit



- consistent with conformal case: rather flat scaling, near constant mass ratios
- inconsistent with conformal case: remnant gauge coupling dependence stronger than expected from conformal picture
- inconsistent with chiral case: light scalar, no systematic chiral fit working for all data

Currently theory seems to be close to conformal, but IR limit not completely established.

Color-flavor center symmetry

- QCD: quarks in fundamental representation break center symmetry
- adjoint matter: no explicit center symmetry breaking
- adjoint matter with periodic boundary conditions: absence of deconfinement at small compactifications, semiclassical confined regime on $\mathbb{R}^3 \times S^1$
- $N_f^{(F)} = N_c$: combined flavor color symmetry with appropriate boundary conditions
- $N_f^{(F)} = N_c$ with adjoint matter: semiclassical confined regime (M. Ünsal, arXiv:2104.12352)

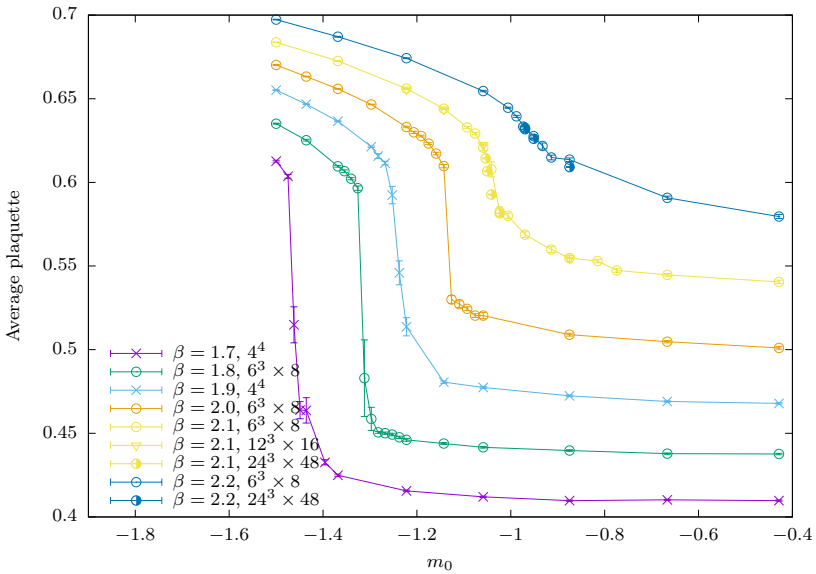
Simulations on the lattice

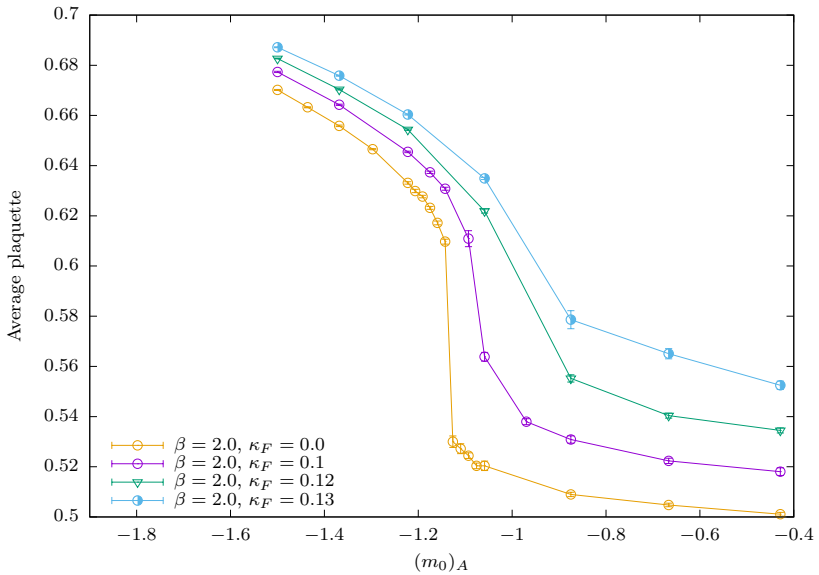
- clover improved Wilson fermions: tuning of two independent mass parameters
- chiral symmetry breaking pattern:

$$\mathrm{SU}(2N_f^{(F)}) \to \mathrm{Sp}(2N_f^{(F)})\,, \quad \mathrm{SU}(2N_f^{(A)}) \to \mathrm{SO}(2N_f^{(A)})$$

- alternative scenario: (near) conformal

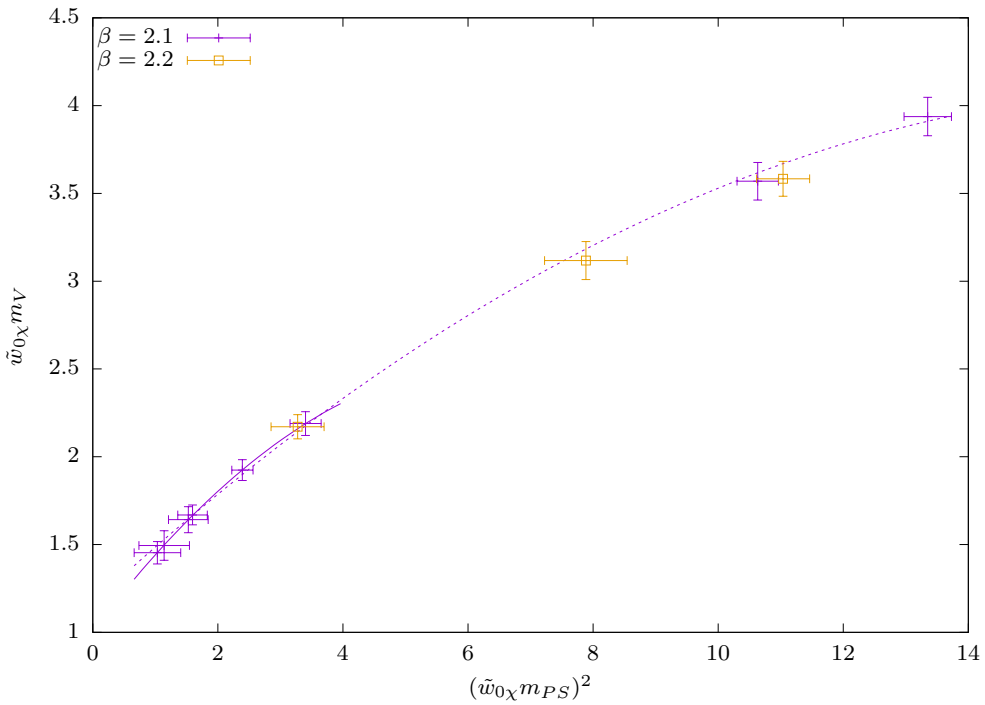
Bulk transition





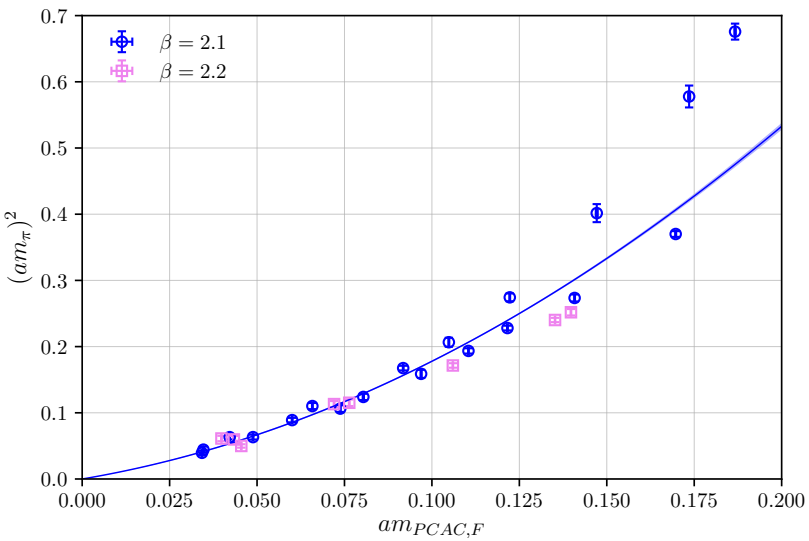
Limiting the β range.

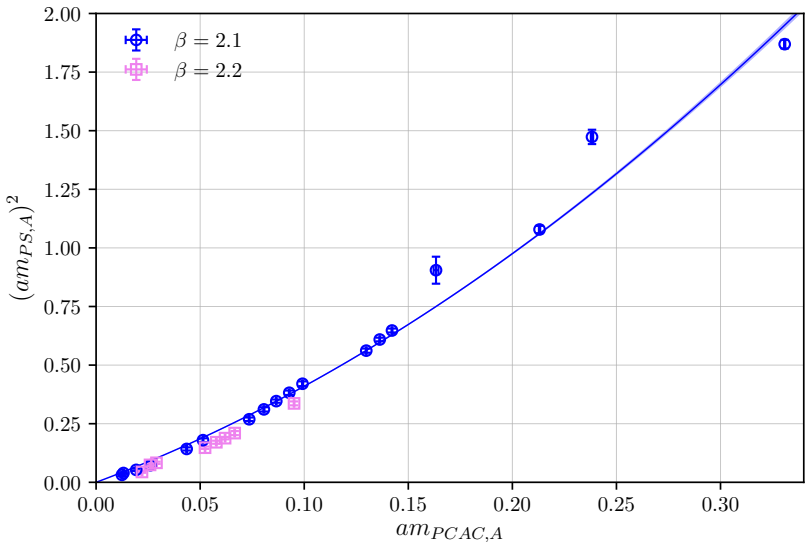
Consistency checks



- cross check with [R. Arthur et al., Phys. Rev. D, arXiv:1602.06559]
- $\tilde{w}_{0\chi} m_{V\chi} = 1.008(9)$ compatible with continuum extrapolation $\tilde{w}_{0\chi} m_{V\chi} = 1.01(3)$

Chiral fits





- simplest analysis: mass dependence in same representation, dominant contribution
- relevant contribution from the other representation, captured by expansion including the two masses

[Ayyar et al., Phys. Rev. D [arXiv:1710.00806]]

Conformal scaling

- near fixed point scaling of correlation function

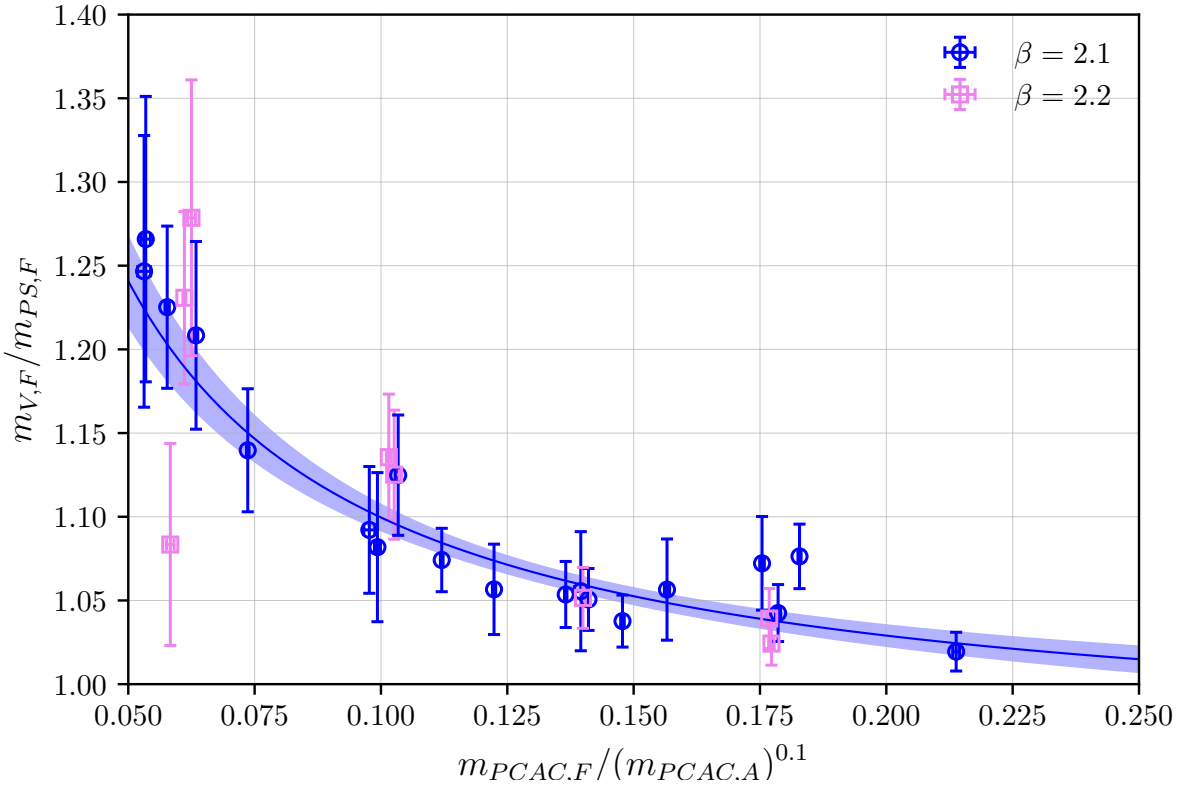
$$C_H(t, g_i, m_i, \mu) = b^{-2y_H} C_H(t/b, b^{y_{g_i}} g_i, b^{y_i} m_i, \mu/b)$$

- assuming $\exp(-M_H t)$ dependence, scaling for one representation $M_H \sim m^{1/y}$
- generalization for two representations, anomalous dimensions y_F, y_A for adjoint, fundamental representations

$$\frac{am_{V,F}}{am_{PS,F}} = F_R(am_{PCAC,F}(am_{PCAC,A})^{-y_F/y_A})$$

[A. Hasenfratz, C. Rebbi, O. Witzel, arXiv:1609.01401]

Conformal scaling



- fit according to dependence on one representation: γ_F, γ_A around $0.5 - 0.8$
- $am_{PCAC,F}(am_{PCAC,A})^{-r}$ dependence favors $r = 0.1$
- not consistent picture of conformal scaling

Summary/Conclusions

- mixed adjoint+fundamental SU(2) gauge theory: interesting non-trivial extension of general picture of strongly interacting gauge theories
- first study of simulations with SU(2) mixed adjoint+fundamental matter
- disfavors conformal scaling, but still quite close to conformal
- indications for a chiral behavior
- future applications: phase transitions and addition of scalar fields