Lattice simulations of technicolour theories with adjoint fermions and supersymmetric Yang-Mills theory – the conformal window for adjoint fermions –

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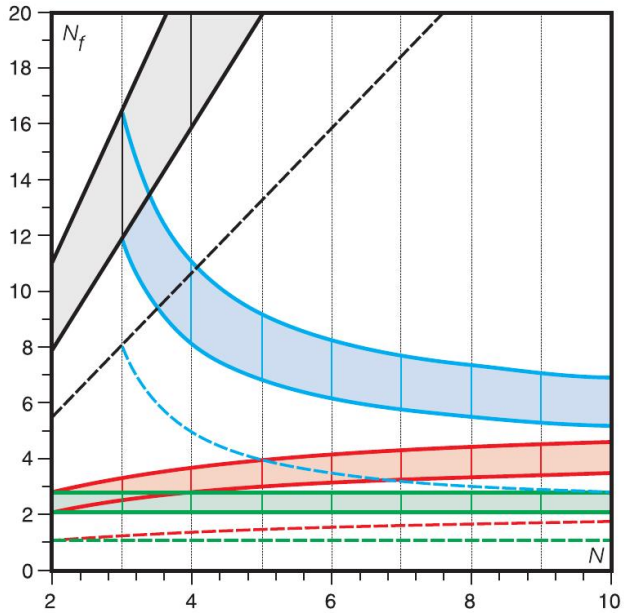
Conformal window for adjoint QCD

Technicolour candidates
(more "natural" EW sector):

- requirement: close to conformal (walking) behaviour, large γ_m, light scalar
- so far: not clear if these requirements can be fullfilled
- perturbative arguments: conformal window starts above $N_f = 2$ adj. QCD



[Dietrich, Sannino, hep-ph/0611341]

Adjoint QCD

adjoint N_f flavour QCD:

$$\mathcal{L} = \mathrm{Tr}\left[-\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \sum_i^{N_f} \bar{\psi}_i(\not{D} + m)\psi_i\right]$$

$$D_\mu\psi = \partial_\mu\psi + ig[A_\mu, \psi]$$

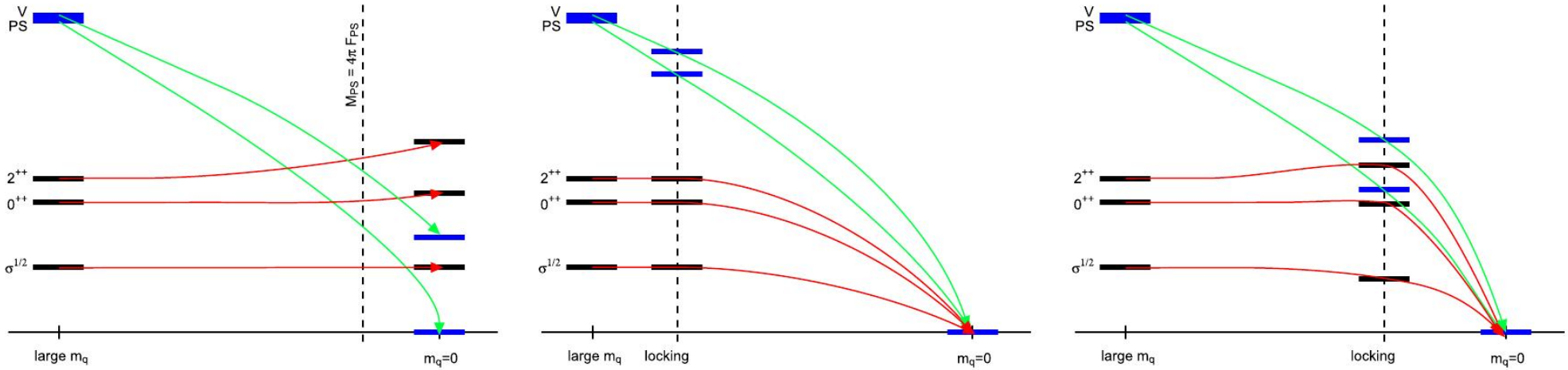
- ψ Dirac-Fermion in the adjoint representation
- adjoint representation allows Majorana condition $\psi = C\bar{\psi}^T$

$\Rightarrow$ half integer values of N_f: $2N_f$ Majorana flavours

Symmetry breaking by condensate:

$$\mathrm{SU}(2N_f) \to \mathrm{SO}(2N_f)$$

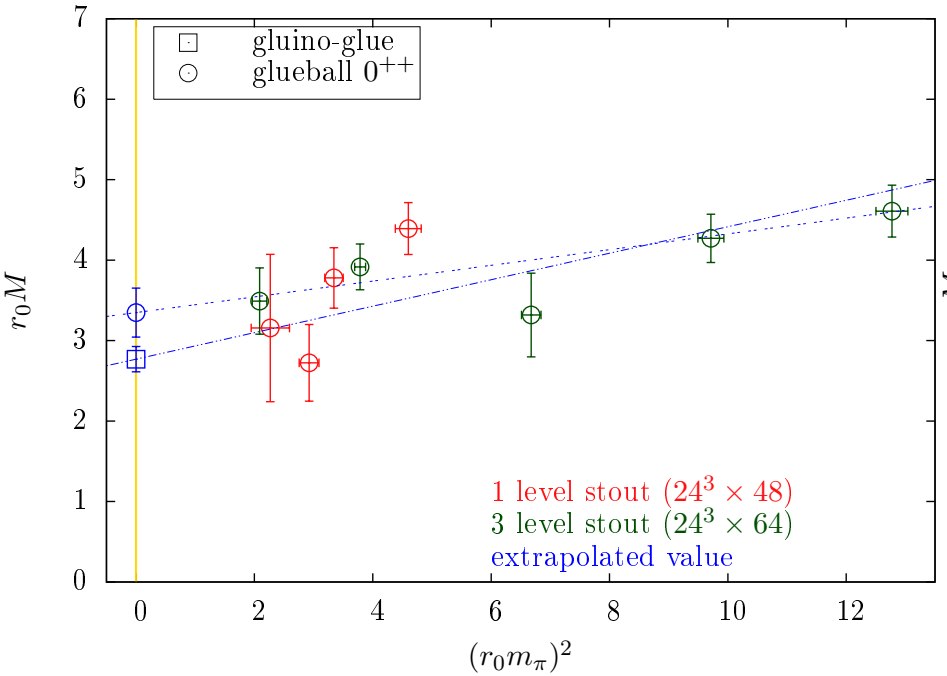
Mass spectrum of near conformal theory

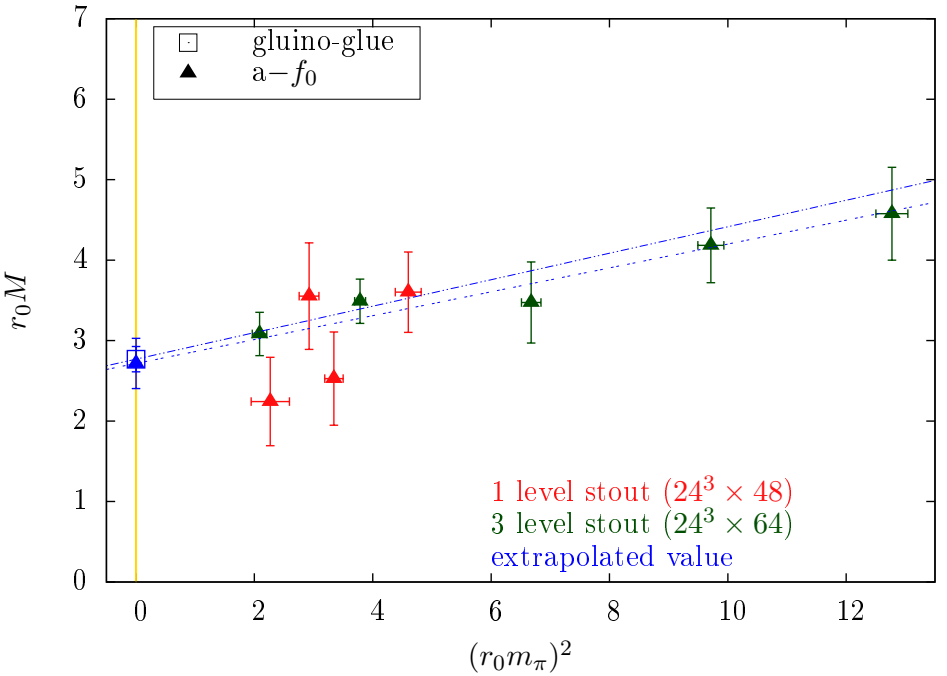


[Lucini, arXiv:1503.00371]

- QCD like: light pNGb from chiral symmetry breaking at $m \to 0$
- (near) conformal: m only scale setting parameter, no mass scale at $m \to 0$
- $M \sim m^{1/(1+\gamma_m)}$

$N_f = 1/2$: Lattice simulations of SYM





Safe lower point:

theory not conformal, multiplet formation 0^-, 0^+, spin-1/2

$m_{0^{++}} > m_{\text{a}-\pi}$; finite mass in chiral limit: $m_{\text{a}-\pi} \to 0$

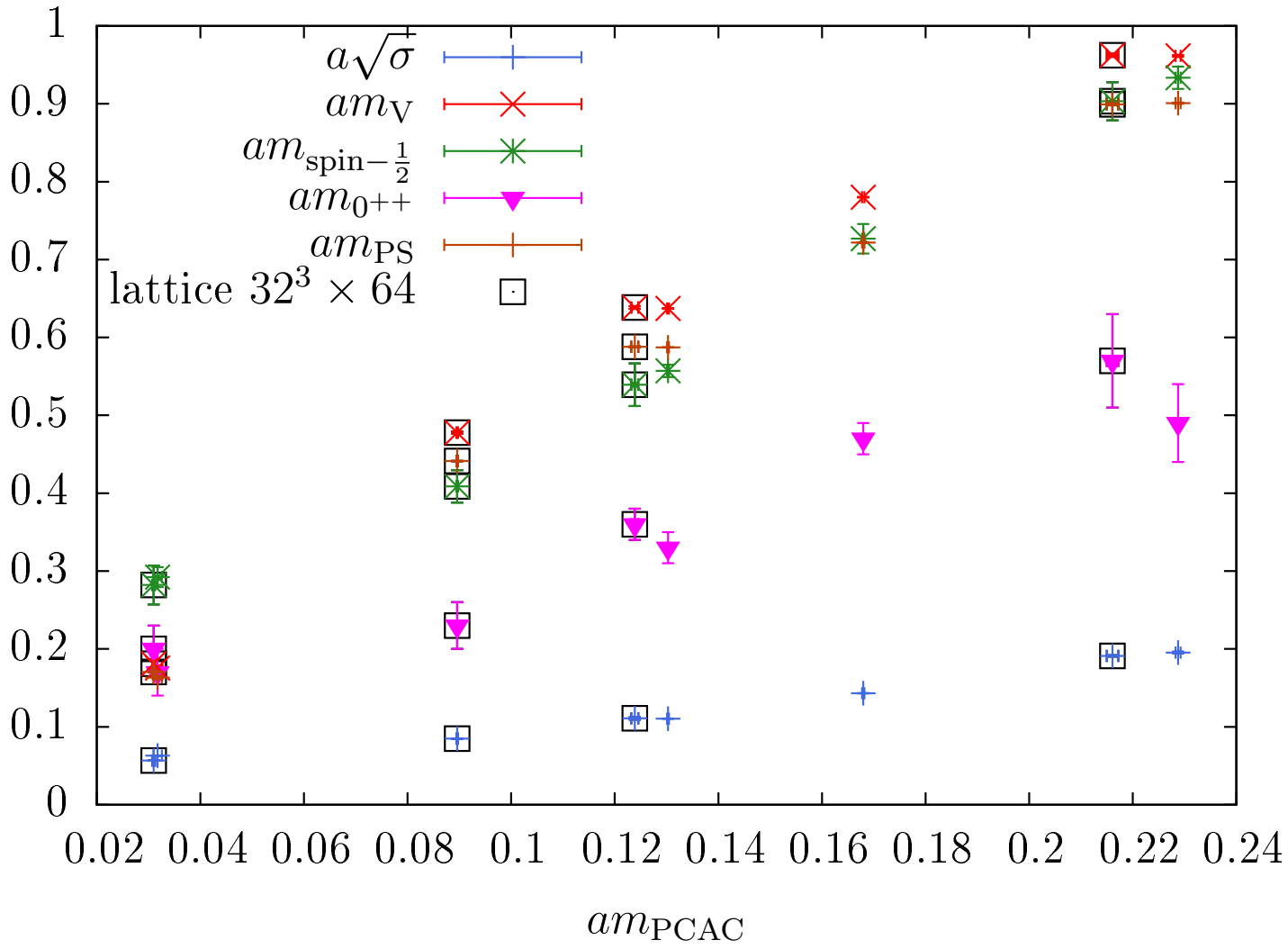
$\longrightarrow$ More on Saturday: Talk by Pietro Giudice and Stefano Piemonte

$N_f = 2$: Lattice simulations of MWT

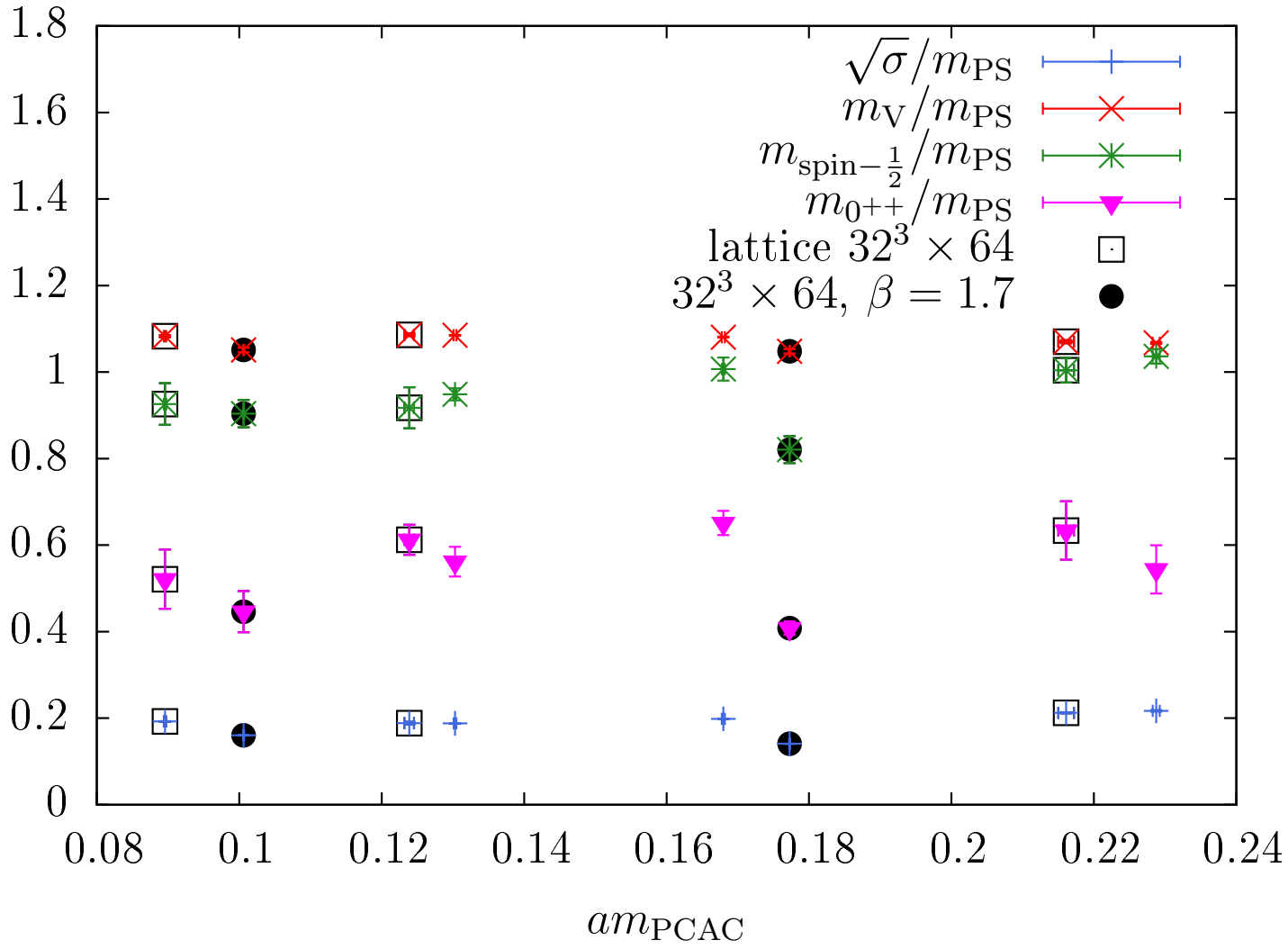
Simulation details:

- DESY-Münster (preliminary)
- two lattice spacings ($\beta = 1.5, 1.7$)
- three volumes (24^3, 32^3, (48^3))
- ~ 5 different residual quark masses
- tree level improved gauge action, stout smeared unimproved Wilson fermions

Mass spectrum of MWT



Mass spectrum of MWT at different β



Observations for MWT

Safe upper point:

theory seems conformal, light scalar
$m_{0^{++}} < m_{PS}$; conformal scaling

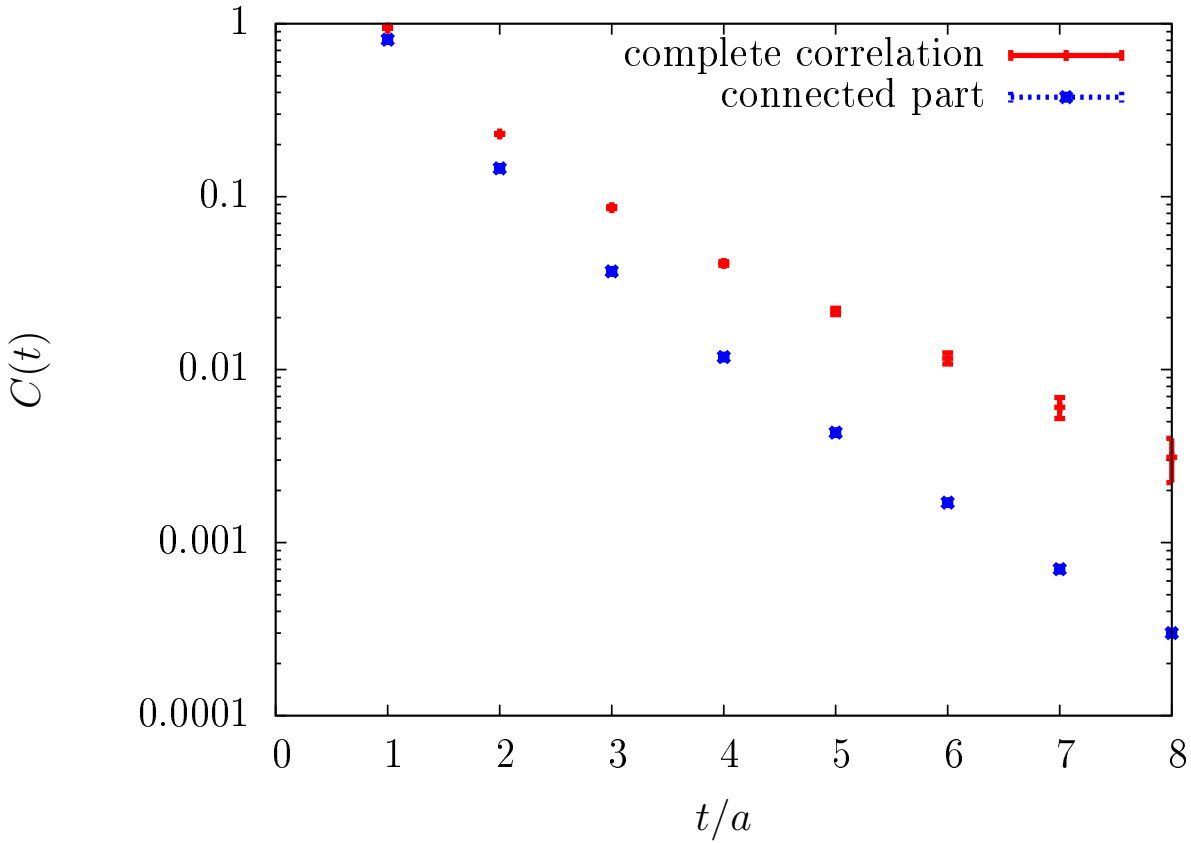
- spectrum consistent with $\gamma_m \sim 0.38 \Rightarrow$ might be too small

New result for $N_f = 2$: Spin-1/2 state

$$\sum_{\mu,\nu} \sigma_{\mu\nu} \mathrm{tr}\left[F^{\mu\nu}\lambda\right]$$

- specific state for adjoint QCD
- fractionally charged particles (?)
- Spin-1/2 first state above scalar glueball, below m_{PS}

New result for $N_f = 2$: Mesonic scalar state



triplet:
0.747(17)
singlet:
0.540(53)
glueball:
0.33(2)
m_{PS}: 0.5873(3)

- dominant disconnected contributions
- below m_{PS} but still much larger than the glueball 0^{++}
- gluonic dominance of the scalar ground state

Lattice simulations of $N_f = 1$ adjoint QCD

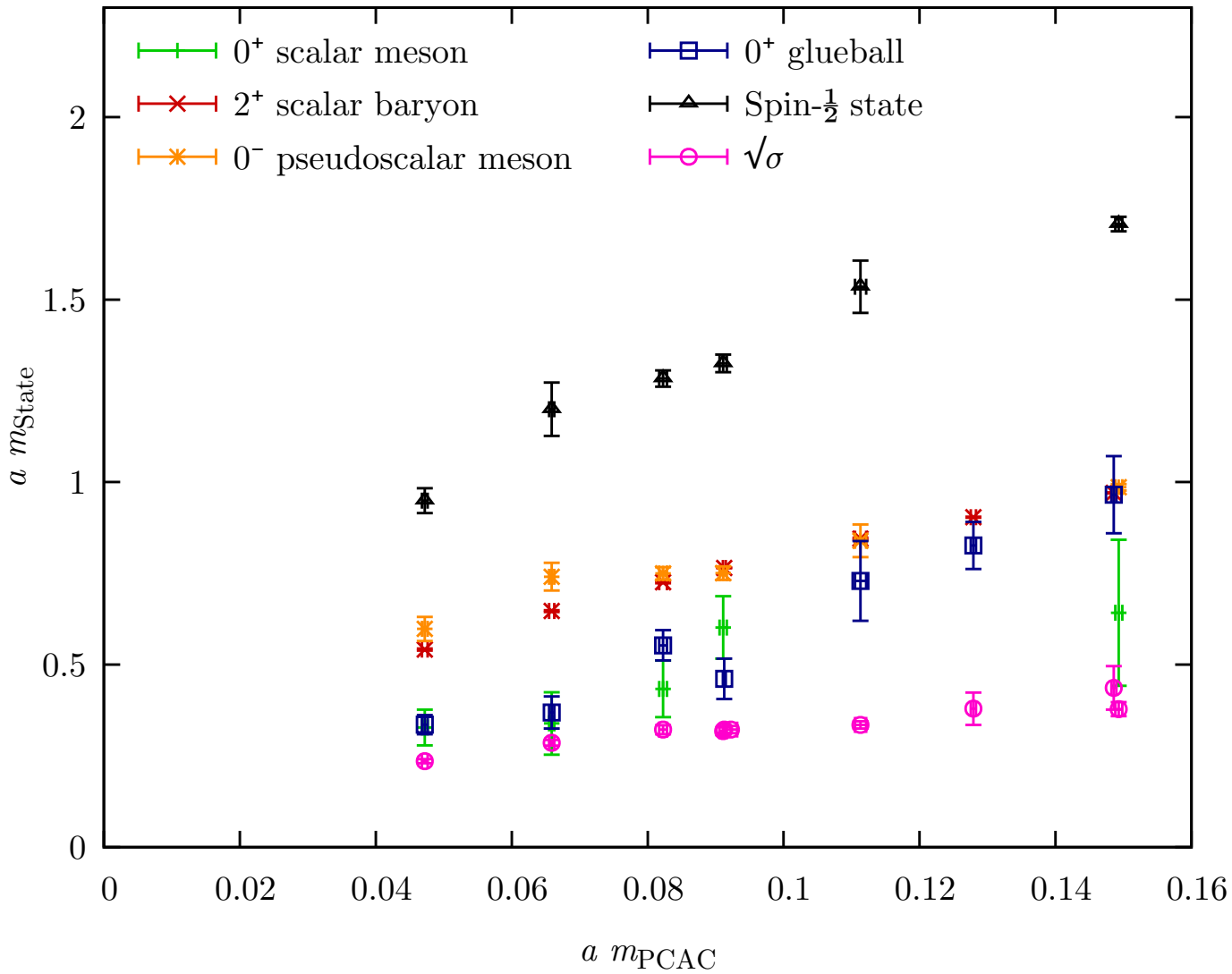
Simulation details:

- investigated finite volume effects (less severe than for MWT)
- unimproved Wilson action
- several states analysed (baryons, mesons, glueballs, . . .)
- presented in: [PoS LATTICE2013 (2014) 066], [Athenodorou, Bennett, GB, Lucini, arXiv:1412.5994]
- new update: second lattice spacing ($\beta = 2.05$, $\beta = 2.2$)

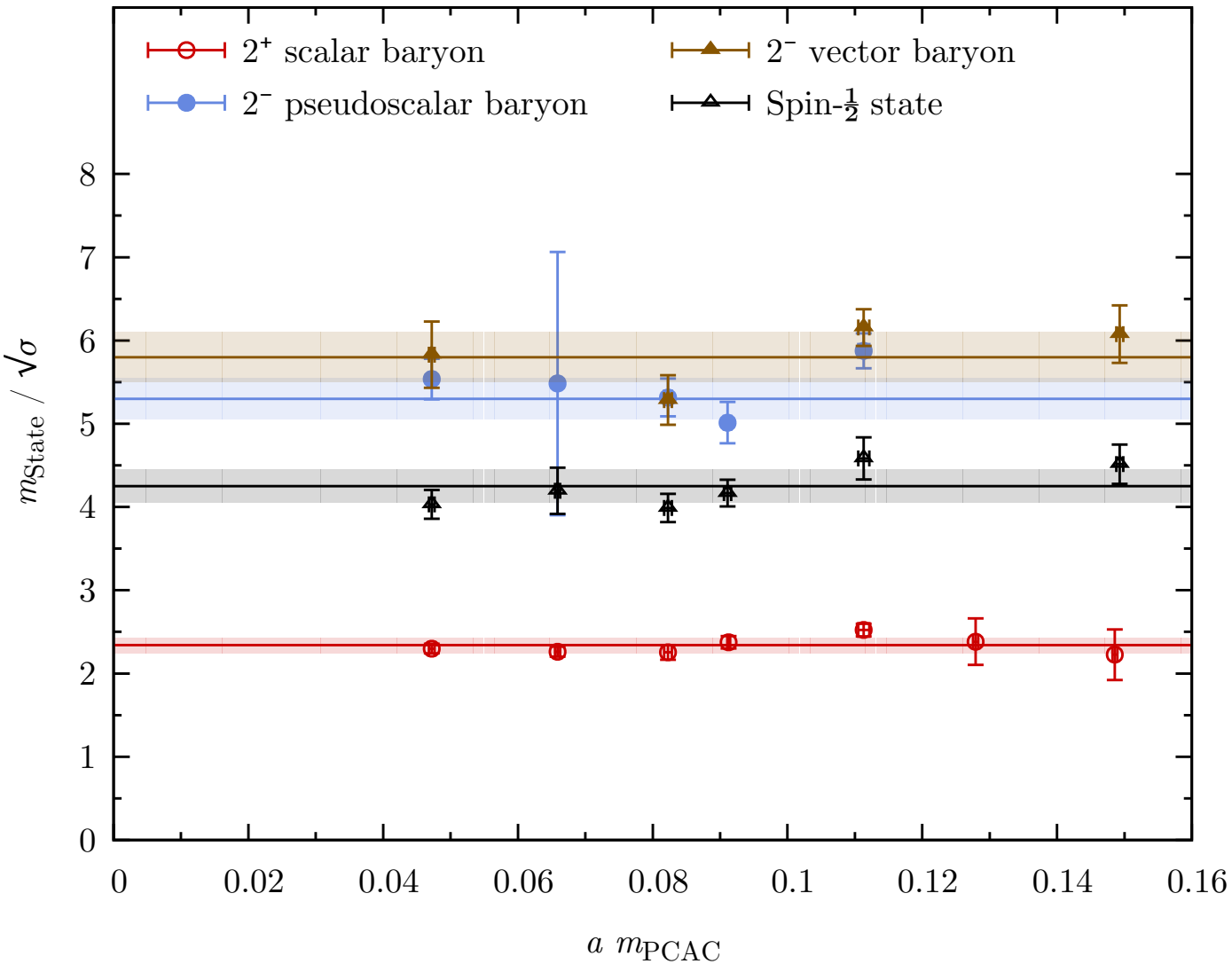
The states of $N_f = 1$ adjoint QCD

- SU(2): baryons (diquarks) from two spinors
- $\mathrm{SU}(2) \to \mathrm{SO}(2) \simeq \mathrm{U}(1)_B$:
  states are labelled by $\mathrm{U}(1)^P$
- $\bar{\psi}\psi$: 0^+, scalar meson ("scalar singlet")
- $\psi^T C\psi$: 2^-, pseudoscalar baryon ("scalar triplet")
- $\psi^T C\gamma_5\psi$: 2^+, scalar baryon ("pseudoscalar triplet") = pNGb

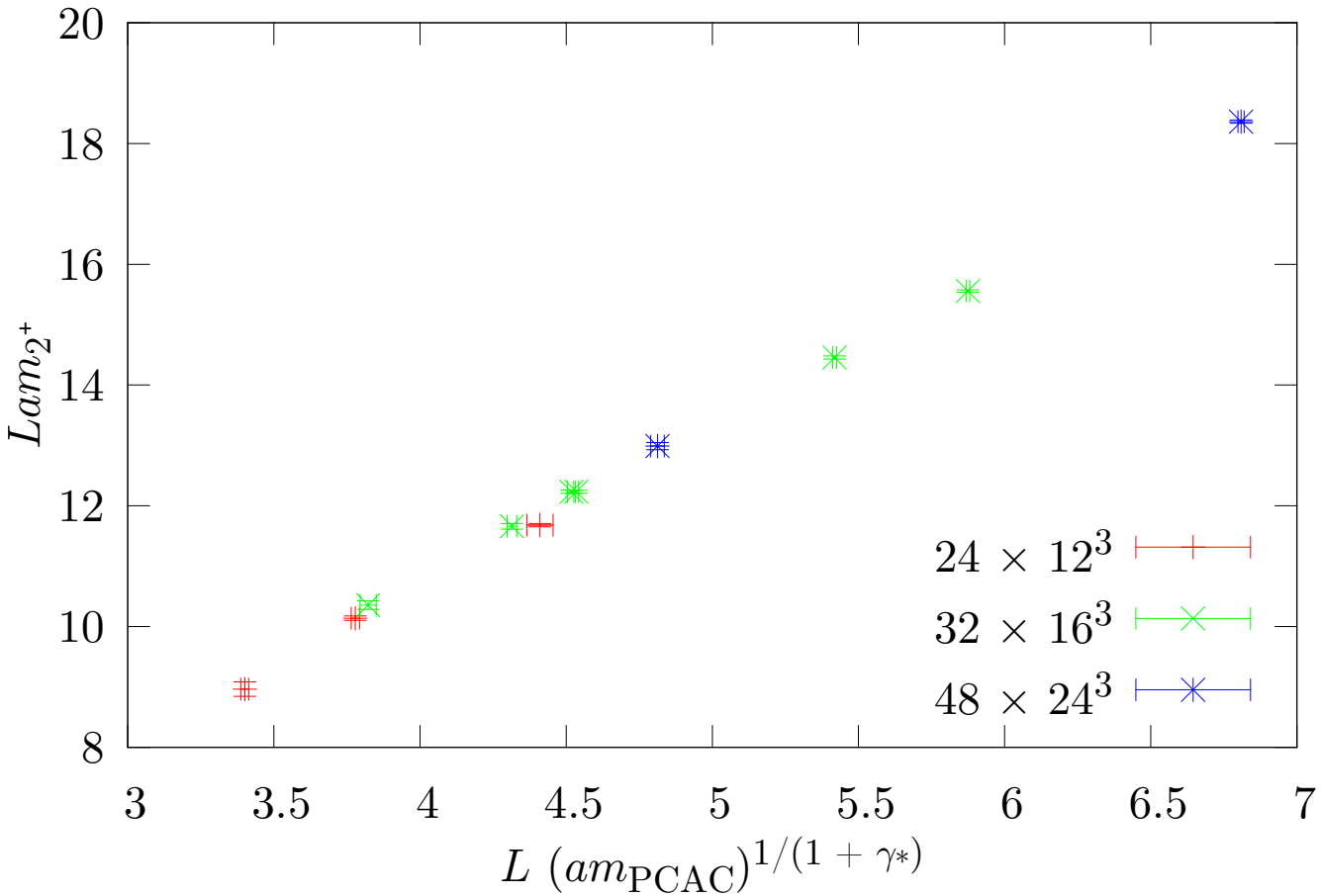
Results for $N_f = 1$ adjoint QCD



Results for $N_f = 1$ adjoint QCD

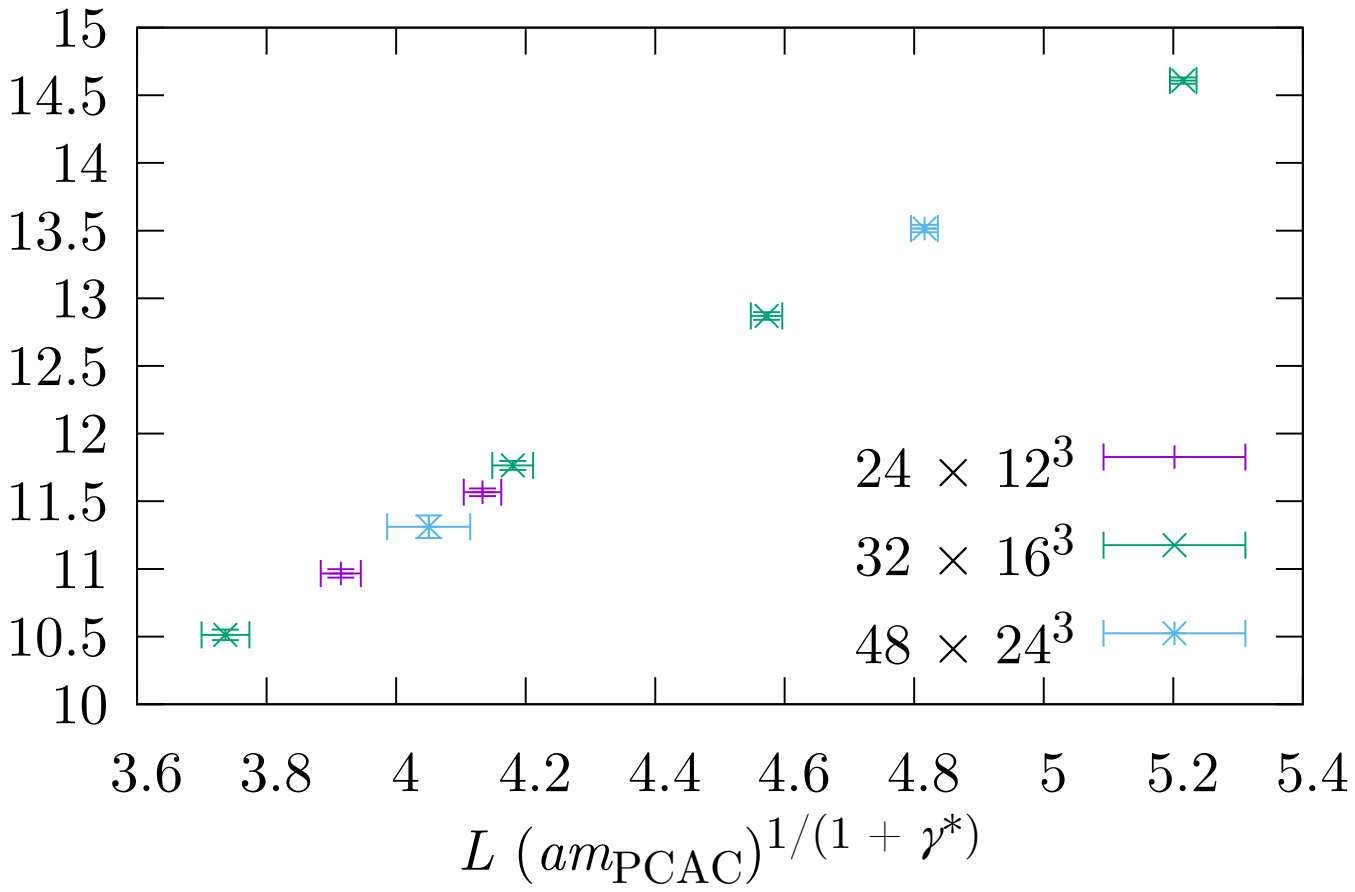


Results for $N_f = 1$ adjoint QCD



$\gamma_m^* = 0.9$, from mode number: $\gamma_m^* = 0.92(1)$

Results for $N_f = 1$ adjoint QCD $\beta = 2.2$



$\gamma_m^* = 0.7$

Results for $N_f = 1$ adjoint QCD

- light scalar ☑
- (near) conformal ☑
- $\gamma_m^* \sim 0.9$ ☑
- smaller lattice spacing: $\gamma_m^* \sim 0.7$ (preliminary)

Further investigations needed:

- combination with additional fermions needed for ew symmetry breaking (UMWT)
- relation to $\mathcal{N} = 2$ supersymmetric YM theory

Conclusions

- lattice simulations show SUSY multiplet structure in SYM
- lattice simulations resolve large difference of non-conformal SYM and conformal MWT
- $N_f = 1$ adjoint QCD on the (near) conformal side and includes light scalar and large γ_m
- SYM below lower end of theories that show light scalar and (near) conformal behaviour
- "exotic" state in adjoint QCD: $m_{\text{spin}-1/2} < m_{PS}$ for $N_f = 2$; $m_{\text{spin}-1/2} > m_{\text{scalar baryon}}$ for $N_f = 1$
- light mesonic scalar state for $N_f = 1$ and 2;
  $N_f = 2$: glueball better signal for low scalar state