The scalar spectrum of many-flavour QCD

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for the LatKMI collaboration

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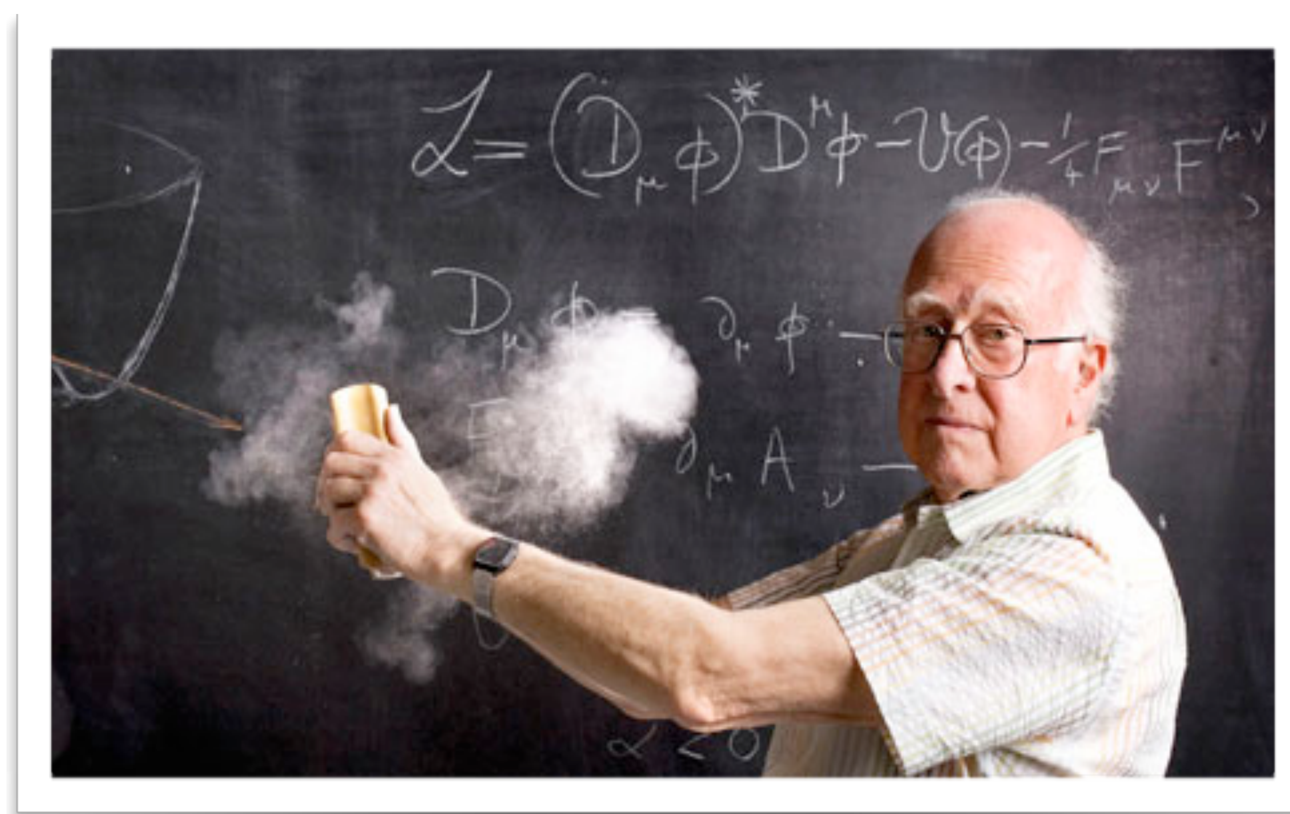
LatKMI collaboration

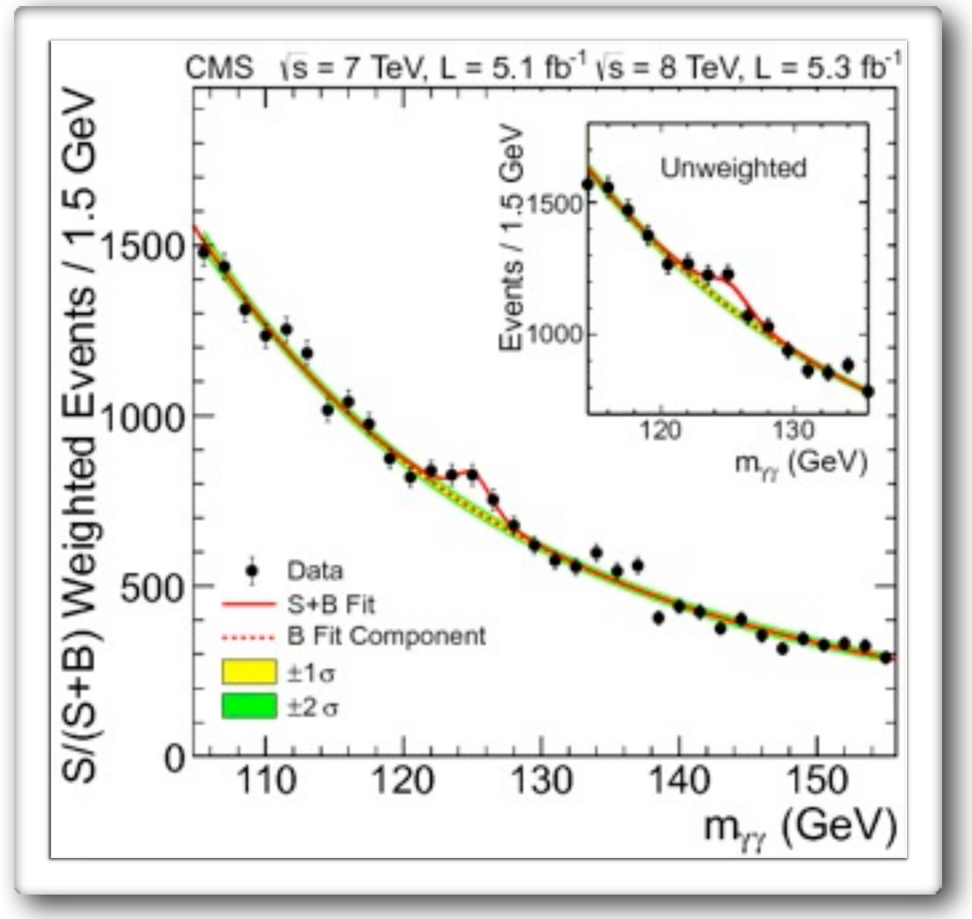
Outline

- Motivations
- Measuring the scalar glueball mass
- Measuring the scalar singlet meson mass
- Results
- Conclusions and outlook



Motivations

- a Higgs-like particle has been found at LHC
  - $m_H \sim 126$ GeV
  - $J^{PC} = 0^{++}$ (not parity odd at 2.5σ)
  - couplings consistent with the Standard Model
- a composite "Higgs" scalar is not ruled out
- this is realised in Walking Technicolor models
- interest in finding the lower edge of the Conformal Window
- a light scalar appears as pseudo-NG boson



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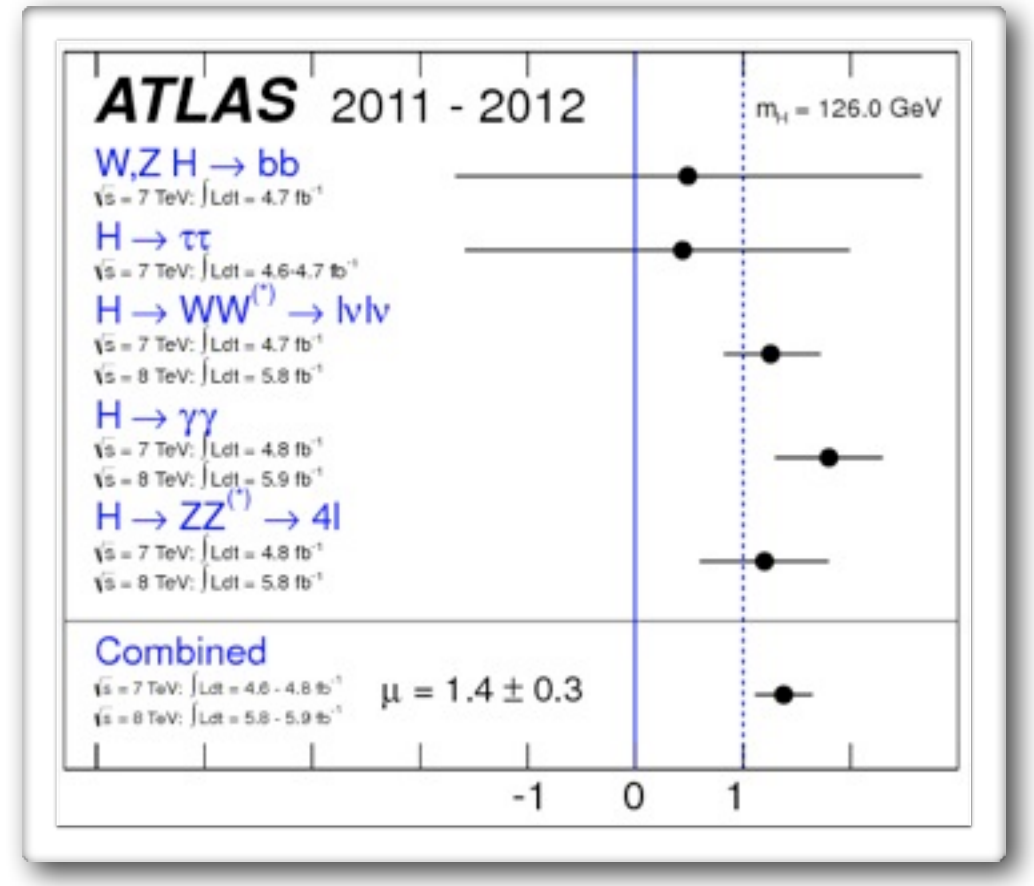

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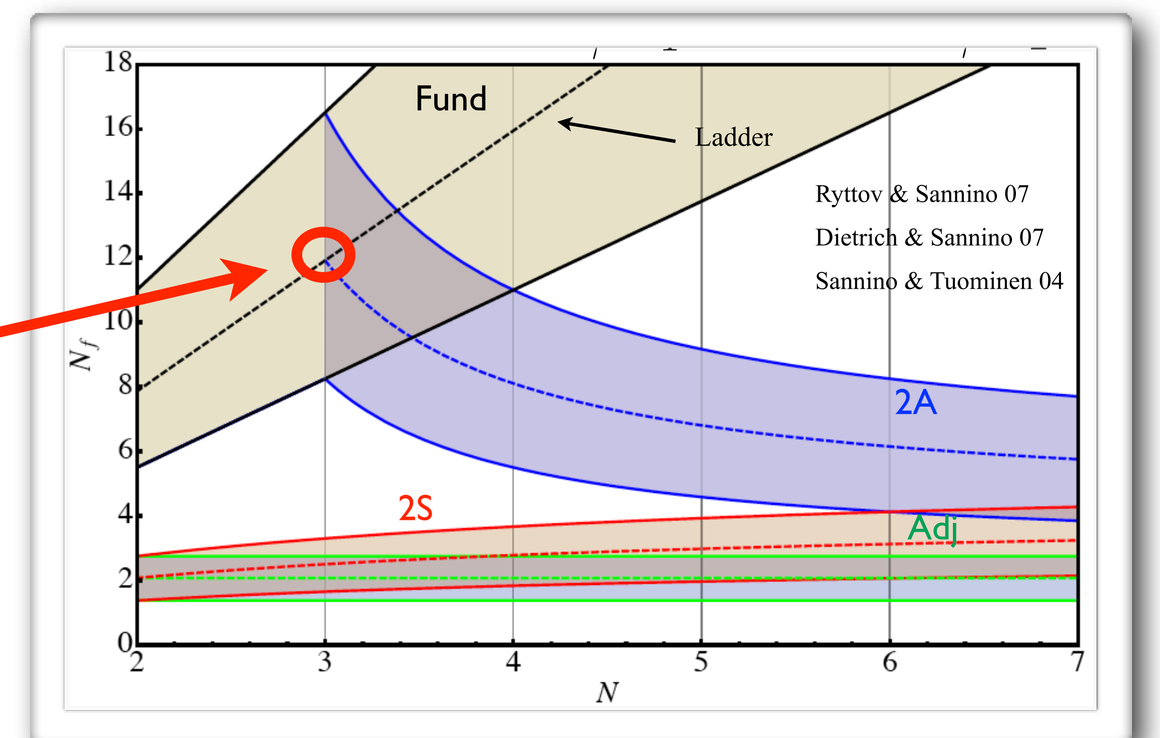
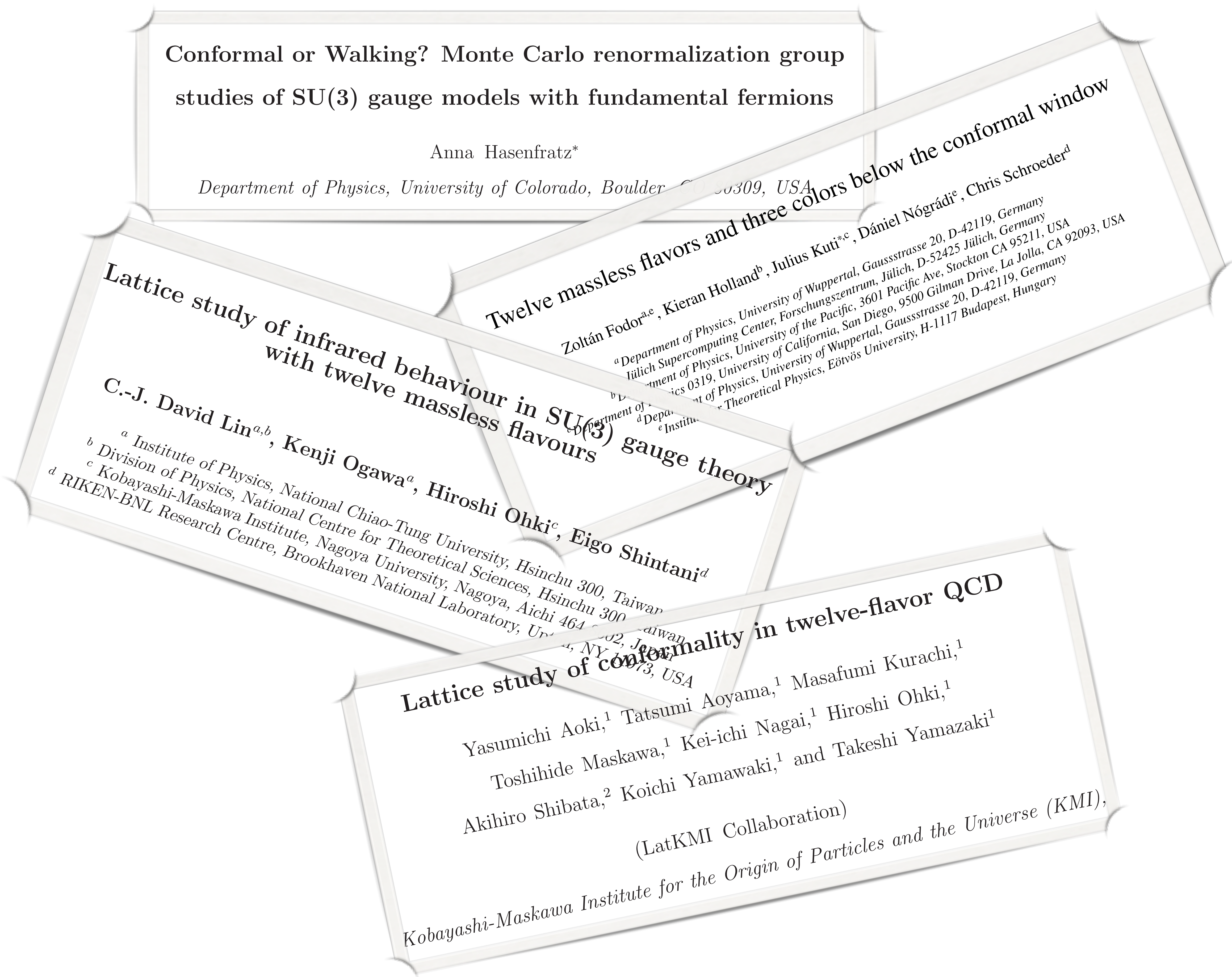
Model



F. Sannino

QCD with 12 fundamental fermions

- well studied by several groups recently
- however the chiral and continuum physics are still controversial
- additional information can be gained by measuring the scalar spectrum
- spectroscopic techniques already used in QCD can be developed for many flavours
- focus on scalar glueballs and scalar mesons
  - masses, mixing, scaling, ...



Lattice simulations

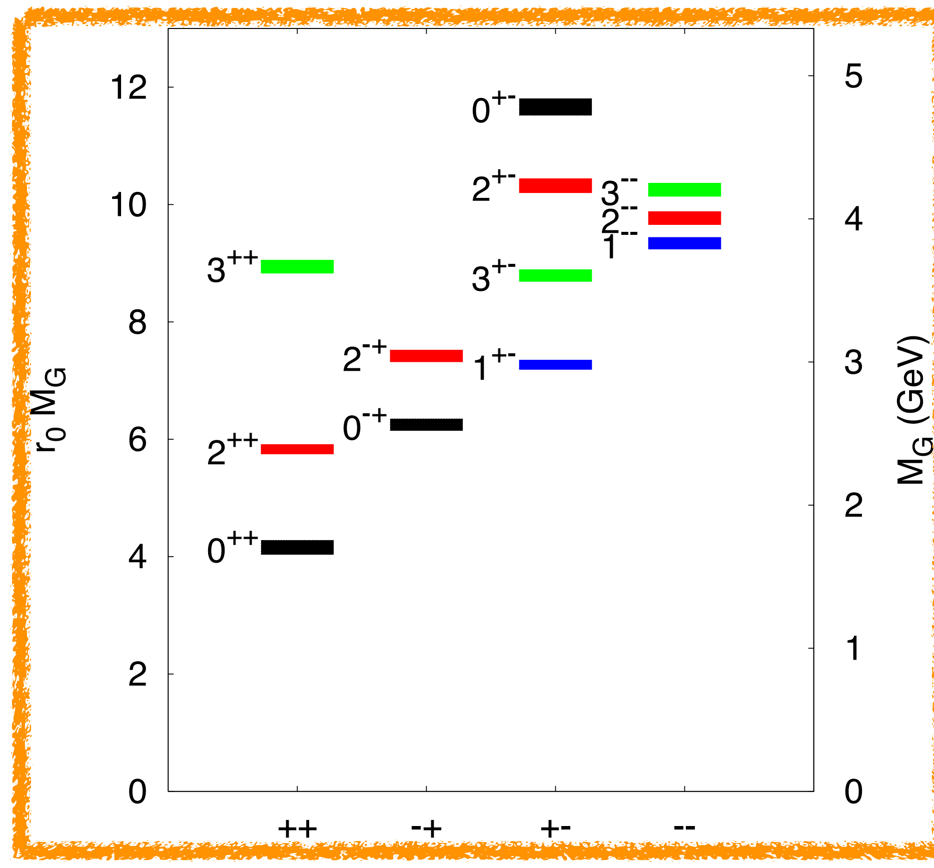
- SU(3) gauge field + 12 dynamical fermions
  - gauge action → tree level Symanzik
  - fermion action → HISQ (Highly Improved Staggered Quarks)
  - modified HMC based on MILC code (v7)
- fixed gauge coupling → $\beta = 4.0$
- three volumes → $V=18^3$, 24^3, 30^3
- five bare fermion masses → $am_f = 0.06 - 0.16$
- long trajectories → >15000 MD units

L	T	am_f	traj.	confs.	bins
18	24	0.06	15445	3090	103
18	24	0.08	25050	5010	167
18	24	0.10	21750	4350	145
18	24	0.12	26000	5200	208
18	24	0.16	21000	4200	140
24	32	0.06	28000	14000	700
24	32	0.08	19280	9640	241
24	32	0.10	18960	9480	237
30	40	0.08	13200	6600	132
30	40	0.10	9900	4950	99

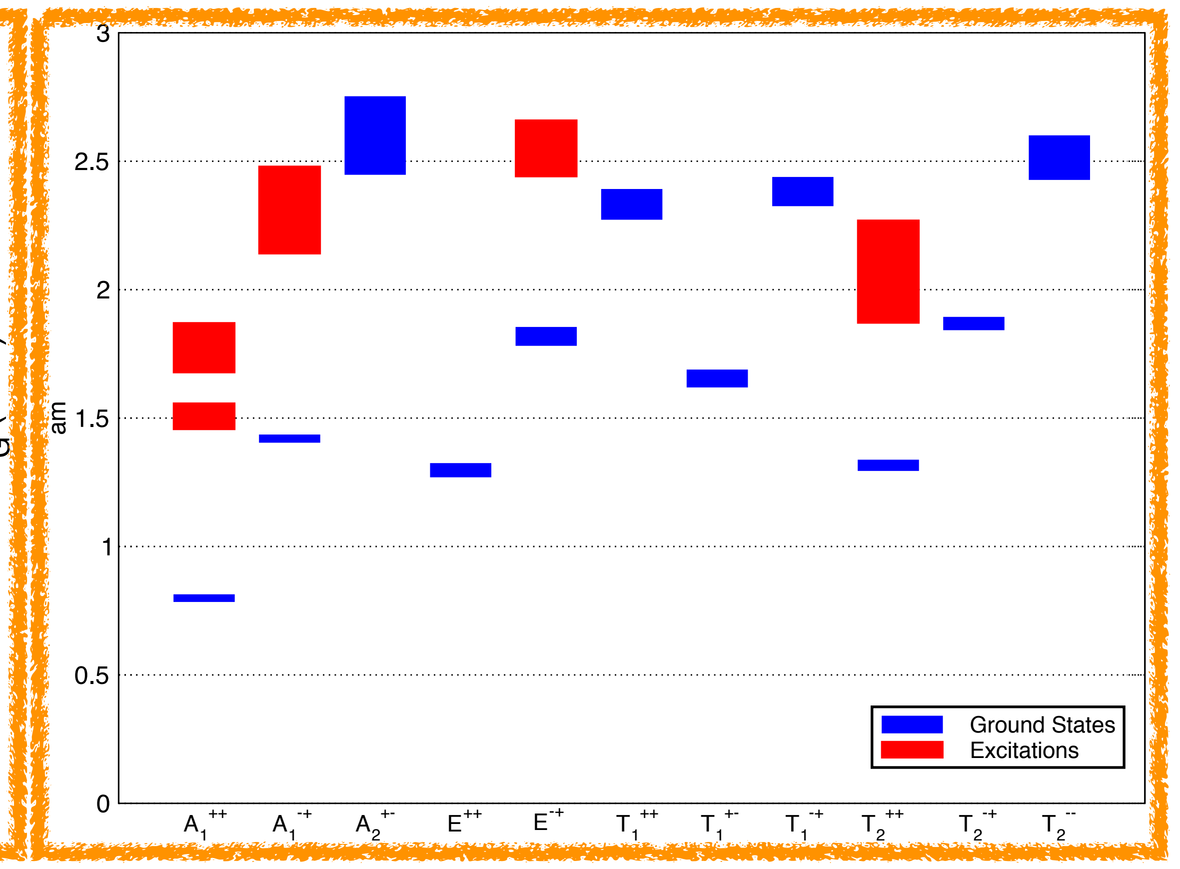
Glueball spectroscopy

- the glueball spectrum is well studied in SU(N) Yang-Mills theories
- the lightest glueballs are starting to be investigated in full LQCD
- yet to be done in many-flavour QCD
  - typically heavy (mass determined by Λ_{QCD})
  - typically noisy (require large statistic)

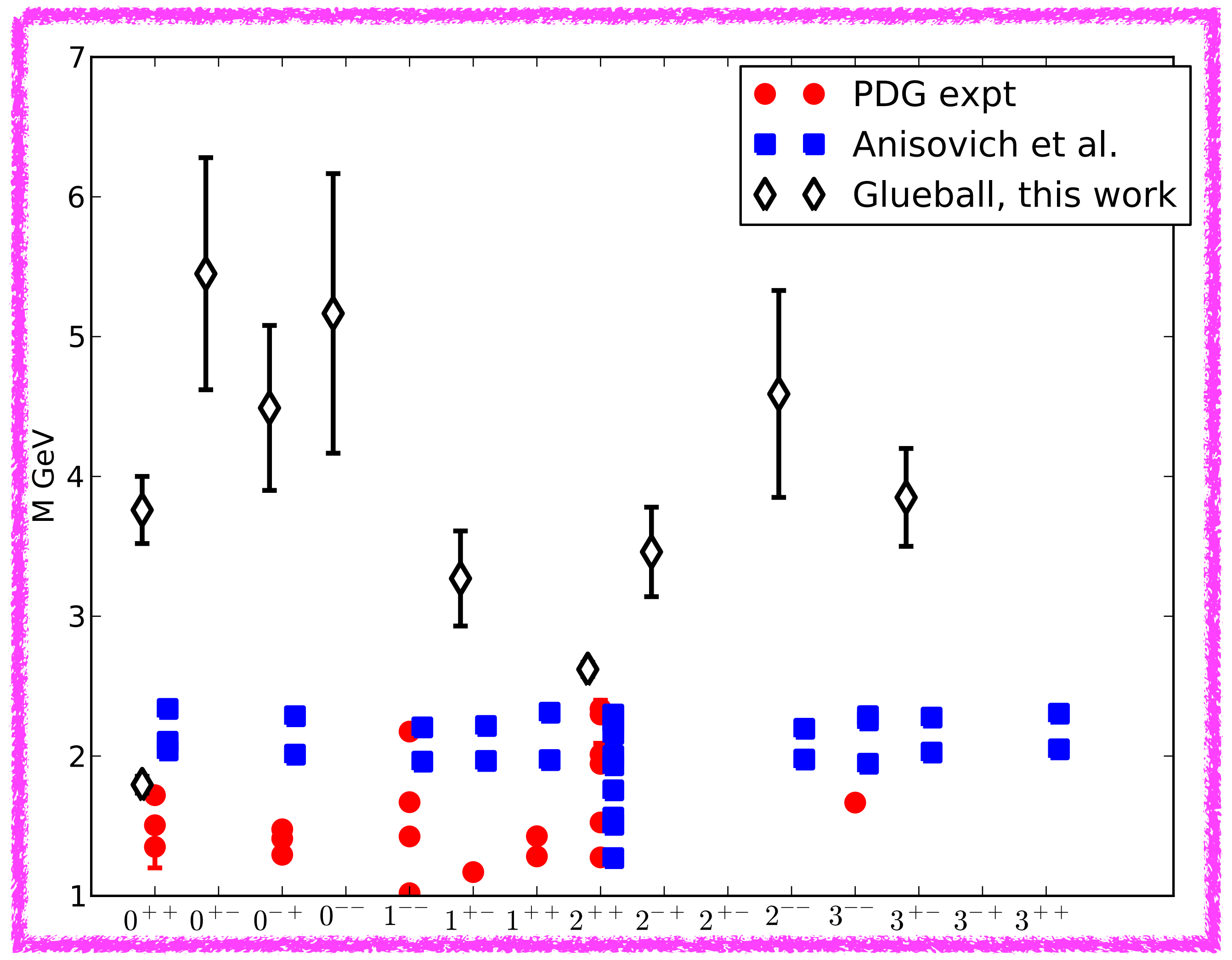
Needs specific and powerful noise-reduction techniques



Chen et al., Phys.Rev.D73(2006)



Lucini, Rago, ER, JHEP08(2010)



Gregory, Irving, Lucini, McNeile, Rago, Richards, ER, JHEP10(2012)

Glueball spectroscopy: operators

- eigenstates of the Hamiltonian are classified according to the irreducible representations of the cubic group

$$\{A_1(1),\, A_2(1),\, E(2),\, T_1(3),\, T_2(3)\}$$

- suitable gauge-invariant operators must be constructed that respect the symmetries

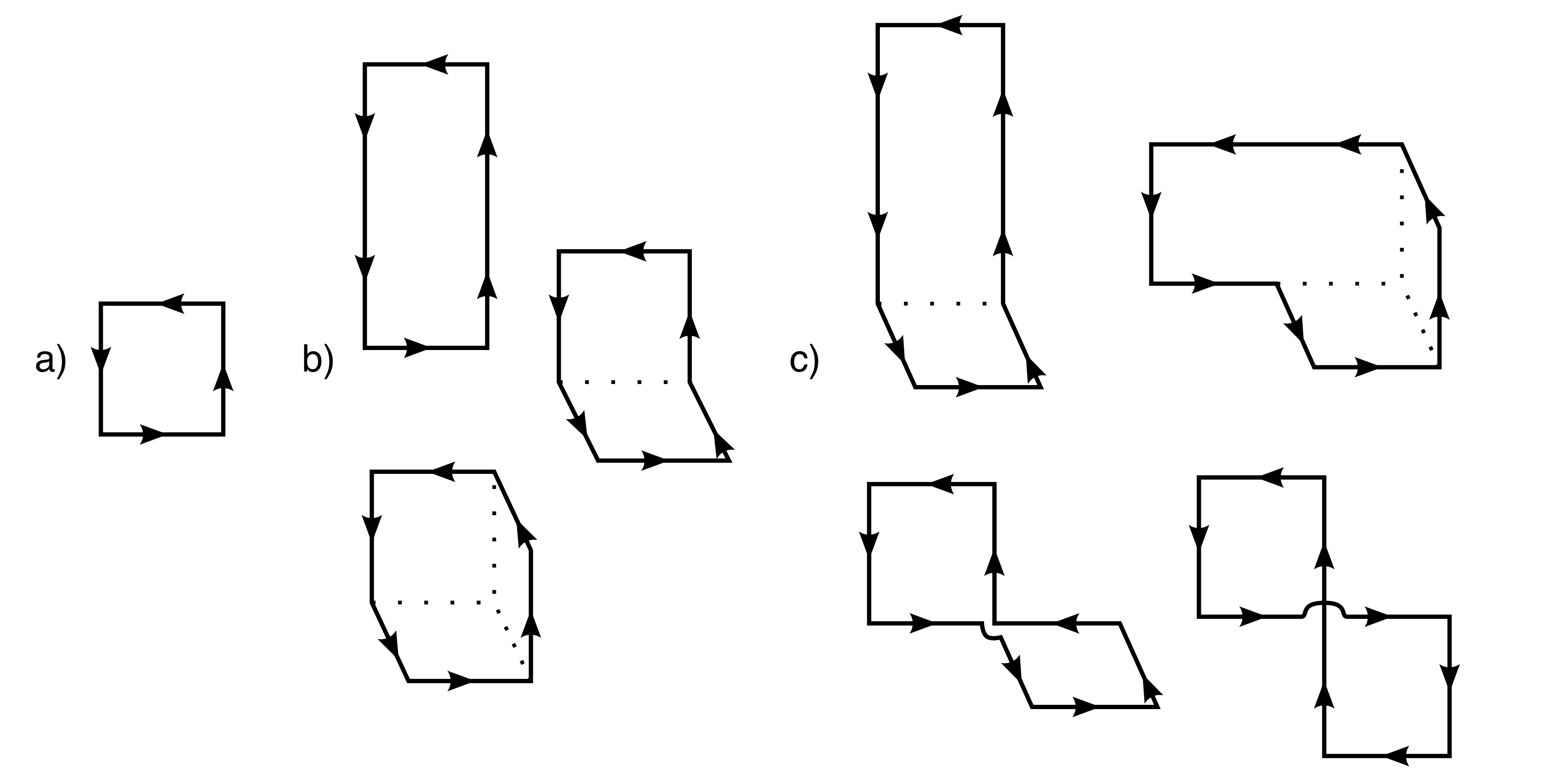
$$\mathcal{O}_G(t) = \frac{1}{L^3}\sum_{x\in L^3} \mathrm{Tr}\left(\prod_{l\in\mathcal{W}(x)} U_l\right) \qquad \mathcal{O}_G^{(R)}(t) = \sum_{\alpha=1}^{24} a_\alpha^{(R)}\mathcal{R}_\alpha\left[\mathcal{O}_G(t)\right]$$

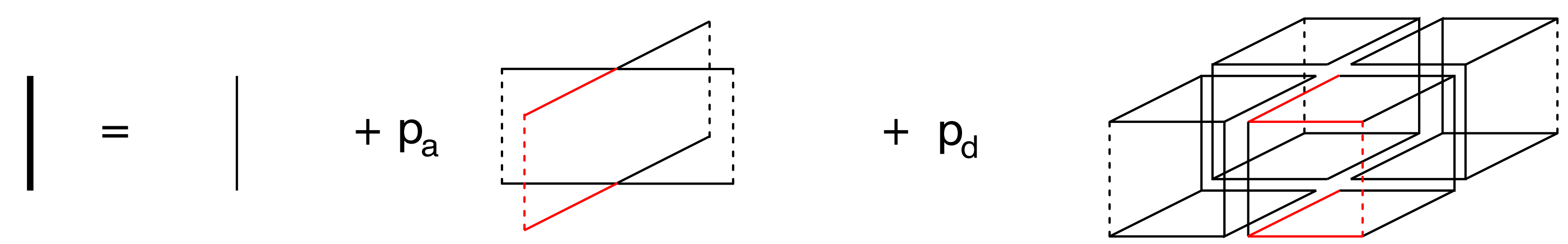
- vacuum contributions must be subtracted in the scalar case

$$\mathcal{O}^{(A_1)}(t) - \langle 0|\mathcal{O}^{(A_1)}|0\rangle$$

- improved operators are obtained by blocking and smearing algorithms

J	A_1	A_2	E	T_1	T_2
0	1	0	0	0	0
1	0	0	0	1	0
2	0	0	1	0	1
3	0	1	0	1	1
4	1	0	1	1	1





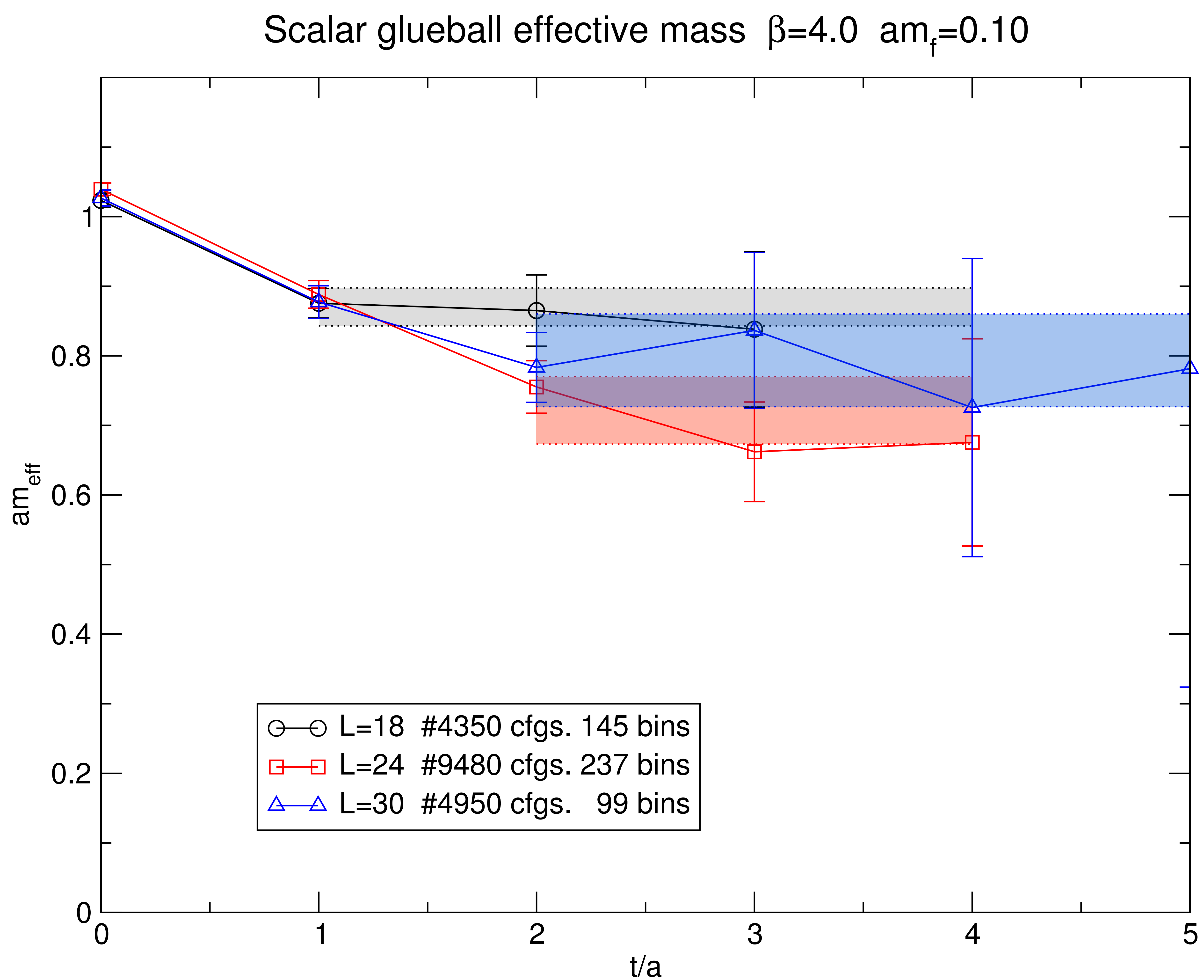
Lucini, Rago, ER JHEP08(2010)

Glueball spectroscopy: variational analysis

- basis of operators ➔ $\{\mathcal{O}_1(t), \ldots, \mathcal{O}_n(t)\}$
- matrix of correlators ➔ $\mathcal{C}_{ij}(t) = \sum_{\tau} \langle 0|\mathcal{O}_i^\dagger(\tau + t)\mathcal{O}_j(\tau)|0\rangle$
- generalized eigenvalue problem ➔ $\mathcal{C}_{ij}(t) v_j^\alpha = \lambda^\alpha v_i^\alpha$ $\qquad \Phi_\alpha(t) = \sum_{i=1}^{n} v_i^\alpha \mathcal{O}_i(t)$
- ground state correlator fit ➔ $\langle \Phi_\alpha^\dagger(t)\Phi_\alpha(0)\rangle = |c_\alpha|^2 \left(e^{-m_\alpha t} + e^{-m_\alpha (T-t)}\right)$

- the effective mass plateaux is used to determine the fitting window on the correlator
- excited states contributions are given by α>0

Results: scalar glueball



$$m_{0^{++}} > m_\pi$$

L=18 → am=0.870(27)

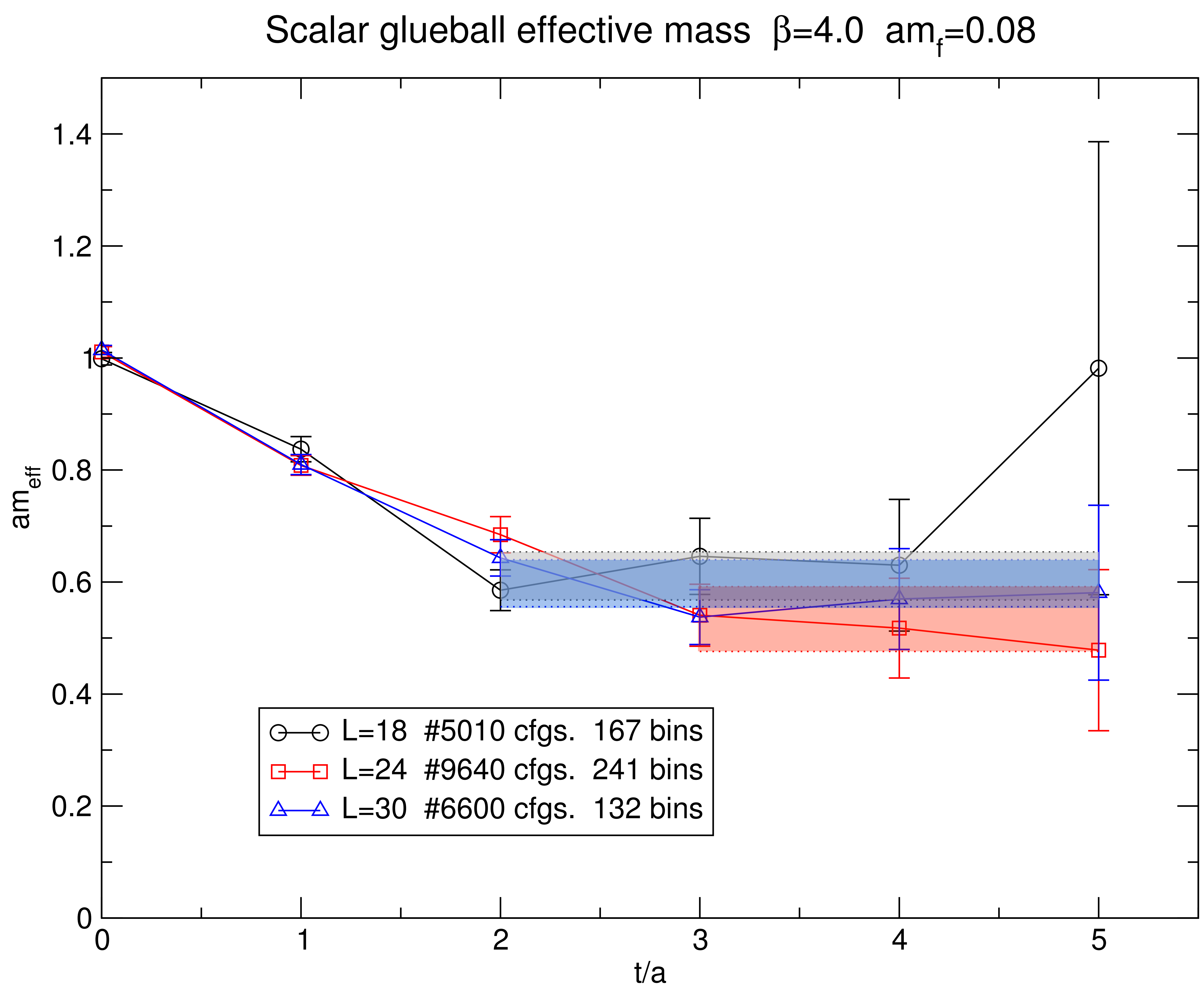
L=24 → am=0.722(49)

L=30 → am=0.794(67)

The fitted mass is shown on top of the corresponding effective mass enabling us to establish the goodness of the estimate

establish the goodness of the estimate

Results: scalar glueball



$$m_{0^{++}} \gtrsim m_\pi$$

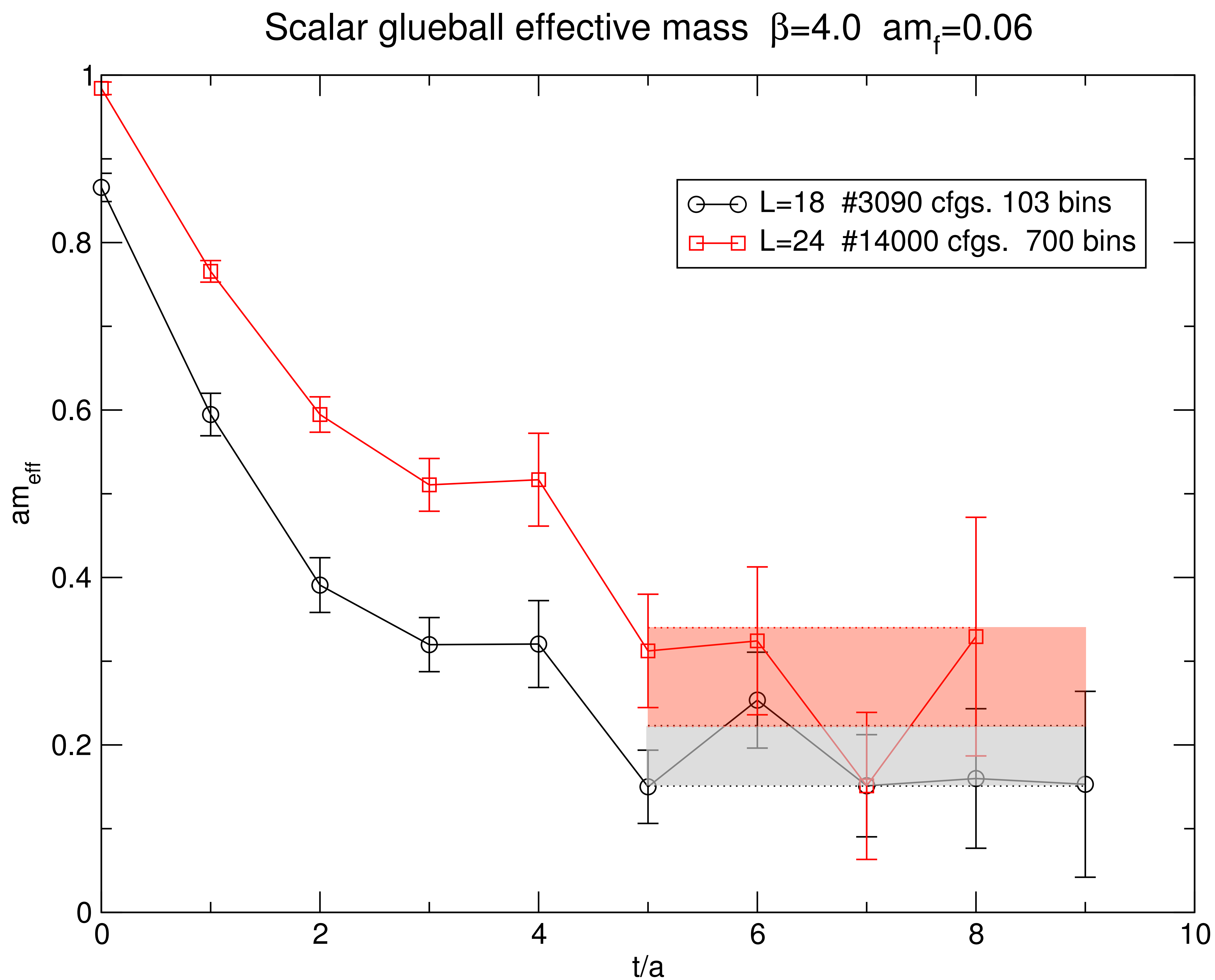
L=18 → am=0.623(46)

L=24 → am=0.534(58)

L=30 → am=0.598(42)

Finite-size effects appear to be under control even when the bare fermion mass is lowered

Results: scalar glueball



$$m_{0^{++}} \lesssim m_\pi$$

L=18 → am=0.187(36)

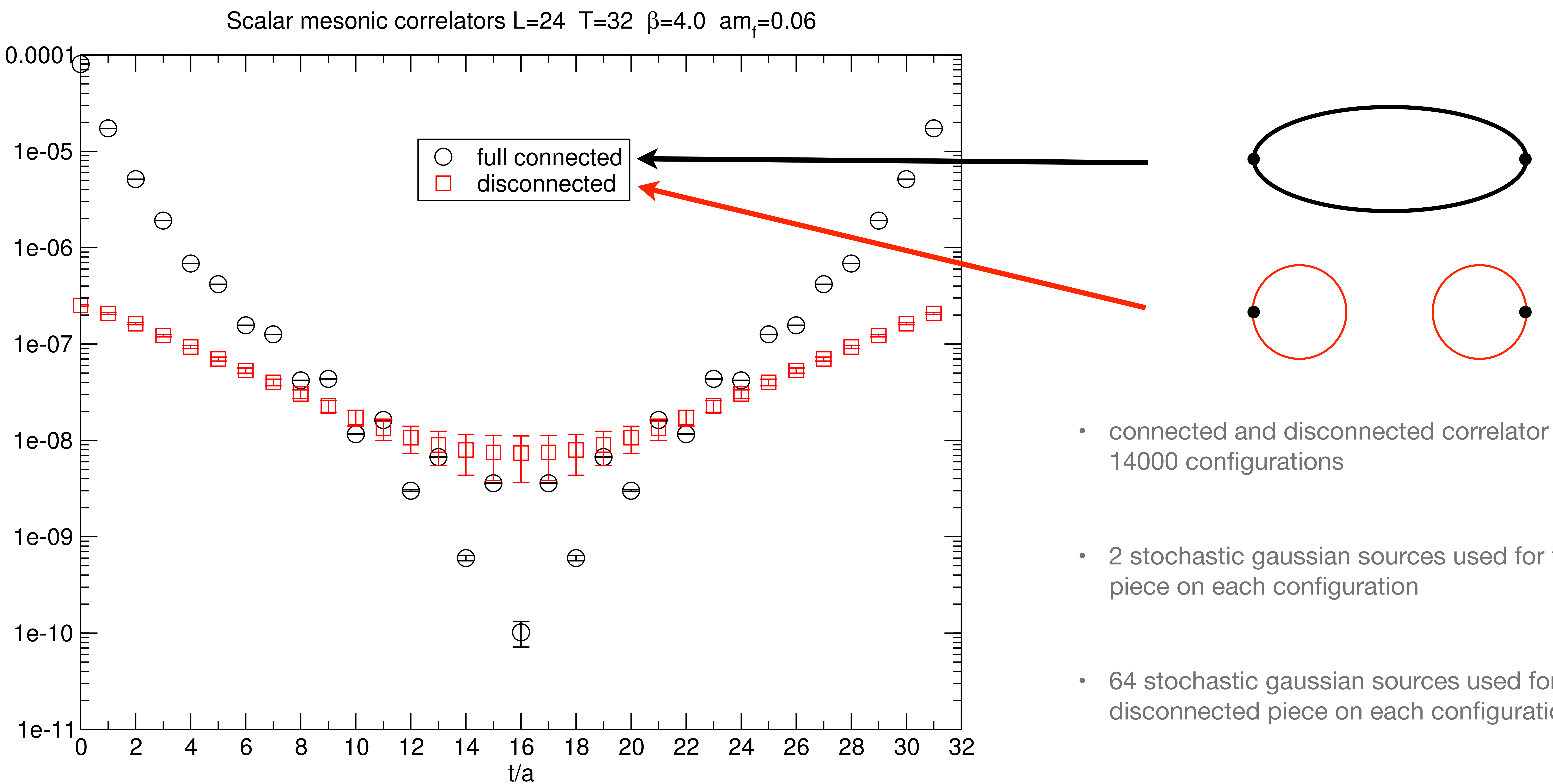
L=24 → am=0.277(61)

The state dominating at large time separation is lighter than the pion

Meson spectroscopy: scalar flavour-singlet

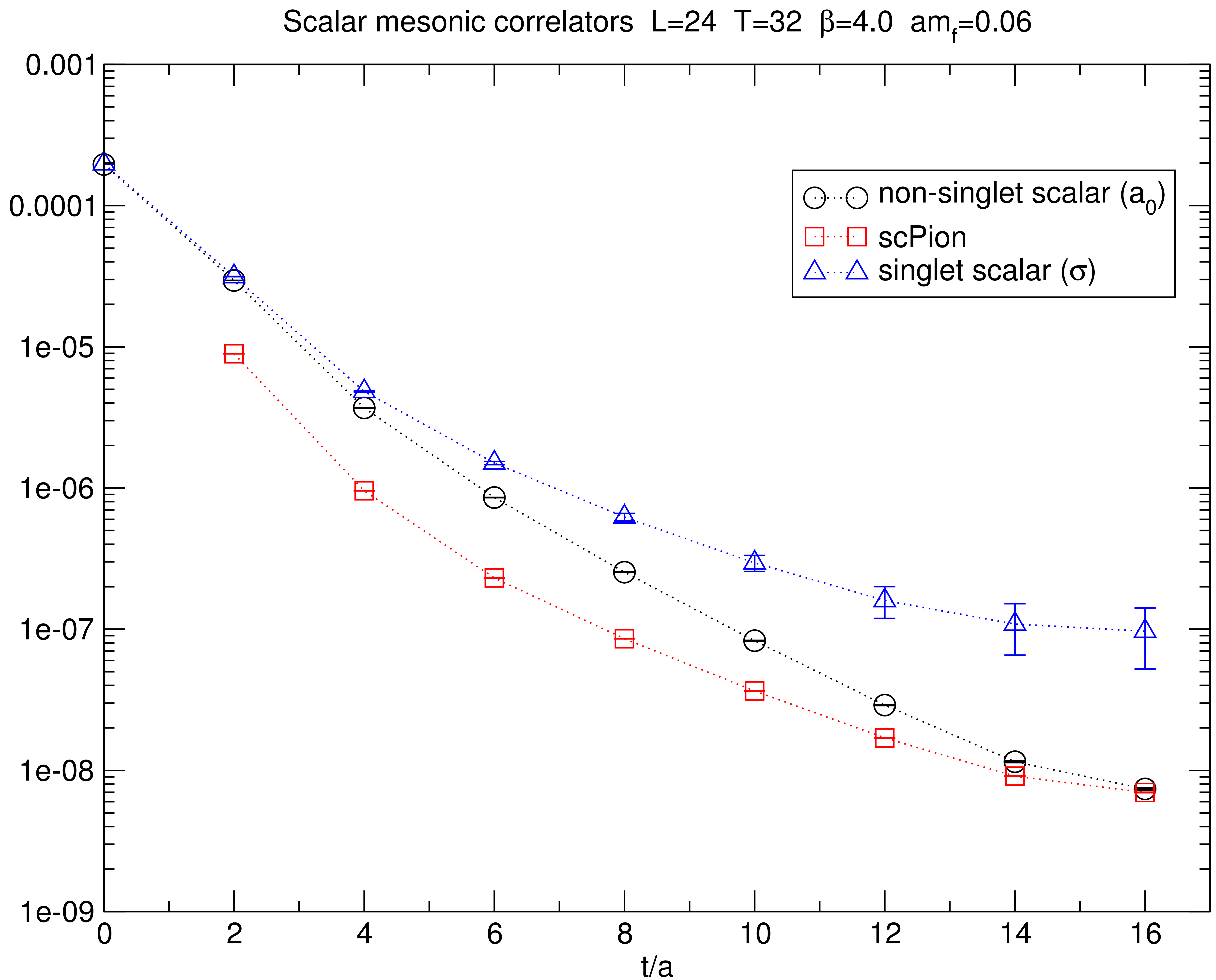
- N_f=12 staggered formalism → the scalar interpolating mesonic operator couples to two states
  - 0^- state → is the scPion (non-goldstone), degenerate with the π (goldstone) state in our simulations
  - 0^+ state → contains the scalar non-singlet a_0 and the scalar flavour-singlet f_0 (or σ in QCD)
- disconnected quark loops must be evaluated in the latter case (together with the vacuum contribution)
  - for this we use stochastic gaussian sources and follow **Gregory et al., PRD77:065019(2008)**
- thanks to the large statistic we are able to get a signal for the scalar flavour-singlet state (*preliminary*)

Results: scalar flavour-singlet meson



- connected and disconnected correlator measured on 14000 configurations
- 2 stochastic gaussian sources used for the connected piece on each configuration
- 64 stochastic gaussian sources used for the disconnected piece on each configuration

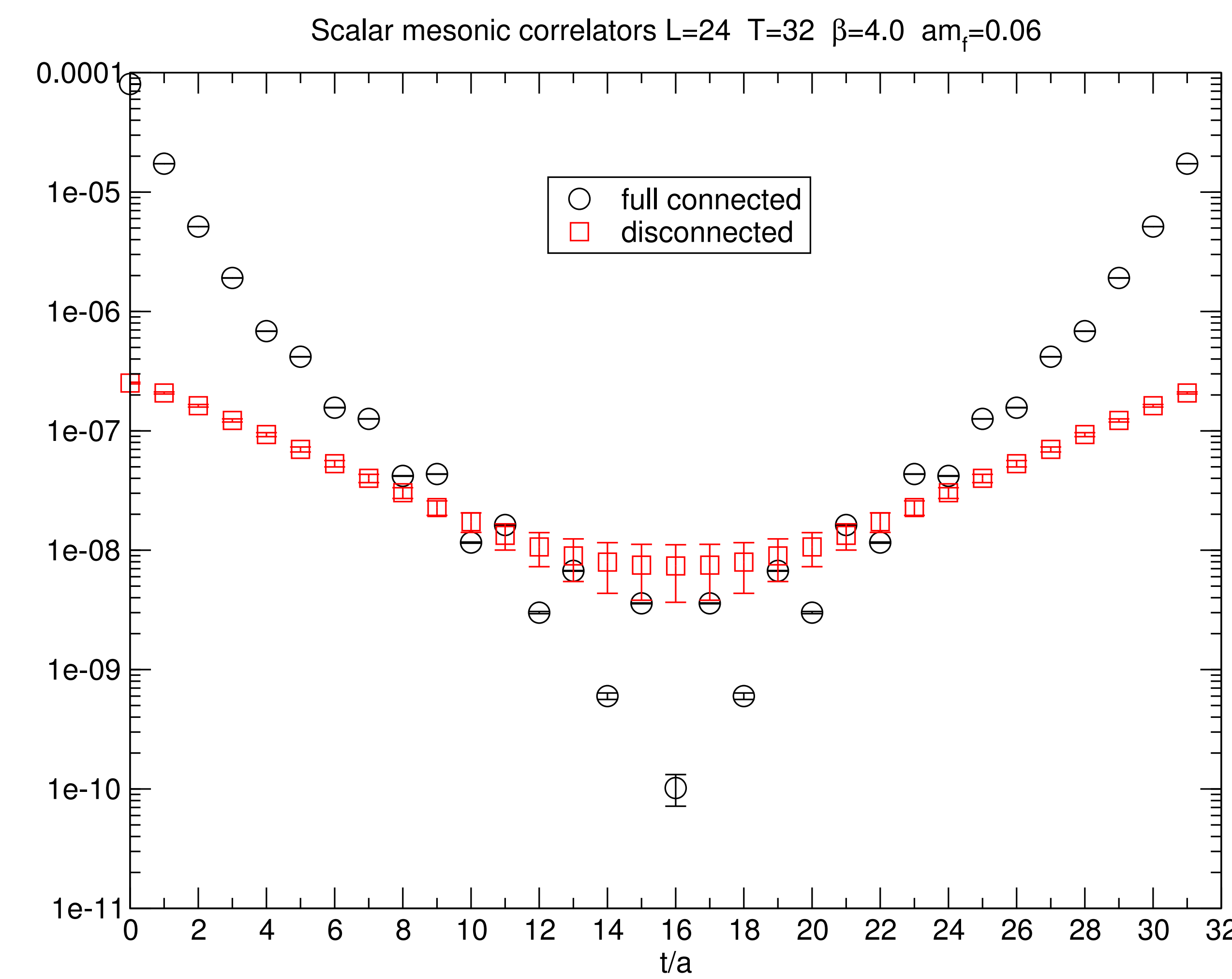
Results: scalar flavour-singlet meson



$$C_{0^+}(t) = 2C(t) + C(t+1) + C(t-1)$$

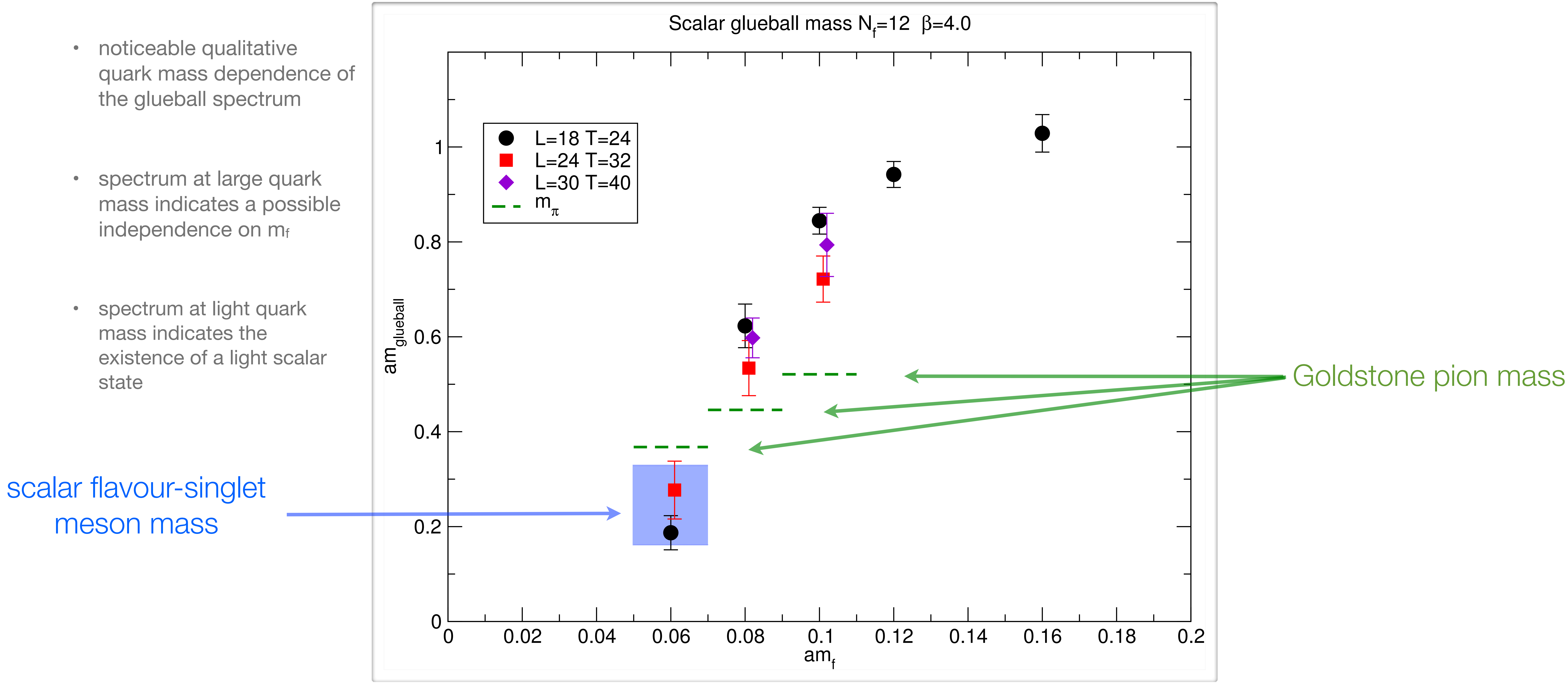
$$C_{0^-}(t) = 2C(t) - C(t+1) - C(t-1)$$

$$C_{\sigma}(t) = -C_{0^+}(t) + 3D^2_{0^+}(t)$$



Results: summary

- noticeable qualitative quark mass dependence of the glueball spectrum
- spectrum at large quark mass indicates a possible independence on m_f
- spectrum at light quark mass indicates the existence of a light scalar state



Conclusions

- first study of scalar spectrum in many-flavour QCD, focused on N_f=12
  - scalar glueball and scalar meson interpolating operators are used
  - mesonic disconnected diagrams are evaluated for the scalar flavour-singlet case
- for light bare quark masses there is a light state in the scalar channel with $m_{sc} < m_\pi$
- both glueball operators and mesonic operators couple to this state
  - important to understand the mixing of such contributions
- starting point of a more careful analysis of light scalar states in (near-)conformal theories
  - important non-perturbative study in phenomenological models of Walking Technicolor

Outlook

- identify and reduce systematic errors
  - larger volumes at light quark masses are necessary to carefully estimate finite size errors
  - possible discretisation effects need to be studied by simulating at different lattice spacing
  - longer trajectories will help improving the identification of effective mass plateaux
- lighter quark masses where the scalar state is light are needed to identify its scaling properties
- a variational analysis including both gluonic and mesonic operators in the scalar channel is in progress
  - can give informations about the mixing between the two kind of operators
- different number of flavours → study the scalar state in a candidate model for the "walking" scenario

Thank you