LATTICE 2015 - The 33rd International Symposium on Lattice Field Theory

Computation of correlation matrices for tetraquark candidates with $J^P = 0^+$ and flavor structure $q_1\bar{q}_2q_3\bar{q}_3$

-ongoing-

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GOETHE UNIVERSITÄT FRANKFURT AM MAIN

Outline

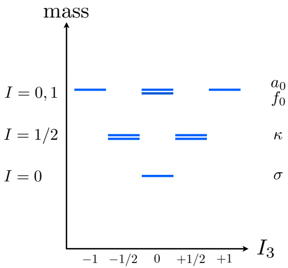
1. Motivation
   - Light scalar mesons as tetraquarks

2. Approach
   - The Operatorbasis
   - Technical aspects

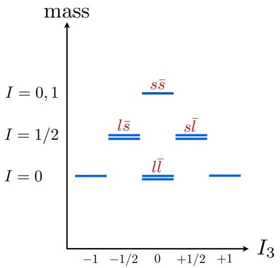
3. Results

Introduction

- nonet of light scalar mesons ($J^P = 0^+$) still poorly understood
  - states are unexpectedly light
  - $I = 1$ (two u/d quarks) states (a_0, f_0) are heavier than the $I = 1/2$ (u/d and s quark) states (κ)



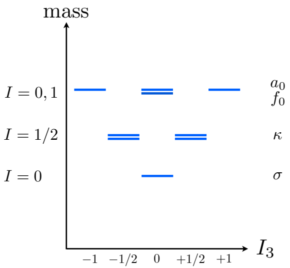
experimental results



standard quark model

Mass ordering

- $qq\bar{q}\bar{q}$ states explain the mass ordering naturally
- $a_0 \equiv us\bar{s}\bar{d}$ and $\kappa \equiv u(u\bar{u} + d\bar{d})\bar{s} \Longrightarrow m_{a_0} > m_\kappa \quad \checkmark$
  - $a_0(980) \longrightarrow K\bar{K}[\bar{s}u][\bar{d}s]$ & $a_0(980) \longrightarrow \eta_s\pi[\bar{s}s][\bar{d}u]$



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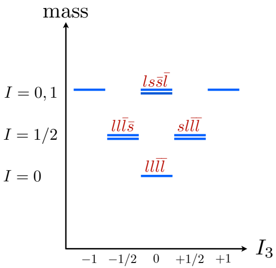


tetraquark model

Approach

Study of **effective masses** from mesonic two-quark and four-quark operators.

- Information about possible stable states around threshold
- Composition of states from the solution of the generalized eigenvalue problem
- Relies on large operator basis, in particular 2 meson states

Gauge configurations:

- 2+1 dyamical clover fermions and Iwasaki gauge action
- generated by the PACS-CS Collaboration

  S. Aoki *et al.* [PACS-CS Collaboration], Phys. Rev. D **79** (2009) 034503 [arXiv:0807.1661 [hep-lat]].
- Lattice: $32^3 \times 64$, $a \approx 0.09$fm
- ≈ 400 configurations at $M_\pi \approx 300$MeV

The correlation function

Fundamental element is the correlation function:

$$C_{jk}(t) = \langle \mathcal{O}_j(t)\mathcal{O}_k^\dagger(0)\rangle = \sum_{n=0}^{\infty} \langle 0|\mathcal{O}_j(t)|n\rangle \, \langle n|\mathcal{O}_k^\dagger(0)|0\rangle \, \exp(-E_n t).$$

Solving the generalized eigenvalue problem

$$C(t)\, v_n(t,t_0) \;=\; \lambda_n(t,t_0)\, C(t_0)\, v_n(t,t_0),$$

yields

$$E_0 = \lim_{t \gg a} E_n^{\text{eff}}(t,t_0) = \lim_{t \gg a} \frac{1}{a} \log \frac{\lambda_n(t,t_0)}{\lambda_n(t+a,t_0)}.$$

Example **creation operator**: $\mathcal{O}^{\text{pion}}(t) = \sum_{\mathbf{x}} \bar{d}(\mathbf{x})\, \gamma_5\, u(\mathbf{x})$.

Operator basis

In our study: 6 operators with the quantum numbers of $a_0(980)$.

$$\mathcal{O}^{q\bar{q}} = \sum_{\mathbf{x}} \left(\bar{d}_{\mathbf{x}} u_{\mathbf{x}}\right)$$

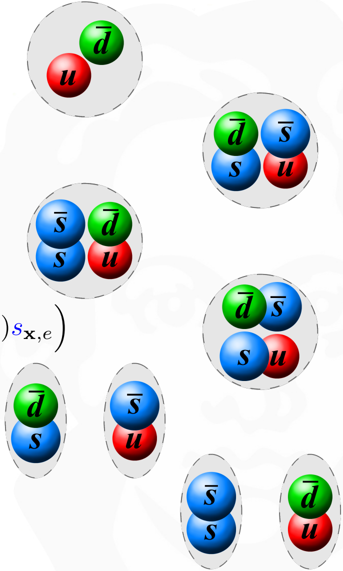
$$\mathcal{O}^{K\bar{K},\,\text{point}} = \sum_{\mathbf{x}} \left(\bar{s}_{\mathbf{x}} \gamma_5 u_{\mathbf{x}}\right)\left(\bar{d}_{\mathbf{x}} \gamma_5 s_{\mathbf{x}}\right)$$

$$\mathcal{O}^{\eta_s\pi,\,\text{point}} = \sum_{\mathbf{x}} \left(\bar{s}_{\mathbf{x}} \gamma_5 s_{\mathbf{x}}\right)\left(\bar{d}_{\mathbf{x}} \gamma_5 u_{\mathbf{x}}\right)$$

$$\mathcal{O}^{Q\bar{Q}} = \sum_{\mathbf{x}} \epsilon_{abc}\left(\bar{s}_{\mathbf{x},b}(C\gamma_5)\bar{d}^T_{\mathbf{x},c}\right)\epsilon_{ade}\left(u^T_{\mathbf{x},d}(C\gamma_5)s_{\mathbf{x},e}\right)$$

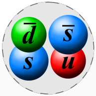
$$\mathcal{O}^{K\bar{K},\,\text{2-part}} = \sum_{\mathbf{x},\mathbf{y}} \left(\bar{s}_{\mathbf{x}} \gamma_5 u_{\mathbf{x}}\right)\left(\bar{d}_{\mathbf{y}} \gamma_5 s_{\mathbf{y}}\right)$$

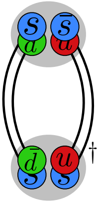
$$\mathcal{O}^{\eta_s\pi,\,\text{2-part}} = \sum_{\mathbf{x},\mathbf{y}} \left(\bar{s}_{\mathbf{x}} \gamma_5 s_{\mathbf{x}}\right)\left(\bar{d}_{\mathbf{y}} \gamma_5 u_{\mathbf{y}}\right)$$

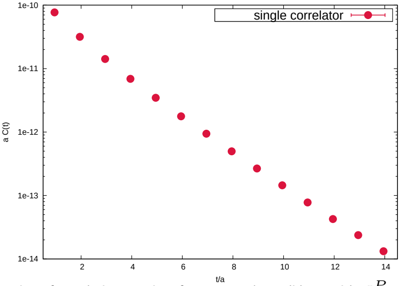


Correlationfunctions with closed fermion loops

$$C(t) = \langle \mathcal{O}(t)\mathcal{O}^\dagger(0)\rangle$$

$\mathcal{O} \approx$ 





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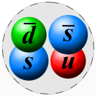
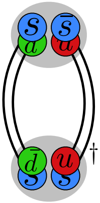
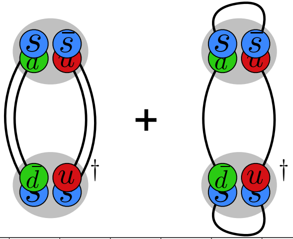
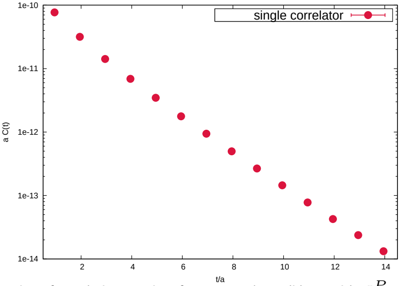
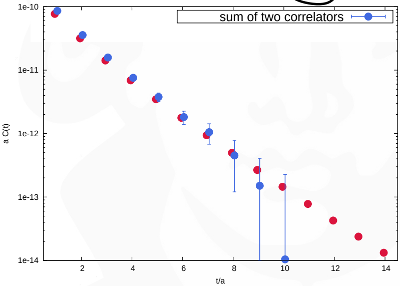
$\mathcal{O} \approx$ 



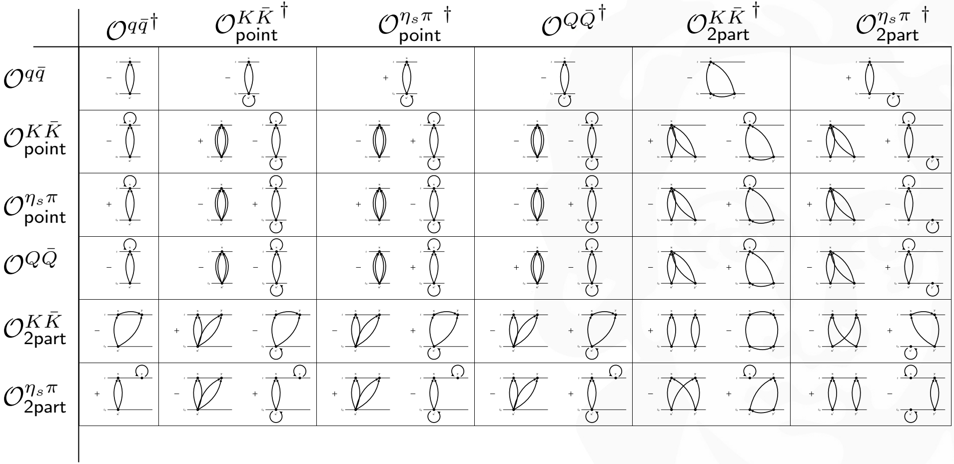




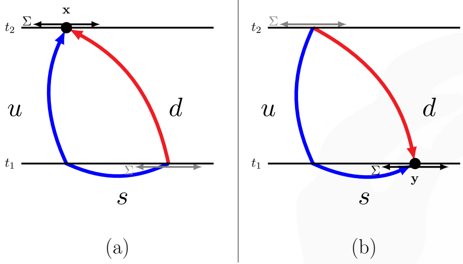


$C_{jk}(t)$

$$C_{jk} = \langle \mathcal{O}_j \mathcal{O}_k^\dagger \rangle$$



Sequential propagators

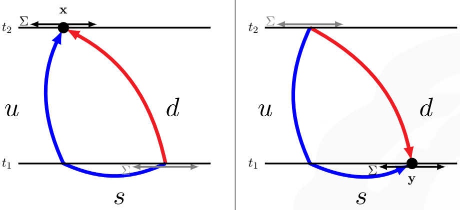


$$C(\Delta t) = -\langle \sum_{\mathbf{x},\mathbf{y},\mathbf{z}} \mathrm{tr}\Big(G^s(\mathbf{z}, t_1; \mathbf{y}, t_1)^\dagger \gamma_5 G^u(\mathbf{x}, t_2; \mathbf{z}, t_1)^\dagger \gamma_5 G^d(\mathbf{x}, t_2; \mathbf{y}, t_1) \Big) \rangle$$

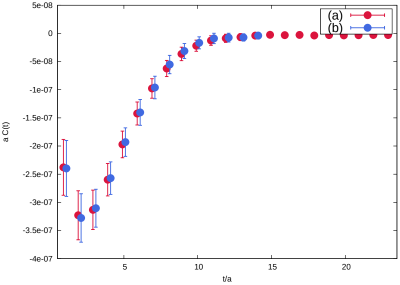
(a) $-\langle \sum_{\mathbf{x},\mathbf{z}} \mathrm{tr}\Big(\underbrace{[\phi^s(z)\delta_{z_0,t_1}]^\dagger \gamma_5 G^u(\mathbf{x}, t_2; \mathbf{z}, t_1)^\dagger}_{\text{seq. inversion}} \gamma_5 \phi^d(x) \Big) \rangle \rightarrow -\langle \sum_{\mathbf{x}} \mathrm{tr}\Big(\psi^{u/s}(x)^\dagger \gamma_5 \phi^d(x) \Big) \rangle$

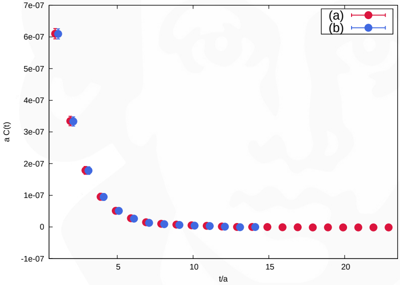
(b) $-\langle \sum_{\mathbf{y},\mathbf{z}} \mathrm{tr}\Big(\phi^d(y)^\dagger \gamma_5 \underbrace{G^s(\mathbf{y}, t_1; \mathbf{z}, t_1) \gamma_5 \phi^u(z)}_{\text{seq. inversion}} \Big) \rangle \rightarrow -\langle \sum_{\mathbf{y}} \mathrm{tr}\Big(\phi^d(y)^\dagger \gamma_5 \psi^{s/u}(y) \Big) \rangle$

Sequential propagators

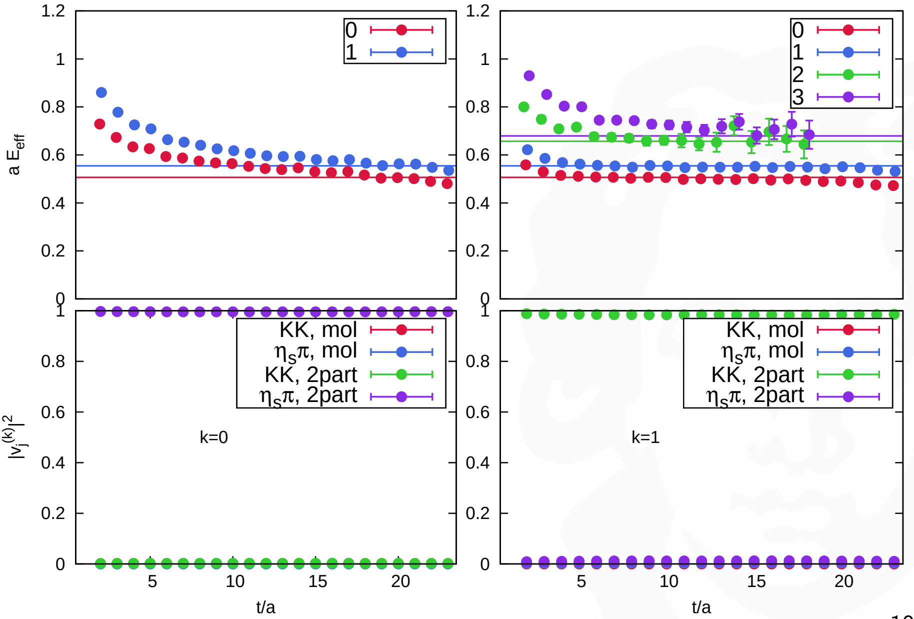


(a) (b)

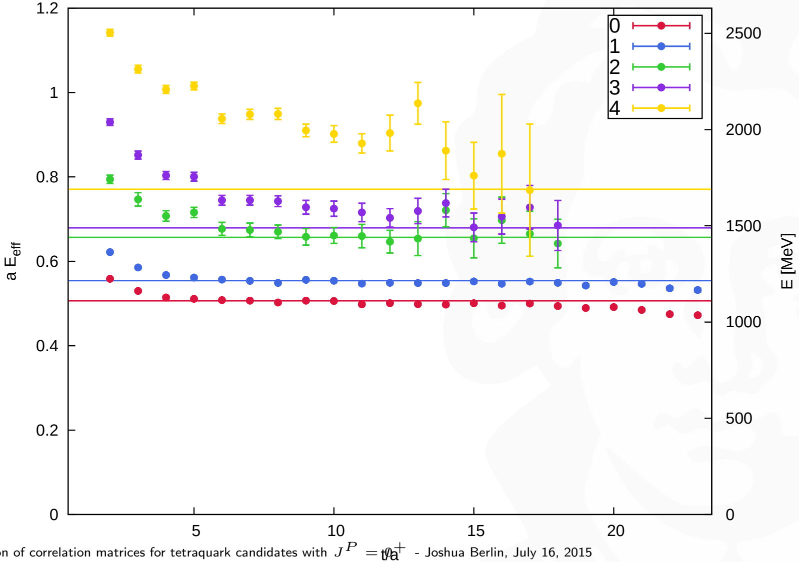




2×2 and 4×4 submatrices



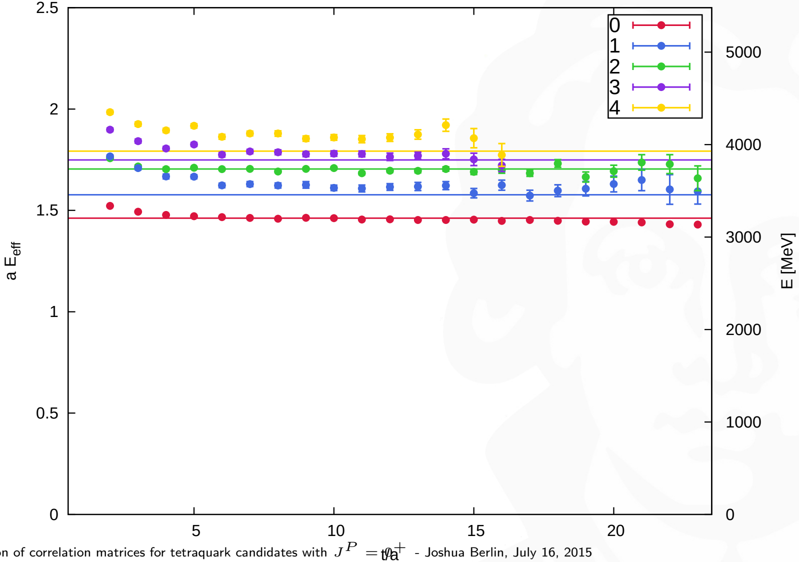
The 5×5 submatrix (excluding $\mathcal{O}^{q\bar{q}}$)



The 5×5 submatrix (excluding $\mathcal{O}^{q\bar{q}}$)

Here increased quark masses: $u\bar{d}s\bar{s} \longrightarrow u\bar{d}c\bar{c}$.

c.f. also L. Leskovec, S. Prelovsek, C. B. Lang and D. Mohler, PoS LATTICE **2014** (2015) 118 [arXiv:1410.8828 [hep-lat]].



Summary & Outlook

Summary

- applying standard point-to-all and stochastic propagators **different methods** are tested for many diagram-types
- neglecting closed fermion loops:

  $a_0(980)$ does **not** appear to be a $qq\bar{q}\bar{q}$ state.

  - unchanged for increased quark masses

Outlook

- inclusion of propagators **within a timeslice** at **large** statistics
- investigation of other 0^+ tetraquark candidates