Investigation of the tetra-quark candidate $a_0(980)$: preliminary results

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Lattice 2014, 23-28 June 2014, Columbia University

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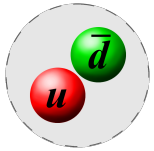
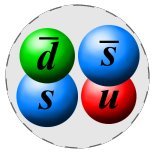
Interpolating Operators

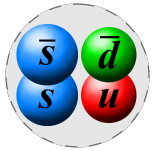
$$\mathcal{O}^{q\bar{q}} = \sum_{\mathbf{x}} \left(\bar{d}_{\mathbf{x}} u_{\mathbf{x}} \right)$$



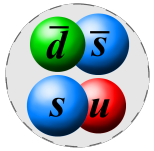
$$\mathcal{O}^{K\bar{K},\ \text{point}} = \sum_{\mathbf{x}} \left(\bar{s}_{\mathbf{x}} \gamma_5 u_{\mathbf{x}} \right) \left(\bar{d}_{\mathbf{x}} \gamma_5 s_{\mathbf{x}} \right)$$



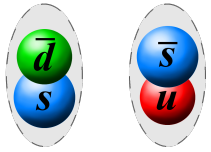
$$\mathcal{O}^{\eta_s \pi,\ \text{point}} = \sum_{\mathbf{x}} \left(\bar{s}_{\mathbf{x}} \gamma_5 s_{\mathbf{x}} \right) \left(\bar{d}_{\mathbf{x}} \gamma_5 u_{\mathbf{x}} \right)$$



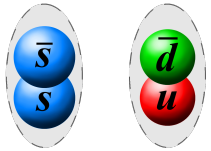
$$\mathcal{O}^{Q\bar{Q}} = \sum_{\mathbf{x}} \epsilon_{abc} \left(\bar{s}_{\mathbf{x},b} (C\gamma_5) \bar{d}^T_{\mathbf{x},c} \right) \epsilon_{ade} \left(u^T_{\mathbf{x},d} (C\gamma_5) s_{\mathbf{x},e} \right)$$



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

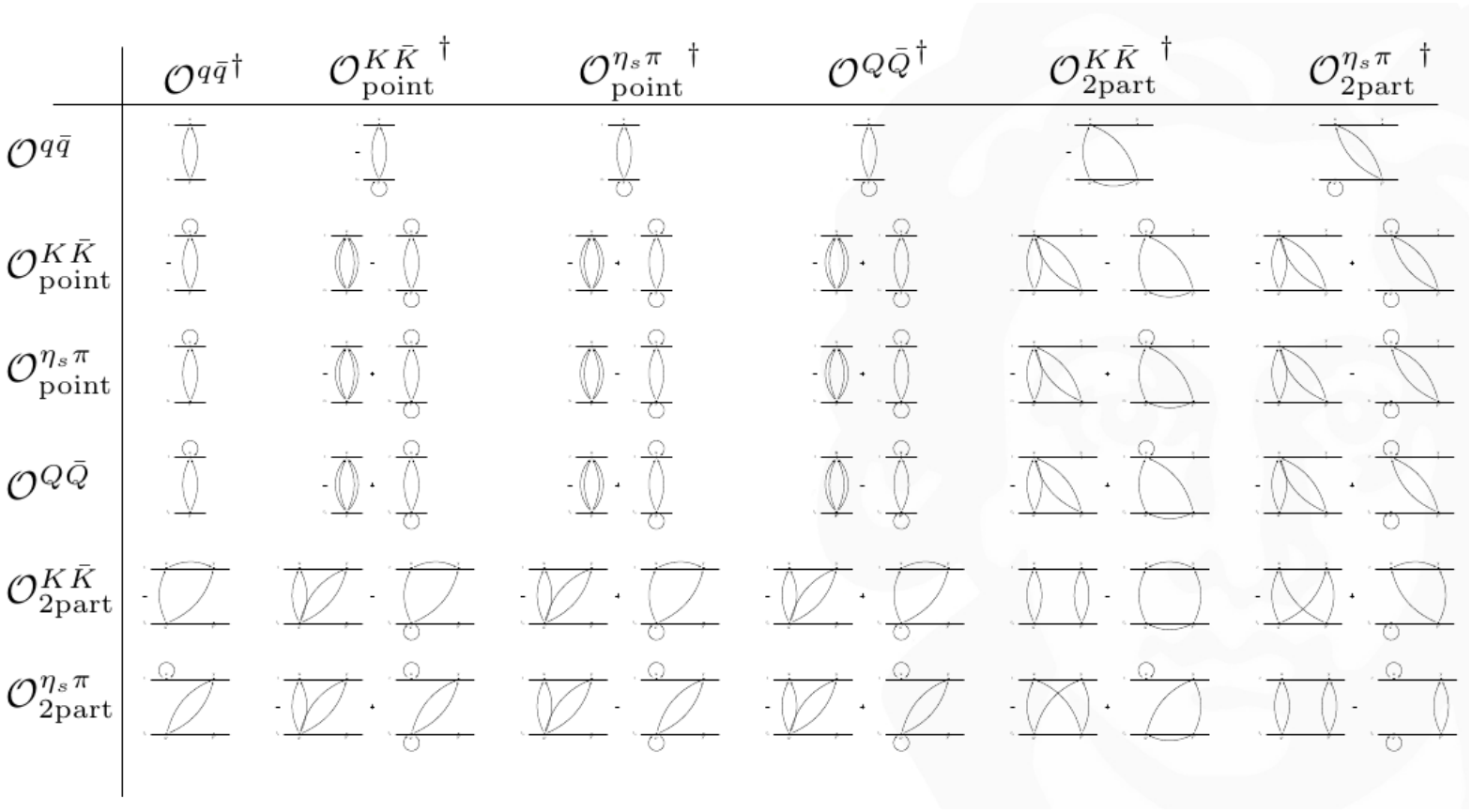


$$\mathcal{O}^{\eta_s \pi,\ \text{2-part}} = \sum_{\mathbf{x},\mathbf{y}} \left(\bar{s}_{\mathbf{x}} \gamma_5 s_{\mathbf{x}} \right) \left(\bar{d}_{\mathbf{y}} \gamma_5 u_{\mathbf{y}} \right)$$



The Correlation Matrix

$$C_{jk}(t) = \langle \mathcal{O}_j(t)\mathcal{O}_k^\dagger(0)\rangle$$



For more details, see previous talk by Joshua Berlin (Wed. 11:30-11:50)

Gauge Configurations

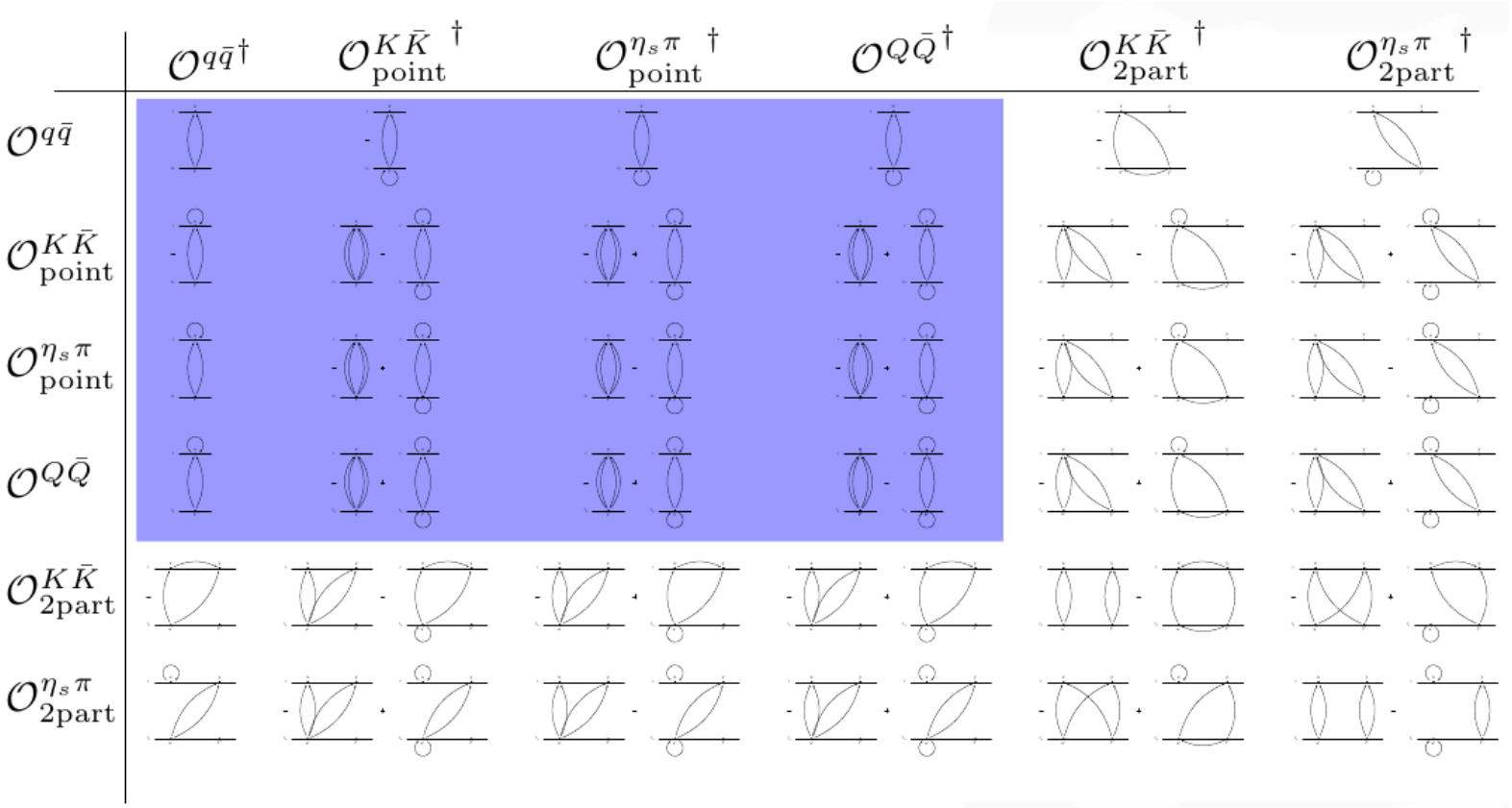
- Gauge configurations with 2+1 dynamical clover fermions and the Iwasaki gauge action.
- Configurations available through the PACS-CS collaboration.

  PACS-CS Collaboration: S. Aoki, et. al. Phys.Rev.D79:034503,2009, arXiv:0807.1661
- Lattice: $32^3 x 64$, Lattice spacing ≈ 0.09 fm.
- 500 configurations at $M_\pi \approx 300$ MeV.
- 198 configurations at $M_\pi \approx 150$ MeV.

Quark Propagators

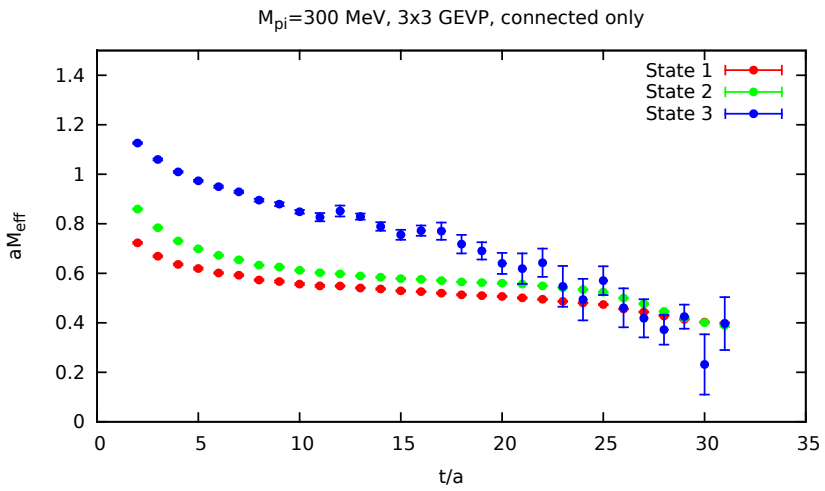
- Propagators are smeared at the source and sink with APE smeared links and invariant Gaussian quark smearing.
- Forward propagators for u, d, s quarks computed for 5 random source locations on each configuration.
- Strange quark loops computed with Z_4 noises diluted in time.
- 5 noises per time slice and only 15 time steps from the source.

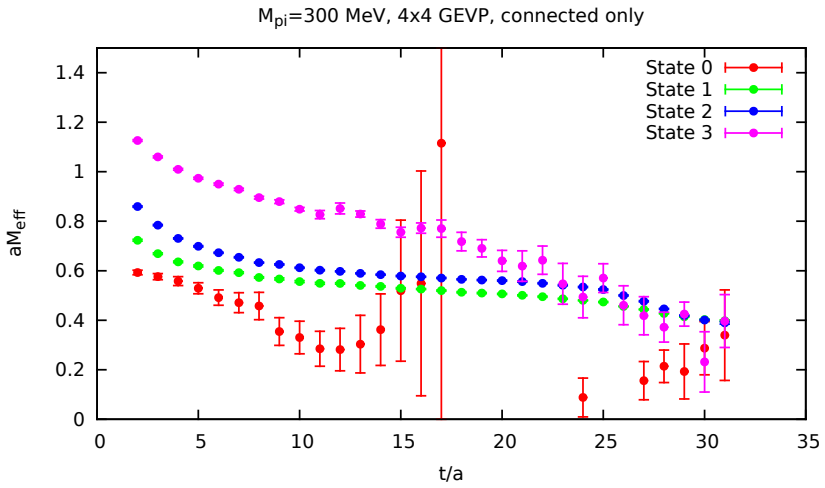
Results I: no 2-particle operators



Results for $m_\pi \approx 300$ MeV, 2500 measurements

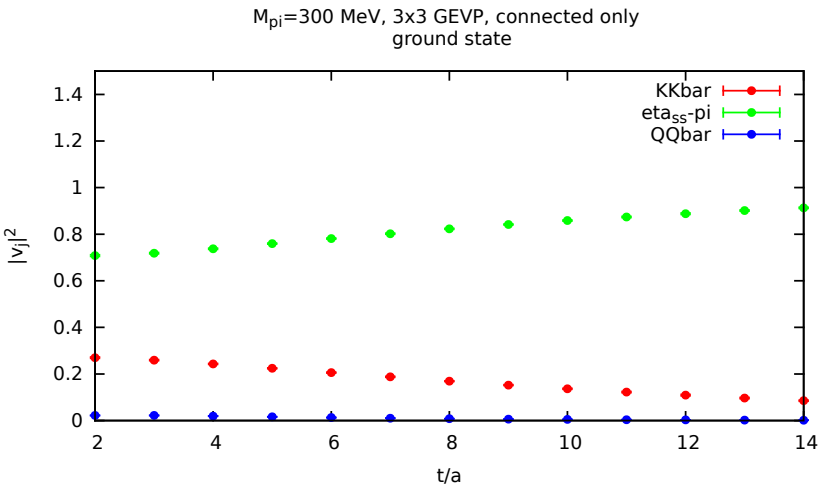
Effective Mass, Connected Only

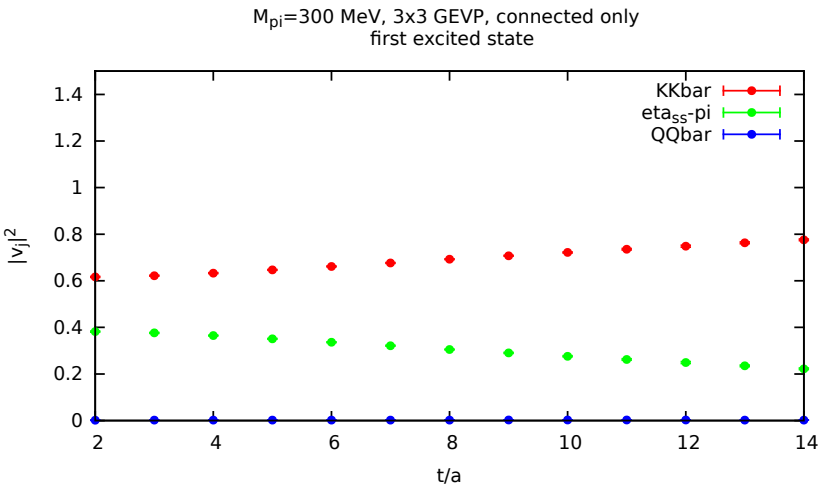


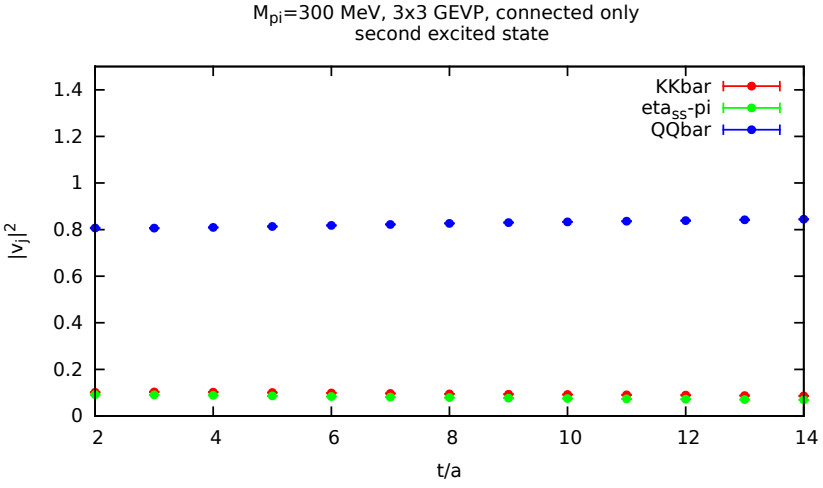


Note: no mixing between $q\bar{q}$ and tetra-quarks (as expected)

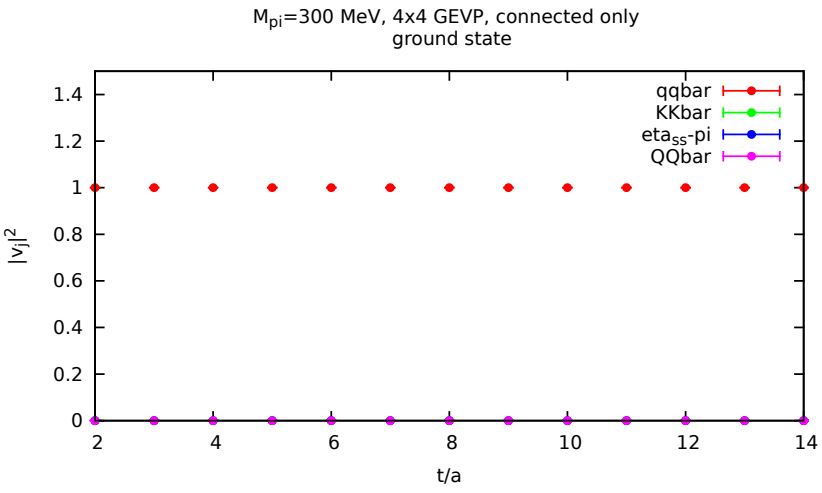
Eigenvector Components, 3x3 connected

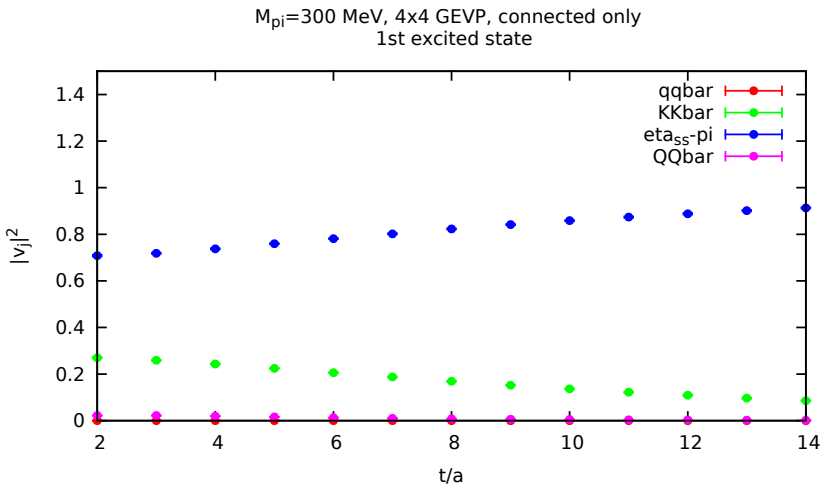


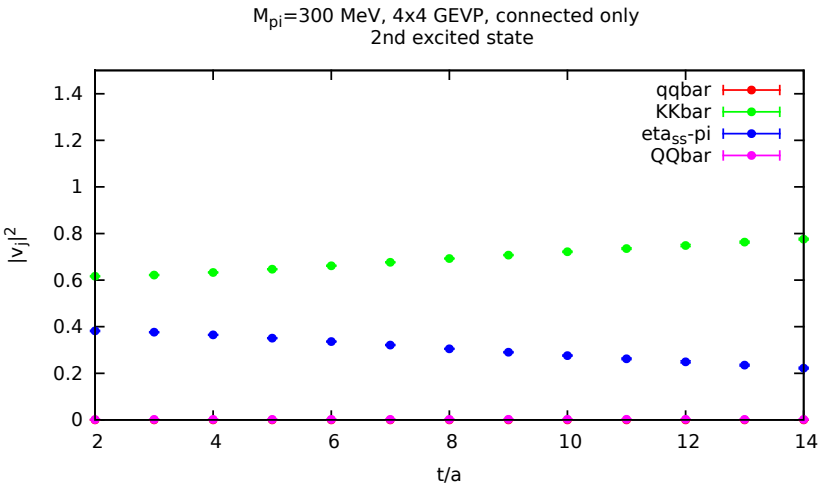


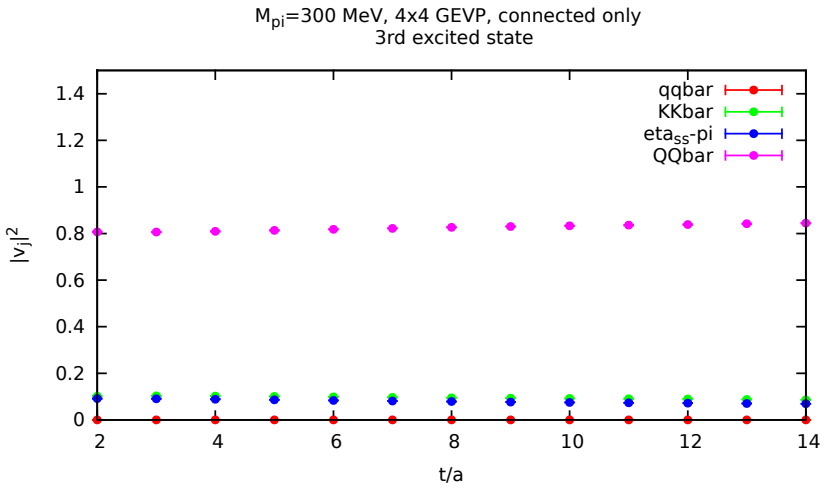


Eigenvector Components, 4x4 connected

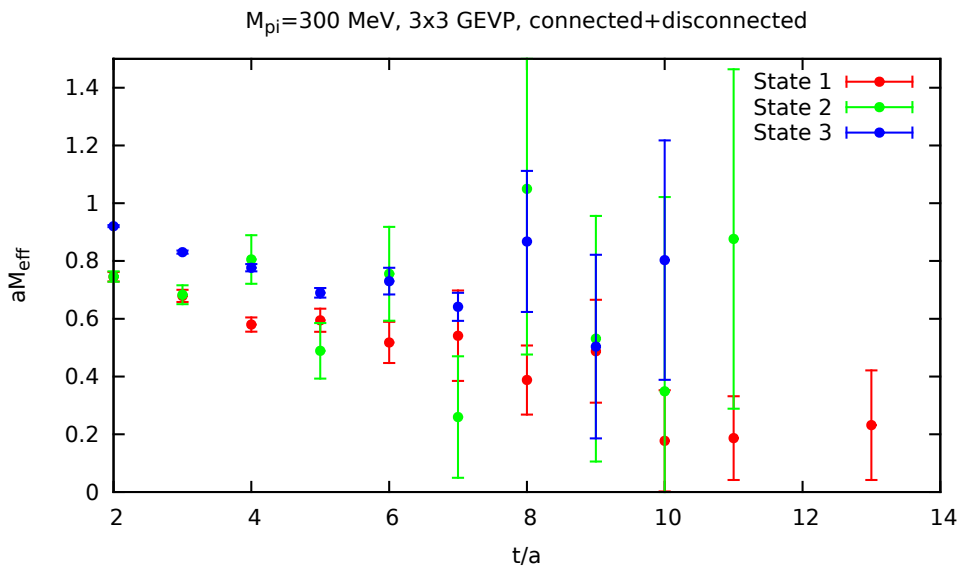


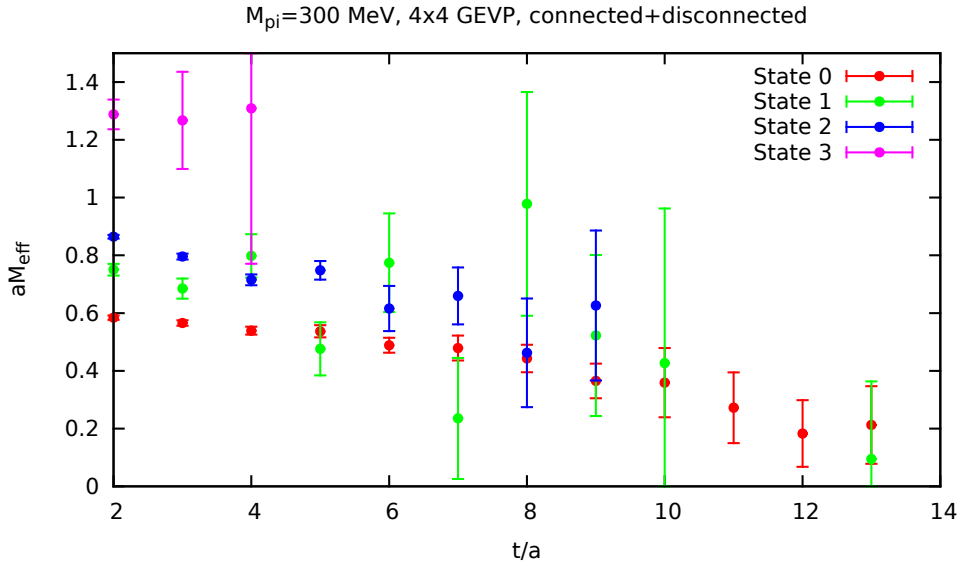




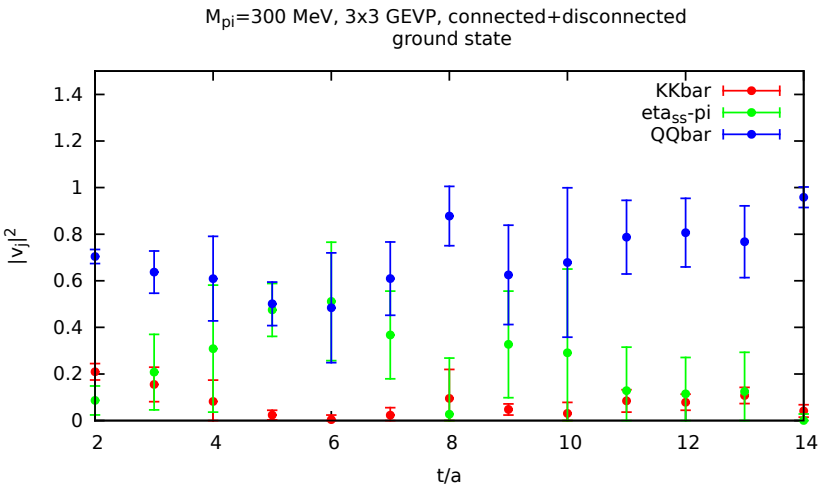


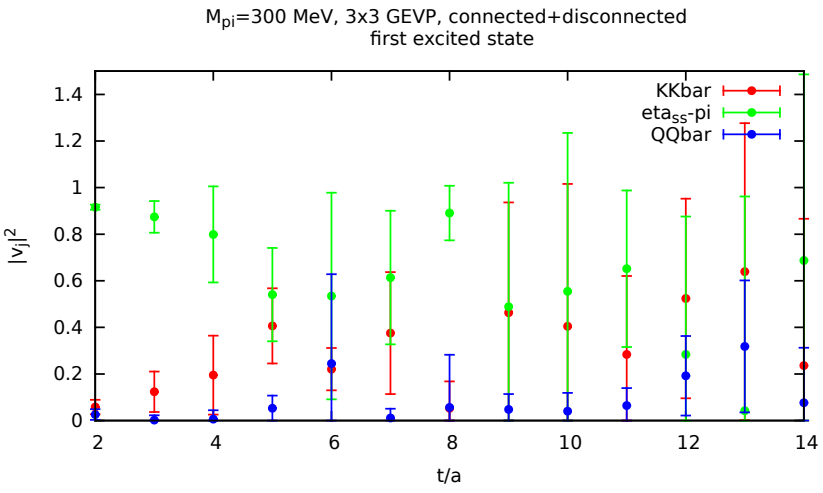
Effective Mass, Connected+disconnected

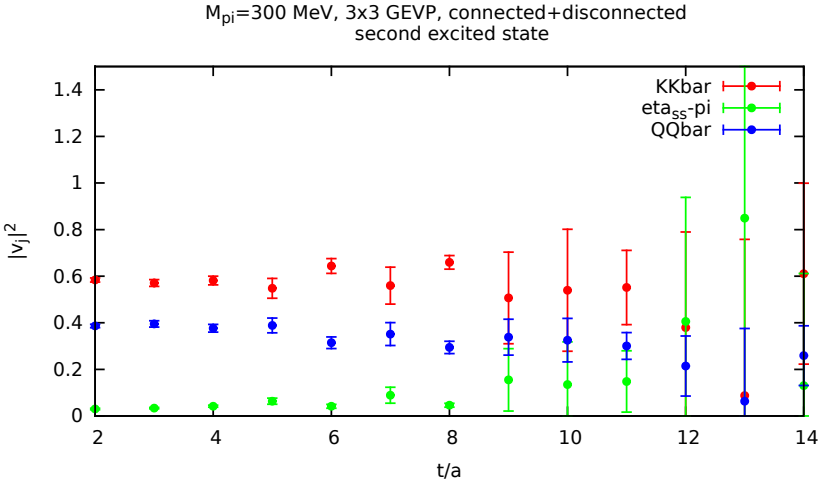




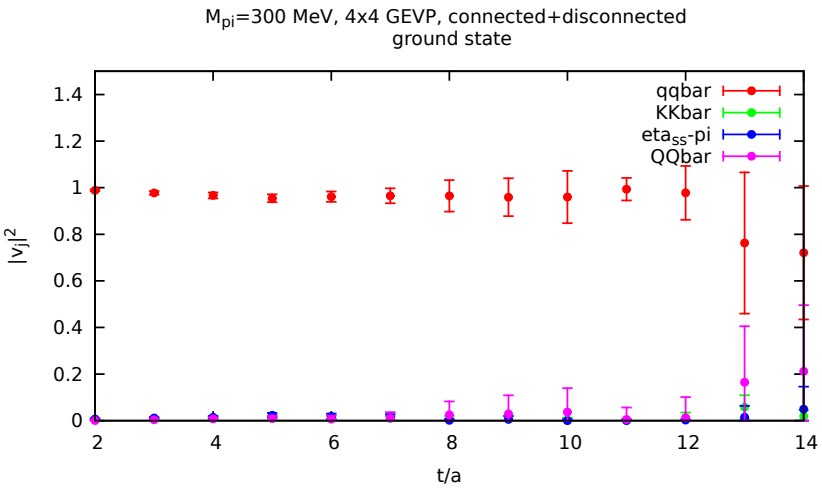
Eigenvector Components, 3x3 connected+disconnected

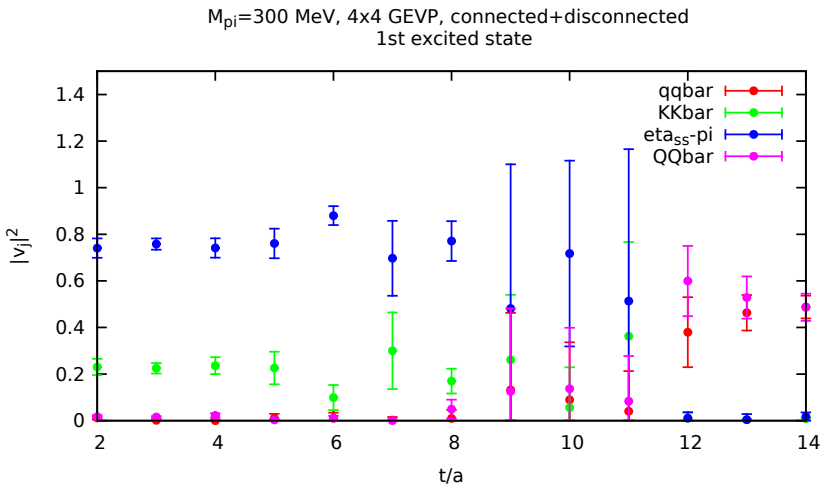


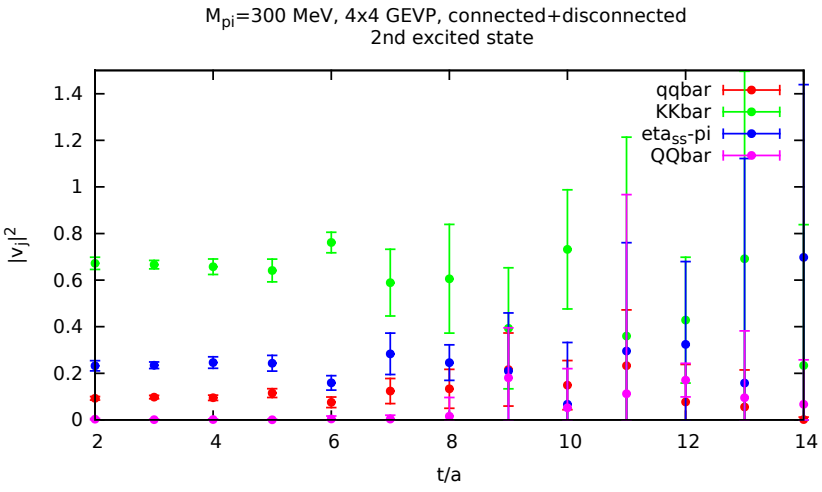


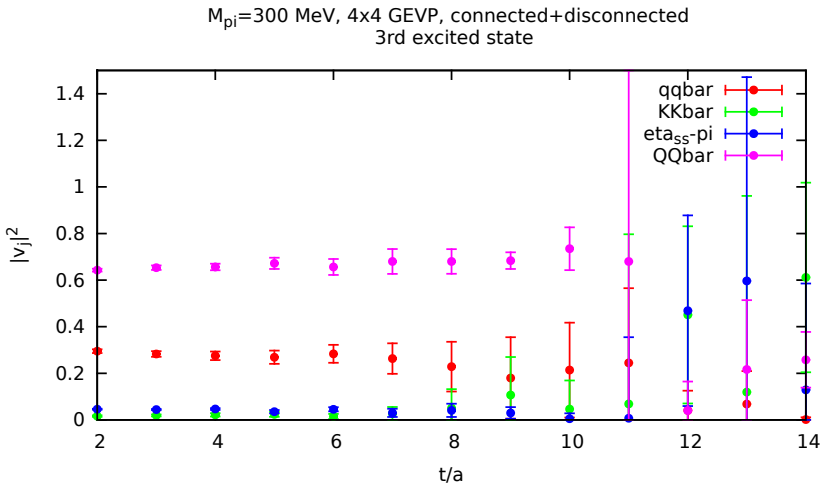


Eigenvector Components, 4x4 connected+disconnected







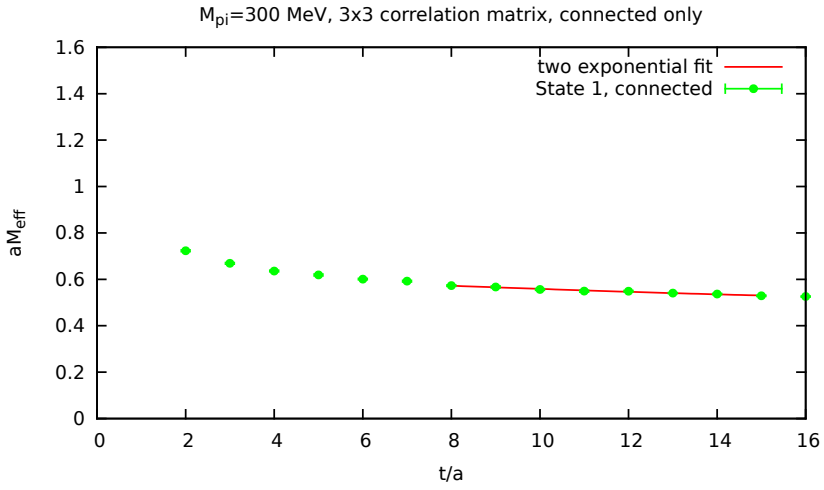


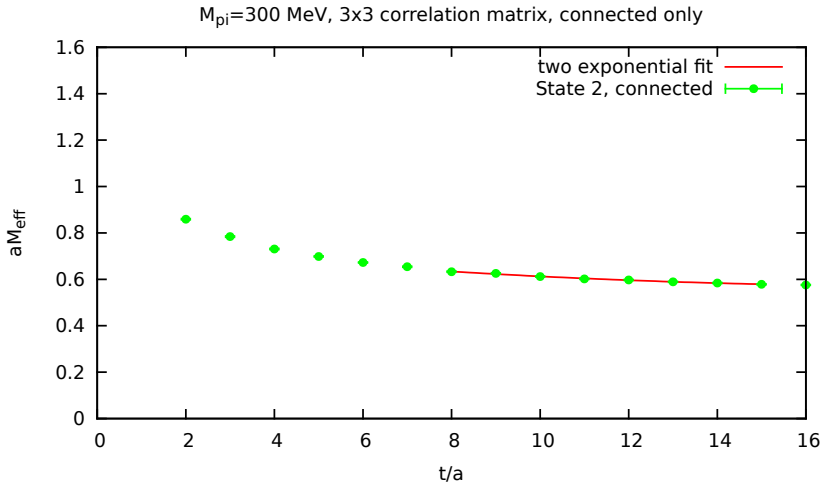
Comments on the eigenvector components

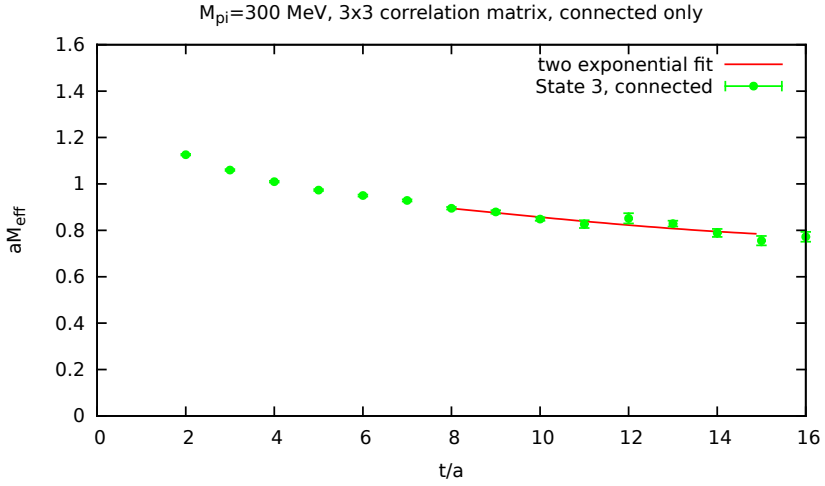
- $q\bar{q}$ mixing with tetraquark operators seem to be small but seems to affect the eigenvalues.
- Including disconnected diagrams but ignoring the $q\bar{q}$ seems to increase the diquark-antidiquark component of the lowest two states.
- Including $q\bar{q}$ seems to give a more consistent picture with or without disconnected diagrams where:
  - Ground state mainly $q\bar{q}$.
  - First and second excited states mainly a mix of $K\bar{K}$ and $\eta - \pi$.
  - Diquark-anti-diquark is the heaviest.

Two Exponential Fits

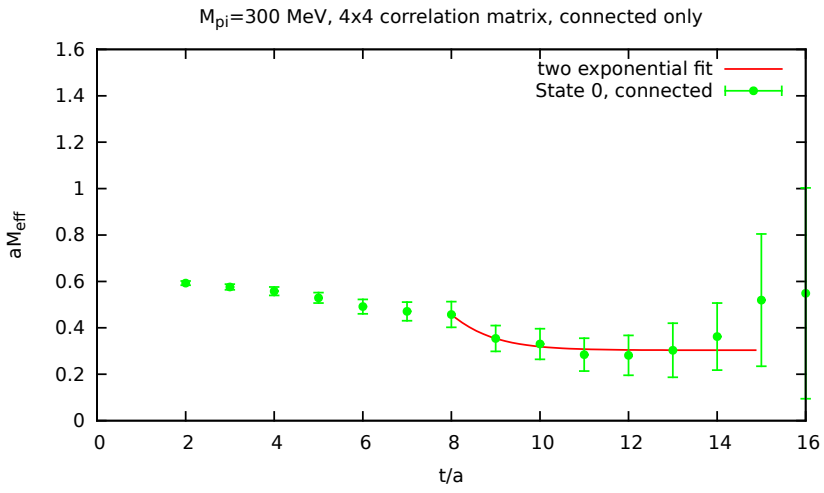
Two-Exponential Fits, 3x3 connected

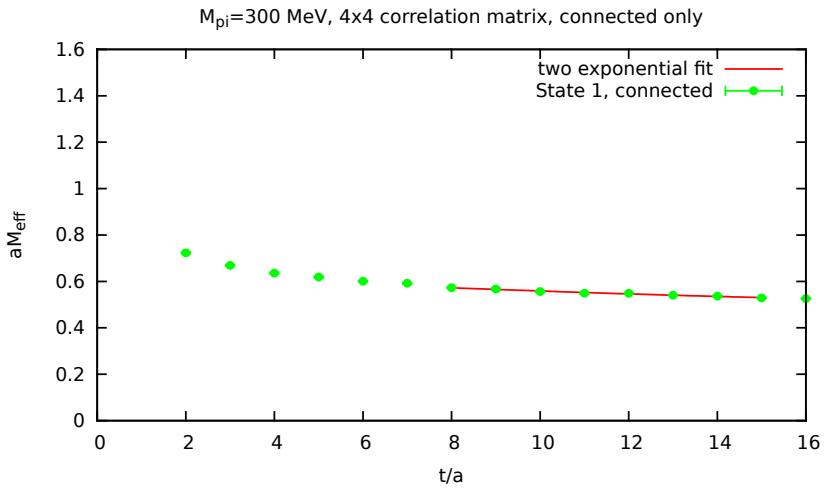


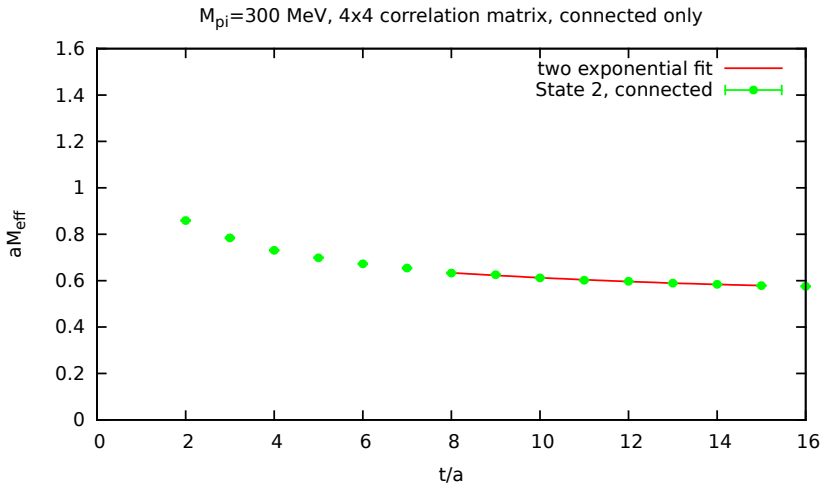


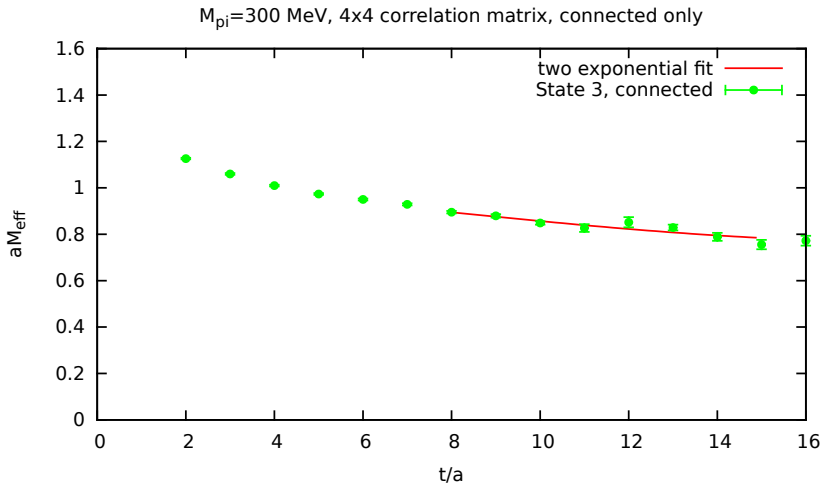


Two-Exponential Fits, 4x4 connected

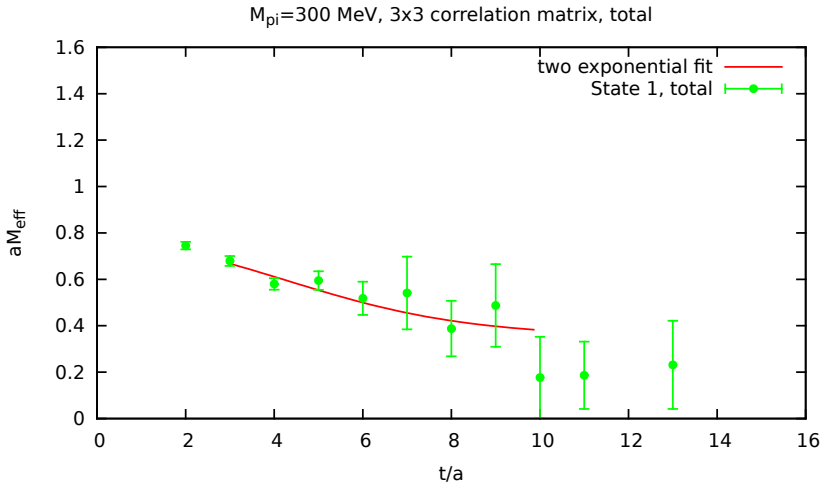


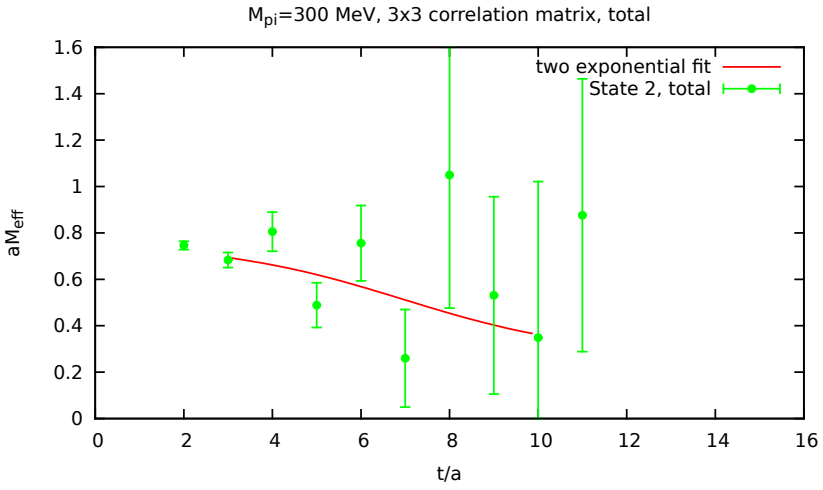


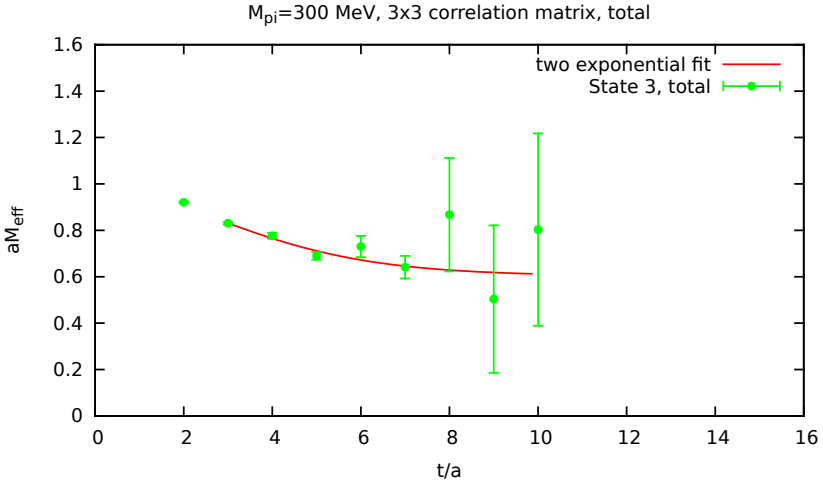




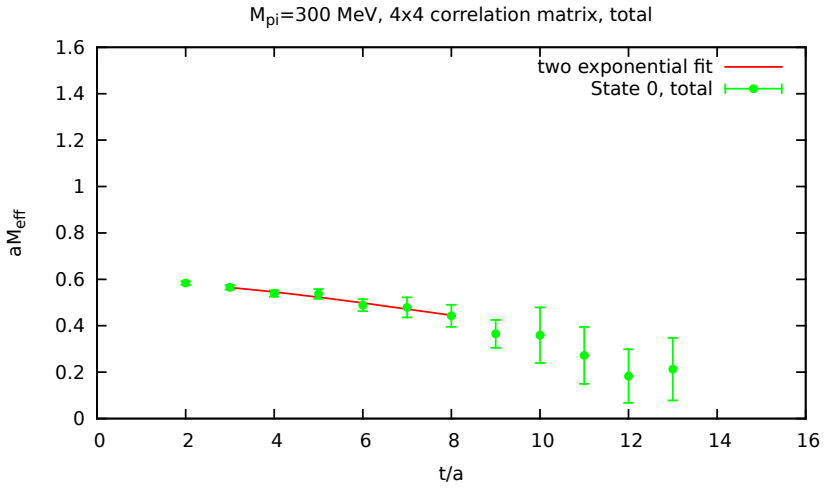
Two-Exponential Fits, 3x3 connected+disconnected

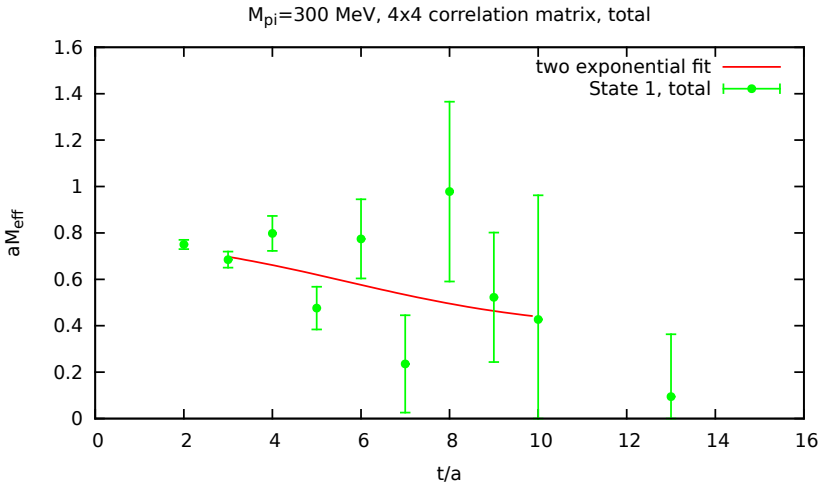


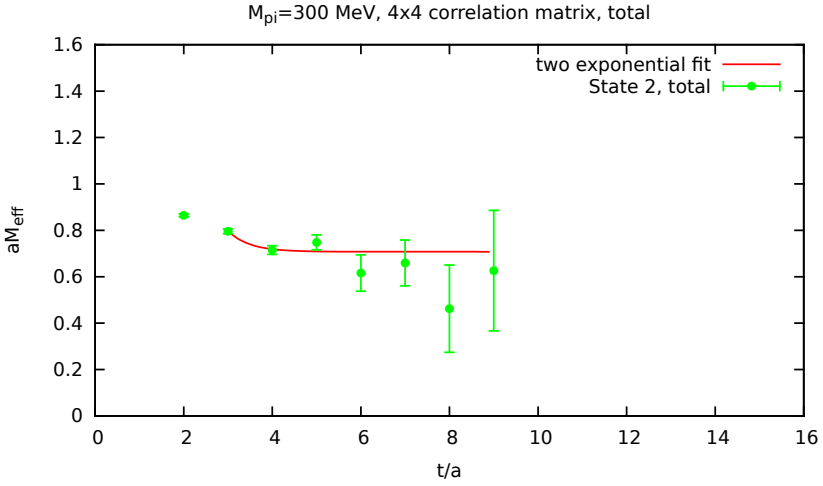




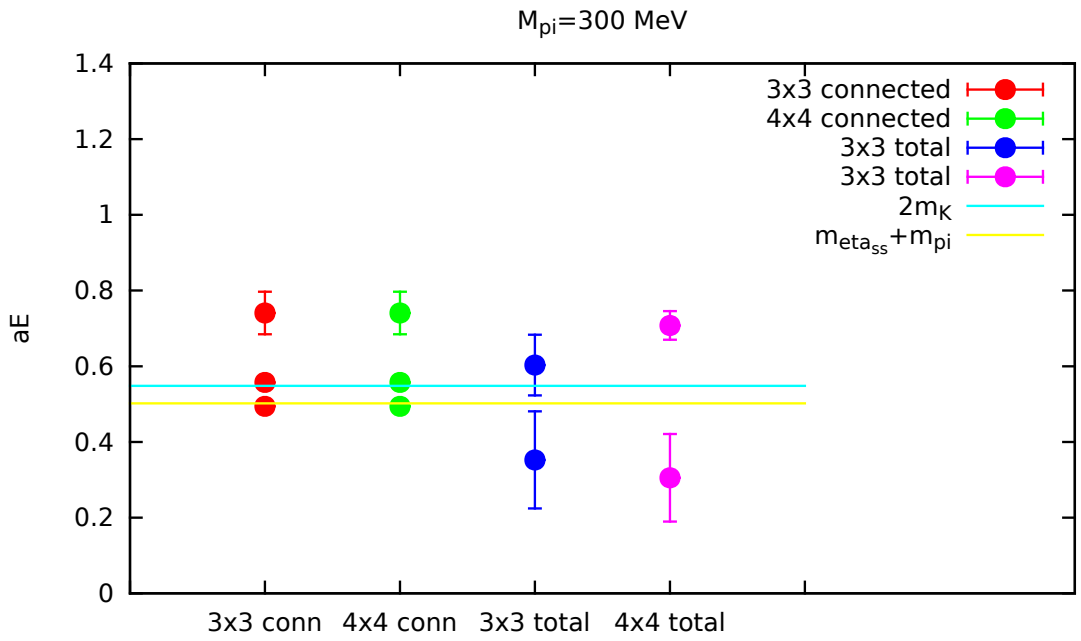
Two-Exponential Fits, 4x4 connected+disconnected







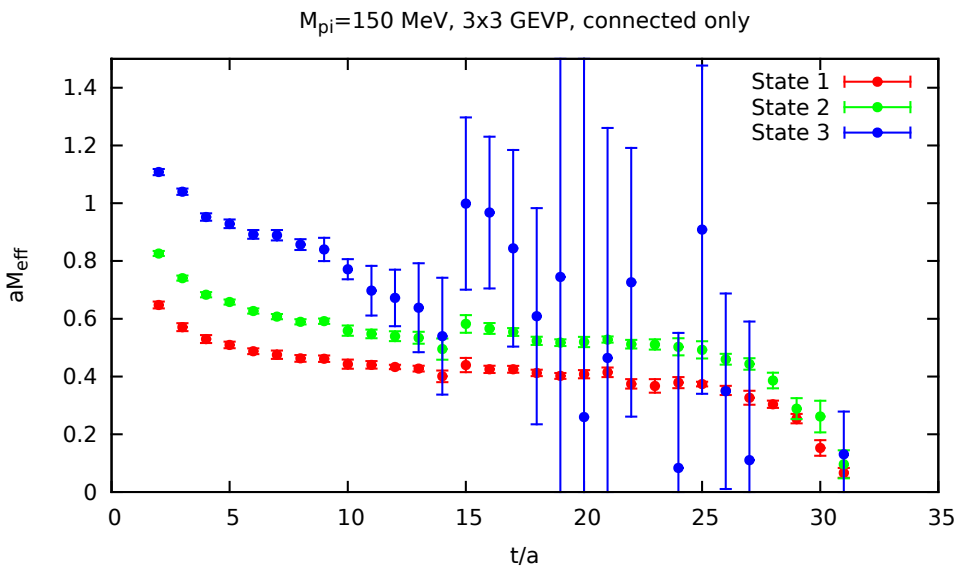
Extracted Energy Levels at $m_\pi \approx 300$ MeV

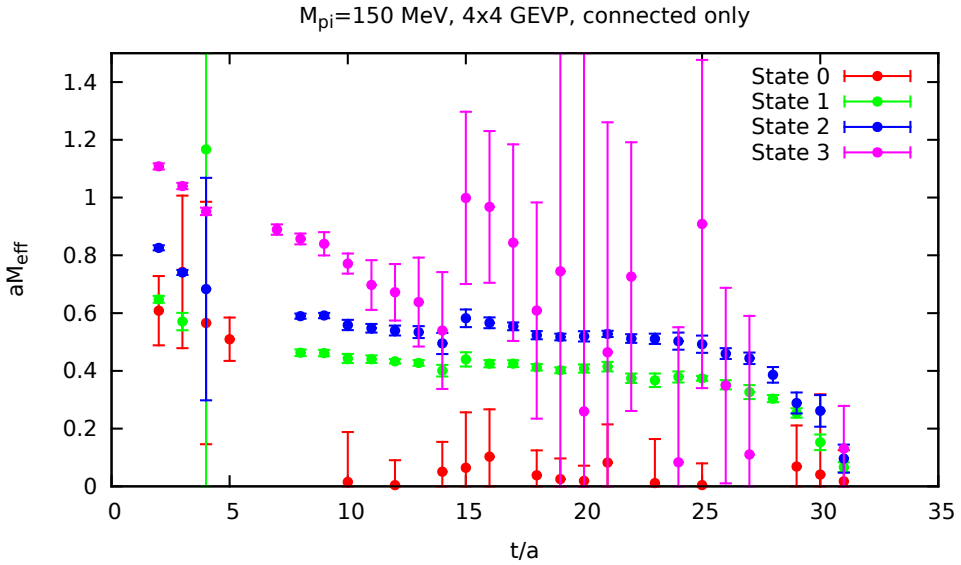


- States not shown were either undetrmined by the fit or the data was too noisy.
- Only scattering states can be resolved unambigously at this level of statistics.
- Currently adding the 2-particle operators to the correlation matrix and also using one-end trick to improve the $q\bar{q}$ correlator. This will hopefully allow us to resolve the $a_0(980)$

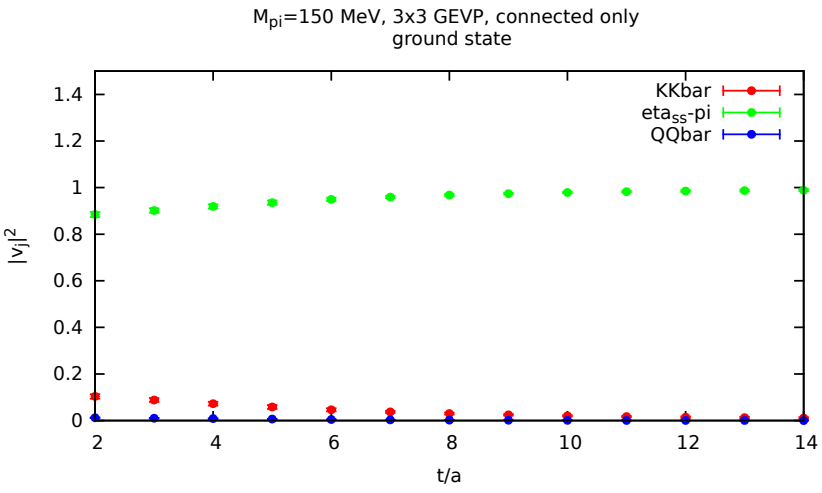
Results for $m_\pi \approx 150$ MeV, 198 measurements

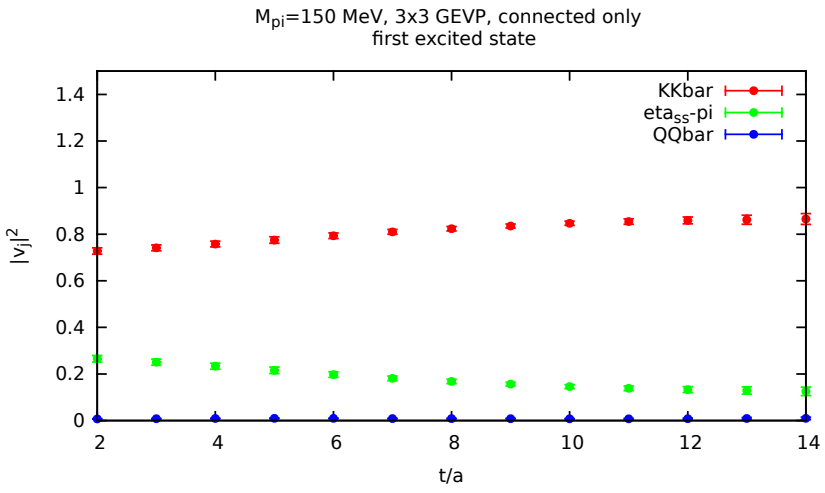
Effective Mass, Connected Only

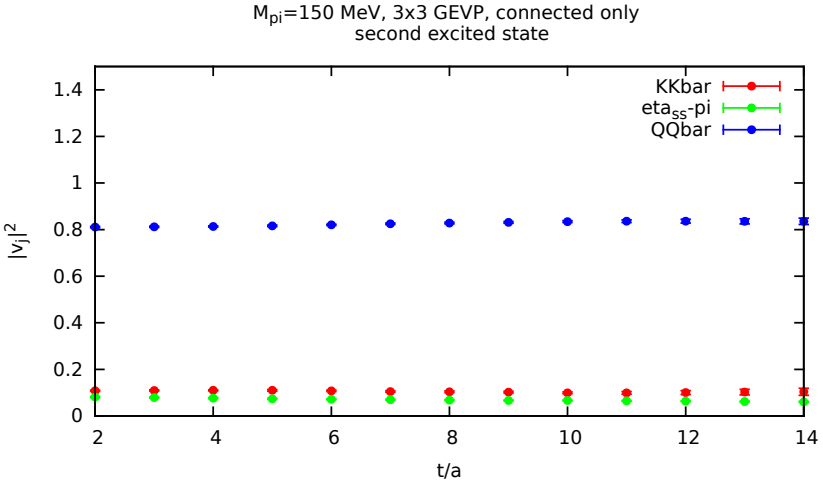




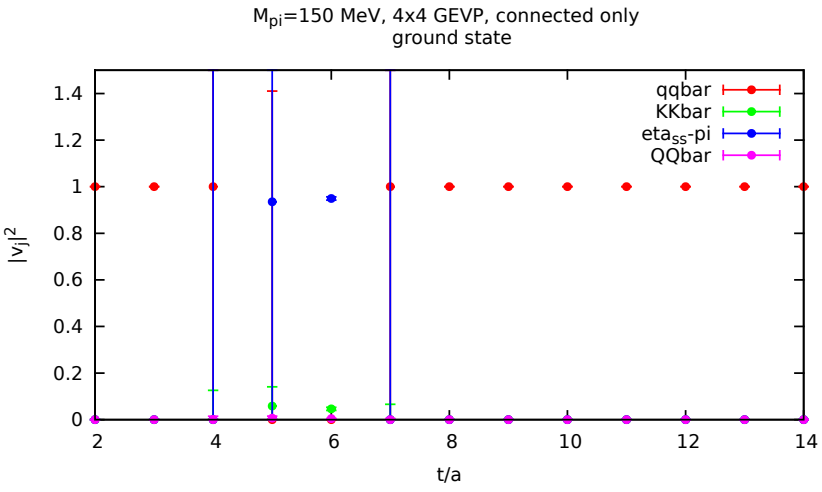
Eigenvector Components, 3x3 connected

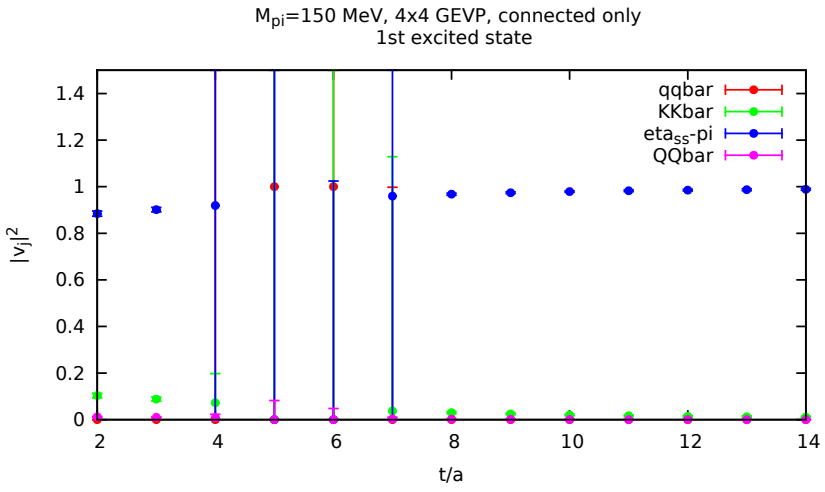


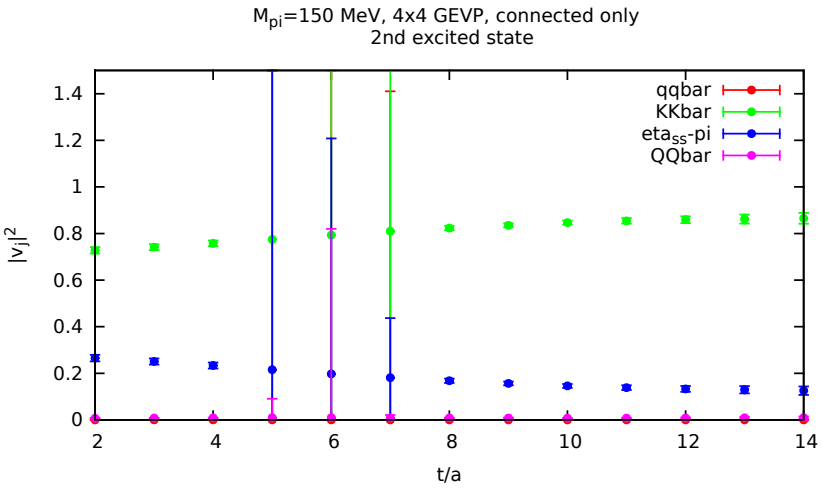


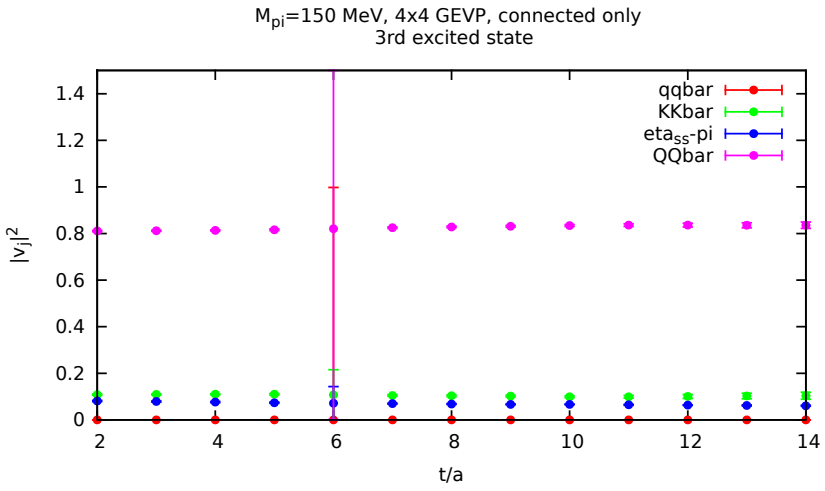


Eigenvector Components, 4x4 connected

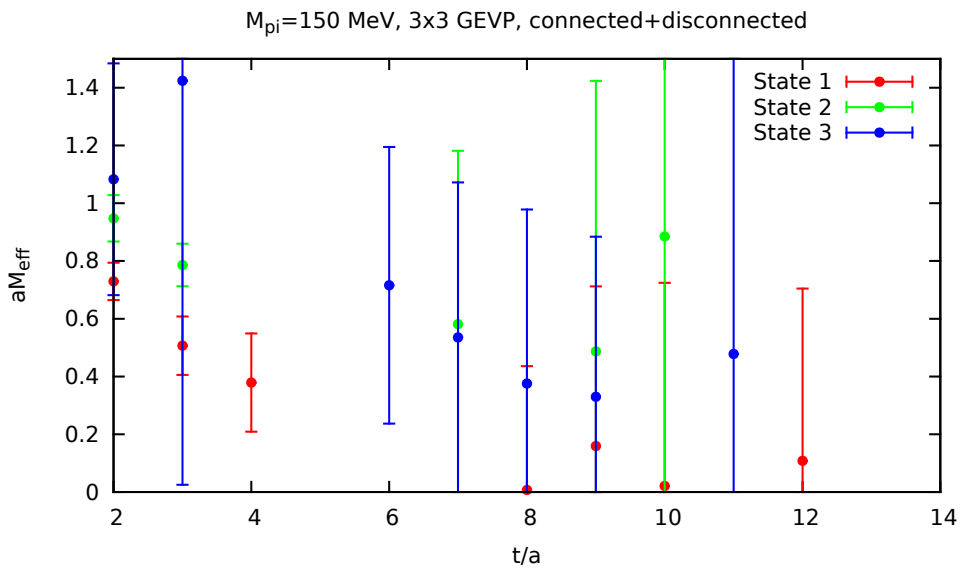


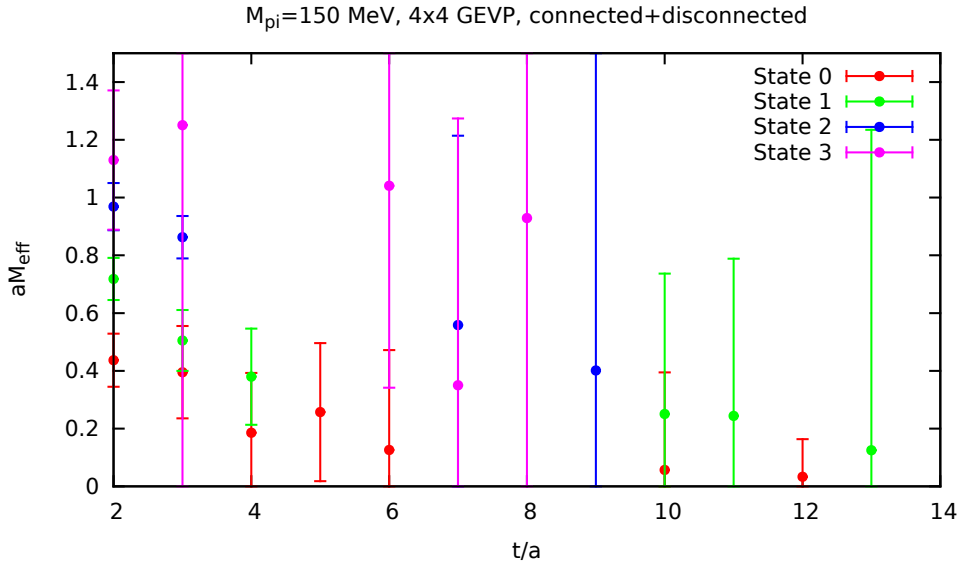




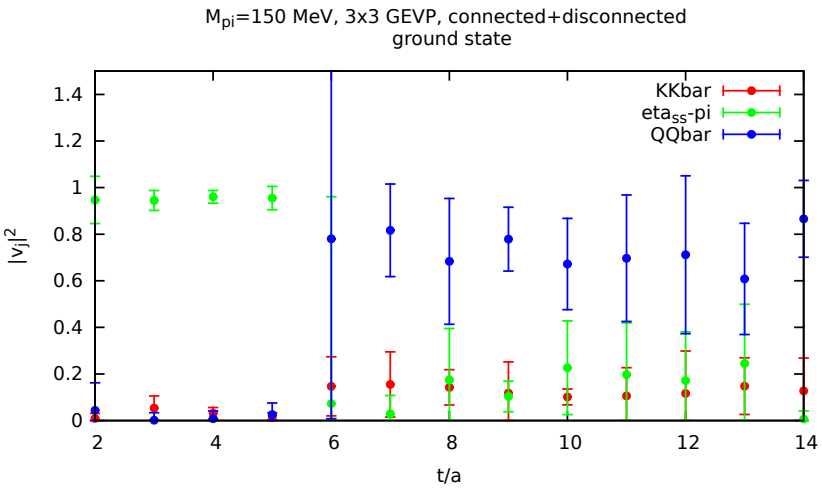


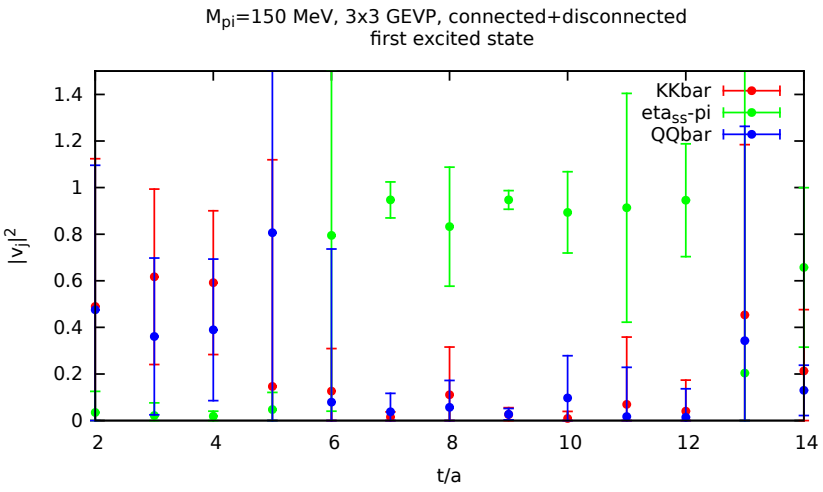
Effective Mass, Connected+disconnected

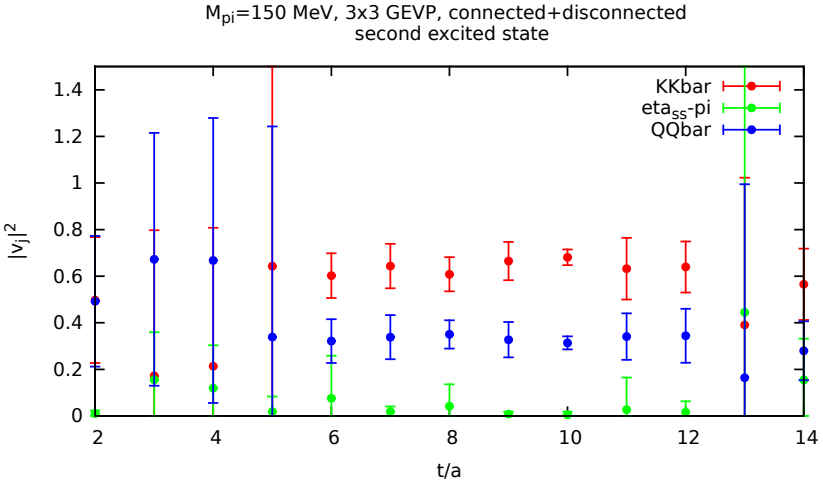




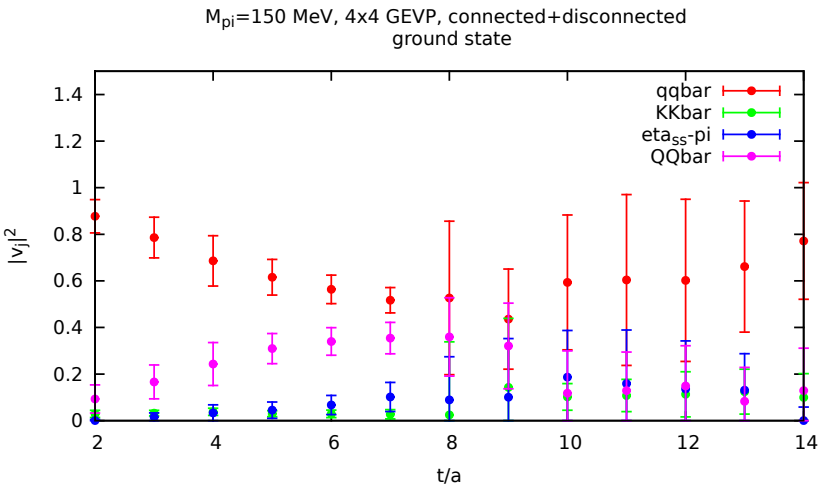
Eigenvector Components, 3x3 connected+disconnected

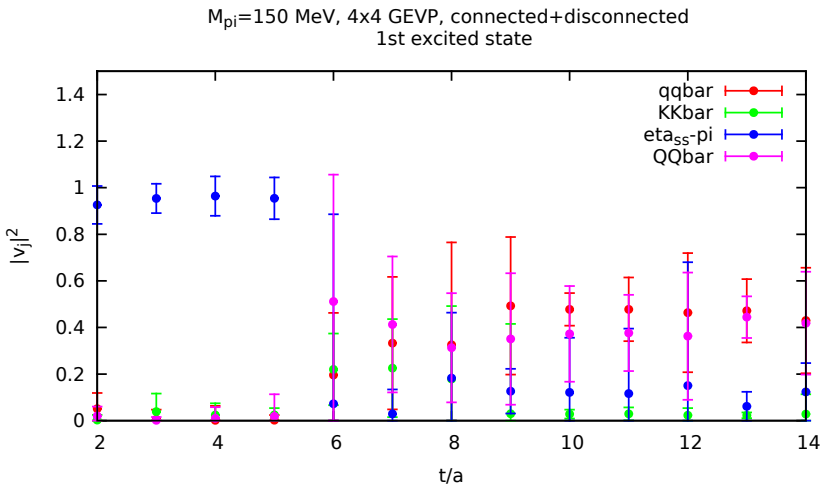


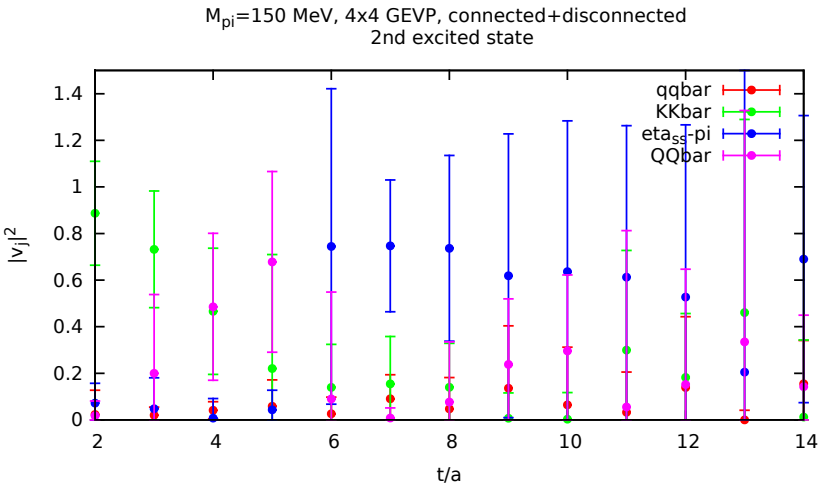


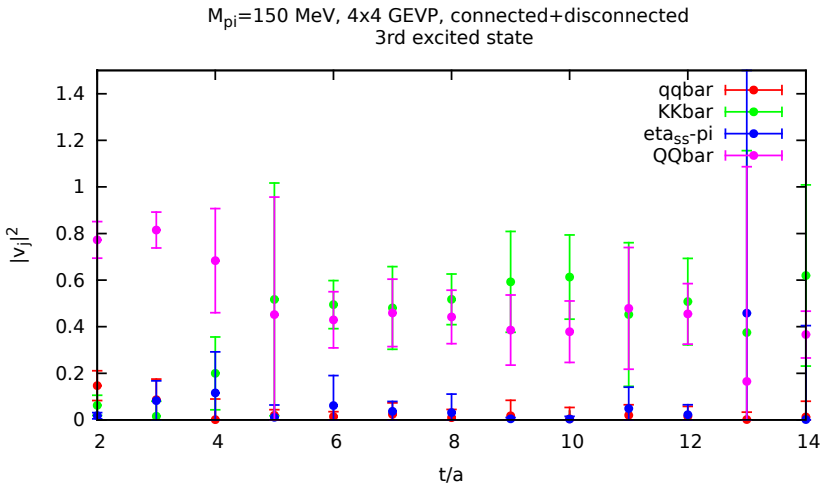


Eigenvector Components, 4x4 connected+disconnected









Conclusions & Outlook

- We reported on ongoing study of the scalar $a_0(980)$ using interpolating operators with two and four quarks.
- Both connected and disconnected contributions are included.
- The goal is to isolate this state and understand its quark sub-structure.
- Initial results show that including quark-antiquark operators as well as disconnected diagram will have an important effect on the spectrum.
- quark-antiquark operator seems to be noisy.
- Outlook: currently using the one-end trick to compute the 2-particle operators as well as improve the statistics of the $q\bar{q}$ correlation functions.
- Outlook: perform more elaborate fit including 2-particle states with opposite momenta.