Coupling to Multihadron States with Chiral Fermions

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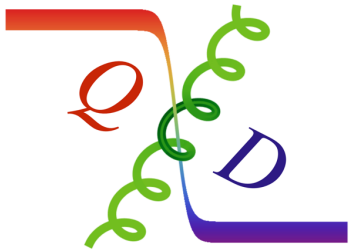
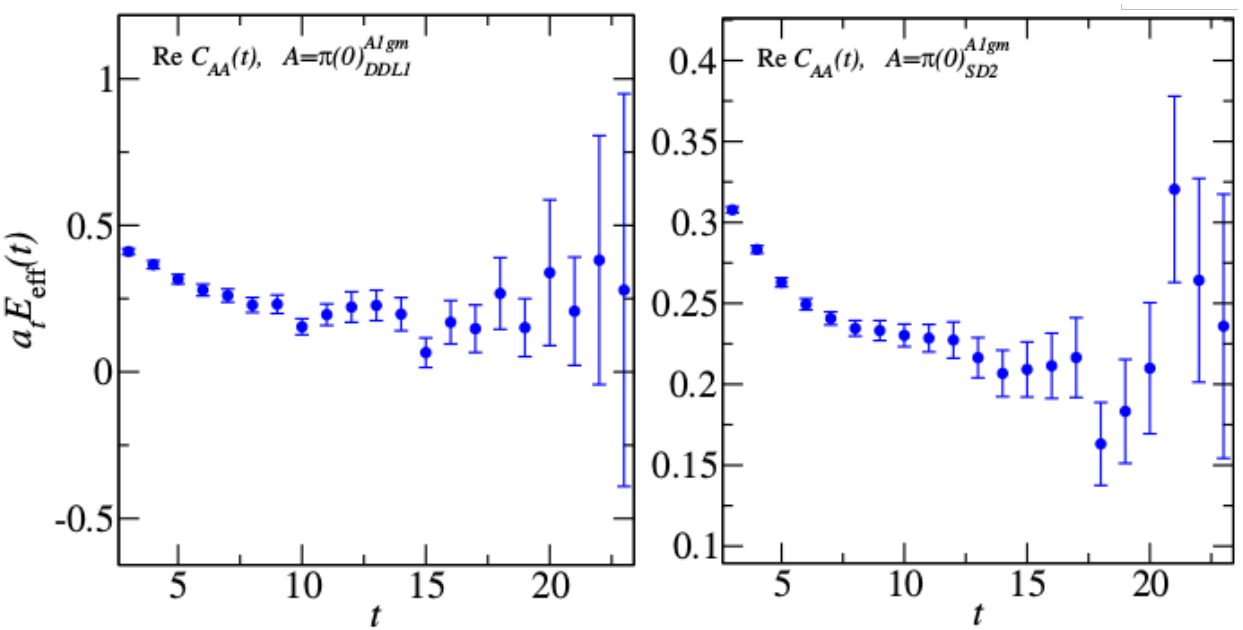


Introduction

- Variational Method uses many different (single-hadron, two-hadron, etc) interpolating operators to extract energy states
- In principle, any such operator alone should go to lowest energy state in its symmetry channel
- "Why don't we see $\eta\pi$ state in scalar isovector channel, with $q\bar{q}$-type operators?"



Rauirí Brett, Drew Hanlon, Colin Morningstar

- Just a matter of statistics, or is there more?

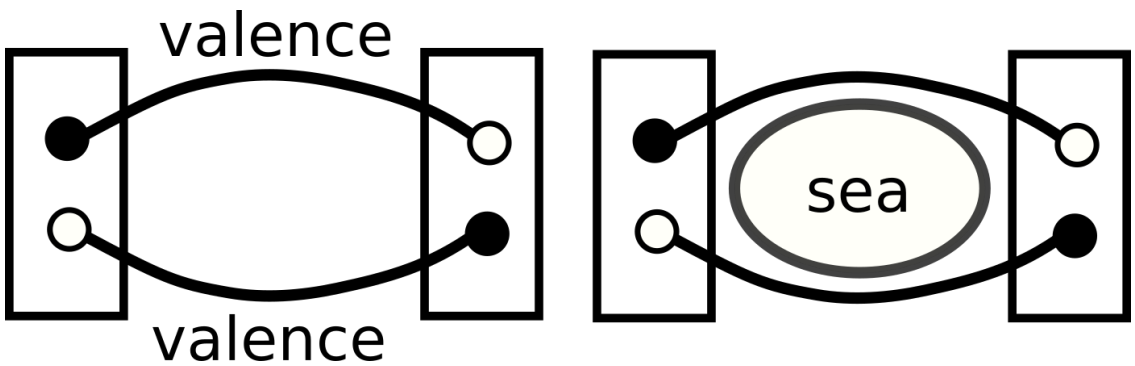
Introduction

- $48^3 \times 96$ with $N_f = 2 + 1$ Domain-Wall Fermions (sea)
- $N_s a \approx 5.5\,\mathrm{fm},\ a^{-1} \approx 1.73\,\mathrm{GeV}$ $(a = 0.114\,\mathrm{fm})$
- valence quark mass corresponding to unitary *and* physical point occurs between $am_q = 0.0024$ and $am_q = 0.003$
- $m_\pi^{(\mathrm{sea})} = 139.2(4)\,\mathrm{MeV}$

- Valence Overlap Fermions
  - 12 m_π values from 113 to 660 MeV, 81 configurations, 8 source times
- Valence Clover Fermions
  - 6 m_π values from 140 MeV to 660 MeV, 81 configurations, 1 source time

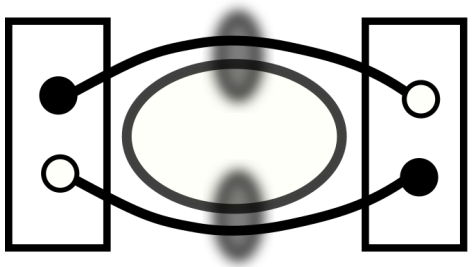
Introduction

- Mixed Action
- $\int DU\, \mathcal{F}(M^{-1}_{\text{valence}}[U])\, \det M_{\text{sea}}[U] e^{-S_g[U]}$
- Different fermions for sea ($\det M$ in configuration generation) and valence (M^{-1} matrix inversions for quark contractions)
- Different types of quark lines contribute to correlators



Introduction

- $q\bar{q}$-coupling to multihadron states
- Loops from sea
- Hairpin diagrams, or Z-graphs, from valence
- Intermediate states made from two sea, two valence, or a mix!
- $m_{vs}^2 = \frac{1}{2}(m_{vv}^2 + m_{ss}^2) + a^2\Delta_{\mathrm{mix}}$ Orginos, Walker-Loud PRD**77**,094505(2008)
- unitary point is "fuzzy"

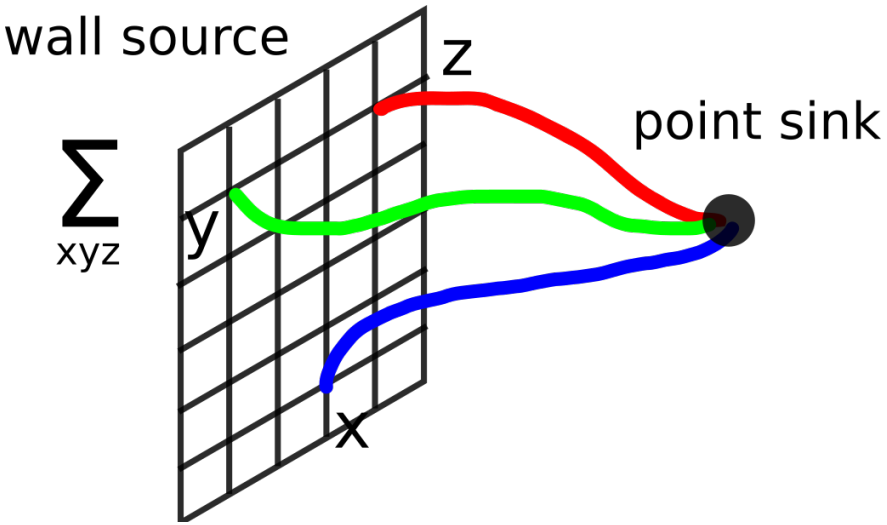


2 valence-sea

2 valence-valence

Introduction

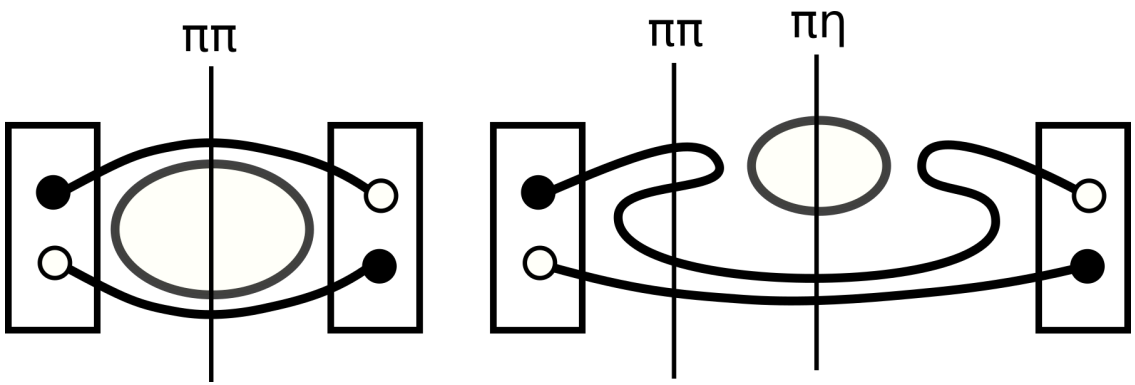
- Wall Source
- Spatial sum supresses nonzero relative momentum
- (S-wave good, higher partial waves bad)



- Spectral Decomposition of Correlator
- $C(t) = \sum A_i e^{-E_i\, t}$
- A_i unitless $\Rightarrow$ not really a spectral weight

$\eta\pi$ state

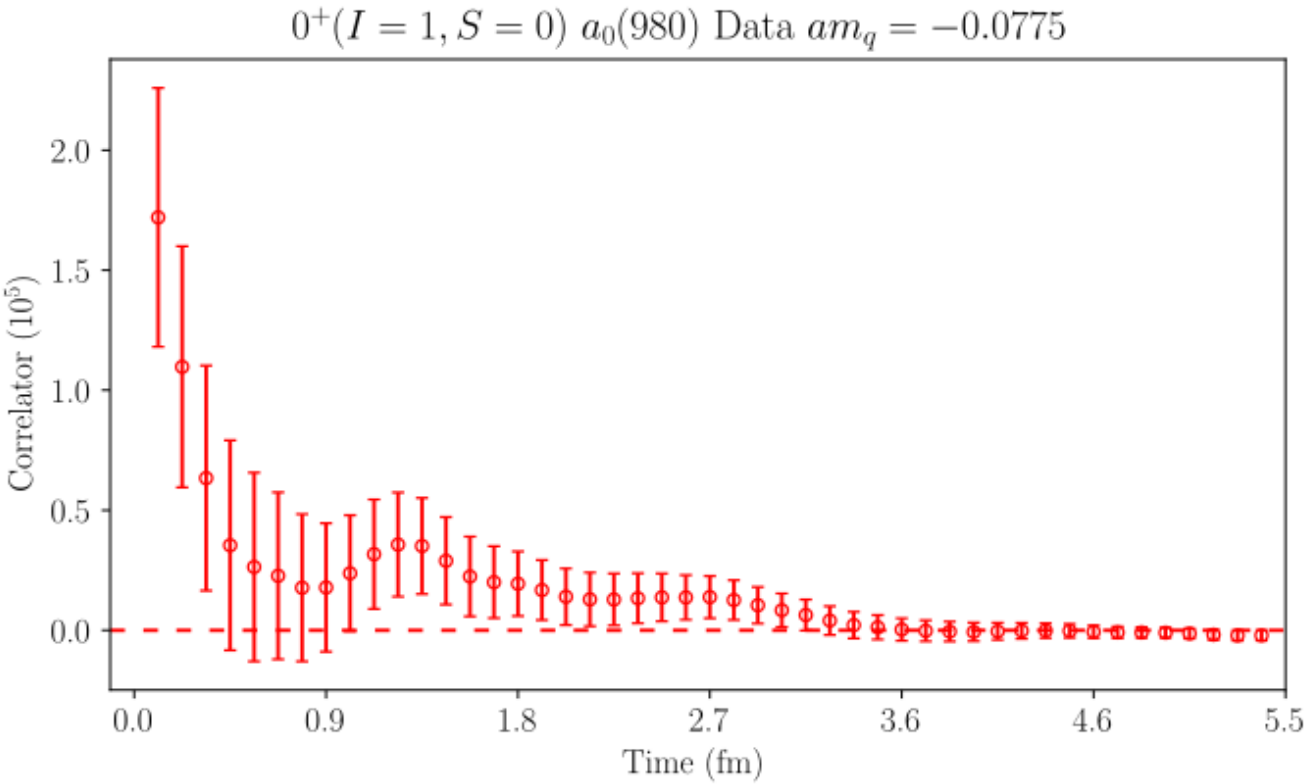
- $0^+(I = 1, S = 0)$ $q\bar{q}$-coupling to $\eta\pi$



- $+\exp(-2m_\pi^{vs}t)$, $-\exp(-2m_\pi^{vv}t)$ and $+\exp(-(m_\pi^{vv}+m_\eta^{ss})t)$
- Cancellation between $2m_\pi$-terms at unitary point $\Rightarrow$ find $\eta\pi$
- Should see $2\pi^{vs}$ above, $2\pi^{vv}$ below (as a negative correlator!)
- No hairpin diagram $\Rightarrow$ no $\eta\pi$-state $\Rightarrow$ no ghost!

$\eta\pi$ state

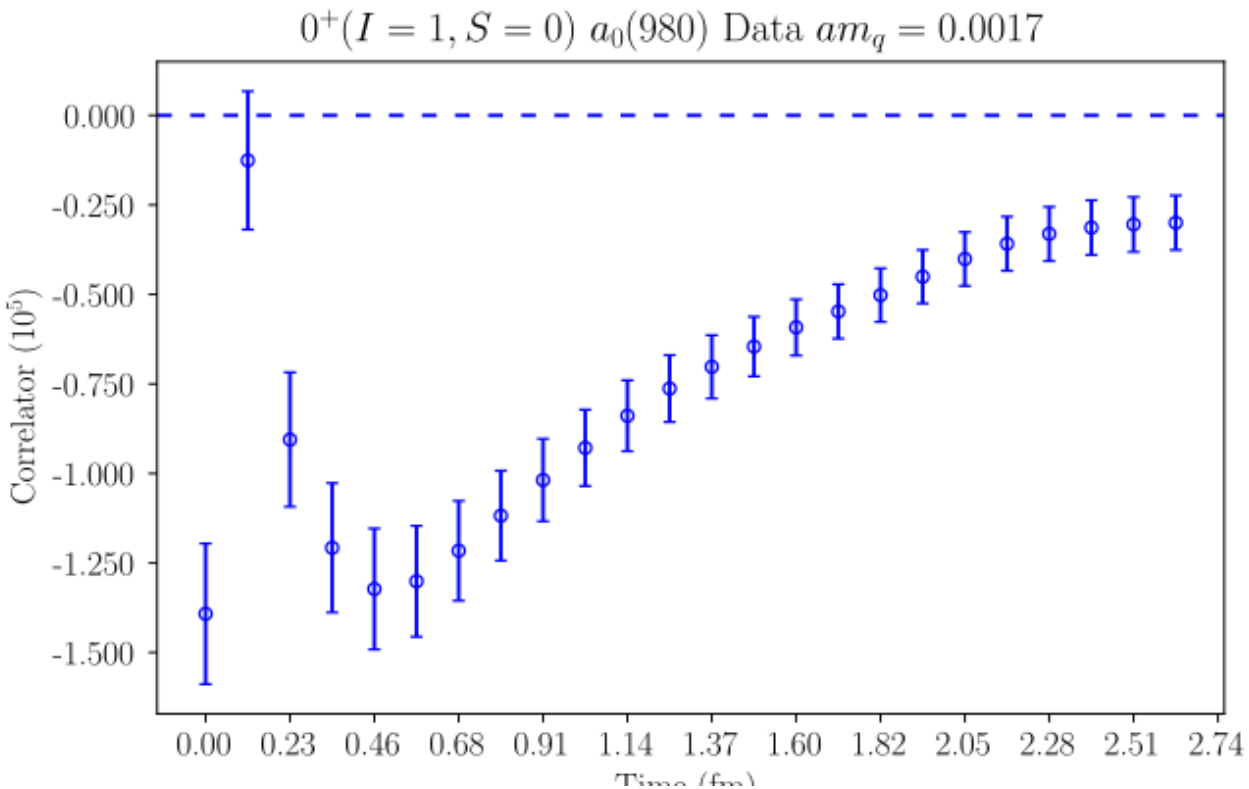
- Clover valence $q\bar{q}$-operator in $0^+(1,0)$ channel ($m_\pi \approx 150\,\mathrm{MeV}$)



- Noisy data, but central values stay positive
- No ghost! $\Rightarrow$ hairpin diagram supressed

$\eta\pi$ state

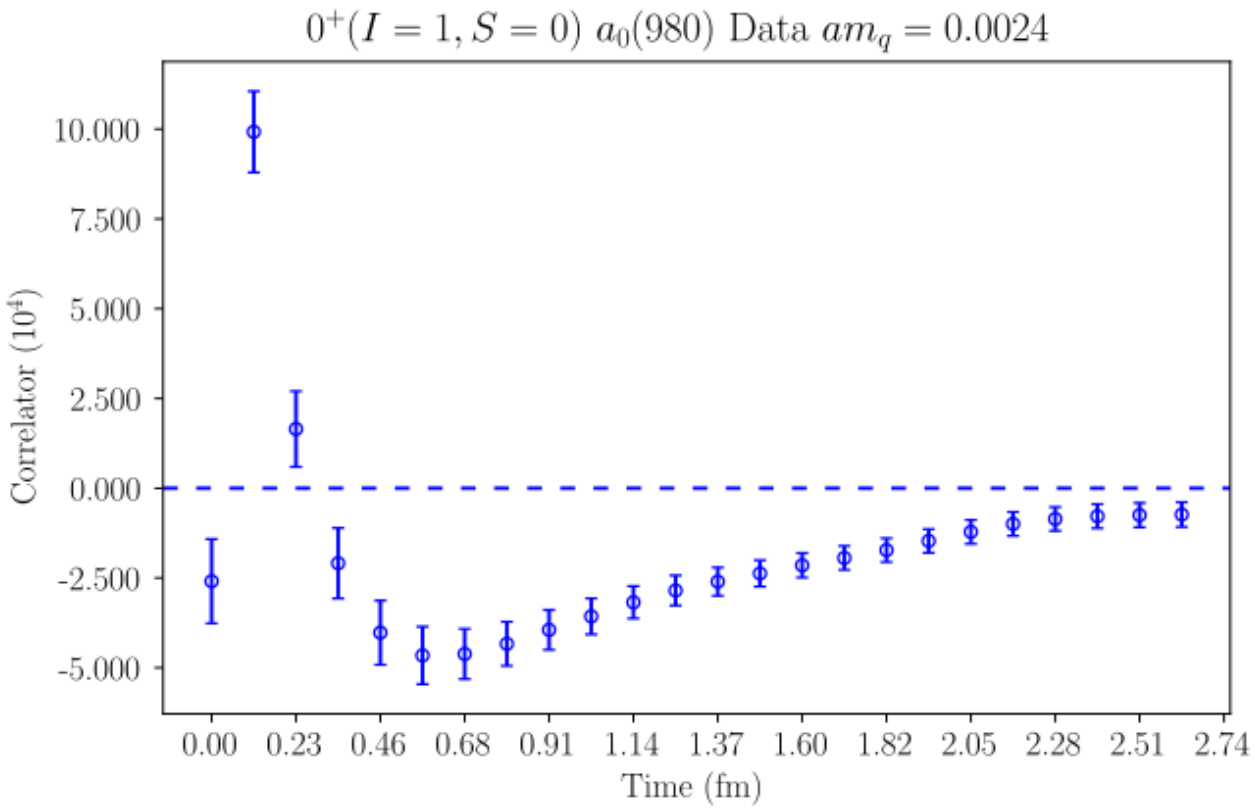
- Overlap valence $q\bar{q}$-operator in $0^+(1,0)$ channel ($m_\pi \approx 114\,\mathrm{MeV}$)



- Clearly a large ghost contribution
- Chiral fermion does not supress hairpin diagram

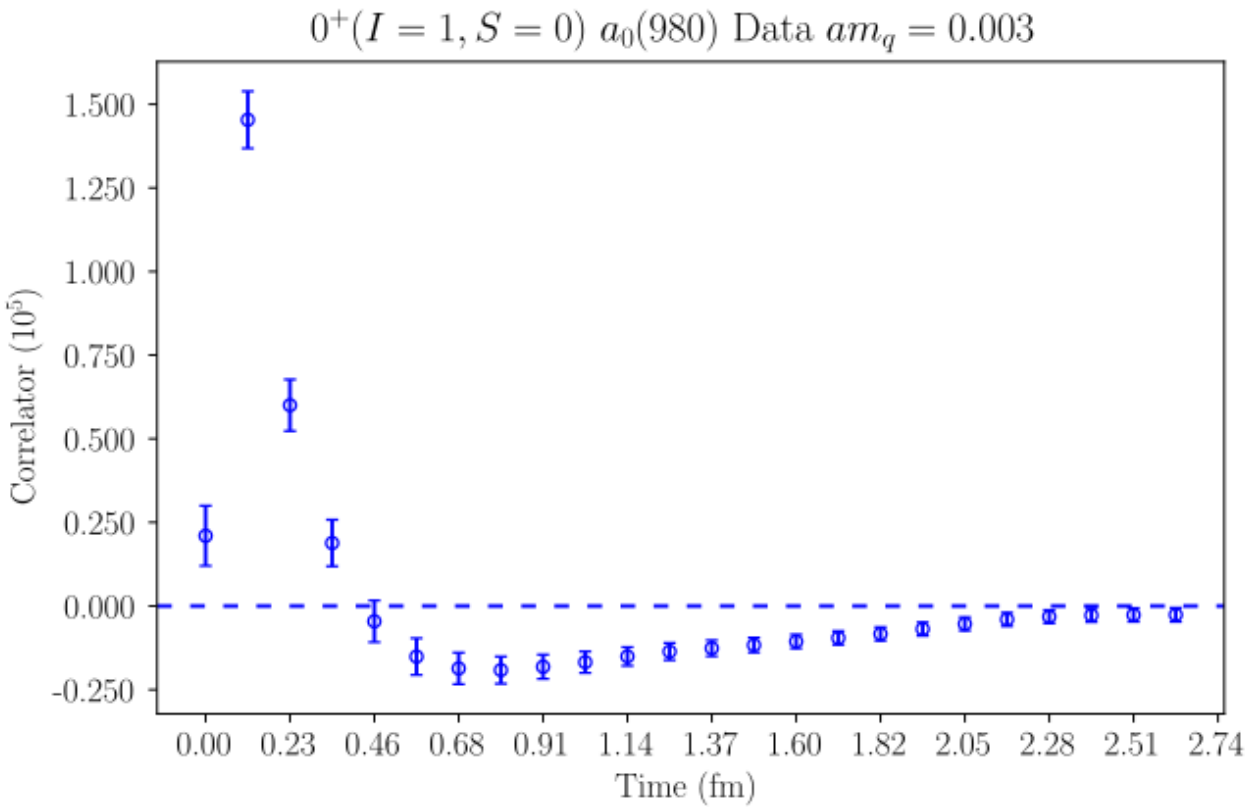
$\eta\pi$ state

- Overlap valence $q\bar{q}$-operator in $0^+(1,0)$ channel ($m_\pi \approx 133\,\mathrm{MeV}$)



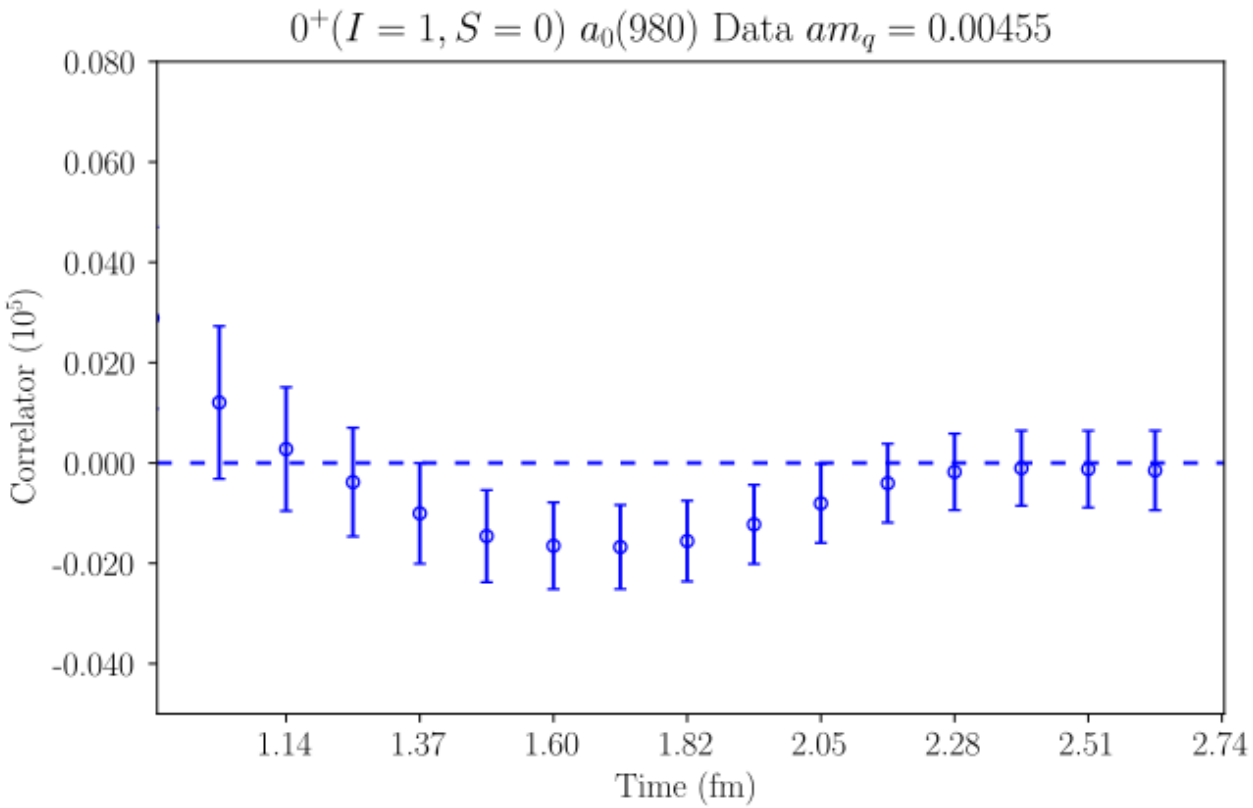
$\eta\pi$ state

- Overlap valence $q\bar{q}$-operator in $0^+(1,0)$ channel ($m_\pi \approx 148\,\mathrm{MeV}$)



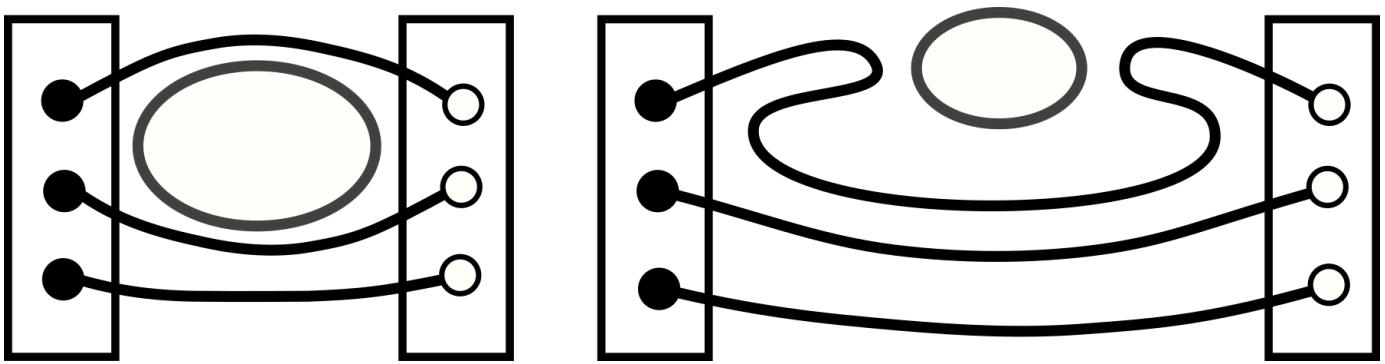
$\eta\pi$ state

- Overlap valence $q\bar{q}$-operator in $0^+(1,0)$ channel ($m_\pi \approx 180\,\mathrm{MeV}$)



Other ghosts?

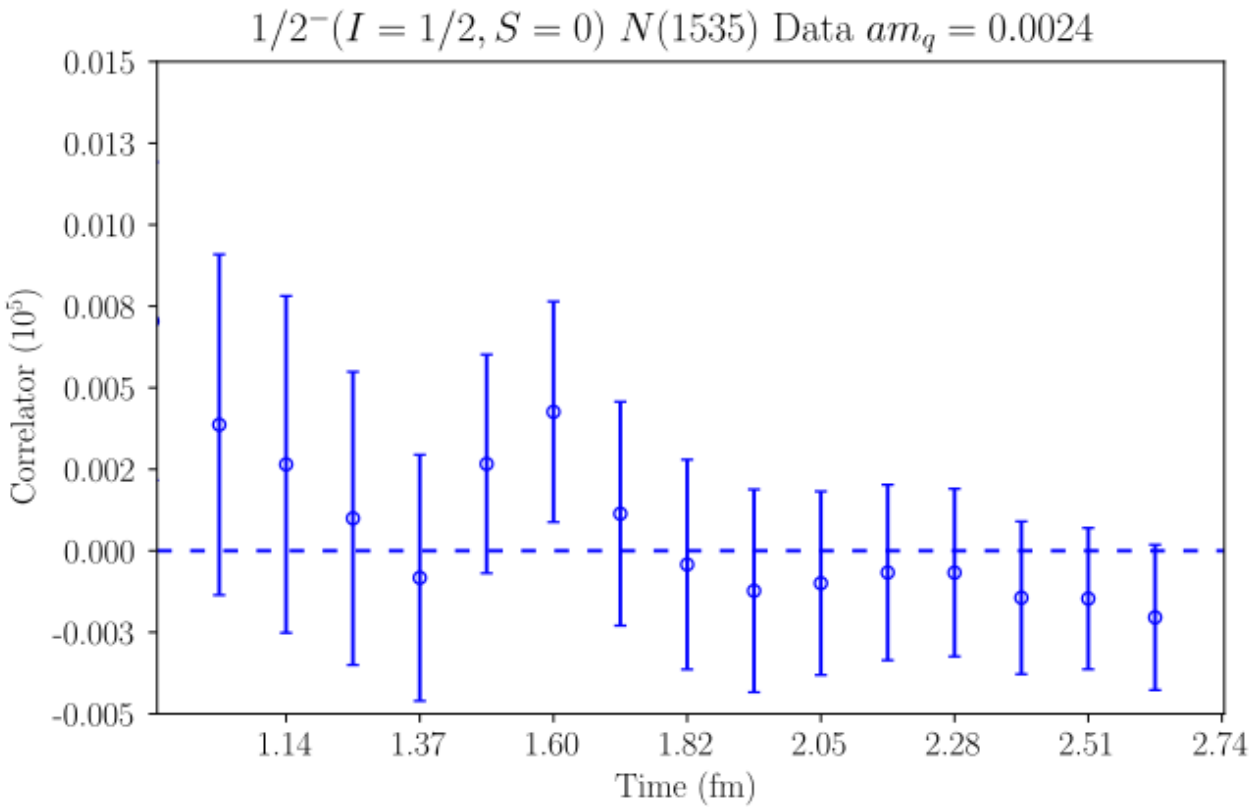
- Quenched Roper $N^+(1440)$ and S_{11} $N^-(1535)$ study
- $0^-(1/2, 0)$ has πN below $N^-(1535)$ Mathur, Liu et al PL**B**,605(2005)



- Any hint of ghosts?

$N^-(1535)$ channel

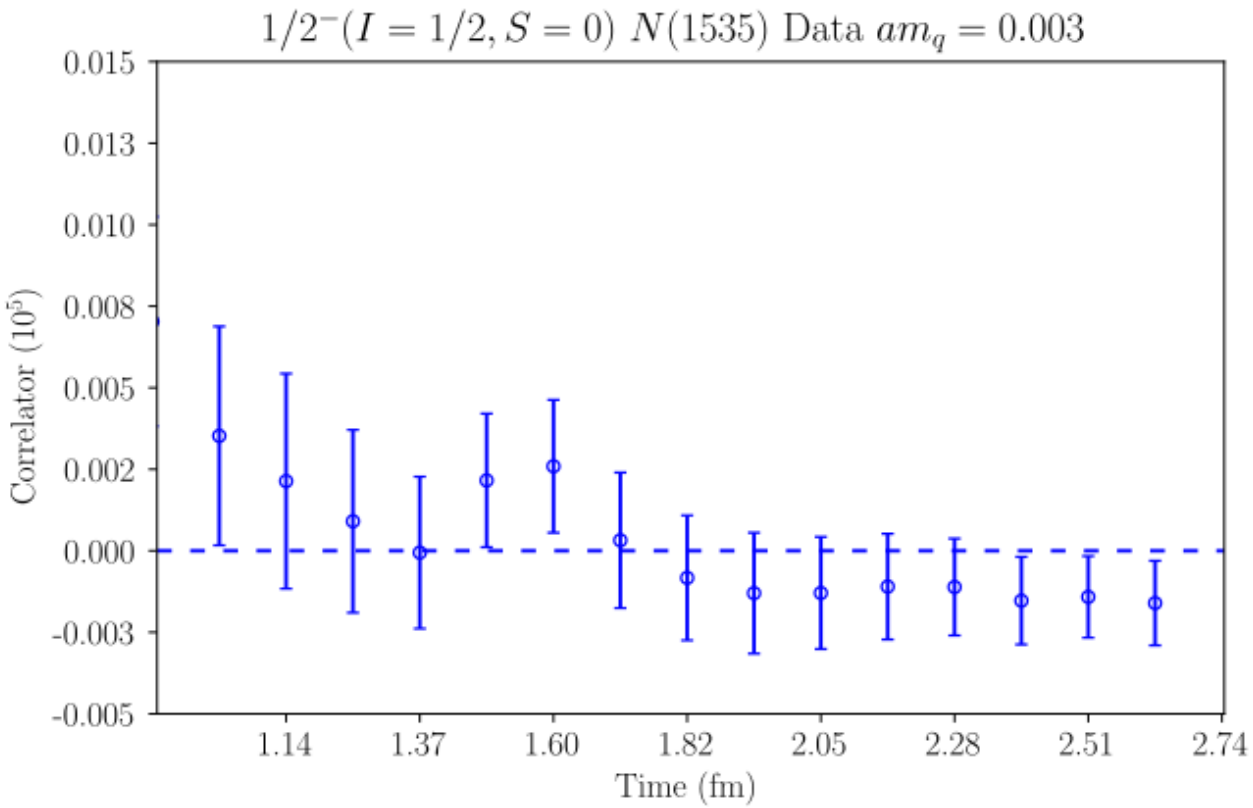
- $1/2^-(1/2, 0)$ channel ($m_\pi \approx 133\,\mathrm{MeV}$)



- Central values suggest ghost

$N^-(1535)$ channel

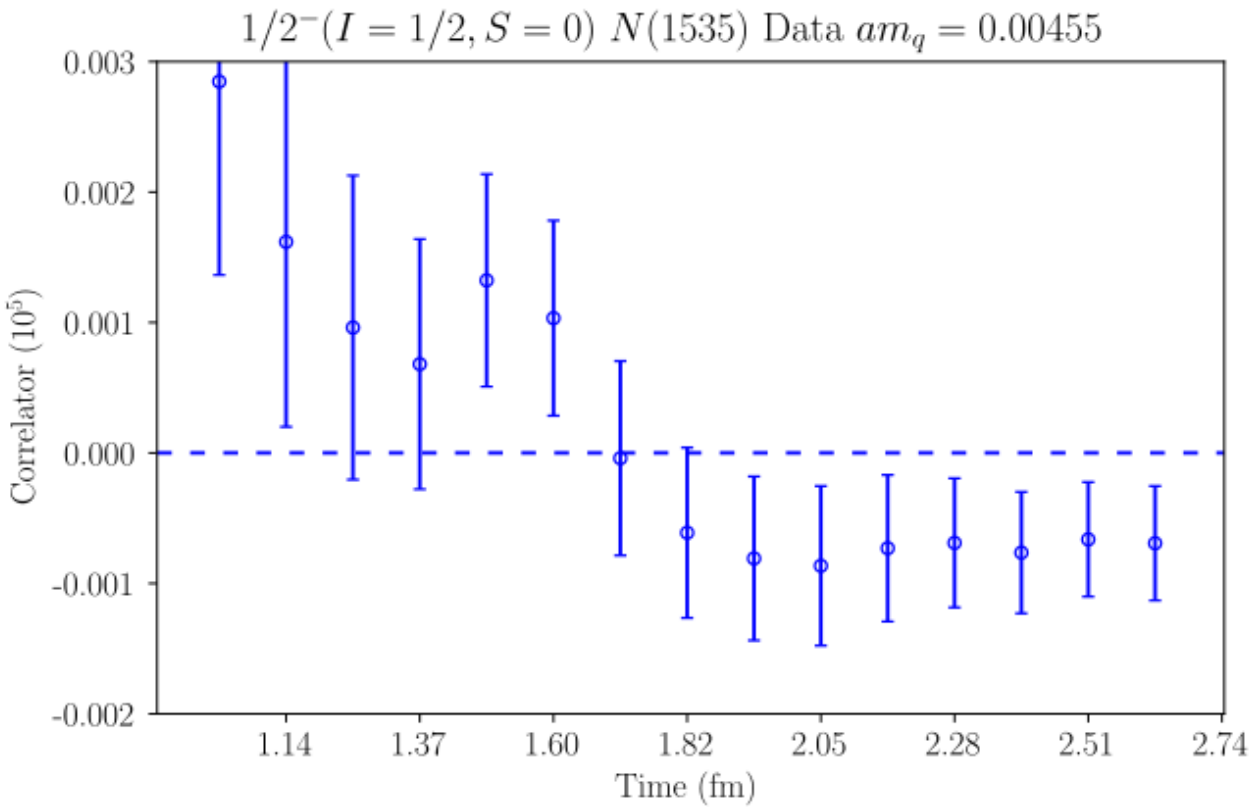
- $1/2^-(1/2, 0)$ channel ($m_\pi \approx 148\,\mathrm{MeV}$)



- Central values still suggest ghost

$N^-(1535)$ channel

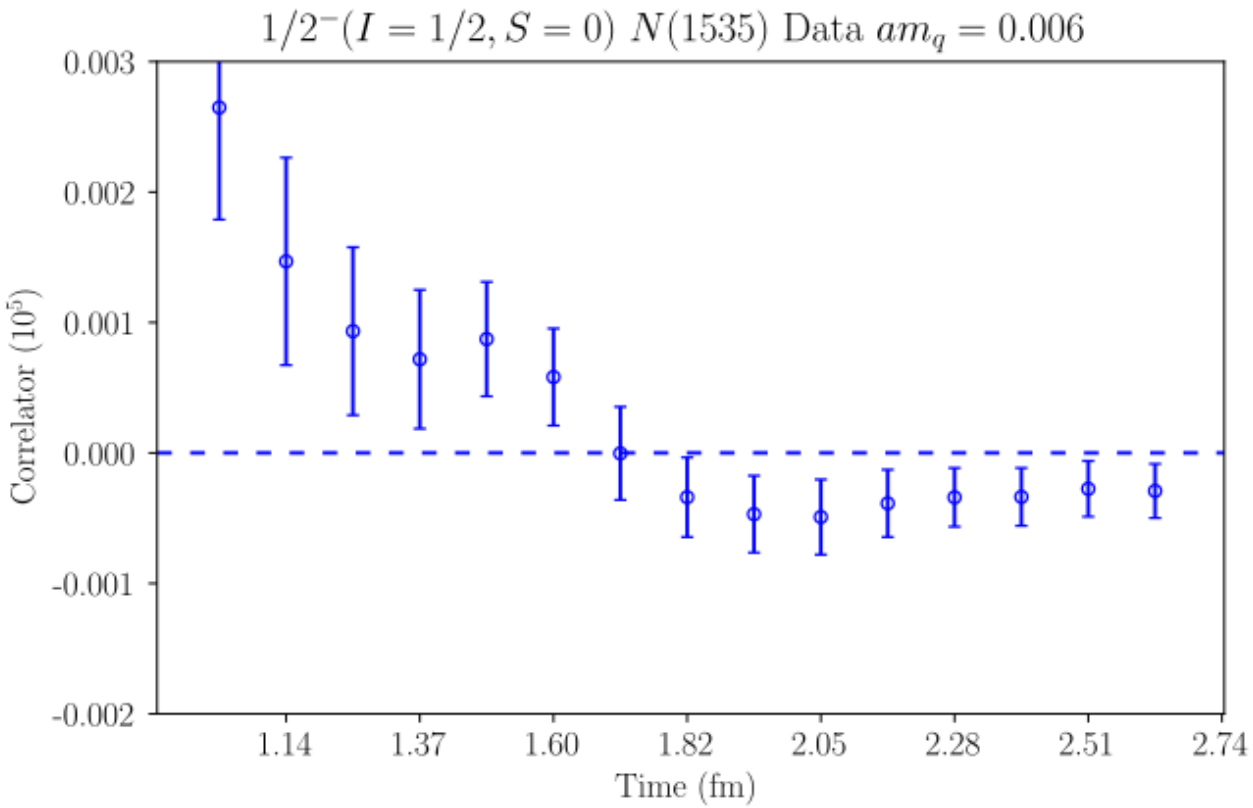
- $1/2^-(1/2, 0)$ channel ($m_\pi \approx 180\,\mathrm{MeV}$)



- Central values and error show clear ghost

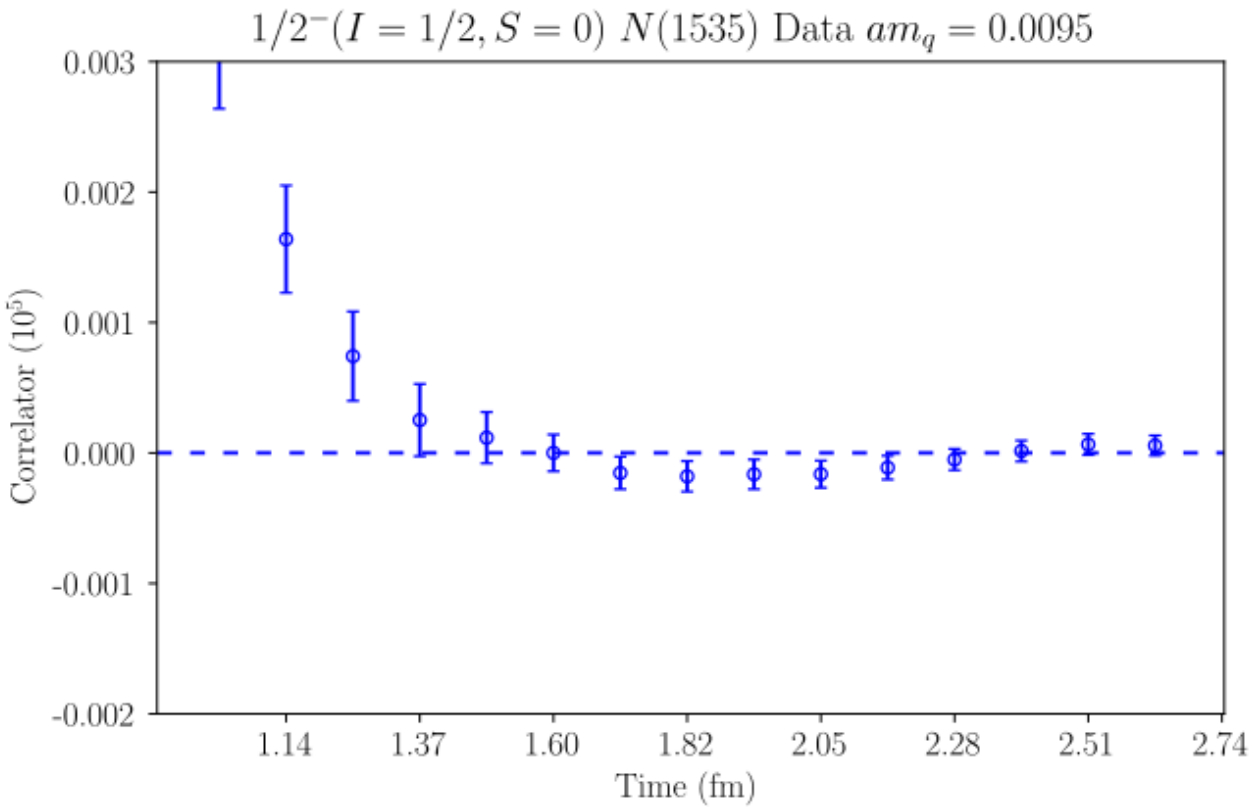
$N^-(1535)$ channel

- $1/2^-(1/2, 0)$ channel ($m_\pi \approx 206\,\mathrm{MeV}$)



$N^-(1535)$ channel

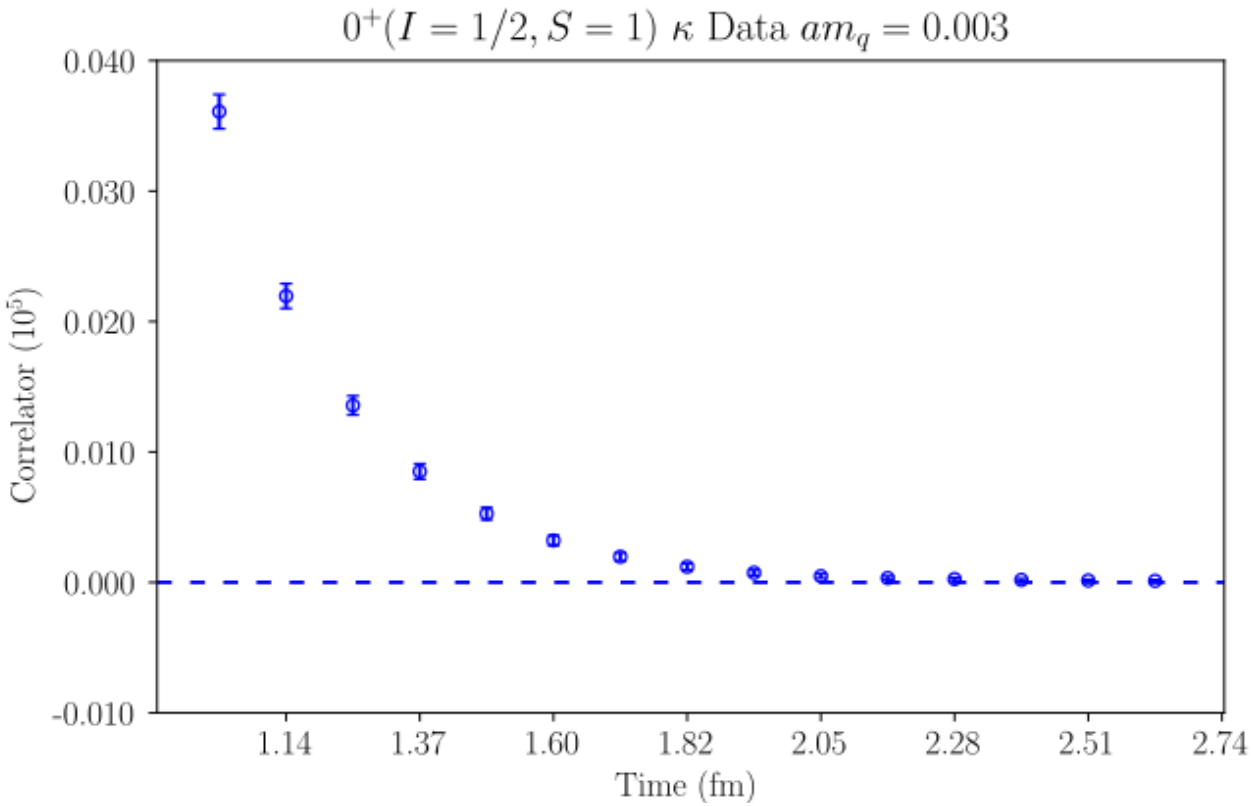
- $1/2^-(1/2, 0)$ channel ($m_\pi \approx 257\,\mathrm{MeV}$)



- Ghost contribution clear much later in time than scalar-isovector case

Other ghosts?

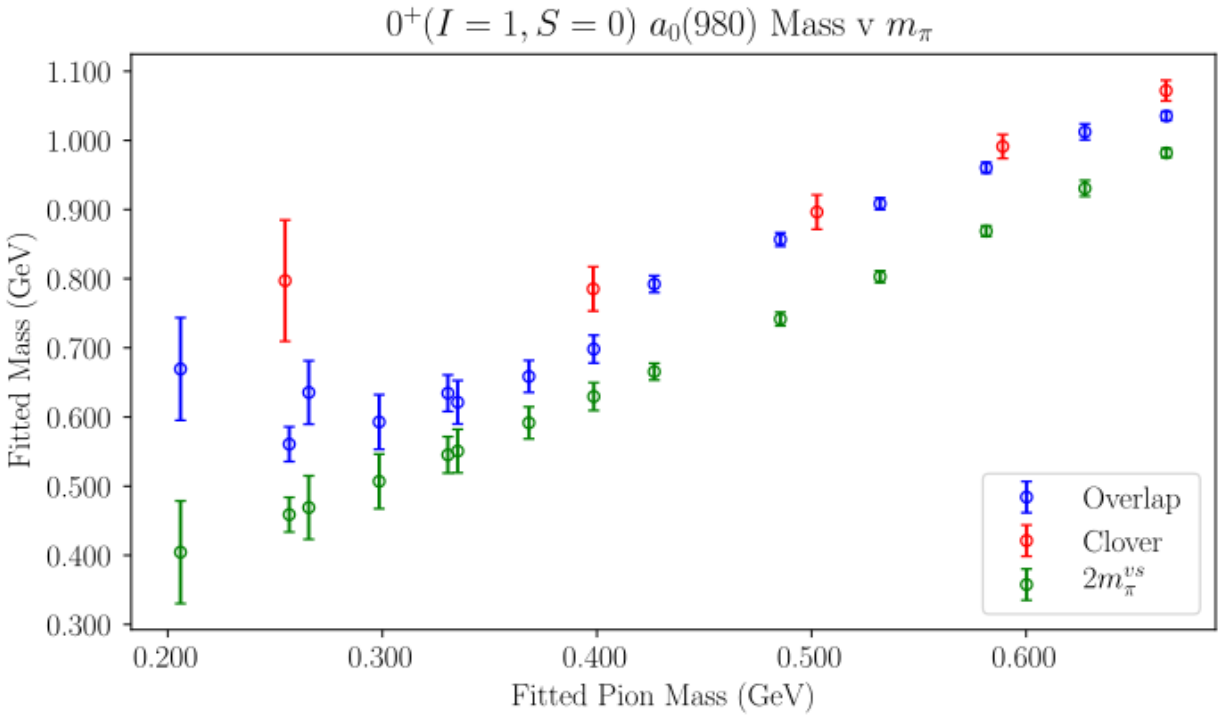
- $0^+(1/2,1)$ κ channel (same as scalar-isovector with spectator strange quark)
- $m_\pi \approx 148\,\mathrm{MeV}$



- No clear ghost state

Other clover/overlap comparisons

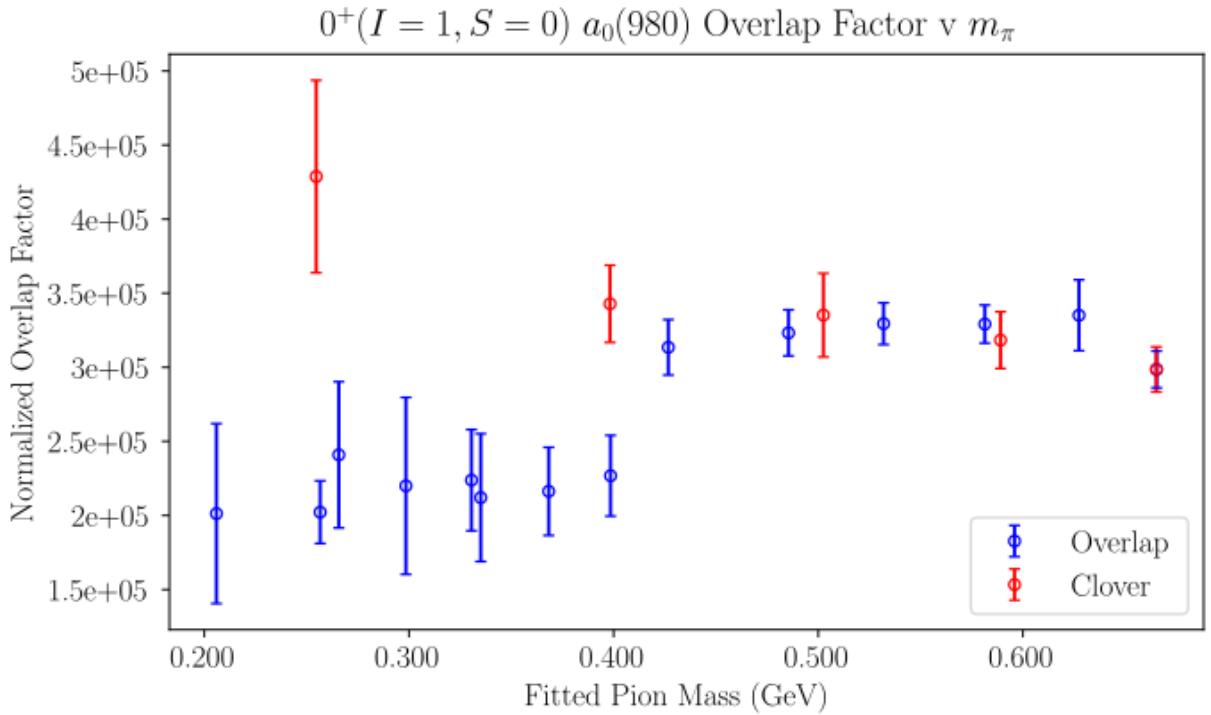
- Examine $0^+(1,0)$-energy



- Potential $\eta\pi$ state (for lower pion masses)
- Kink at 400-420 MeV
- Clover state not identifiable (unknown Δ_{mix} parameter)
- Could use clover-on-clover (no mixed action)

Other clover/overlap comparisons

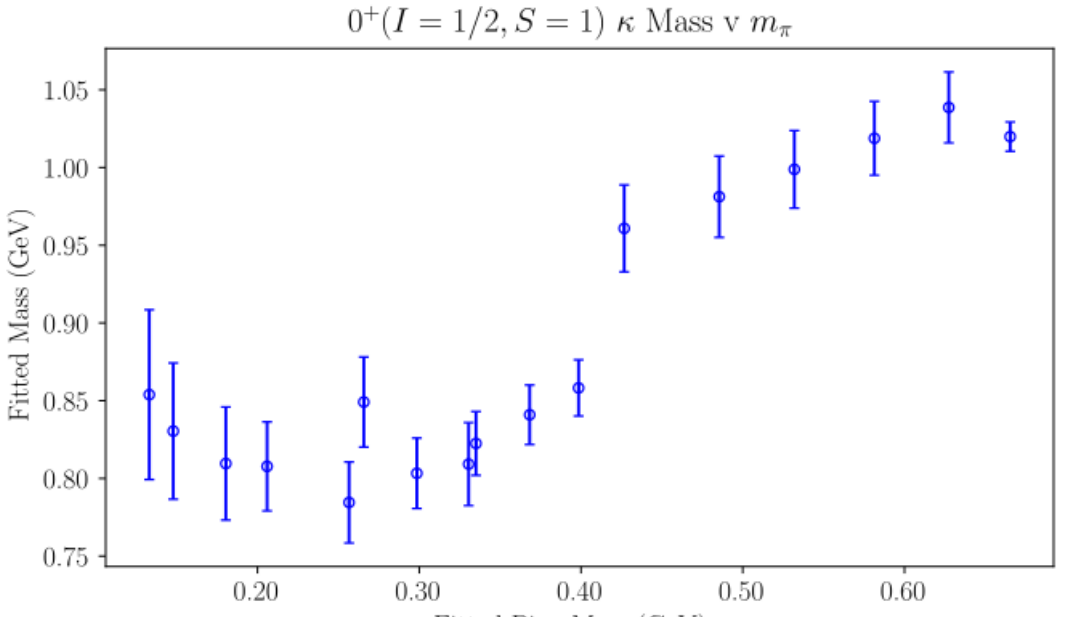
- Examine $0^+(1,0)$-spectral factors

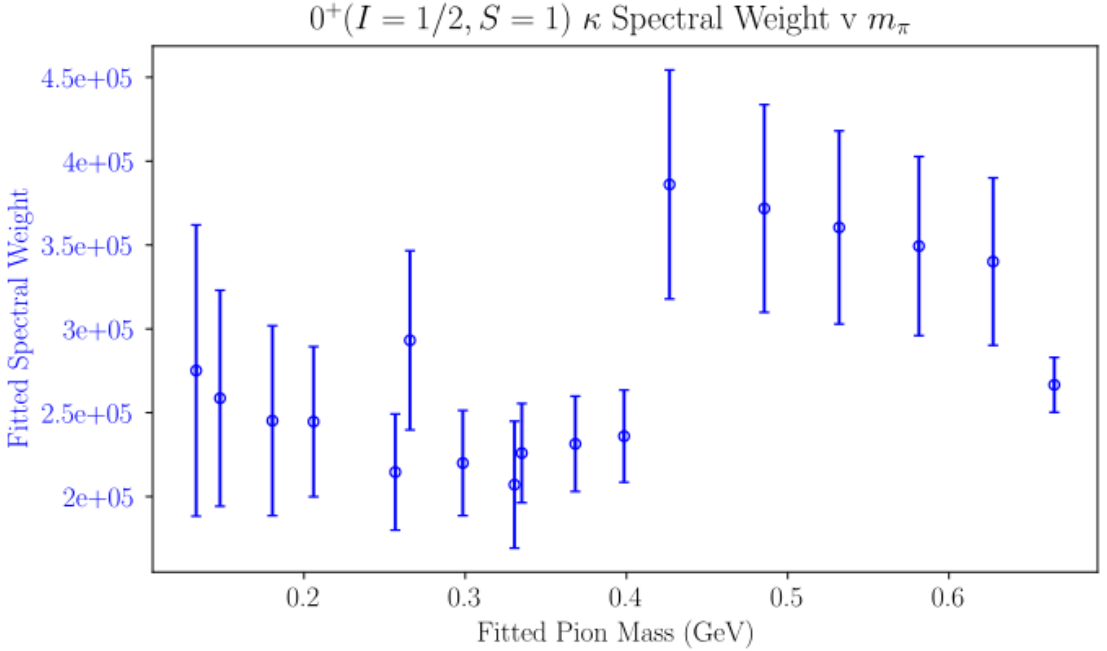


- Same kink at 400-420 MeV
- Clover seems much higher than overlap
- Need clover-on-clover and better statistics

κ-channel plots

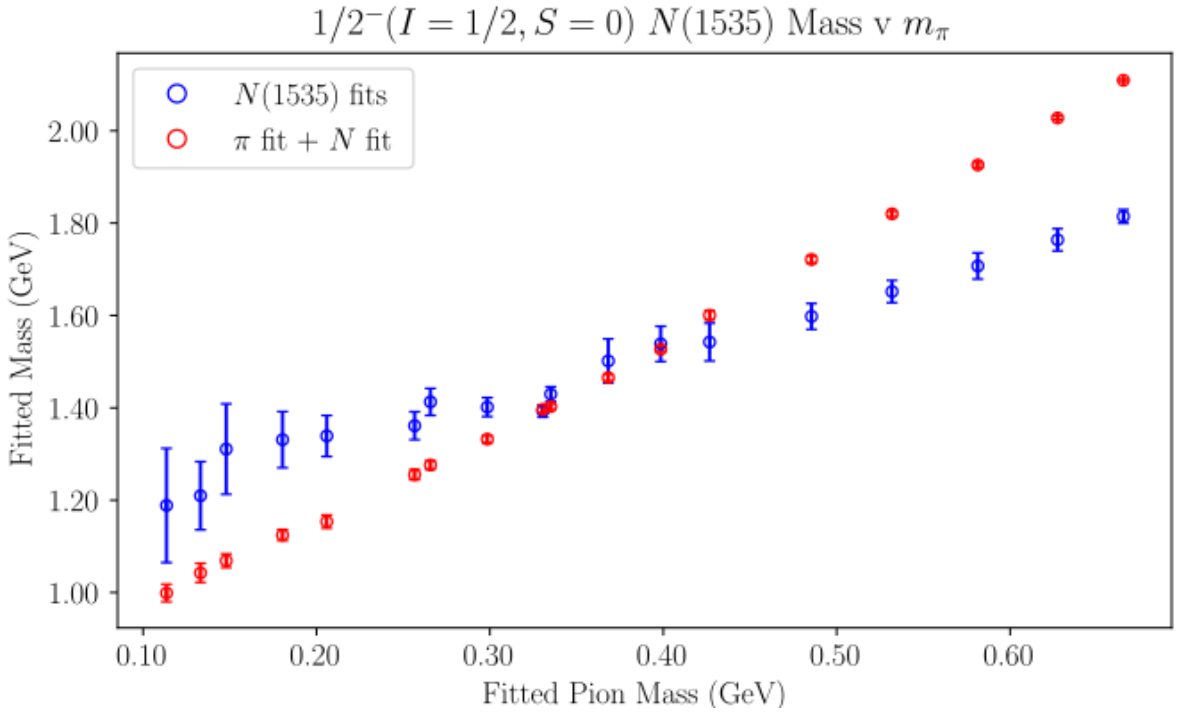
- Kinks also present in $0^+(1/2,1)$ channel
- Can't resolve state content





Conclusions

- Chirality can be very important (e.g., a_0-channel ghost)
- Exactly when is unknown (e.g., no κ-channel ghost)
- $q\bar{q}$ chiral fermions can have not insignificant coupling to multihadron states
- Chiral properties of clover seem sufficient for larger pion masses ($\approx 400\,\mathrm{MeV}$) at this lattice spacing ($0.1\,\mathrm{fm}$)



- Overlap fermions expensive, need better statistics
- Reuse existing propagators with new sinks to get larger plateau regions? (e.g., prony methods)
- Clover-on-clover to make comparisons more rigorous