## **Roper State from Overlap Fermion**

- Discrepancy in various lattice calculations
- Fitting methods: variation vs sequential empirical Bayes method
- Chiral dynamics: Multi-hadrons from single hadron interpolater ηπ ghost state

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# Many Facets of Roper Resonance Theory: (PDG--1440 MeV)

- Quark potential model prediction is 100-200 MeV too high (Liu and Wong, 1983, Capstick and Isgur, 1986)
- Skyrmion can accommodate it as a radial excitation (J. Breit and C. Nappi, 1984, Liu, Zhang, Black, 1984; U. Kaulfuss and U. Meissner, 1985)
- Suggestion as a pentaquark (Krewald 2000); as a member of the antidecuplet
  - (Jaffe, Wilczek, 2003)
- Perhaps a hybrid
  (Barnes, Close, etc. 1983)
- $\blacksquare \rightarrow \text{Lattice calculations}$



### **Quenched Lattice Calculations of Roper**



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# **Roper on the lattice**

4 issues about lattice calculations:

- Radial excitation or pentaquark state?
- Dynamical fermions
- Variation vs Bayesian fitting
- Chiral dynamics



- Roper is seen on the lattice with three-quark interpolation field.
- Weight :

 $| < 0 | O_N | R > |^2 > | < 0 | O_N | N > |^2 > 0$  (point source, point sink)



# Roper and Nucleon Wavefunctions at $m_{\pi} = 438 \text{ MeV}$ $O_{RN} = 0.59$



R/a

# **Dynamical Fermions**



### Variation on JLab anisotropic $24^3 \times 128$ Clover lattice (m<sub>π</sub> = 390 MeV, a = 0.12 fm)



M<sub>R</sub> = 1.92(6) GeV

4 smearing sizes, the largest  $< r^2 > \frac{1}{2} = 0.86$  fm

M<sub>R</sub> = 2.19(11) GeV

3 smearing sizes, the largest  $< r^2 > \frac{1}{2} = 0.39$  fm

# Variation on $24^3 \times 64$ DWF lattice with overlap valence (m<sub>π</sub> = 330 MeV, a = 0.111 fm)



GEVP with projected correlator

 $\tilde{C}(t) = U^T C(t) U, \quad U = [u_1, u_2]$  $\tilde{C}(t) v_n(t, t_0) = \lambda(t, t_0) \tilde{C}(t_0) v_n(t, t_0)$ 



#### M<sub>R</sub> = 1.55(10) GeV



### Check source size dependence

Method	Source	Sink	$t_0$	$t_{\rm pro}$	$t_{\rm ref}$
1	w0, w2, w4, w8	w0,w2,w4,w8	2	8	none
2	Wall,w12	B2,B6	5	none	6
3	Wall,w12	B4,B8	5	none	6
4	Wall,w12	B8,B12	4	none	6
5	Wall,w8	B2,B6	4	none	6
6	Wall,w8	B4,B8	4	none	6
7	Wall,w8	B8,B12	4	none	6
8	Wall,w5.5	B2,B6	3	none	6
9	Wall,w5.5	B4,B8	3	none	6
10	Wall,w5.5	B8,B12	3	none	6







# Why such a difference between clover and overlap fermion?

Not due to fitting algorithm -- variation agrees with SEB for both clover and overlap fermions

#### Chiral dynamics?

- Dynamical coupled-channle model predicts couplings to N $\pi$ , N $\eta$  and N $\pi\pi$  brings down the bare N by ~ 400 MeV.
- Higher Fock space components needed in experimental electroexcitation amplitude of Roper.
- Bethe-Salpeter wavefunctions of Roper and nuclear are less orthogonal as pion mass decreases.
- Parity reversal of Roper and S<sub>11</sub> might be due to meson exchanges between quarks (Glozman and Riska)

# Isovector scalar correlator in quenched approximation



Ghost would-be  $\eta\pi$  state

 $-W_{\eta\pi}(1+m_{\pi}t) e^{-2m_{\pi}t}$ 



Indication of the strength of coupling to multihadrons with one hadron interpolation field.

# Comparison of would-be ηπ ghost state on quenched lattices



a = 0.12 fm, pion mass = 296 MeV

a = 0.09 fm, pion mass ~ 280 MeV

# Minima of ghost state for overlap and Wilson fermions



Ratio (overlap to Wison) ~ 7.6

Ratio (overlap to Wison) ~ 3.9

## N to Nπ, Nη, Nππ coupling







Using both  $q^3$  and  $q^4 \overline{q}$  operators have not see the Roper below 1.65 GeV.

C.B. Lang et al., 1610.01422 A.L. Kiratidis et al., 1704.08816

### Summary

- SEB method and variational approach give consistent results separately for the clover and overlap fermions, but the Roper from clover fermion is ~ 300 MeV higher than that of overlap.
- Model and experimental electroexcitation suggest large higher Fock space in Roper.
- Compare the ghost would-be ηπ states of Wilson and overlap fermions on quenched lattices and found large discrepancy at a = 0.12 and 0.09 fm.
- Chiral symmetry for clover fermion may be restored below a ~ 0.06 or 0.04 fm(?). Clover calculation at these small lattice spacings may be the final solution to the `Roper Puzzle'.

# Backup

#### Evidence of η'N GHOST State in S<sub>11</sub> (1535) Channel





### N\* spectrum in LQCD & dynamical coupling

Dynamics of P<sub>11</sub>-states:

The bare state at ~1750 MeV through coupling

Lattice N\* states ( $m_{\pi}$ =396MeV)



*R. Edwards, J. Dudek, D. Richards, S. Wallace, PRD84, 074508 (2011)* 

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