The Roper Puzzle

- Discrepancy in various lattice calculations
- Fitting methods: variation vs. sequential Bayesian fitting
- πN state and S_{11}

χQCD Collaboration:

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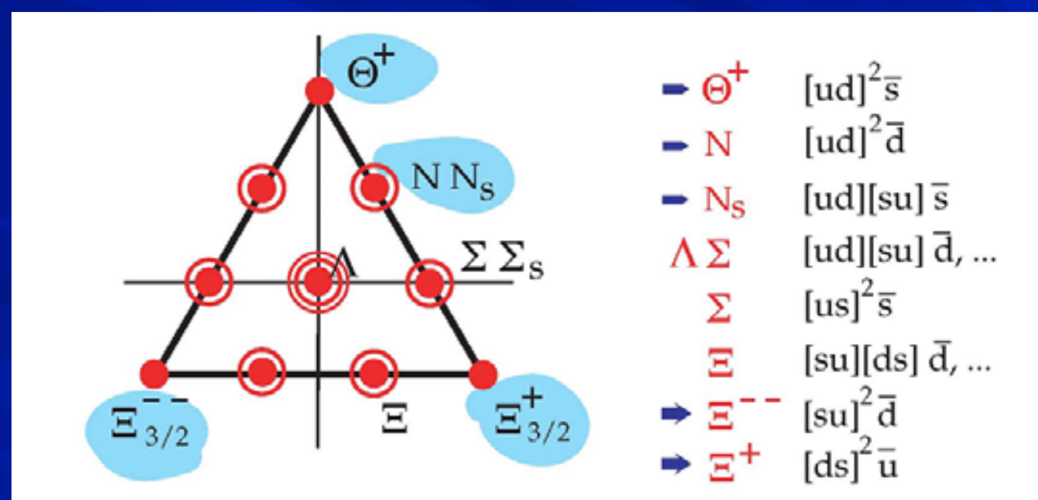
Lattice 2013, Mainz, Aug. 1, 2013

Many Facets of Roper Resonance

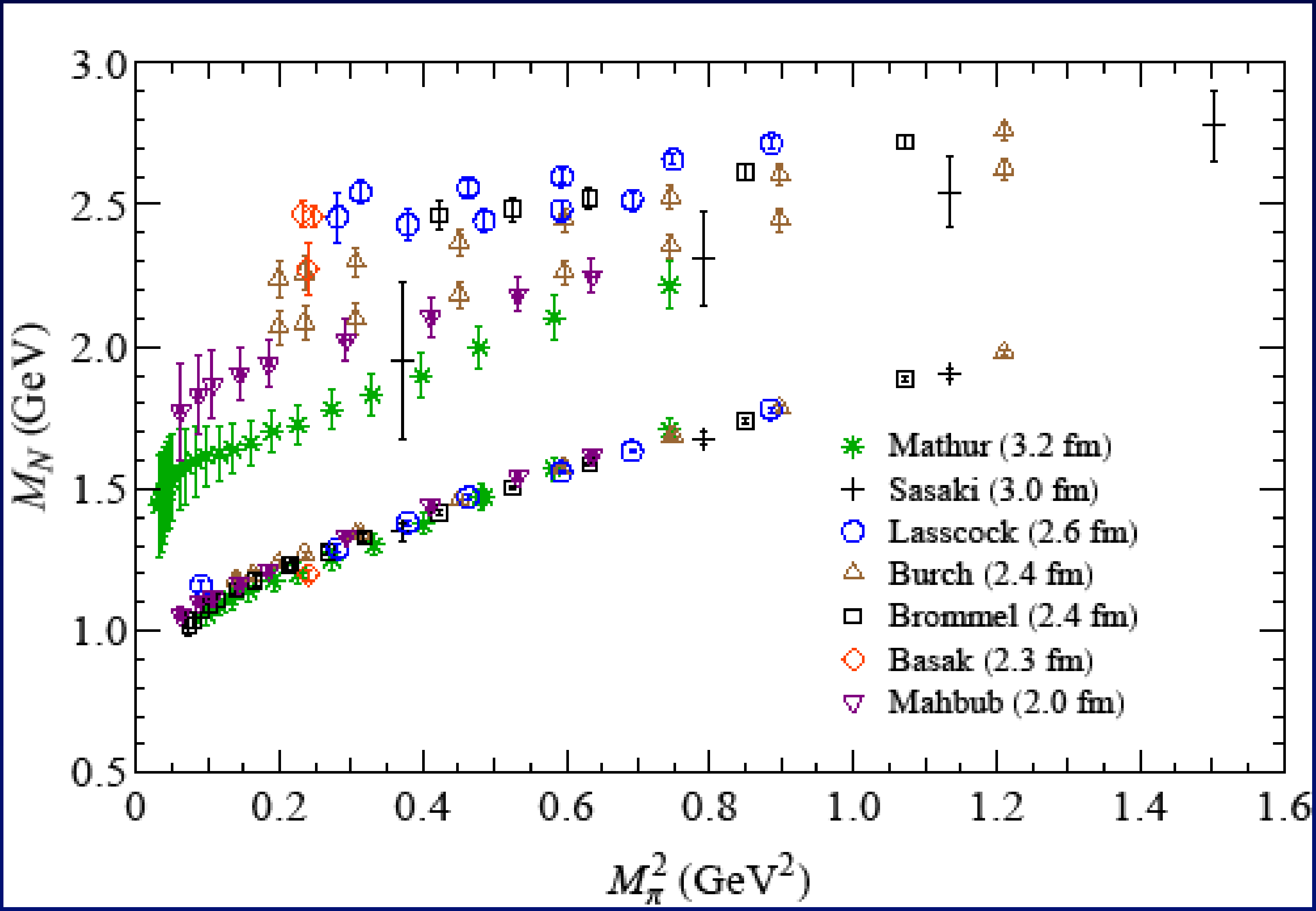
Theory:

(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)
- → Lattice calculations



Quenched Lattice Calculations of Roper



Roper on the lattice

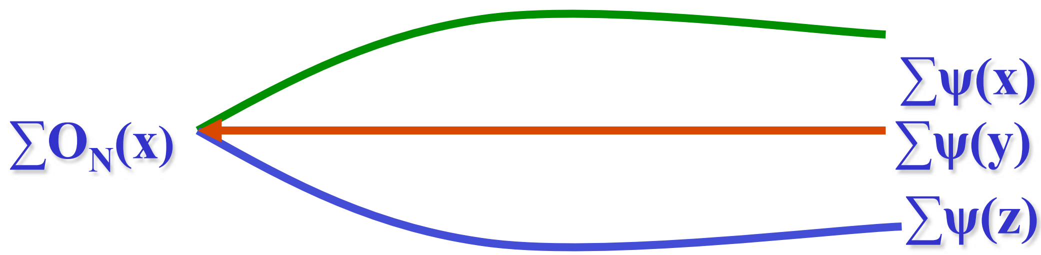
- 4 issues about lattice calculations:
  - Radial excitation or pentaquark state?
  - Dynamical fermions
  - Variation vs Bayesian fitting
  - Dynamical effect

Roper

Radial excitation? $q^4\bar{q}$ State?

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

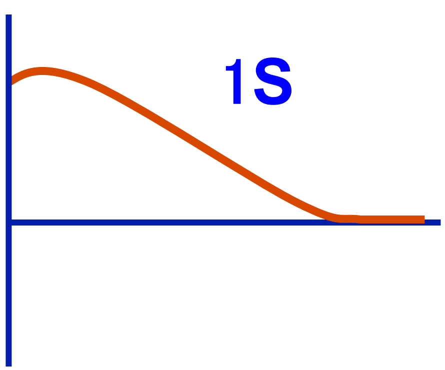
$$|\langle 0|O_N|R\rangle|^2 > |\langle 0|O_N|N\rangle|^2 > 0$$ (point source, point sink)

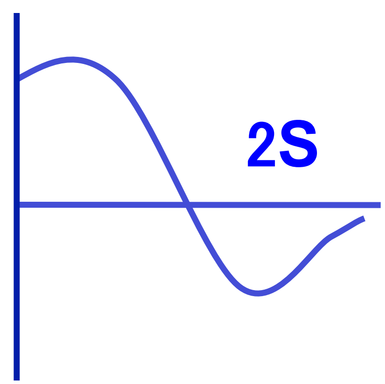


Point sink | Wall source

$$\langle 0|O_N(0)|N\rangle \langle N| \sum\psi(x) \sum\psi(y) \sum\psi(z)|0\rangle > 0$$

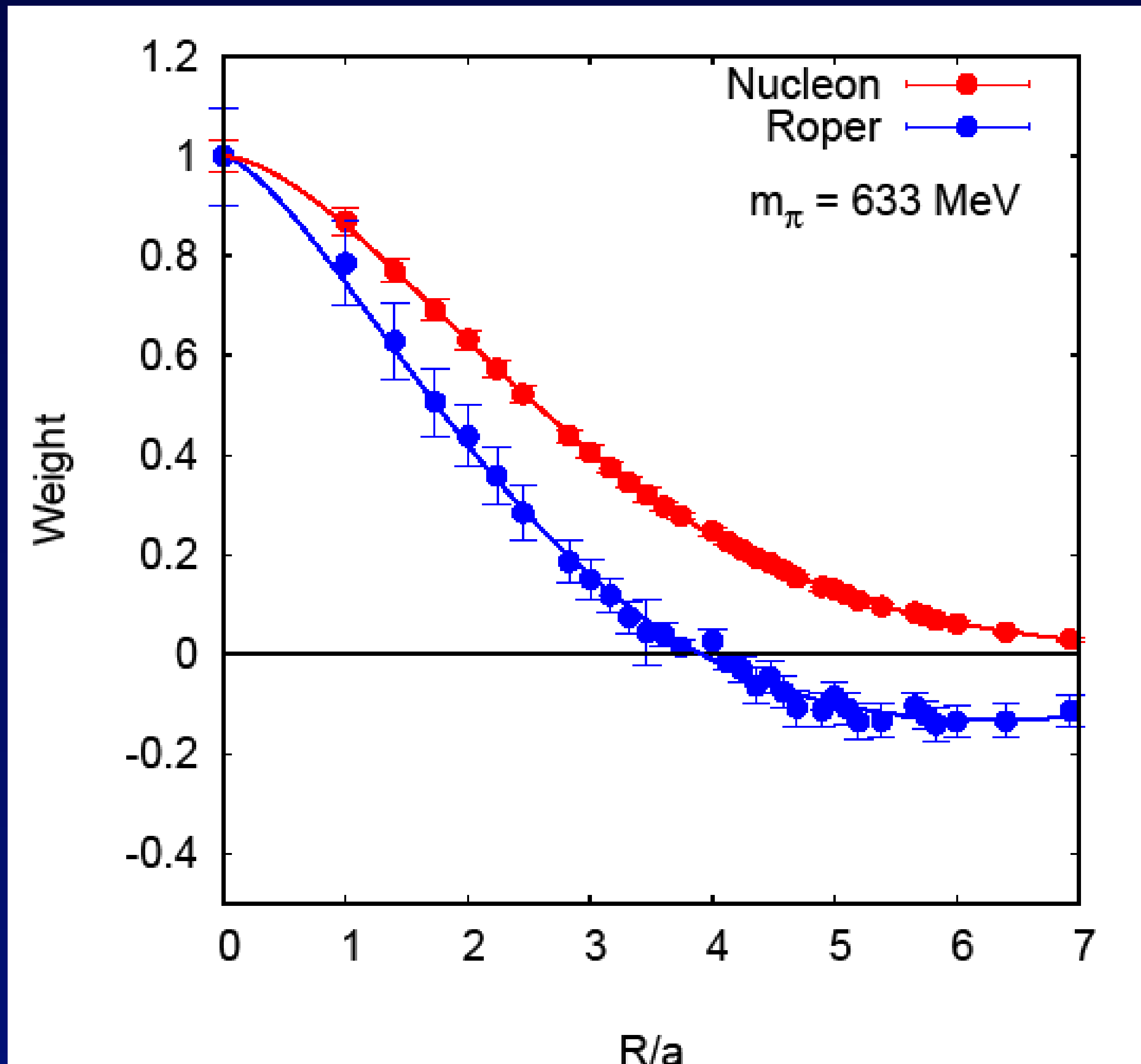
However, $\langle 0|O_N(0)|R\rangle \langle R| \sum\psi(x) \sum\psi(y) | \sum\psi(z)|0\rangle < 0$



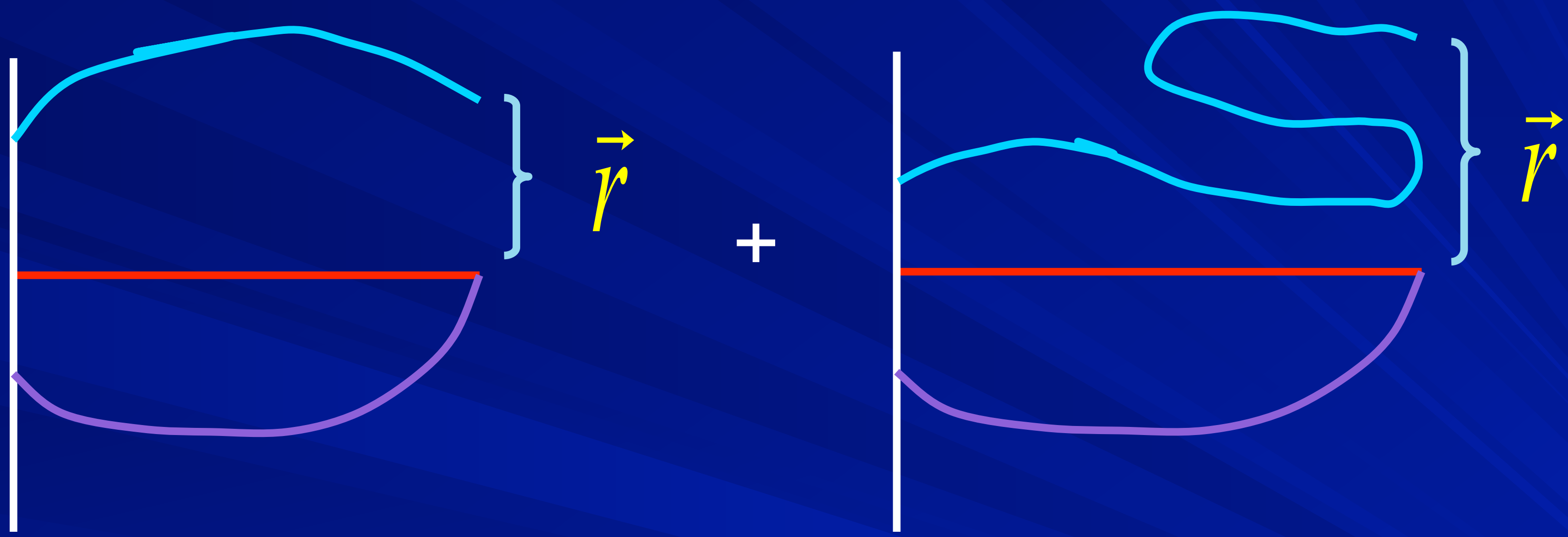


Nucleon and Roper wavefunctions for m_π = 633 MeV

O_{RN} = 0.30



Bethe-Salpeter Wavefunction

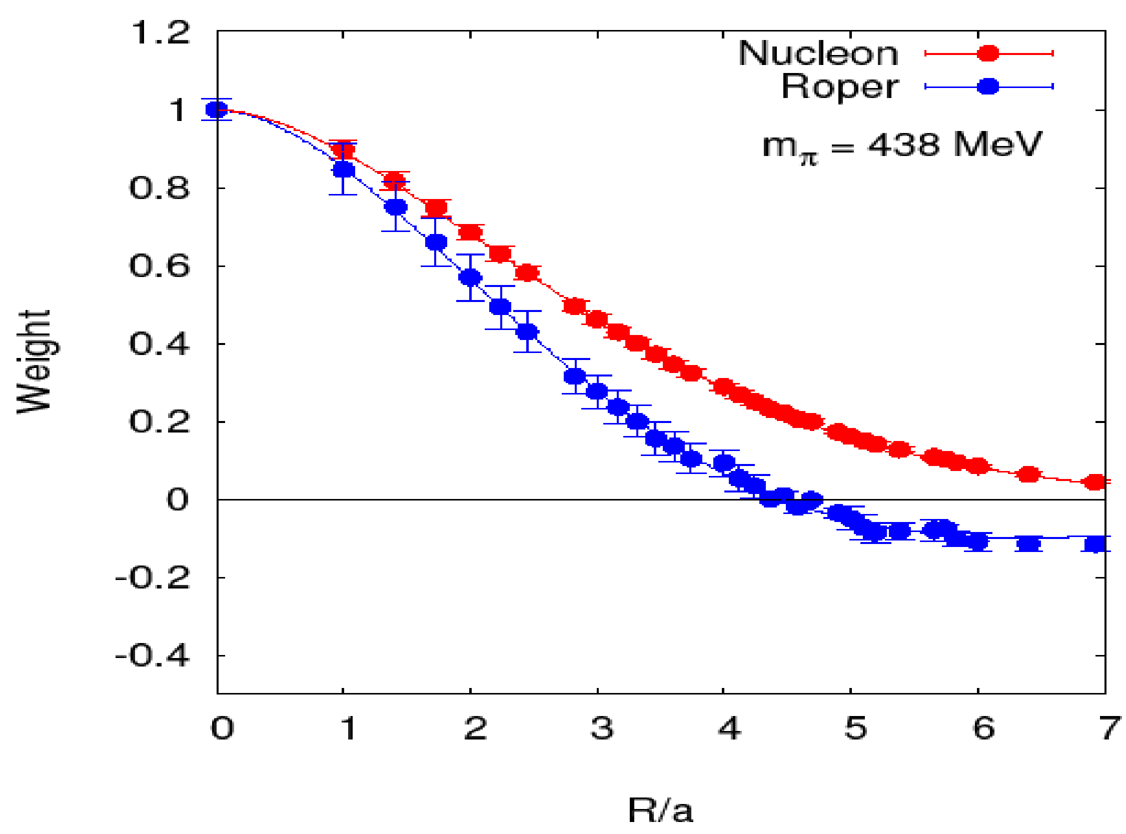


$O_{RN} = \int dr\ \Psi^*_R(r)\Psi_N(r) = 0$ at non-relativistic limit,

$O_{RN} = \int dr\ \Psi^*_R(r)\Psi_N(r)\ \uparrow$ as $m_q\ \downarrow$

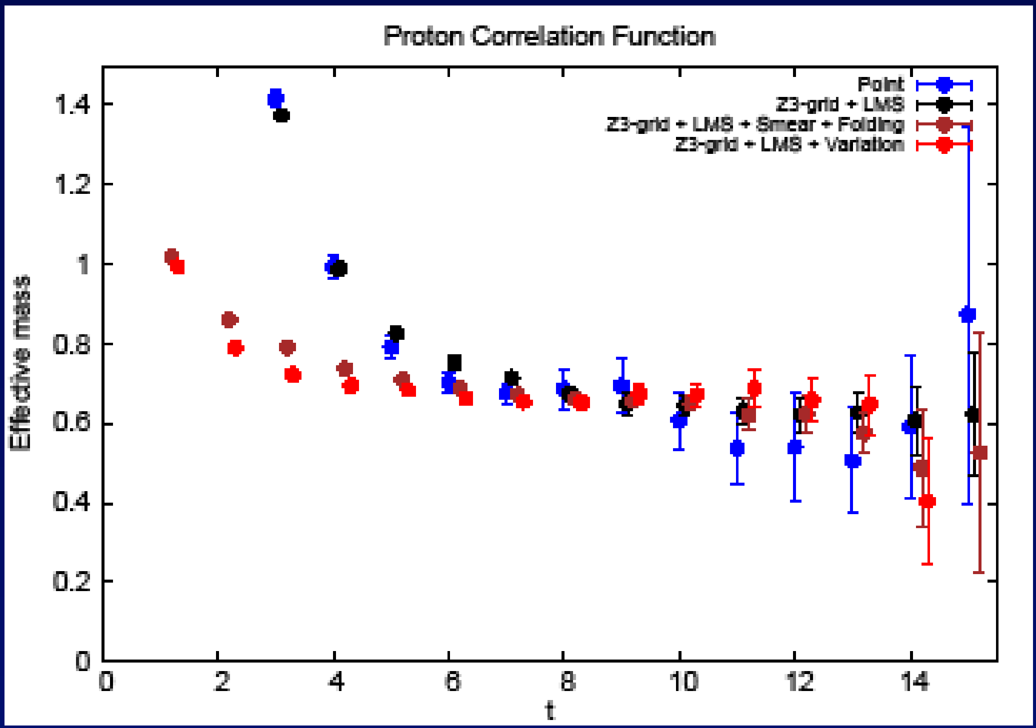
Roper and Nucleon Wavefunctions at m_{π} = 438 MeV

O_{RN} = 0.59



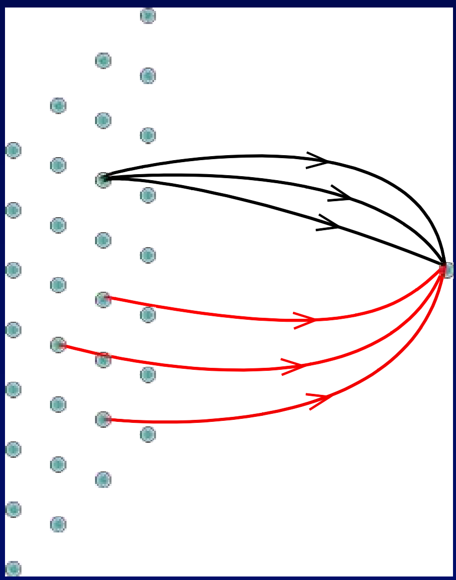
Dynamical Fermions
(Overlap on DWF Configurations)

- Improvement of nucleon correlator with low-mode substitution



$24^3 \times 64$ lattice with $m_\pi = 331$ MeV, a = 1.73 GeV^{-1}

47 configurations



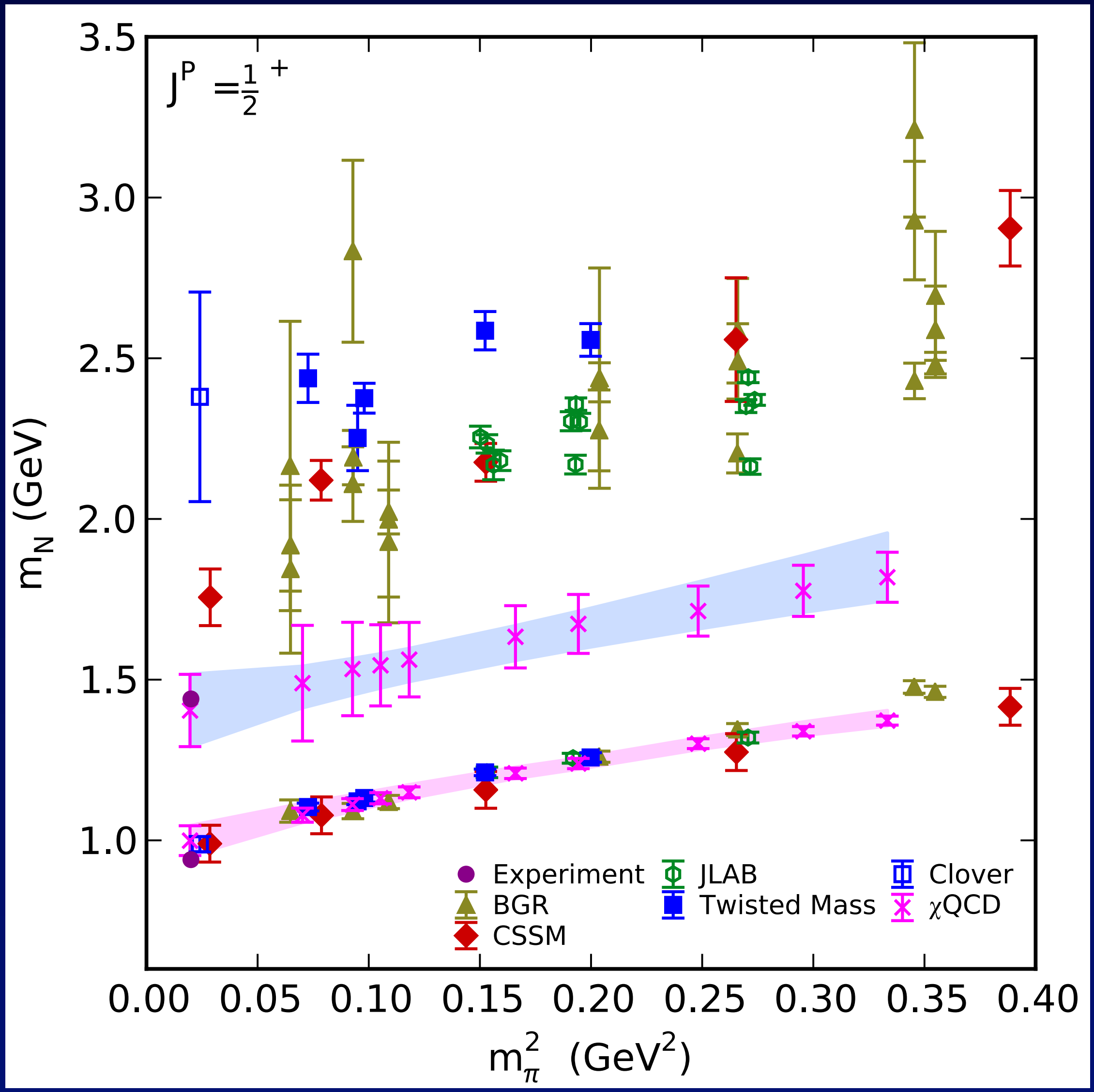
Point source: $m_N = 1.13(14)$ GeV;

Z_3 grid source: $m_N = 1.08(5)$ GeV;

Z_3 grid smeared source: $m_N = 1.14(2)$ GeV;

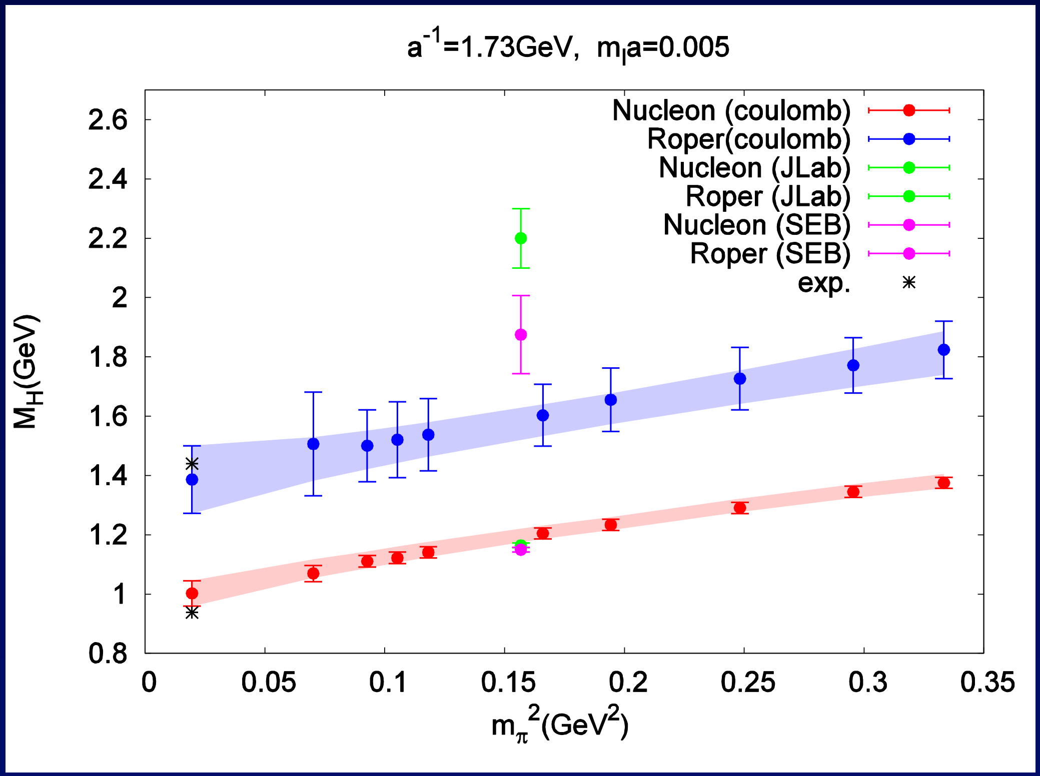
Variation: $m_N = 1.16(1)$ GeV

Roper state from Coulomb wall source



m_N = 999(46) MeV
m_R= 1404(112) MeV

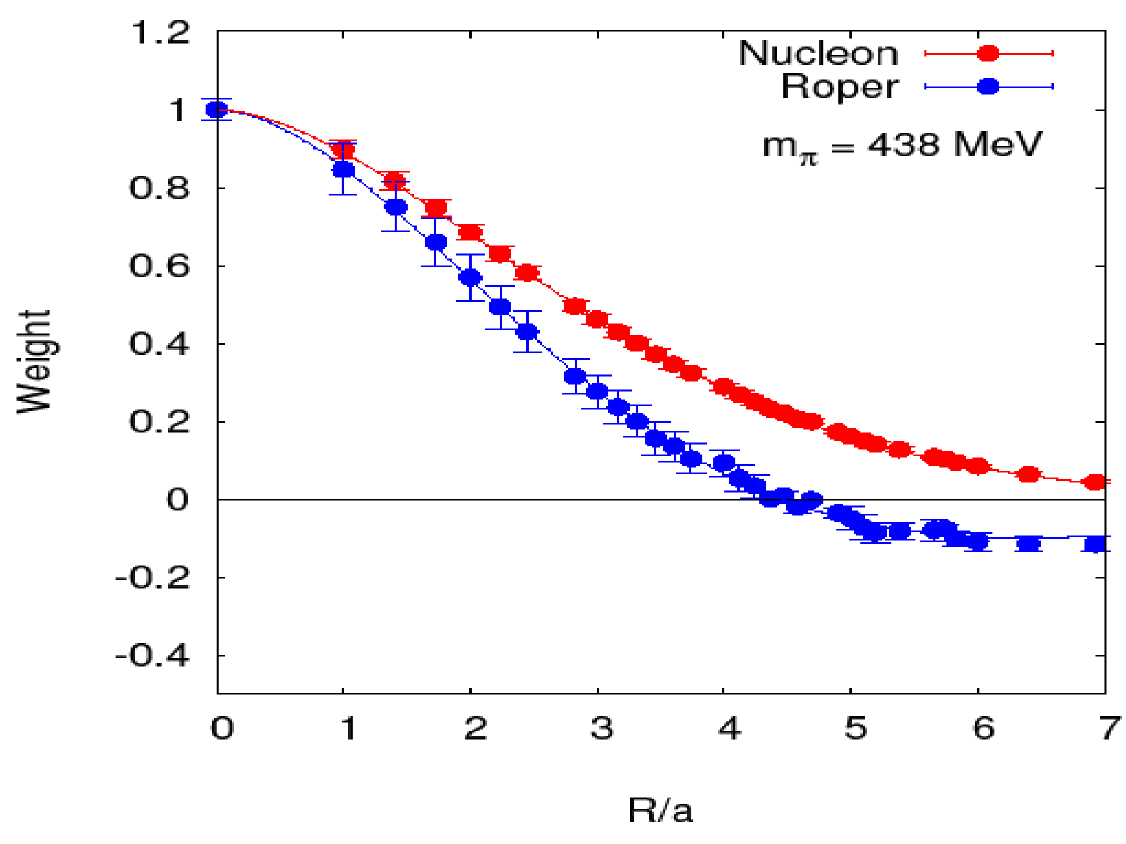
$24^3 \times 64$ lattice with $m_\pi = 331$ MeV(sea), a = 1.73 GeV^{-1}



a^-1=1.73GeV, m_l a=0.005
Nucleon (coulomb)
Roper(coulomb)
Nucleon (JLab)
Roper (JLab)
Nucleon (SEB)
Roper (SEB)
exp.
M_H(GeV)
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
m_π^2(GeV^2)

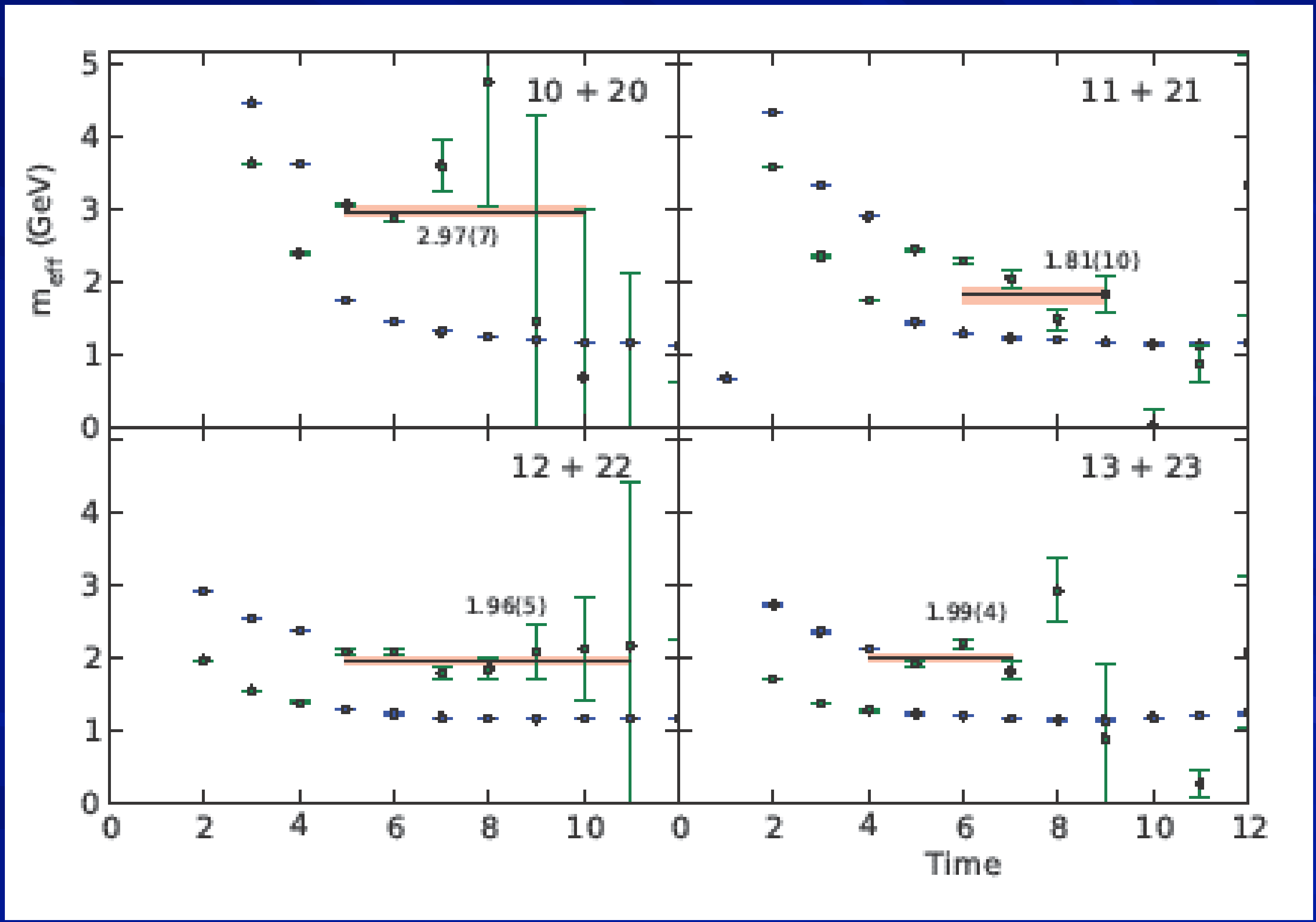
Roper and Nucleon Wavefunctions at m_π = 438 MeV

O_{RN} = 0.59

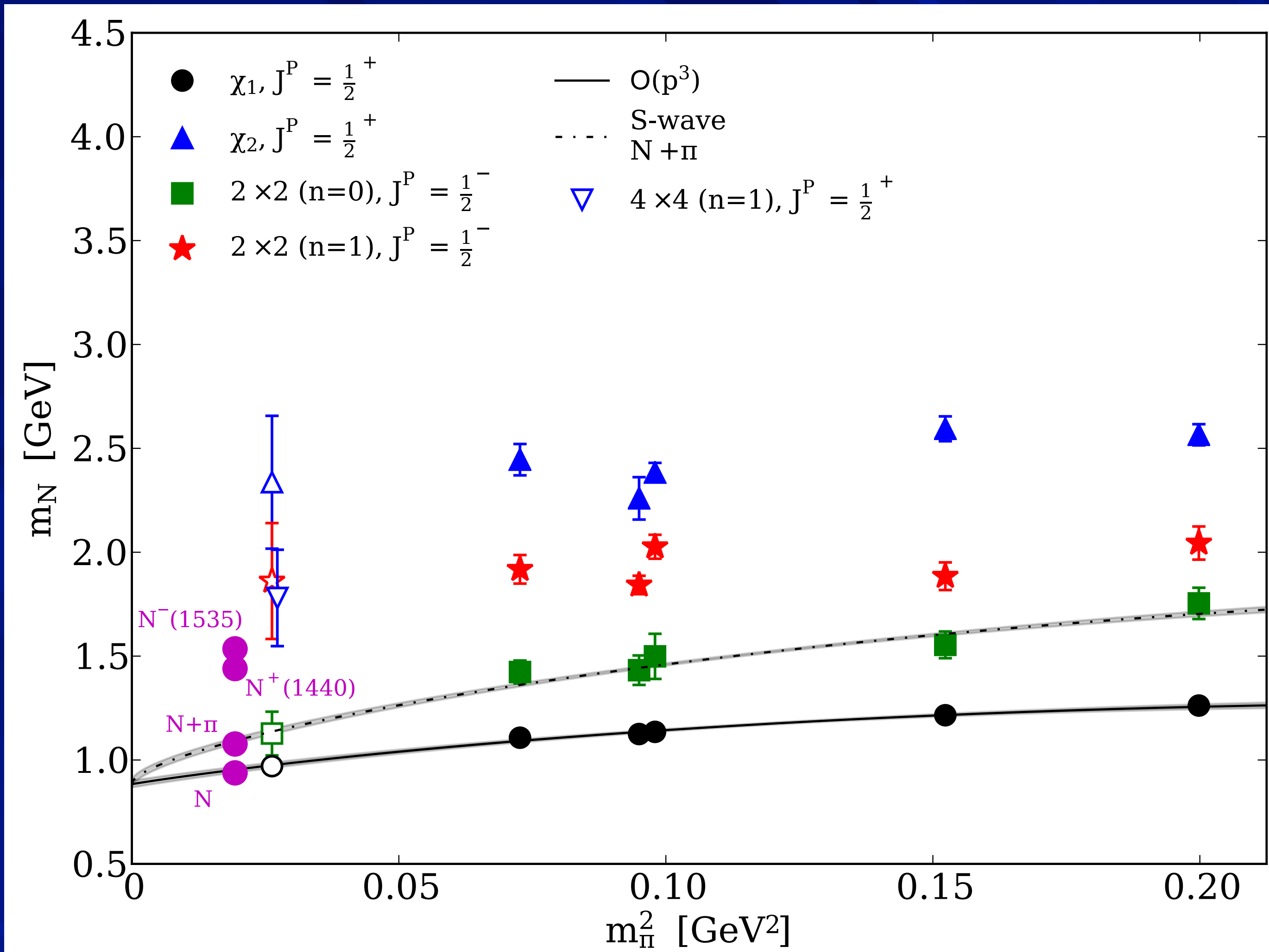


Variation with 2 operators

(10 – operator 1, no smearing, 23 – operator 2, 3 smearing)

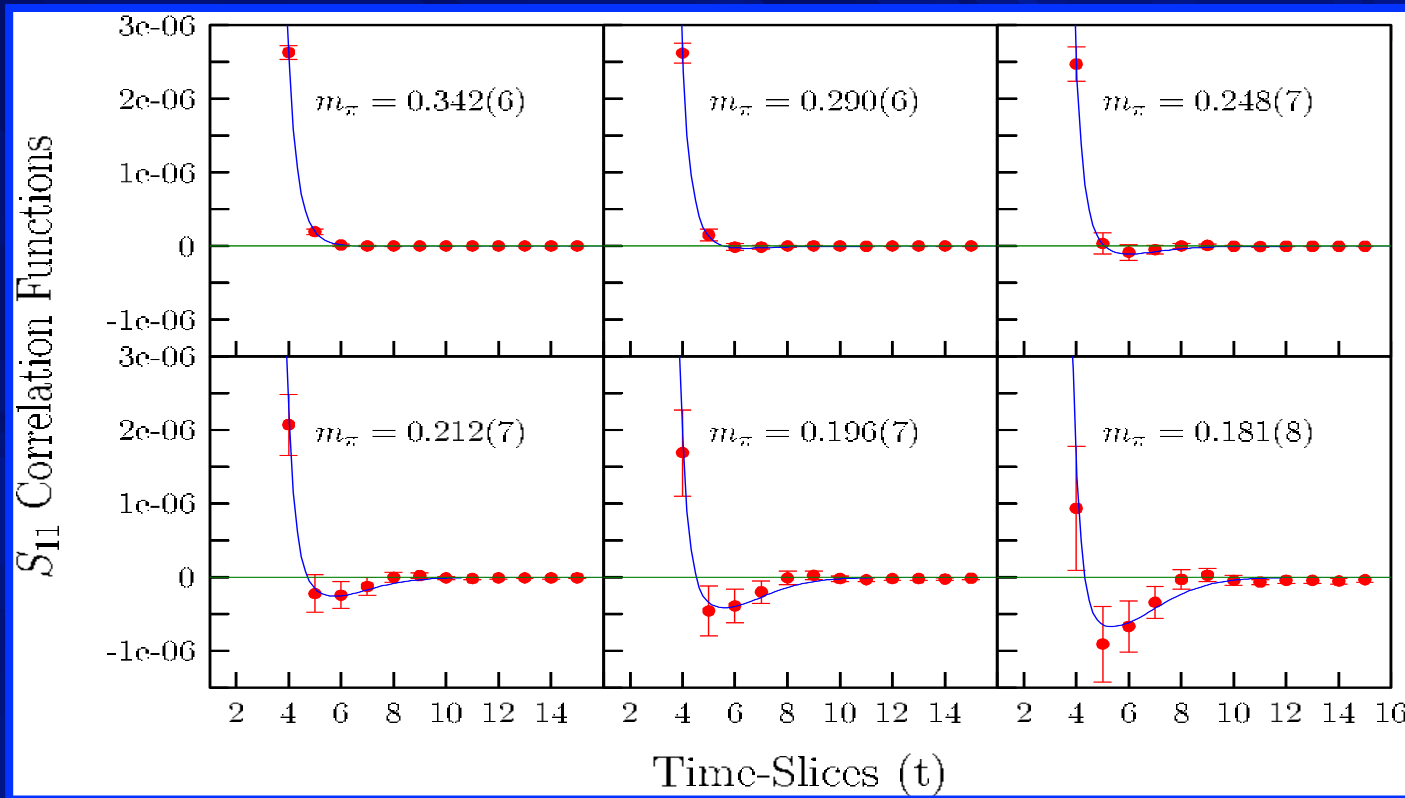


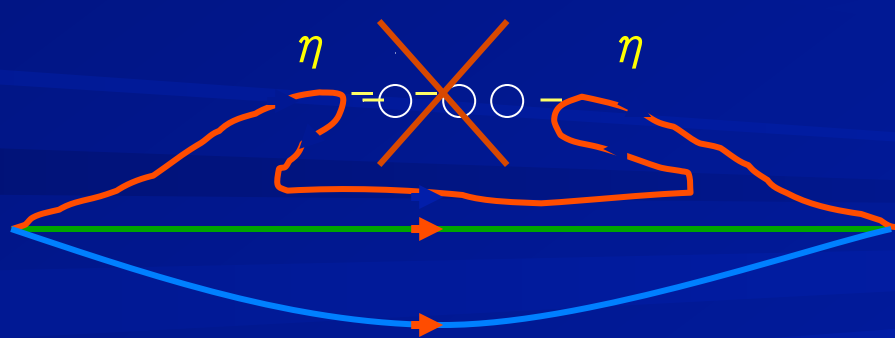
Variation with wall and point sources?

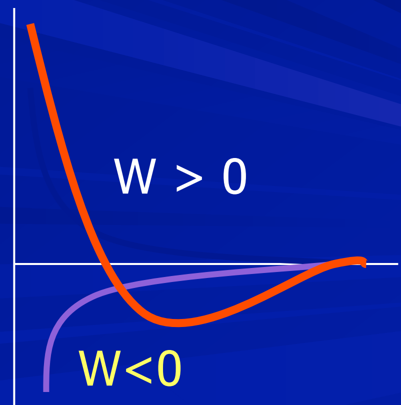


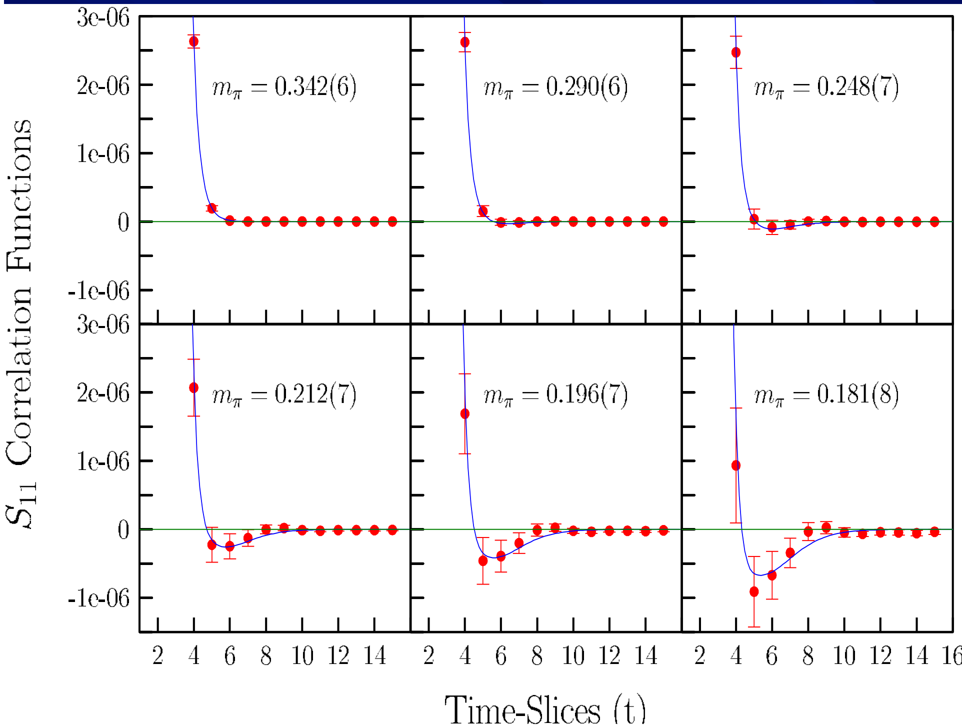
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
0.05
0.10
0.15
0.20
m_N [GeV]
m_π^2 [GeV²]
χ_1, $J^P = \frac{1}{2}^+$
χ_2, $J^P = \frac{1}{2}^+$
2 ×2 (n=0), $J^P = \frac{1}{2}^-$
2 ×2 (n=1), $J^P = \frac{1}{2}^-$
O(p^3)
S-wave
N +π
4 ×4 (n=1), $J^P = \frac{1}{2}^+$
N^-(1535)
N^+(1440)
N+π
N

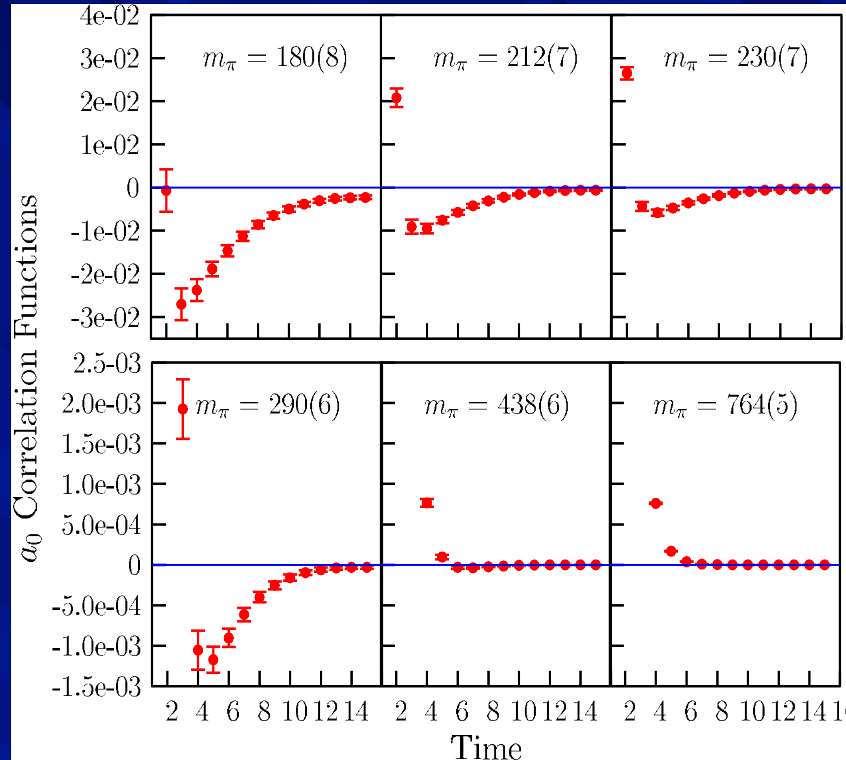
Evidence of η'N GHOST State in S_{11} (1535) Channel

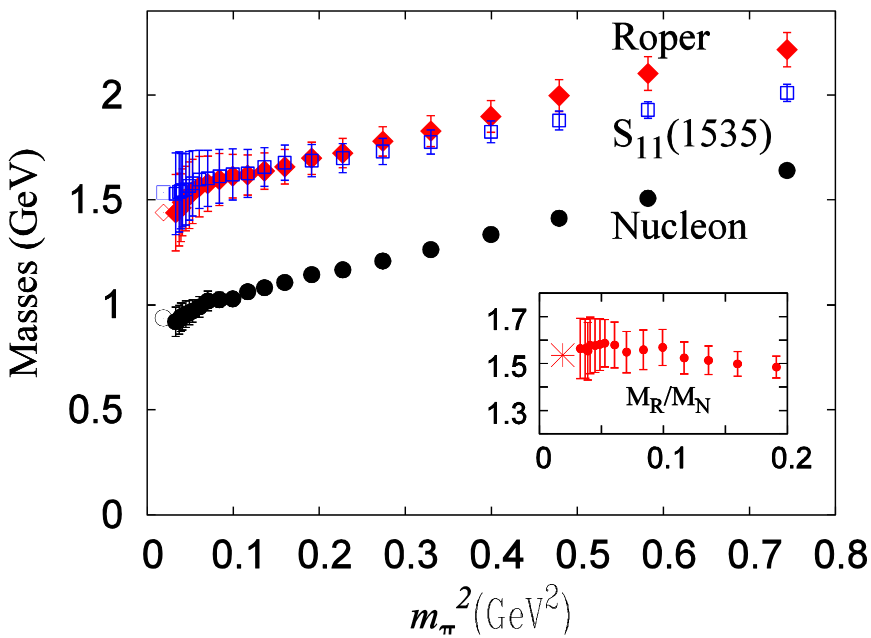




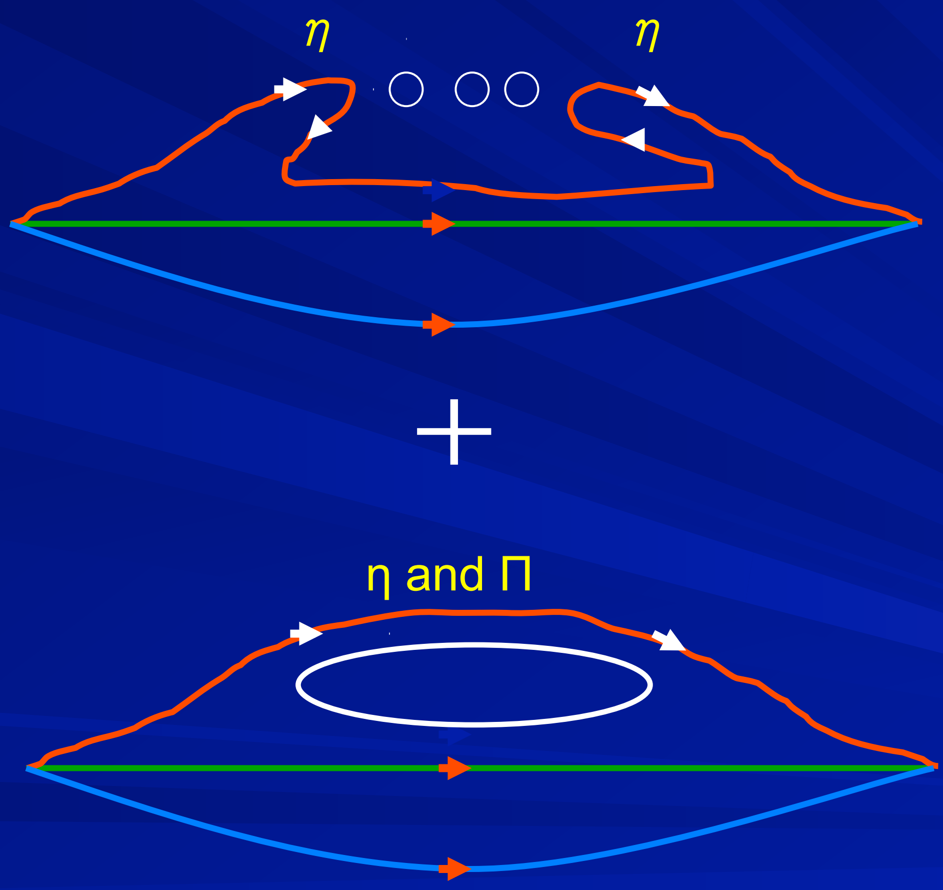



S_{11} Correlation Functions
Time-Slices (t)
$m_\pi = 0.342(6)$
$m_\pi = 0.290(6)$
$m_\pi = 0.248(7)$
$m_\pi = 0.212(7)$
$m_\pi = 0.196(7)$
$m_\pi = 0.181(8)$

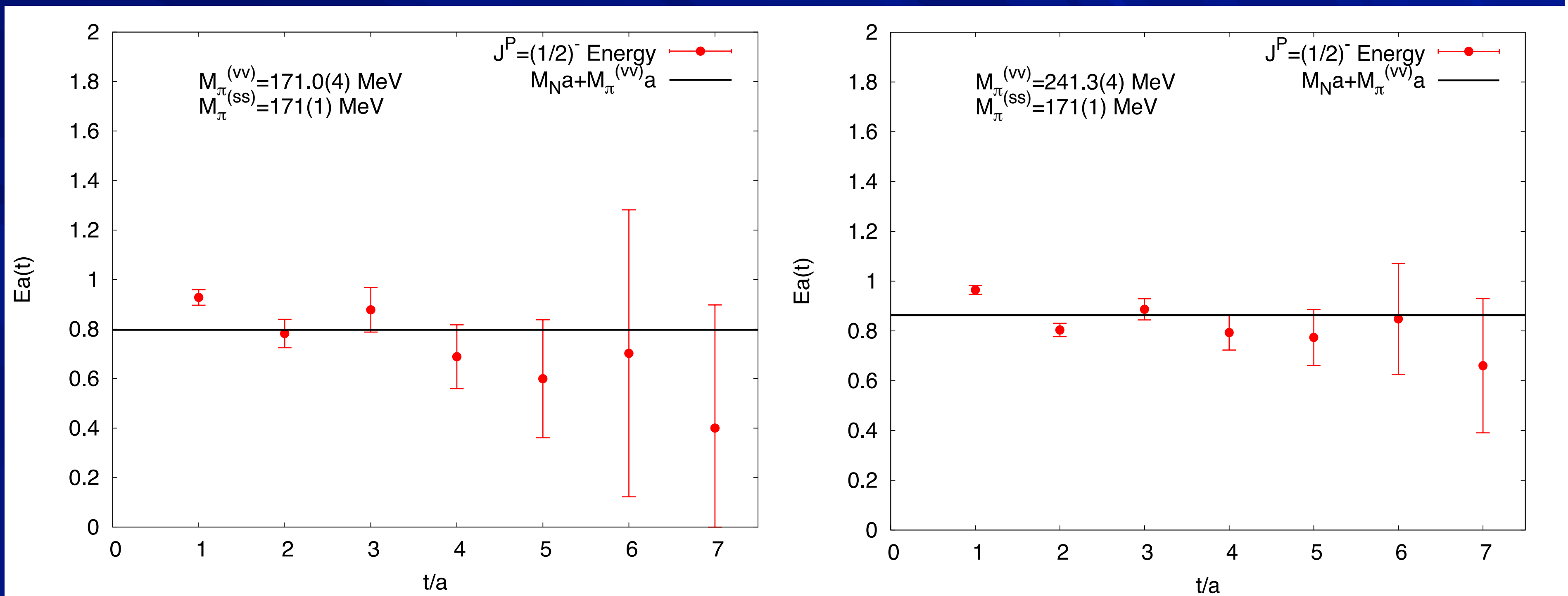

a_0 Correlation Functions
Time
$m_\pi = 180(8)$
$m_\pi = 212(7)$
$m_\pi = 230(7)$
$m_\pi = 290(6)$
$m_\pi = 438(6)$
$m_\pi = 764(5)$


Masses (GeV)
$m_\pi^2 (\mathrm{GeV}^2)$
Roper
$S_{11}(1535)$
Nucleon
M_R/M_N

Dynamical Fermions

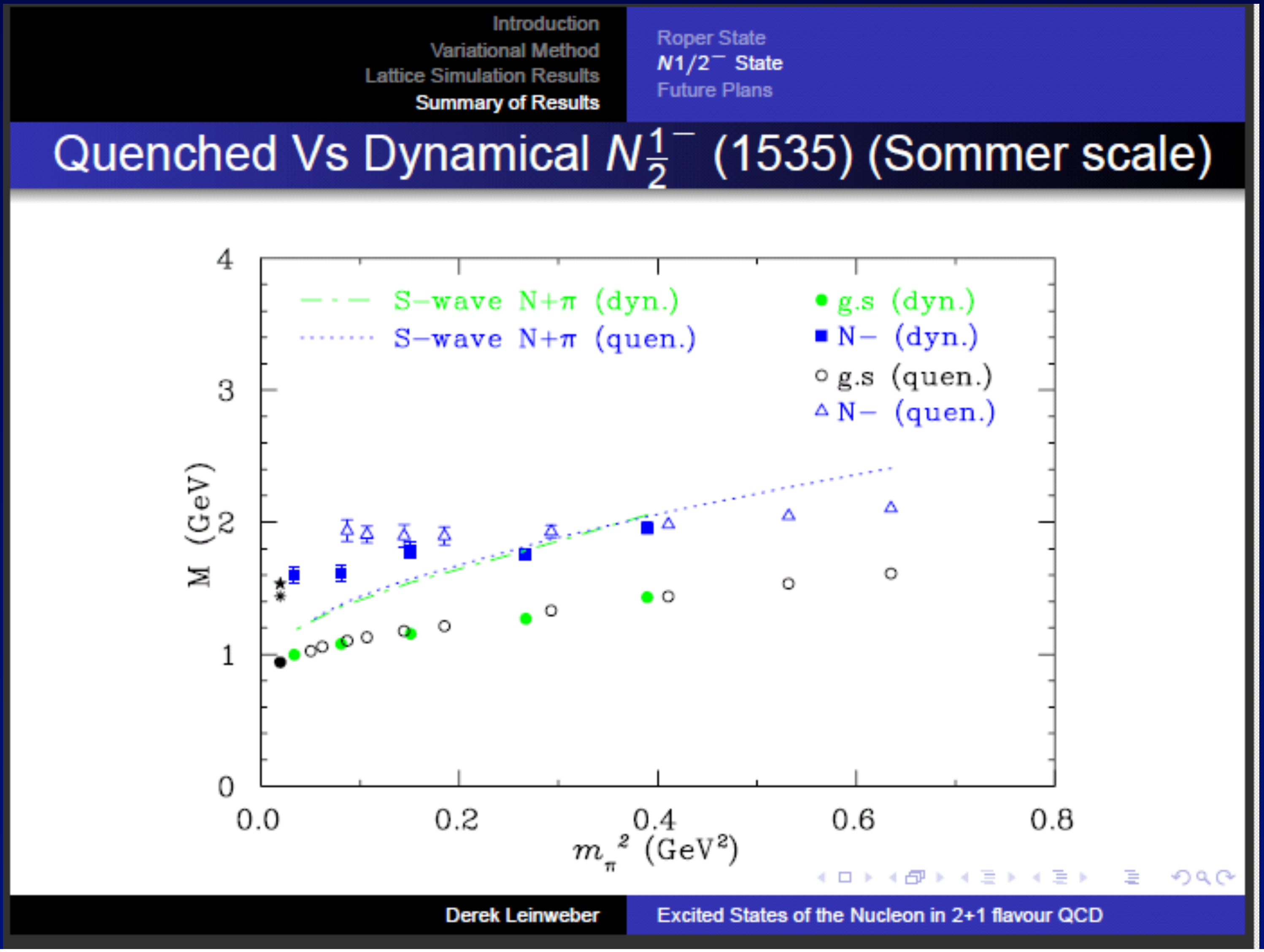


Negative Parity Channel



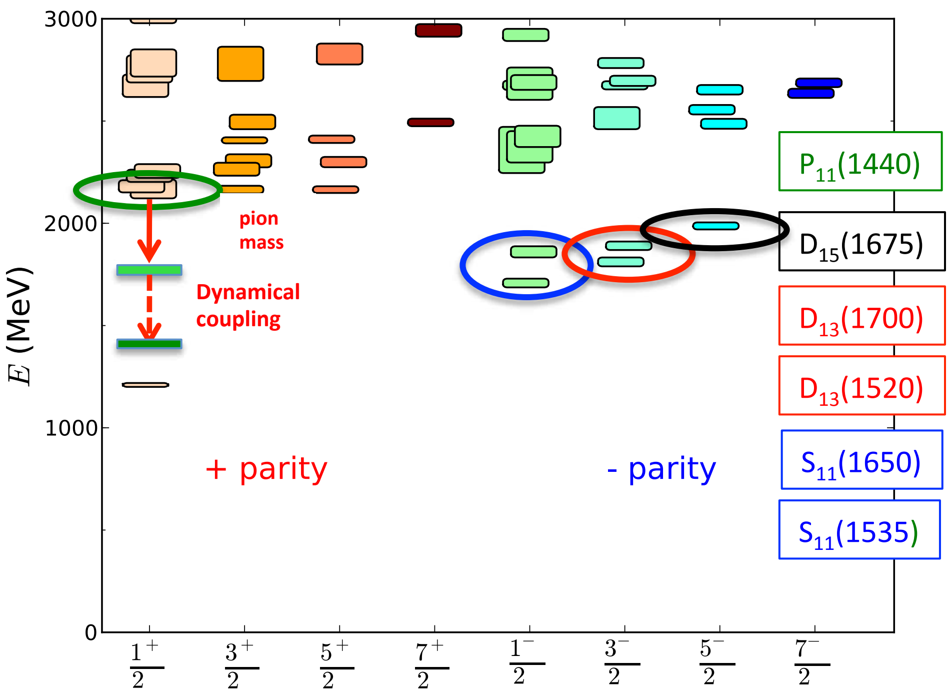
Overlap on 32^3 x 64 DWF lattice, La ~ 4.5 fm,
sea pion mass ~ 170 MeV
with Coulomb wall source

M. Selim Mahbub, et al. (CSSM, 1209.0240)



N* spectrum in LQCD & dynamical coupling

Lattice N* states (m_π=396MeV)

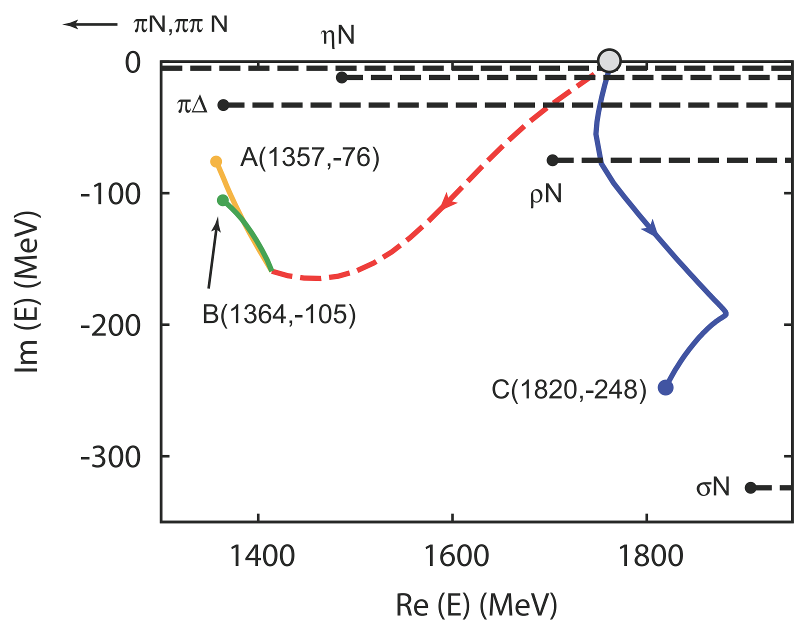


LQCD finds states as predicted in SU(6)xO(3)

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

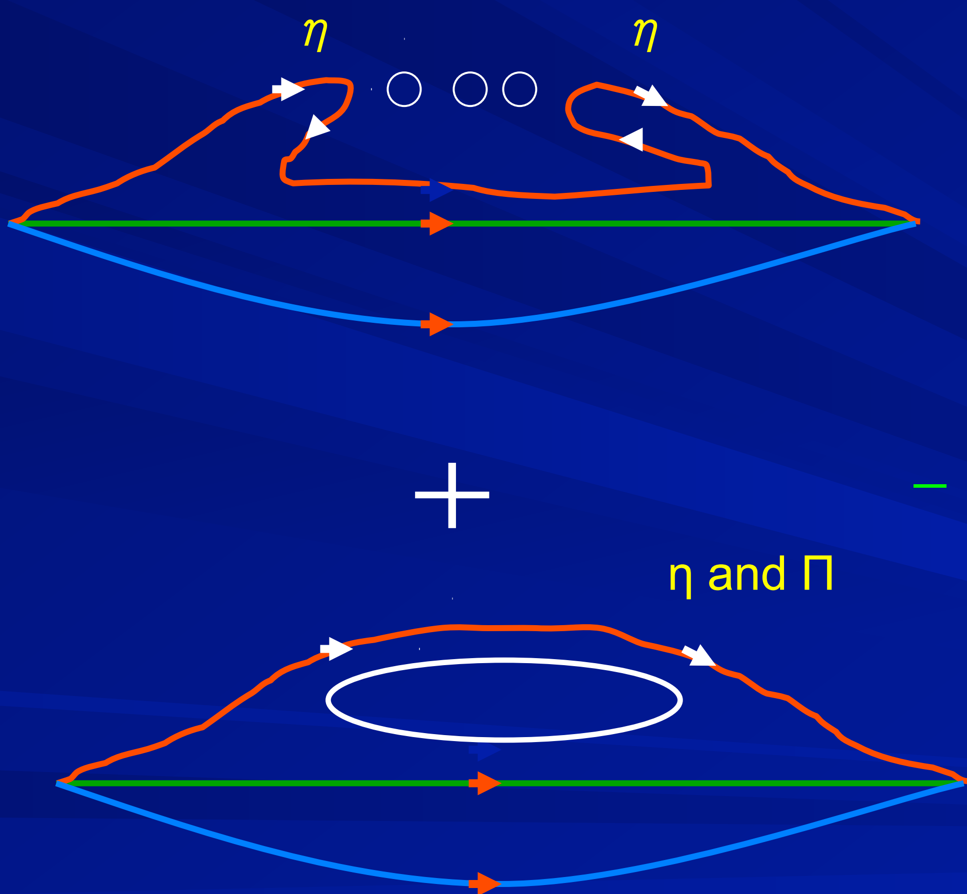
Dynamics of P_{11}-states:

The bare state at ~1750 MeV through coupling to inelastic channels generates 2 poles below 1400 MeV. They are identified with the "Roper" resonance.



N. Suzuki et al. (JLab/EBAC), Phys.Rev.Lett.104:042302,2010

Dynamical Effect



$$-\frac{|\langle 0|\chi_{3q}|\pi N,\eta N(p-wave)\rangle|^2}{\Delta E}$$

Summary

- Part of the discrepancy between the variational method and sequential Bayenes fitting is attributable to the size of the interpolation field.
- Roper is the radial excitation of nucleon with possible large couplings to Nη and Nπ.
- To understand the remaining difference:
  - Use Coulomb wall source/sink in the variation.
  - Compare the following ratios

$$\frac{\langle 0|\chi_{3q}|\pi N(1/2^{\pm})\rangle}{\langle 0|\chi_{3q}|N(1/2^{\pm})\rangle}$$