Pion-Nucleon scattering in the Roper channel

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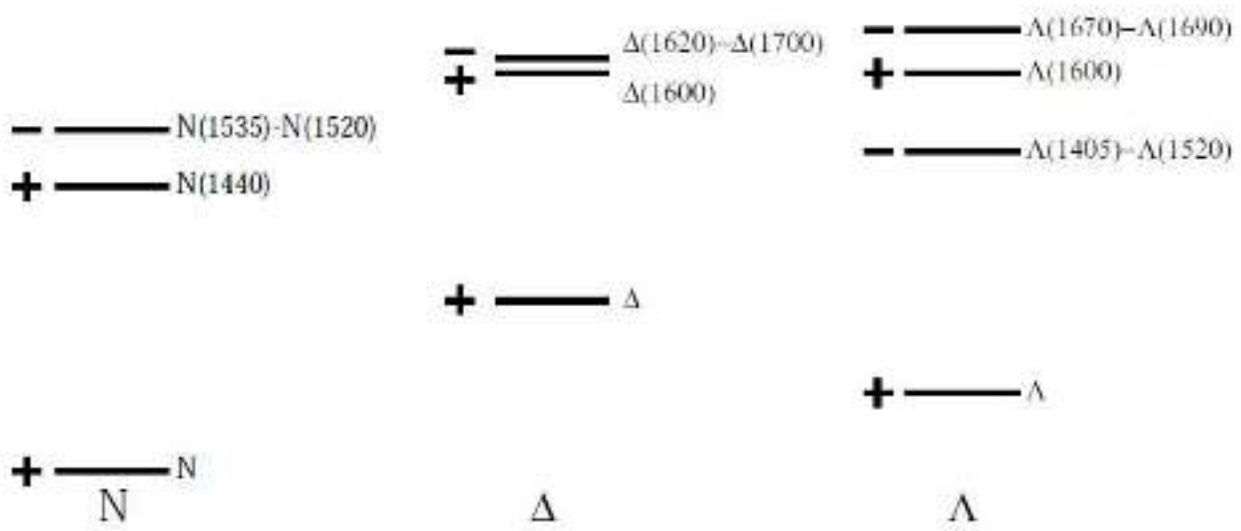
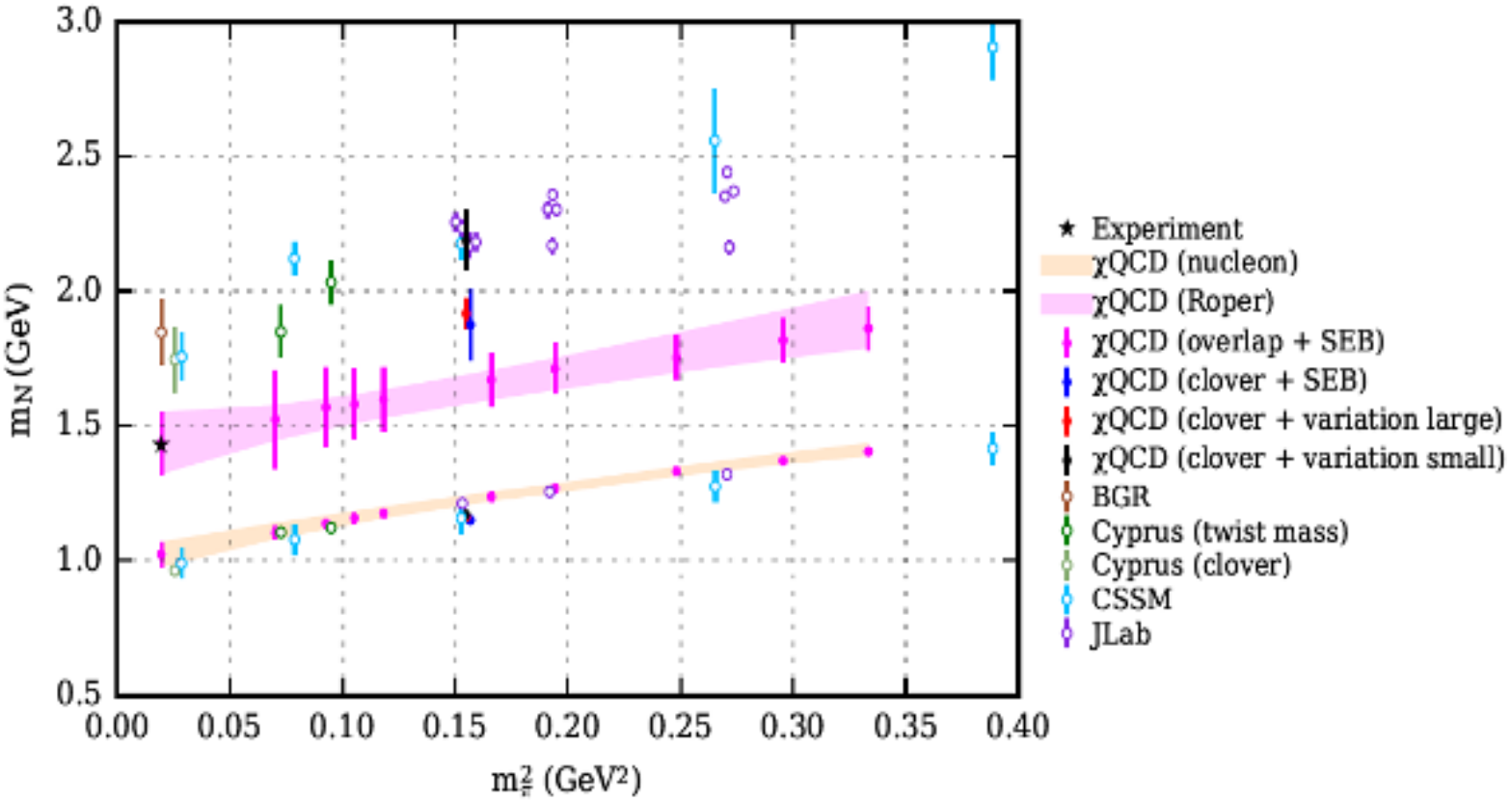
- In collaboration with C. B. Lang, Luka Leskovec and Sasa Prelovsek
- based on Phys. Rev. D **95**, 014510 (2017), arXiv:1610.01422[hep-lat].

Light baryon spectrum



- Inverted hierarchy! Contrary to expectations from simple potentials
- Models motivated by spontaneously broken chiral symmetry
- Goldstone Boson Exchange models Glozman and Riska, Phys.Rept., hep-ph/9505422
- Effective field theories. Suzuki *et al.*, PRL, arXiv:0909.1356 [nucl-th]

Light baryon on the lattice



χQCD : Liu *et al.*, arXiv:1403.6847[hep-ph]

BGR : Engel *et al.*, PRD, arXiv:1301.4318[hep-lat]

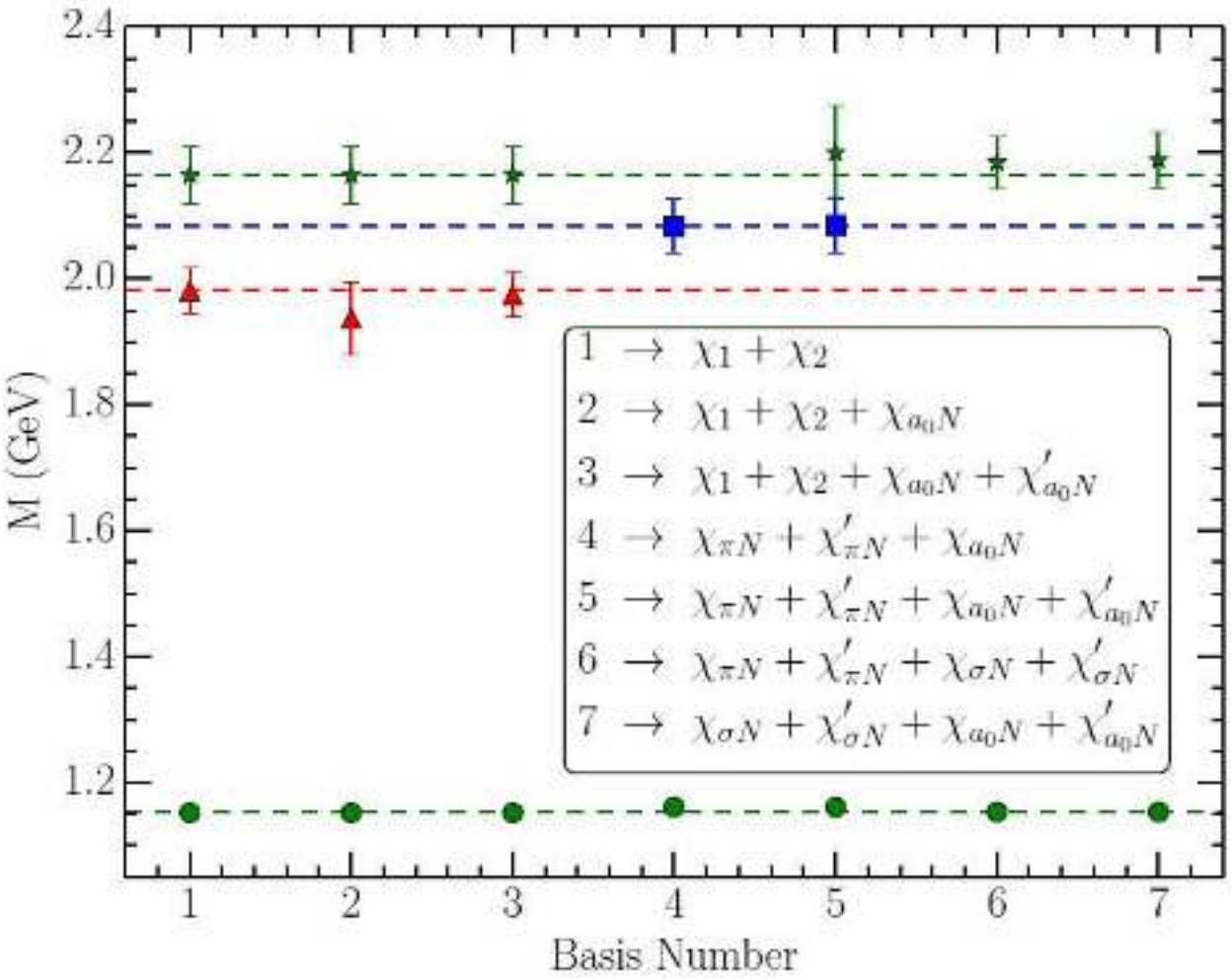
Cyprus : Alexandrou *et al.*, PRD, arXiv:1411.6765[hep-lat]

JLab : Edwards *et al.*, PRD, arXiv:1104.5152[hep-lat]

CSSM : Adelaide group, PLB, arXiv:1011.5724[hep-lat]

Figure courtesy : K. F. Liu, arXiv:1609.02572

Light baryon on the lattice



Local $qqqq\bar{q}$ interpolators!

CSSM : arXiv:1608.03051[hep-lat]

What we aim to do?

- A calculation involving all baryon-meson scattering channels up to $\sim$1.65 GeV.
- qqq-type interpolators, $N\pi$ in p-wave and $N\sigma$ in s-wave.
- Extract and identify all the lattice energy levels in the Nucleon spectra.
- Possible description of Roper resonance using elastic $N - \pi$ scattering?

Lattice we use

Lattice size	N_f	N_{cfgs}	m_π [MeV]	a [fm]	L [fm]
$32^3 \times 64$	$2+1$	197(193)	156(7)(2)	0.0907(13)	2.9

PACS-CS lattices, Aoki *et al.*, PRD, arXiv:0807.1661.

Pion mass dependence!

config. set	m_π [MeV]	m_N [MeV]
all	153.9 ± 4.1	951 ± 19
all-1	163.9 ± 2.4	965 ± 13
all-4	164.4 ± 2.1	969 ± 12

We will present results from "all-4".

Interpolators : single hadrons

Nucleon interpolators (in the Dirac basis)

$$N^i_{m_s=1/2}(\mathbf{n}) = \mathcal{N}^i_{\mu=1}(\mathbf{n}) \ , \ N^i_{m_s=-1/2}(\mathbf{n}) = \mathcal{N}^i_{\mu=2}(\mathbf{n})$$

$$\mathcal{N}^i_\mu(\mathbf{n}) = \sum_{\mathbf{x}} \epsilon_{abc} [u^{aT}(\mathbf{x},t)\Gamma^i_2 d^b(\mathbf{x},t)] \ [\Gamma^i_1 q^c(\mathbf{x},t)]_\mu \ \mathrm{e}^{i\mathbf{x}\cdot\mathbf{n}\frac{2\pi}{L}}$$

$$i = 1,2,3: \quad (\Gamma^i_1, \Gamma^i_2) = (\mathbf{1}, C\gamma_5), \ (\gamma_5, C), \ (i\mathbf{1}, C\gamma_t\gamma_4)$$

π interpolators

$$\pi^+(\mathbf{n}) = \sum_{\mathbf{x}} \bar{d}(\mathbf{x},t)\gamma_5 u(\mathbf{x},t)\mathrm{e}^{i\mathbf{x}\cdot\mathbf{n}\frac{2\pi}{L}}$$

$$\pi^0(\mathbf{n}) = \frac{1}{\sqrt{2}} \sum_{\mathbf{x}} [\bar{d}(\mathbf{x},t)\gamma_5 d(\mathbf{x},t) - \bar{u}(\mathbf{x},t)\gamma_5 u(\mathbf{x},t)]\mathrm{e}^{i\mathbf{x}\cdot\mathbf{n}\frac{2\pi}{L}}$$

σ interpolators

$$\sigma(0) = \frac{1}{\sqrt{2}} \sum_{\mathbf{x}} [\bar{u}(\mathbf{x},t)u(\mathbf{x},t) + \bar{d}(\mathbf{x},t)d(\mathbf{x},t)] \ .$$

Our interpolators

$$O^{N\pi}_{1,2} = -\sqrt{\frac{1}{3}}\ [p^{1,2}_{-\frac{1}{2}}(-e_x)\pi^0(e_x) - p^{1,2}_{-\frac{1}{2}}(e_x)\pi^0(-e_x) - ip^{1,2}_{-\frac{1}{2}}(-e_y)\pi^0(e_y) + ip^{1,2}_{-\frac{1}{2}}(e_y)\pi^0(-e_y) + p^{1,2}_{\frac{1}{2}}(-e_z)\pi^0(e_z) - p^{1,2}_{\frac{1}{2}}(e_z)\pi^0(-e_z)] + \sqrt{\frac{2}{3}}\ [\{p \to n, \pi^0 \to \pi^+\}] \quad [narrower]$$

$$O^{N_w}_{3,4,5} = p^{1,2,3}_{\frac{1}{2}}(0) \quad [wider]$$

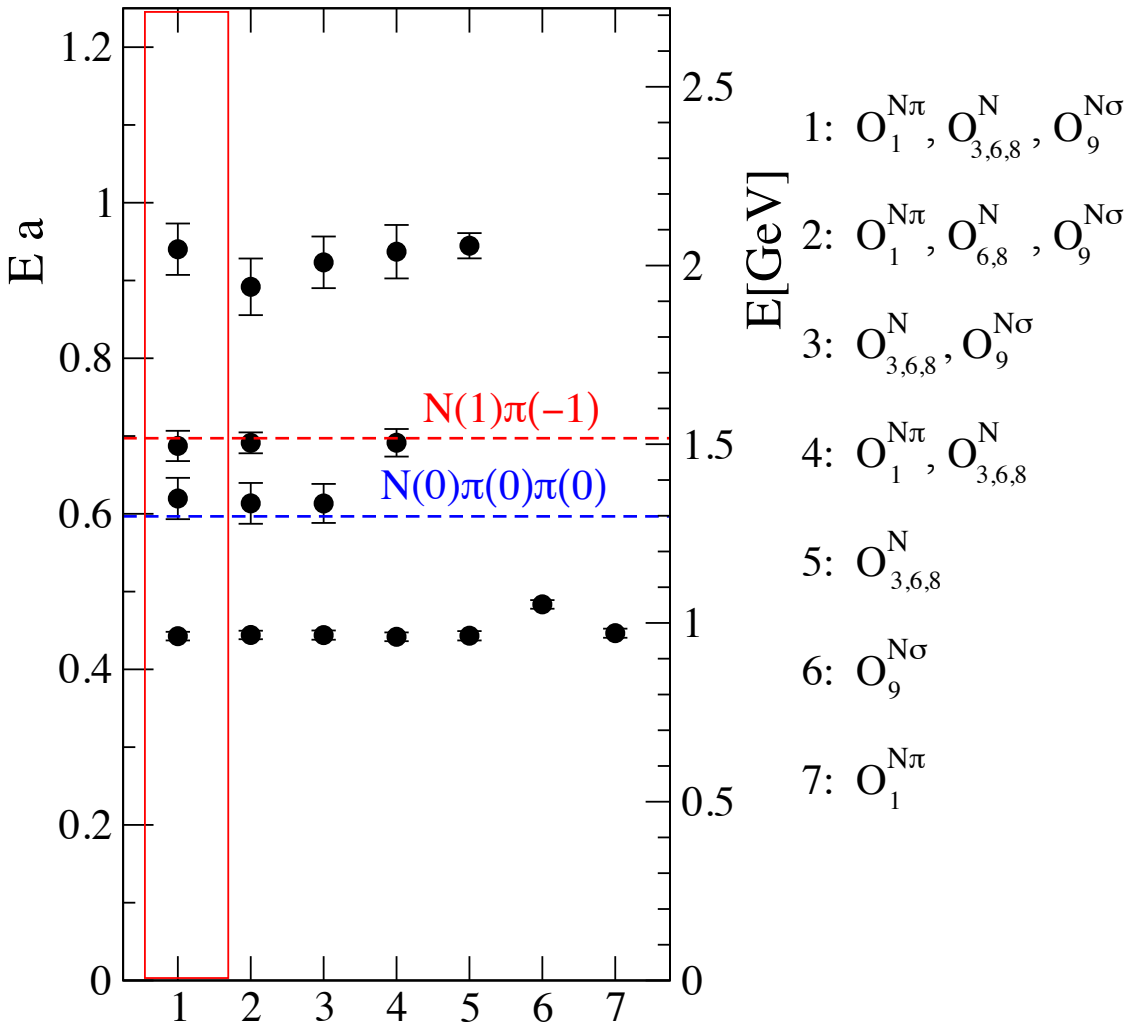
$$O^{N_n}_{6,7,8} = p^{1,2,3}_{\frac{1}{2}}(0) \quad [narrower]$$

$$O^{N\sigma}_{9,10} = p^{1,2}_{\frac{1}{2}}(0)\sigma(0) \quad [narrower]$$

Partial wave projection

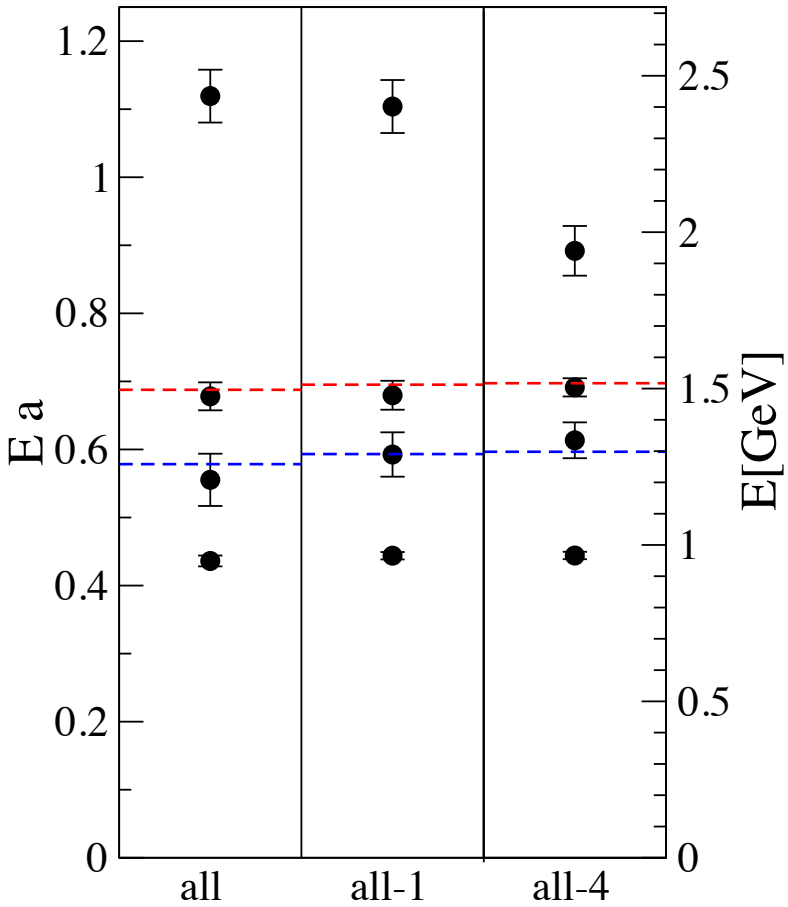
$$O_{J=1/2,M_J=1/2}(|k|) = \sum_{m_s,m_l} CG(J=1/2 M_J=1/2|1m_l\,1/2m_s) \sum_{R\in O_h} Y_{lm_l}(Rk)\pi(Rk)N_{m_s}(-Rk)$$

Results : Excited nucleon spectrum



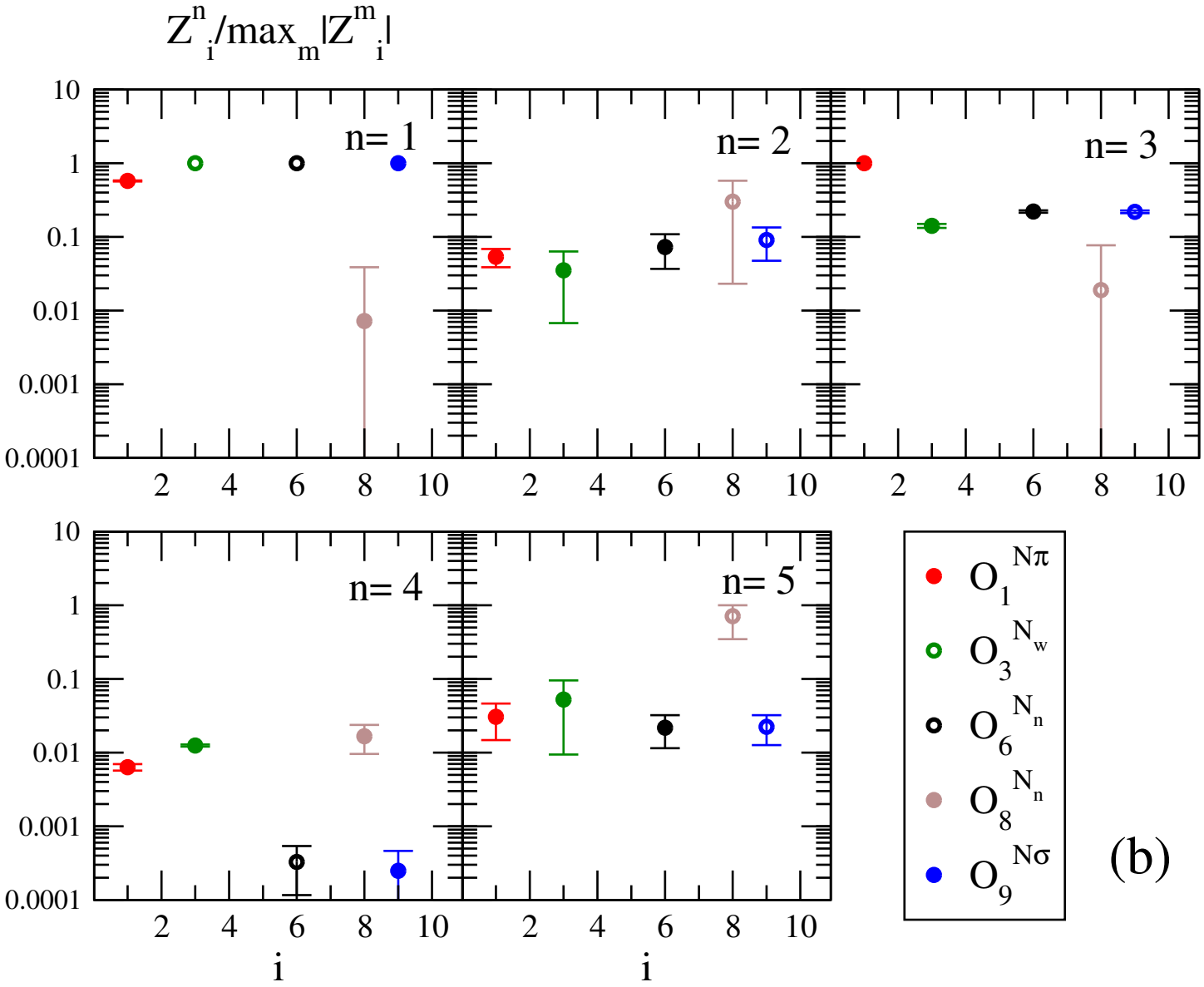
Only three lattice eigenlevels below ∼1.65 GeV.

Results : Level 2

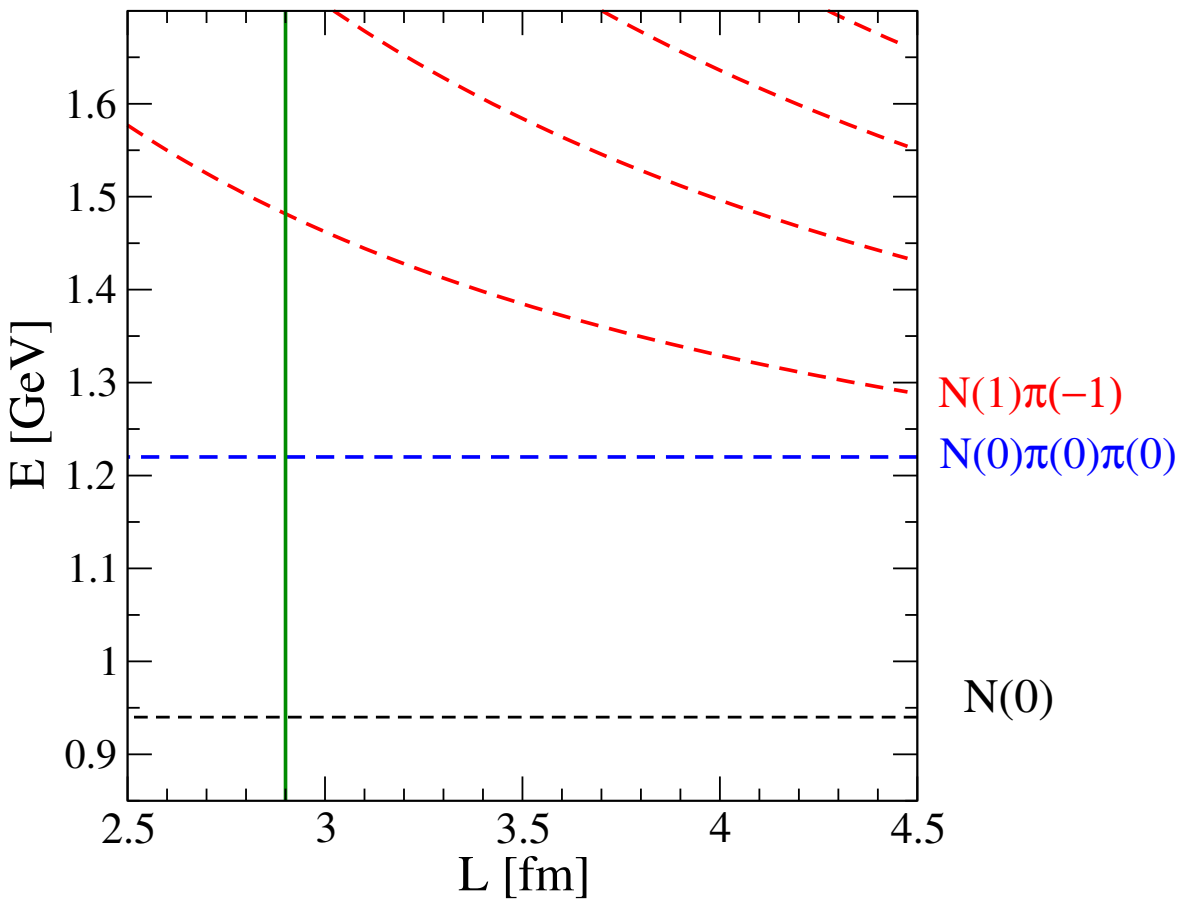


Identification based on m_π dependence.

Results : The spectral overlaps

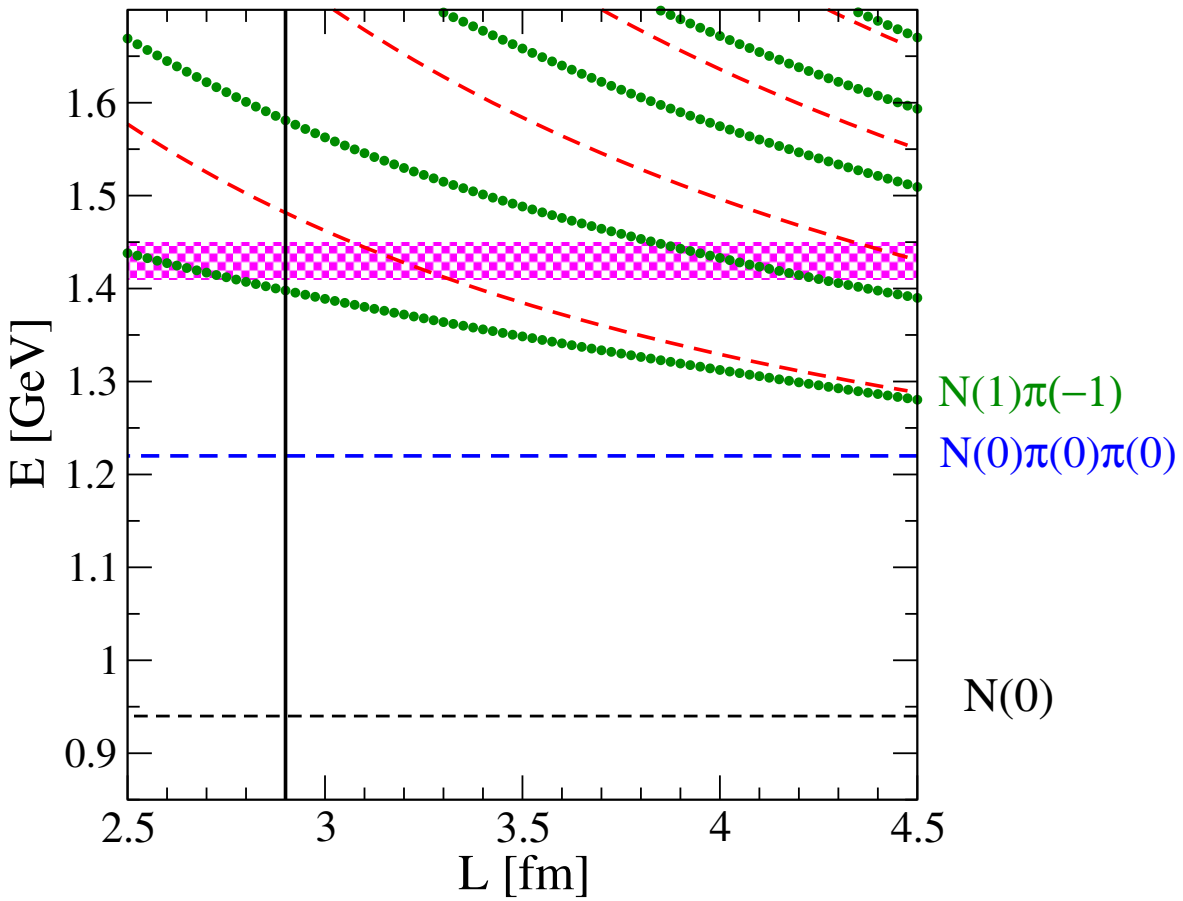


Pion-Nucleon elastic scattering



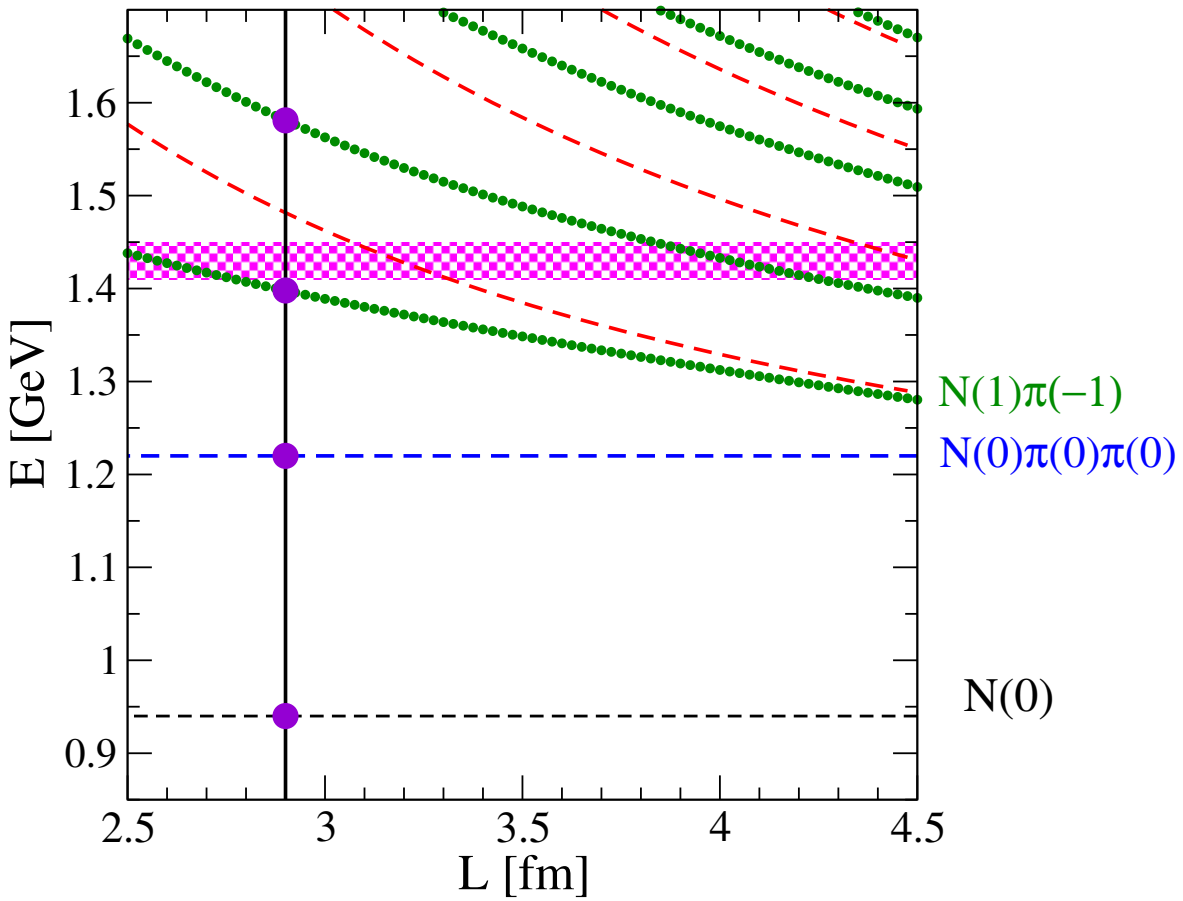
No interaction

Pion-Nucleon elastic scattering



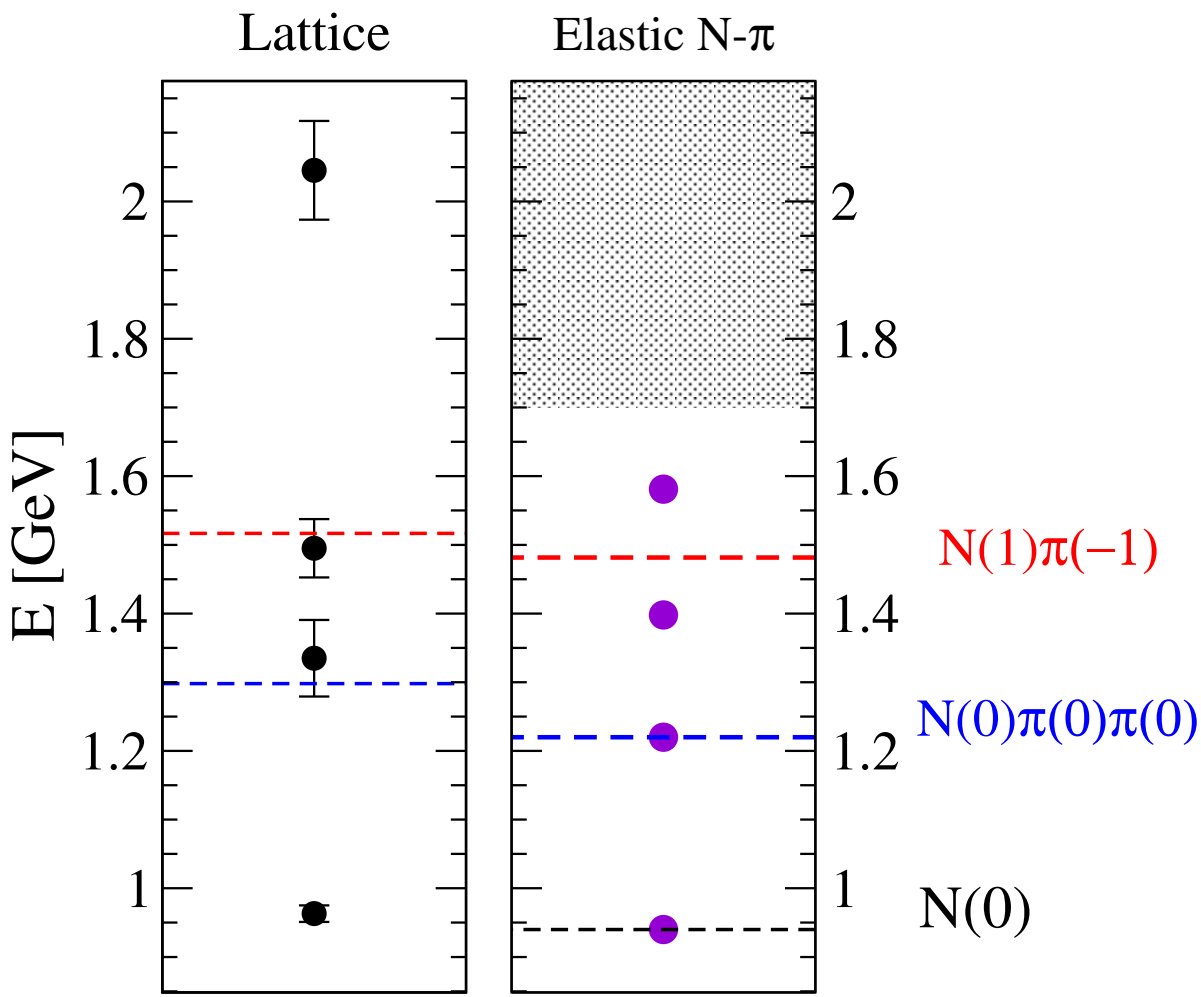
$N\pi$ channel coupled with a Roper like resonance.

Pion-Nucleon elastic scattering

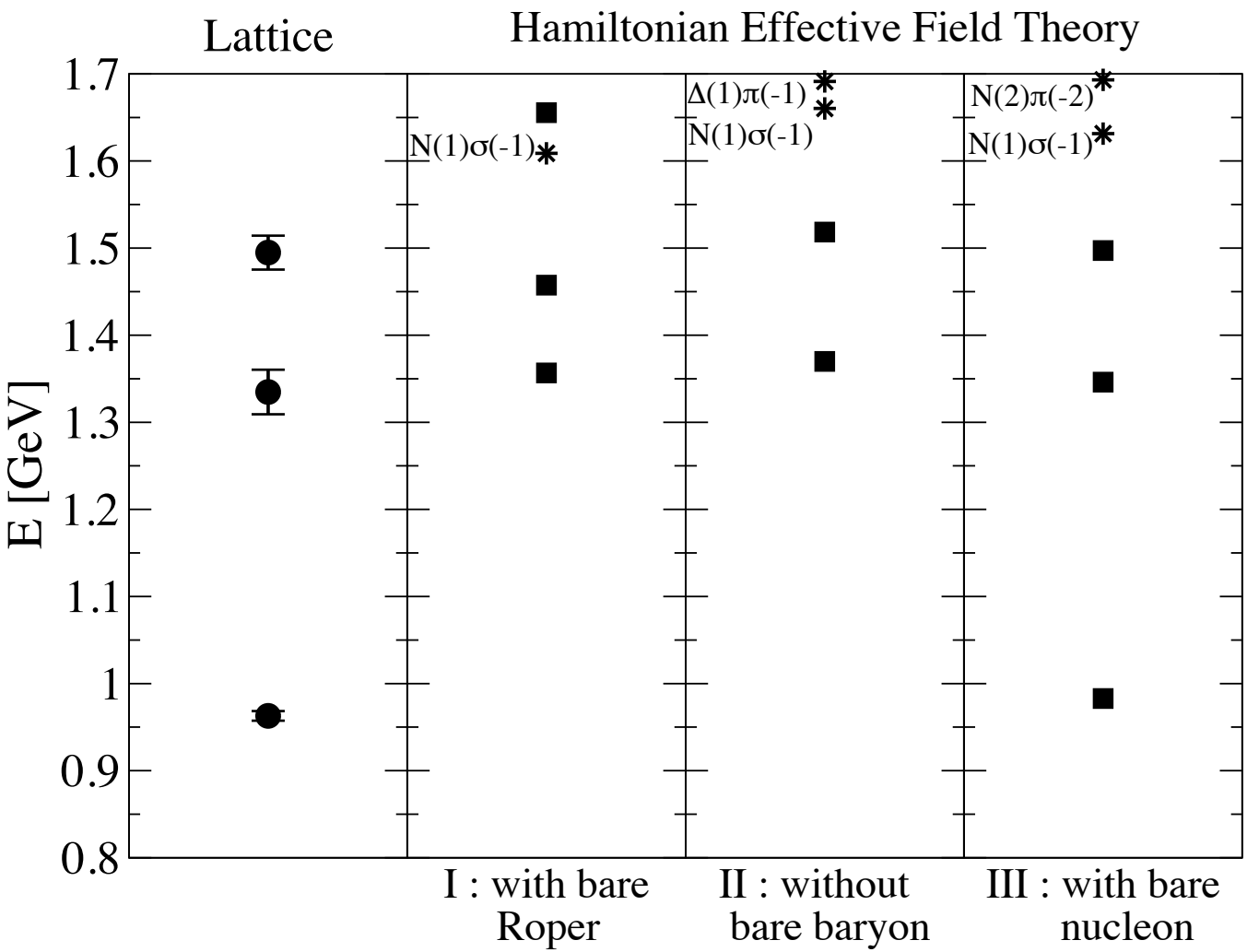


$N\pi$ channel coupled with a Roper like resonance.

Lattice Vs Pion-Nucleon elastic scattering



Lattice Vs HEFT



Scenarios with coupled $N\pi - N\sigma - \Delta\pi$ scattering

Liu *et al.*, arXiv:1607.04536[nucl-th]

Summary and outlook

- We study the excited spectrum of $J = 1/2^+$ and $I = 1/2$ channel below 1.65 GeV.
- Three levels below 1.65 GeV identified as $N(0)$, $N(0)\pi(0)\pi(0)$ and $N(1)\pi(-1)$ based on the energies, the spectral overlaps and other arguments.
- Low lying Roper resonance does not arise on the lattice within $N\pi$ scattering in the elastic limit.
- Lack of additional level, the spectral overlaps and comparative study between our lattice estimates and HEFT predictions points to a possibility of dynamically generated resonance.
- Other possible reasons for the absence of resonance related level
  a) Absence of pentaquark interpolators
  b) Absence non-local qqq like interpolators and hybrid baryons
  c) Fermions with chiral symmetry

Thank you. Backup slides.

Wick contractions

Total no. of Wick contractions to be computed :

$O_i \backslash O_j$	O^N	$O^{N\pi}$	$O^{N\sigma}$
O^N	2	4	7
$O^{N\pi}$	4	19	19
$O^{N\sigma}$	7	19	33

Effective mass plots