Tetra-Neutron Resonance from Chiral Interactions

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Motivation

SFB Project A02

- Inclusion of continuum effects into nuclear structure

Experiment

- Candidate resonance at $(0.83 \pm 1.89_{\text{tot}})$ MeV
  Kisamori *et al.*, PRL **116**, 052501 (2016)
- Experiment by Aumann *et al.* (see Fabia Schindlers talk, project A06)

Theory

- HORSE Method with JISP16 potential
  Shirokov, Papadimitriou, Mazur, Mazur, Roth, Vary, PRL **117**, 182502 (2016)
- Quantum Monte-Carlo with local chiral interactions
  Gandolfi, Hammer, Klos, Lynn, Schwenk PRL **118**, 232501 (2017)
- Gamow-NCSM with two-body chiral interactions
  Fossez, Rotureau, Michel, and Płoszajczak PRL **119**, 032501 (2017)

HORSE

- Harmonic Oscillator Representation of Scattering Equations

$$\tan(\delta_\ell(k)) = -\frac{j_l(ka) - kaR_l j_l'(ka)}{n_l(ka) - kaR_l n_l'(ka)}$$

$$\tan(\delta_\ell(E)) = -\frac{S_{N\ell}(E) - G^\ell_{NN}(E) S_{N+2,\ell}(E)}{C_{N\ell}(E) - G^\ell_{NN}(E) C_{N+2,\ell}(E)}$$

- Single-State HORSE

$$\tan(\delta_\ell(E_\nu)) = -\frac{S_{N+2,\ell}(E_\nu)}{C_{N+2,\ell}(E_\nu)}$$

- Post processing of NCSM calculation

- Systematic study of N_{max} dependency
- For $N_{\text{max}} \to \infty$ results should be exact

HORSE

- Obtaining phase shift curve:
  - Choose model space truncation $N_{\max}$
  - Vary frequency $\hbar\Omega$ (range $\sim$ 1 to 30 $\hbar\Omega$)
  - Extract lowest energy eigenvalue for each $\hbar\Omega$

- Plug into phase shift relation

$$\tan\left(\delta_\ell(E_\nu)\right) = -\frac{S_{N+2,\ell}(E_\nu)}{C_{N+2,\ell}(E_\nu)}$$

- Repeat by systematically increasing $N_{\max}$

Interactions

- JISP16
  - NN forces only
  - Fitted to *n*-*n* and deuteron scattering data

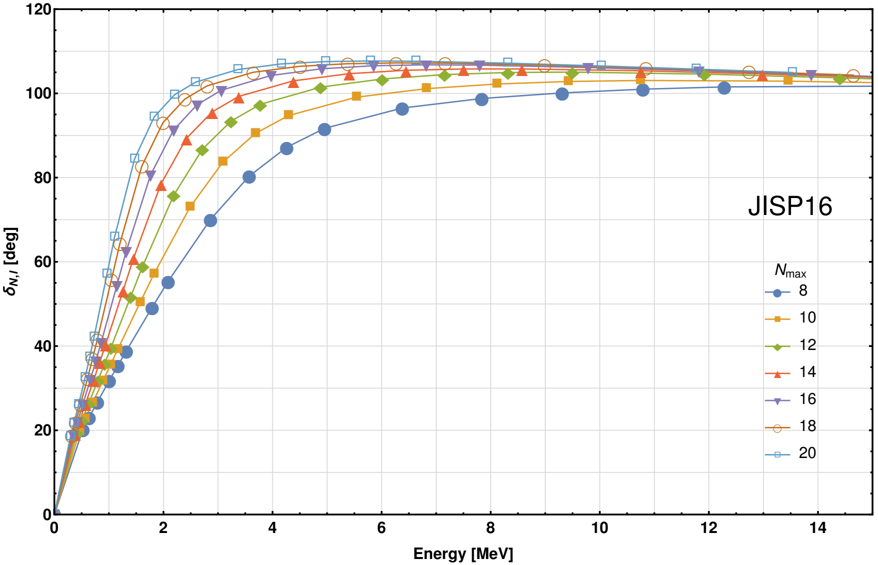
    Shirokov, Vary, Mazur, Weber, PLB **644**, 33 (2007)
- χ2b3b by Entem & Machleidt
  - NN at N3LO
  - 3N at N2LO
  - Cutoff at 500 MeV
  - Fit to Triton binding energy and half-life
  - SRG evolved with $\alpha = 0.08$ fm^4

    NN: Entem and Machleidt, PRC **68** , 41001 (2003)

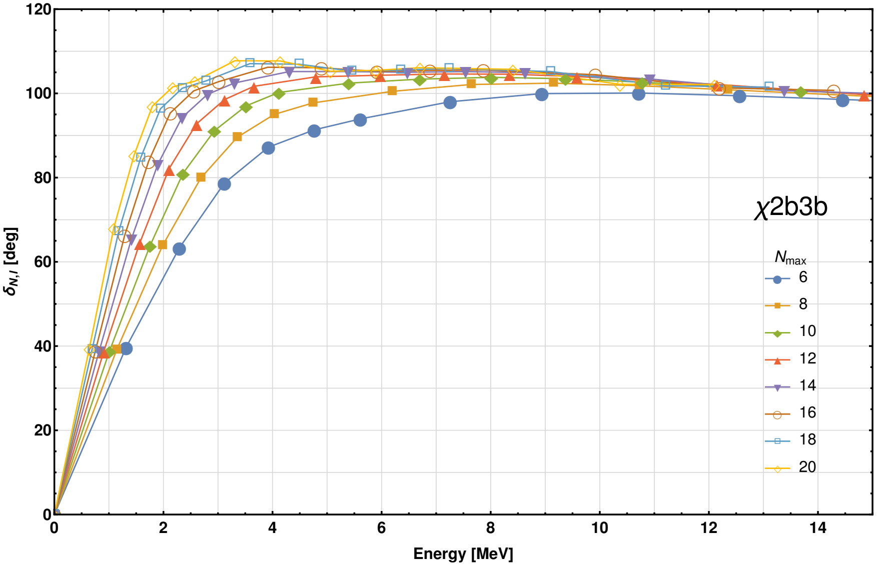
    3N: Navratil, Few-Body Syst. **41**, 117 (2007)
- N2LO SAT by Ekström et al.
  - NN at N2LO
  - 3N at N2LO
  - Fit to few- and many-body data
  - SRG evolved $\alpha = 0.08$ fm^4

    Ekström, Jansen, Wendt, Hagen, Papenbrock, Carlsson, Forssen, Hjorth-Jensen, Navratil, Nazarewicz, PRC **91**, 051301 (2015)

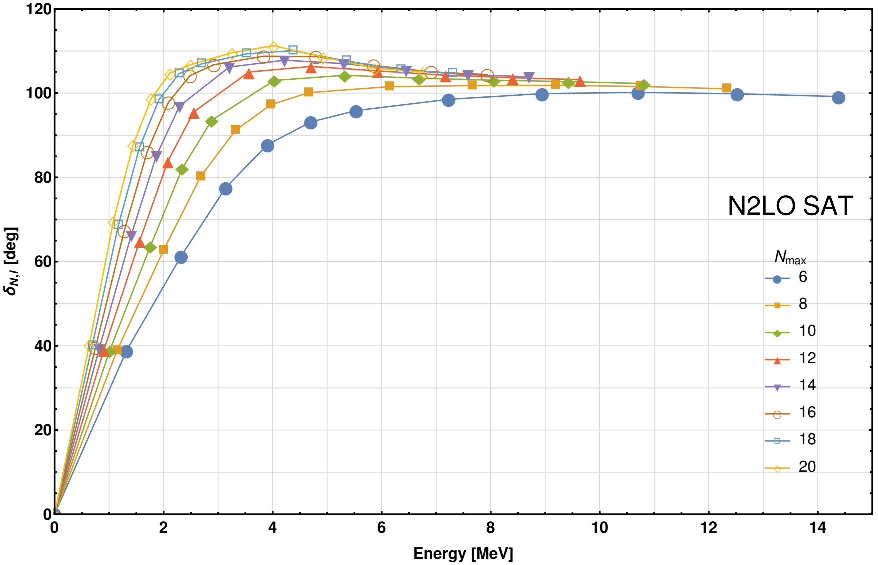
Results - Phase shifts



Results - Phase shifts



Results - Phase shifts



Obtaining resonance parameters

- Parametrize phase shift

$$\delta_\ell(E) = \delta_R(E) + \phi(E)$$

- Resonant part

$$\delta_R(E) = -\tan^{-1}\left(\frac{a\sqrt{E}}{E - b^2}\right)$$

- Resonance energy

$$E_R = b^2 - \frac{a^2}{2}$$

- Resonance width

$$\Gamma = 2a\sqrt{b^2 - \frac{a^2}{4}}$$

Obtaining resonance parameters

- Background
  - Taylor expansion

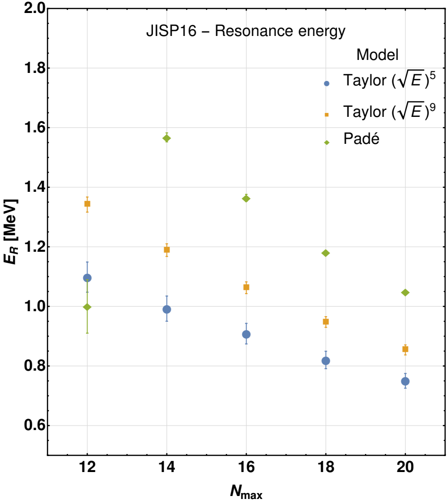
$$\phi_1(E) = c\sqrt{E} + d\sqrt{E}^3 + f\sqrt{E}^5$$

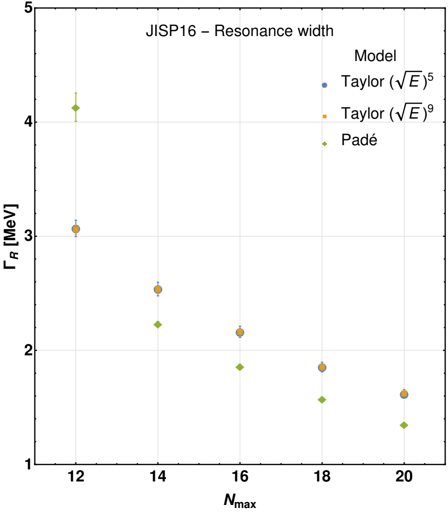
$$\phi_2(E) = c\sqrt{E} + .. + h\sqrt{E}^9$$

  - Padé expansion

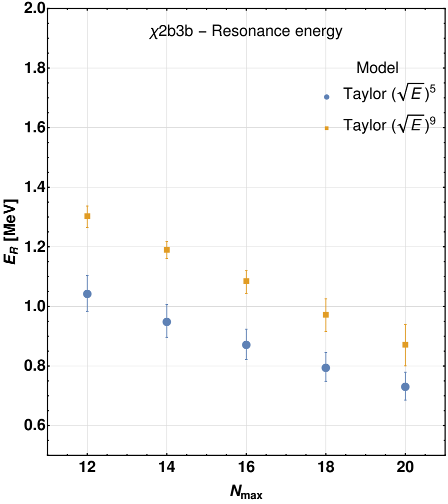
$$\phi_3(E) = \frac{w_1\sqrt{E} + w_3\sqrt{E}^3 + c\sqrt{E}^5}{1 + w_2 E + w_4 E^2 + w_6 E^3 + d E^4}$$

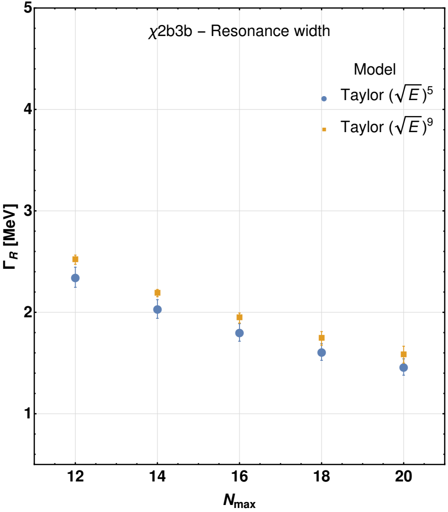
Results - Resonance energy and width



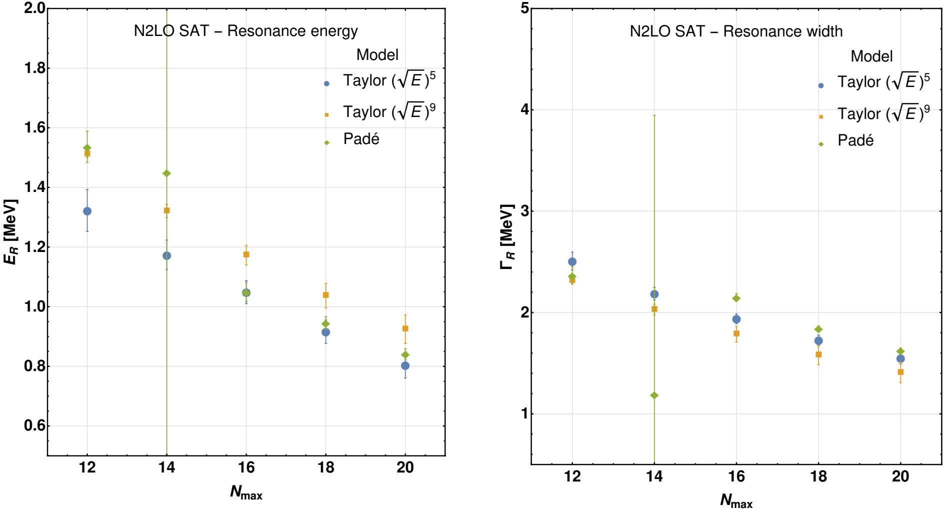


Results - Resonance energy and width





Results - Resonance energy and width



Summary

- HORSE method leads to typical NCSM systematics
- Convergence w.r.t to N_{max} not yet reached
- Model and fitting dependencies
- **Interactions produce consistent results**

Outlook

- Determine cause of instability in χ2b3b phase shifts
- Refine fitting procedure
- Compare to Gamow NCSM (implementation WIP)
- Constrain with experimental results

Epilog

- **Thanks to my group & collaborators**
  - D. Derr, E. Gebrerufael, A. Geißel, T. Hüther, **R. Roth**, S. Schulz, C. Stumpf, A. Tichai, K. Vobig, R. Wirth
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- **Thank you for your attention!**

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