Energy distribution of the 3n system in pionless effective field theory

TECHNISCHE UNIVERSITÄT DARMSTADT

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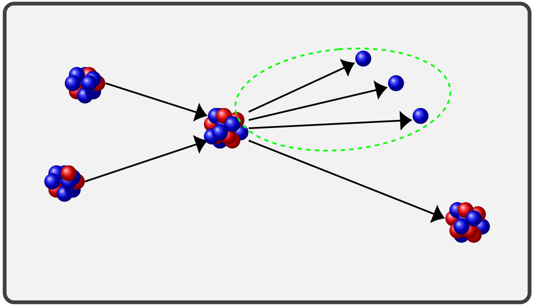
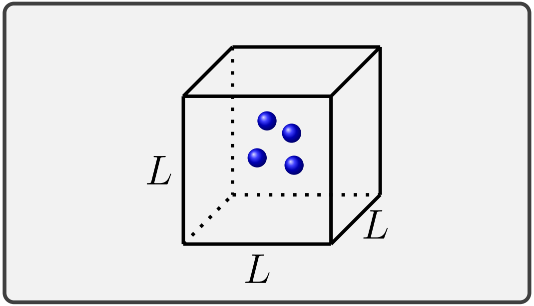
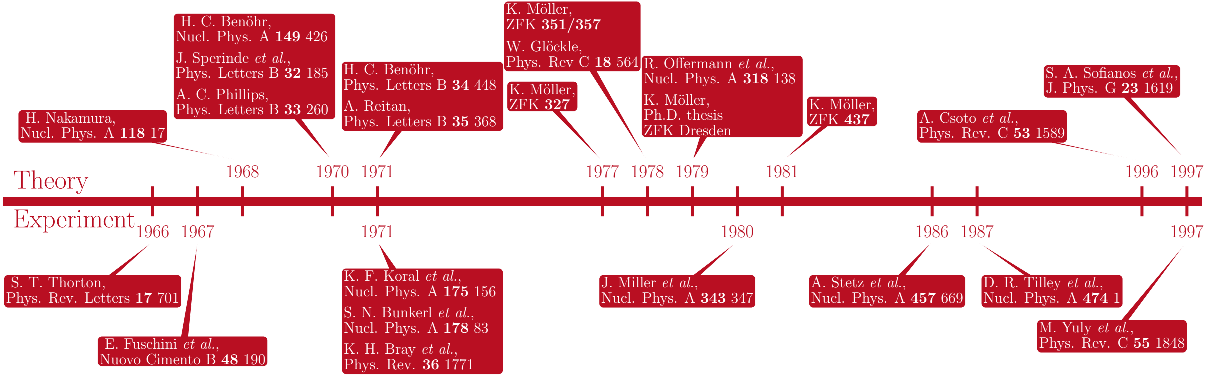
SFB Workshop 2022

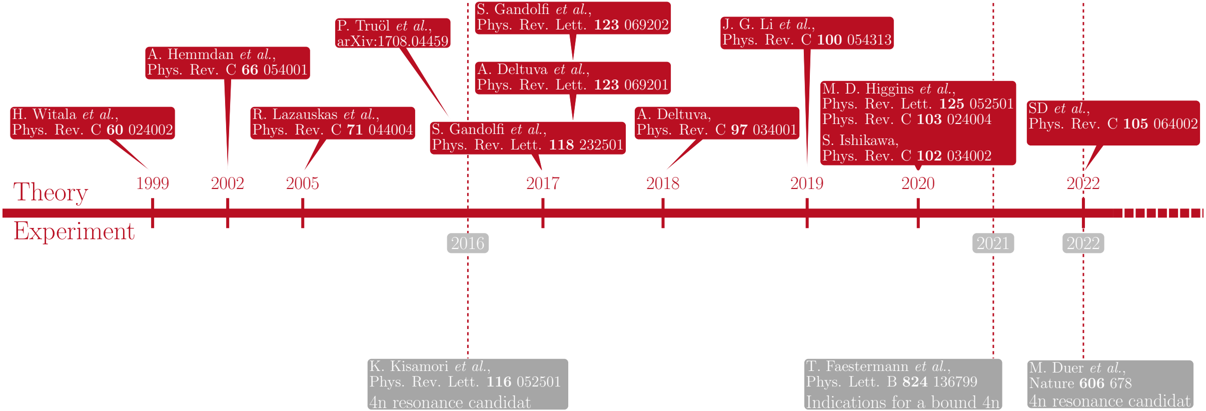




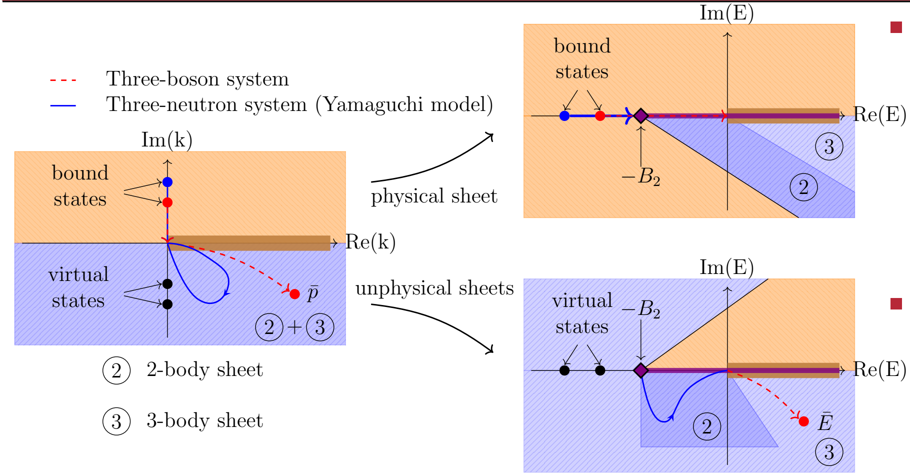
Three neutrons: The history I



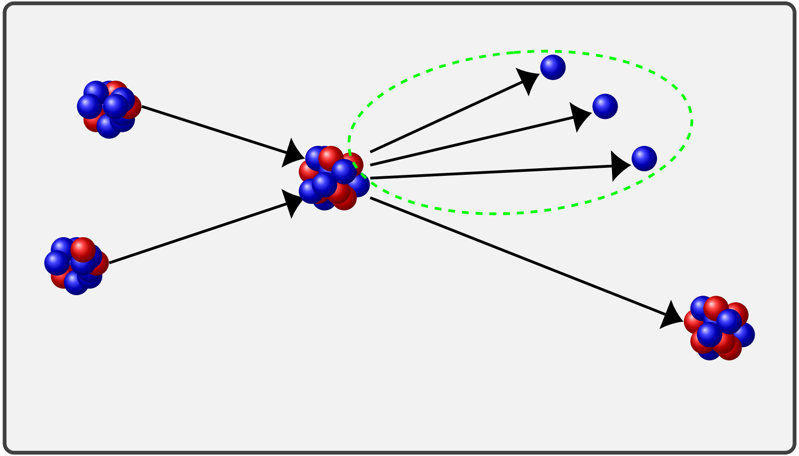
Three neutrons: The history II



Sheet structure

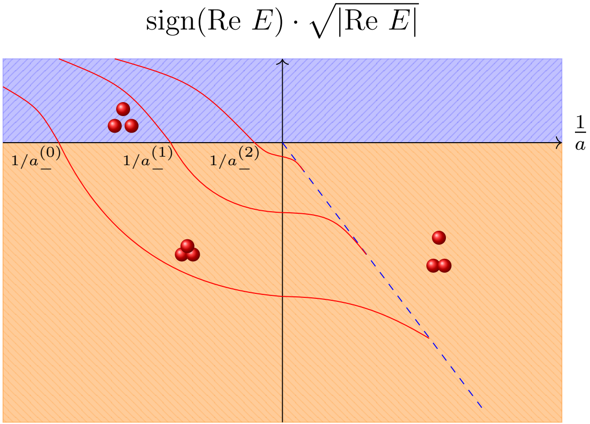


- SD, H.-W. Hammer, S. König, A. Schwenk, PRC **105** 064002 (2002)
  - No evidence for 3n resonance using analytical continuation & finite-volume approach
- Today:
  - Search along positive real momentum/ energy axis
  - Finite volume



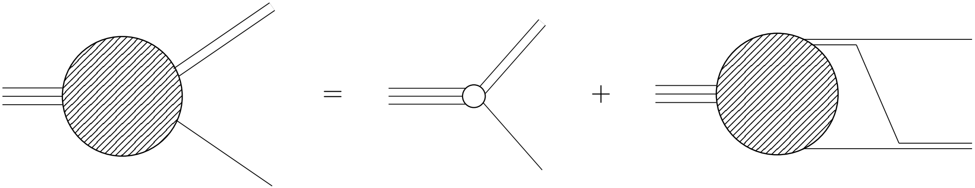
Three bosons
The Efimov effect

- Use 3b system as benchmark
- Presents resonances for virtual 2b system;
  similar to 3n



The three-boson system - Faddeev equation

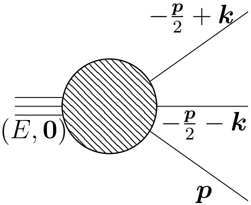
- Starting point: Faddeev equation for amplitude Γ_l
- Set three-body force D_0 to zero and vary cutoff Λ
- Arbitrary coupling g_3; has to be fitted to (experimental) data



$$i\Gamma_l(E;p) = ig_{3,l}p^l + \int_0^\infty \mathrm{d}q\, q^2 Z_{2,l}(E;q,p)\tau\,(E;q)\, i\Gamma_l(E;q)$$

The 3b system - Symmetrization

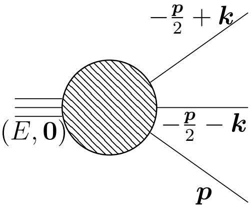
- Interested in 3b final state; not 2b + b



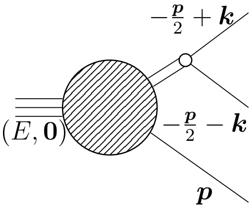
$$i\bar{\Gamma}_l\left(E;\boldsymbol{p},-\frac{\boldsymbol{p}}{2}+\boldsymbol{k}\right)$$

The 3b system - Symmetrization

- Interested in 3b final state; not 2b + b
- Symmetrization due to bosonic nature



$$= \left(1 + P_{13}P_{23} + P_{23}P_{13}\right)$$

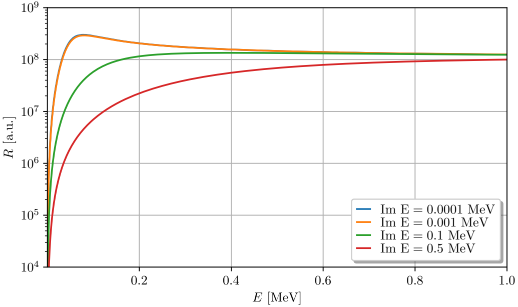


$$i\bar{\Gamma}_l\left(E; \boldsymbol{p}, -\frac{\boldsymbol{p}}{2} + \boldsymbol{k}\right)$$

The 3b system - Production amplitude

- Experimentally measurable: Production amplitude $R(E)$

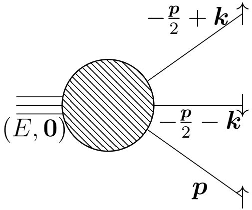
$$R(E) = \int \frac{d^3k}{(2\pi)^3} \int \frac{d^3p}{(2\pi)^3} \left| \bar{\Gamma} \left(E, \boldsymbol{p}, -\frac{\boldsymbol{p}}{2} + \boldsymbol{k} \right) \right|^2 2\pi\delta \left[E - E_{\boldsymbol{p}} - E_{-\frac{\boldsymbol{p}}{2}+\boldsymbol{k}} - E_{-\frac{\boldsymbol{p}}{2}-\boldsymbol{k}} \right]$$



$\longrightarrow$ See influence of resonance!

The 3n system - Antisymmetrization

- Antisymmetrization due to fermionic nature



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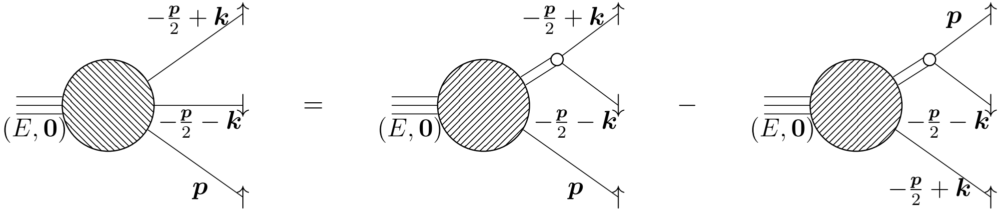

$$i\bar{\Gamma}_l\left(E;\boldsymbol{p},-\frac{\boldsymbol{p}}{2}+\boldsymbol{k}\right)$$

The 3n system - Conformal scaling

- Nonrelativistic conformal symmetry: H.-W. Hammer and D. T. Son, Proc. Natl. Acad. Sci. **118**, e2108716118 (2021)
  $\longrightarrow$ Spectrum is determined (up to overall normalization) by scaling dimension Δ for energies

$$\frac{1}{ma^2} \approx 0.1\ \mathrm{MeV} \ll E \ll \frac{1}{mr_0^2} \approx 5\ \mathrm{MeV}$$

N	S	L	Δ
3	0.5	0	4.66622
3	0.5	1	4.27272
3	0.5	2	5.60498

Y. Nishida and D. T. Son, Phys. Rev. D **76**, 086004 (2007)
H. W. Grießhammer, Nucl. Phys. A **760** (2005)

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- Cross section/ amplitude scale as

$$\frac{\mathrm{d}\sigma}{\mathrm{d}E} \sim E^{\Delta-\frac{5}{2}}\,, \qquad |\Gamma_l(E,\boldsymbol{p})|^2 \sim E^{\Delta-\frac{7}{2}}\,, \qquad R \sim E^{\Delta-\frac{5}{2}}$$

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- Noninteracting particles

$$\frac{\mathrm{d}\sigma}{\mathrm{d}E} \sim E^{\frac{3N-5}{2}+\#\nabla}\,, \qquad |\Gamma_l(E,\boldsymbol{p})|^2 \sim E^{\frac{3N-7}{2}+\#\nabla}\,, \qquad R \sim E^{\frac{3N-5}{2}+\#\nabla}$$

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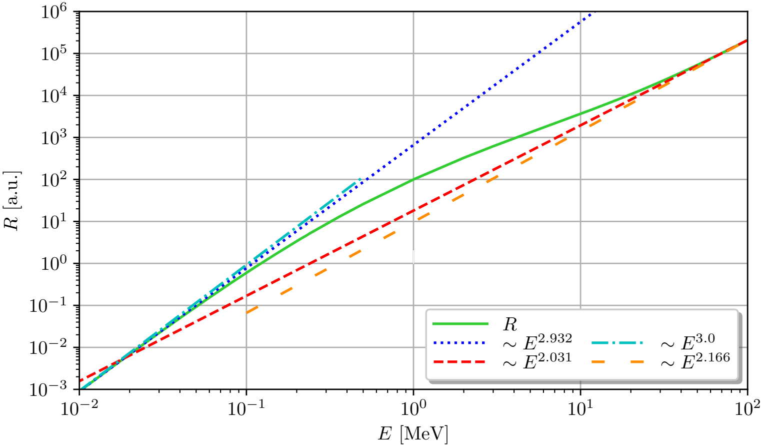
The 3n system - Results

- S-wave

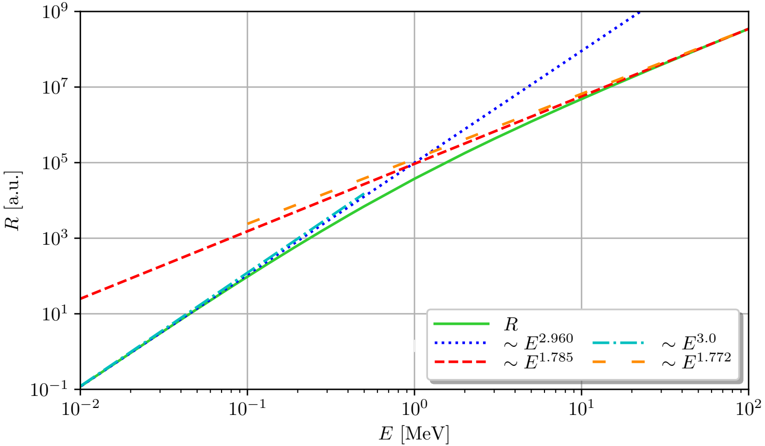
$$R(E) \sim \left|\bar{\Gamma}_0\right|^2$$



The 3n system - Results

- P-wave

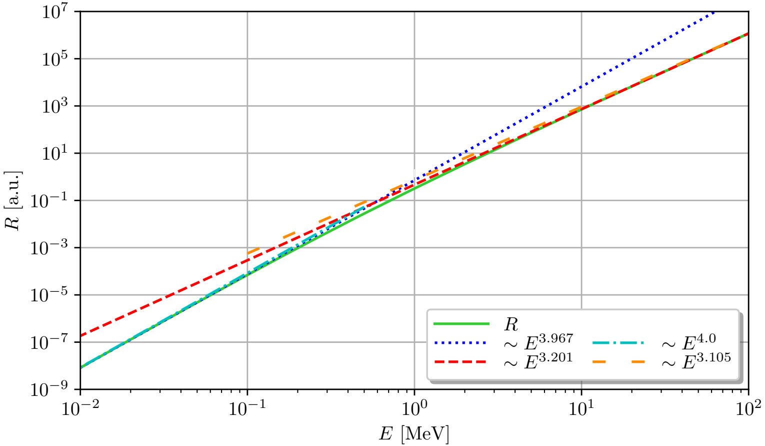
$$R(E) \sim \left|\bar{\Gamma}_1\right|^2$$



The 3n system - Results

- D-wave

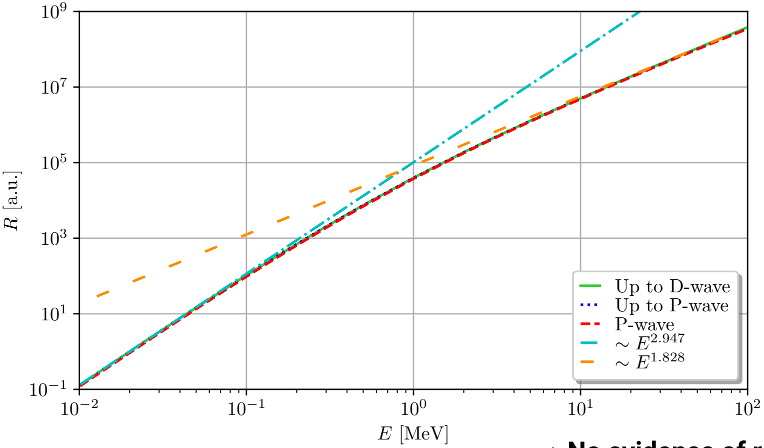
$$R(E) \sim \left|\bar{\Gamma}_2\right|^2$$



The 3n system - Results

- Up to D-wave

$$R(E) \sim \left| \sum_{l=0}^{2} \bar{\Gamma}_l \right|^2$$



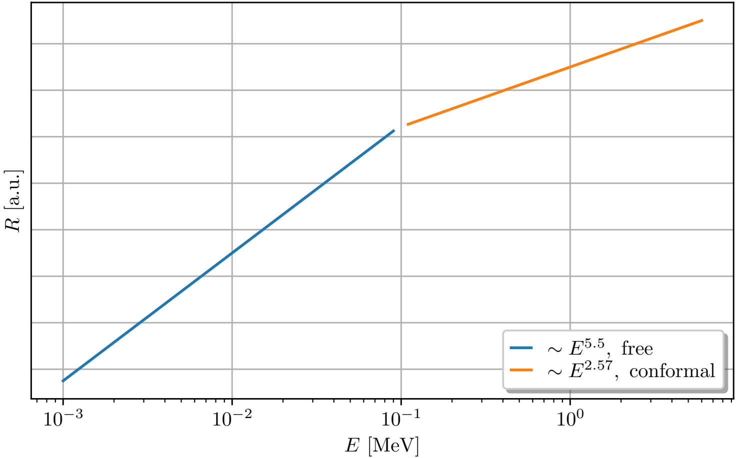
$\longrightarrow$ **No evidence of resonance!**

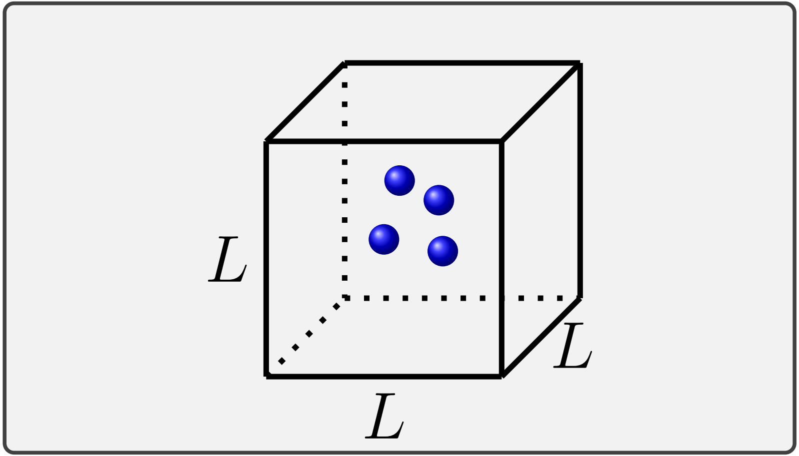
The four-neutron system

Predictions by nonrelativistic conformal field theory (NR-CFT)

- 4n: Predictions for point production amplitude by nonrelativistic conformal field theory

- No peak structure
  $\longrightarrow$ **No evidence of resonance**

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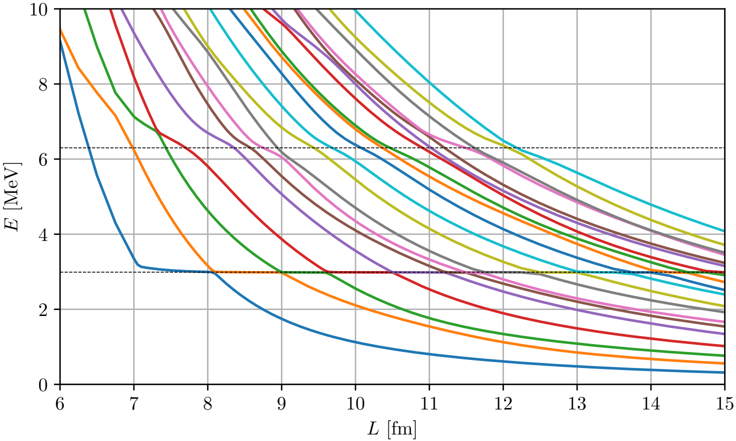
Finite volume
Avoided Level Crossing

- Resonance in finite volume: Avoided level crossing
- S-wave Gaussian toy potential with resonances at:
  - $E = (2.9826 - 0.0007i)$ MeV
  - $E = (6.3287 - 0.3252i)$ MeV

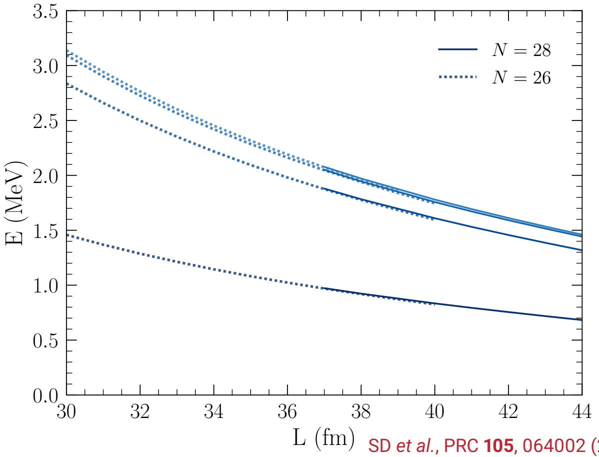


Finite volume

Three-neutron system

- LO pionless EFT potential for $a_{\mathrm{nn}} = -18.9$ fm
- nn interaction in $^1S_0$-channel
- Third neutron in relative P-wave
- Apply discrete variable representation (DVR)
- N: Mesh points for DVR basis
- Super-Gaussian regulator $\sim \exp\left(-k^4/\Lambda^4\right)$

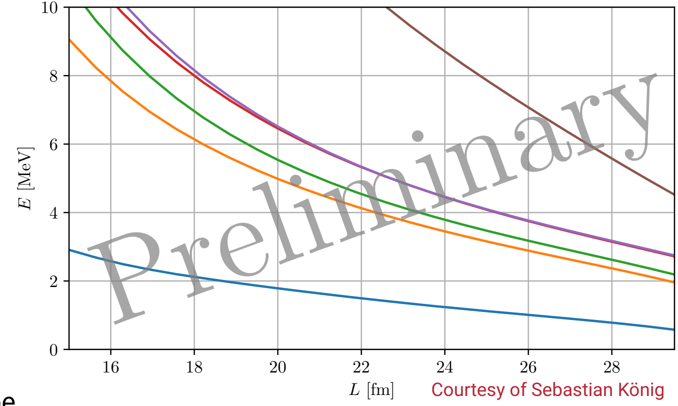
- **No sign of three-neutron resonance**



SD *et al.*, PRC **105**, 064002 (2022)

Finite volume
Four-neutron system

- LO pionless EFT potential for $a_{\text{nn}} = -18.9$ fm
- nn interaction in ${}^1S_0$-channel
- $S = 0$
- $A_1^+ \to L = 0, 4$
- $N = 10$
- Super-Gaussian regulator $\sim \exp\left(-k^4/\Lambda^4\right)$
- DVR + Finite volume eigenvector continuation (FVEC)
  Yapa, König, PRC **106**, 014309 (2022)
- Numerical convergence needs to be analyzed in more detail



Courtesy of Sebastian König

- **No sign of four-neutron resonance**

Summary & Outlook

- Summary:
  - Point production
    - Derived point production amplitude *R* for 3b/3n system
    - 3b: Showed influence of resonance on *R*
    - Presented NR-CFT & predictions for spectrum
    - 3n: Compared to predictions by NR-CFT & showed that no resonance exists
    - 4n: Resonance unlikely by NR-CFT
  - Finite volume
    - Discussed resonances in FV
    - 3n: Presented spectrum calculated using DVR & showed that no resonance exists
    - 4n: Presented spectrum calculated using DVR + FVEC & showed that no structure of resonance is present
- Outlook:
  - Point production
    - Calculate *R* using Faddeev-Yakubovsky equations $\longrightarrow$ 4n
  - Finite volume
    - Calculate spectrum for Gaussian regulator $\sim \exp\left(-k^2/\Lambda^2\right)$
    - Check convergence for higher *N*

Thank you for your attention!