Few-body resonances from finite-volume calculations

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in collaboration with P. Klos, J. Lynn, H.-W. Hammer, and A. Schwenk

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work in progress

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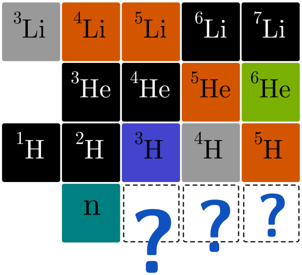
TECHNISCHE UNIVERSITÄT DARMSTADT

Few-neutron systems

terra incognita
at the doorstep. . .



- bound dineutron state not excluded by pionless EFT
  Hammer + SK, PLB **736** 208 (2014)
- recent indications for a three-neutron resonance state. . .
  Gandolfi *et al.*, PRL **118** 232501 (2017)
- . . . although excluded by previous theoretical work
  Offermann + Glöckle, NPA **318**, 138 (1979); Lazauskas + Carbonell, PRC **71** 044004 (2005)
- **possible evidence for tetraneutron resonance**
  Kisamori *et al.*, PRL **116** 052501 (2016)

Finite-volume resonance signatures

Lüscher formalism: phase shift ↔ box energy levels

$$p\cot\delta_0(p) = \frac{1}{\pi L} S(\eta) \quad , \quad \eta = \left(\frac{Lp}{2\pi}\right)^2 \quad , \quad p = p(E(L))$$

Lüscher, Nucl. Phys. B **354** 531 (1991); ...

resonance contribution ⇝ **avoided level crossing**

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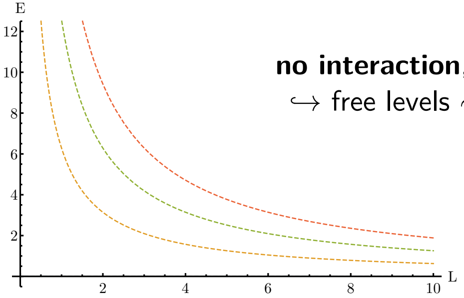

no interaction, $\delta(p) = 0$

$\hookrightarrow$ free levels $\sim 1/L$

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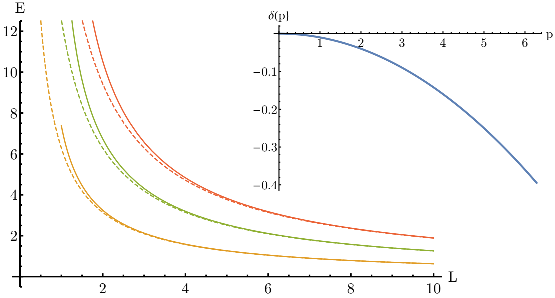

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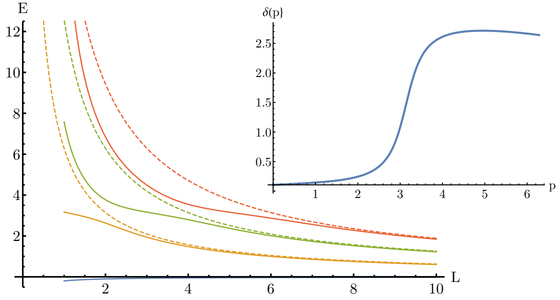

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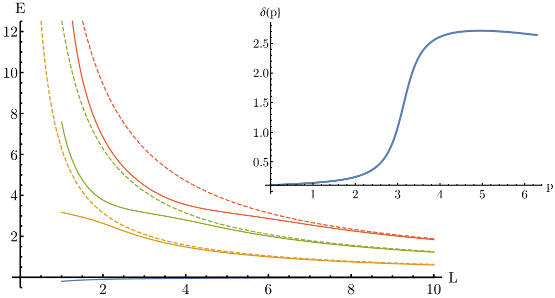


Effect can be very subtle in practice...

Bernard *et al.*, JHEP **0808** 024 (2008); Döring *et al.*, EPJA **47** 139 (2011); ...

Discrete variable representation

Needed: calculation of several few-body energy levels

- difficult to achieve with GFMC/AFDMC methods Klos *et al.*, PRC **94** 054005 (2016)
- simple direct discretization possible, but not very efficient

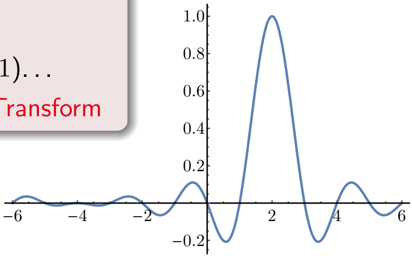
$\hookrightarrow$ **use a Discrete Variable Representation (DVR)**

well established in quantum chemistry, suggested for nuclear physics by Bulgac+Forbes, PRC **87** 87, 051301 (2013)

Main features

- basis functions localized at grid points
- potential energy matrix diagonal
- kinetic energy matrix sparse (in $d > 1$)...
- ...or implemented via Fast Fourier Transform

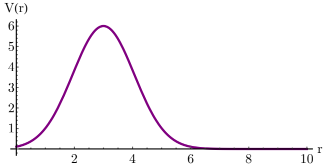
periodic boundary conditions
$\leftrightarrow$ **plane waves as starting point**

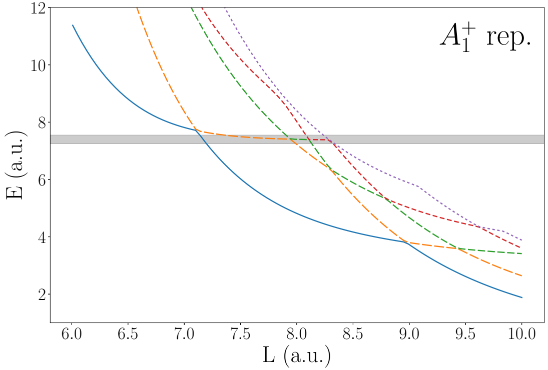


Three-body resonance example

three-boson system

- shifted Gaussian 2-body potential





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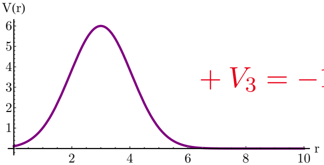
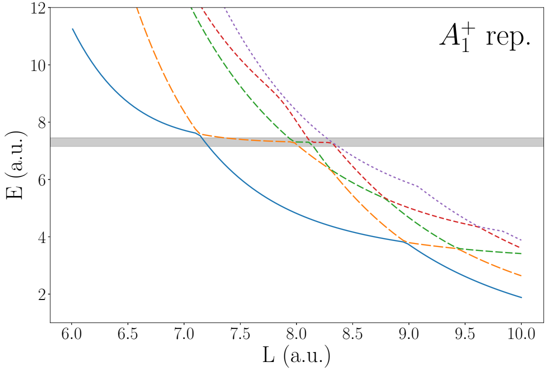


$+V_3 = -1.0$



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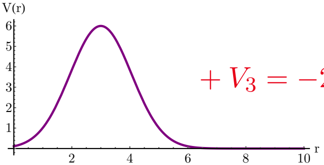

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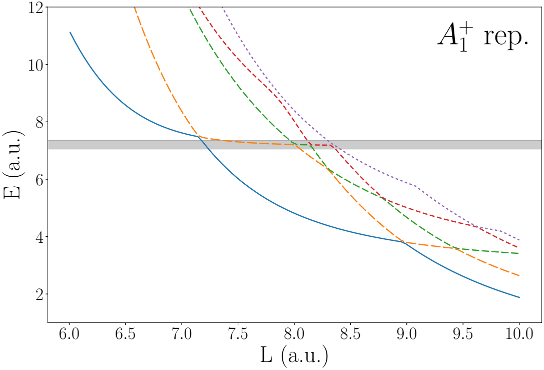

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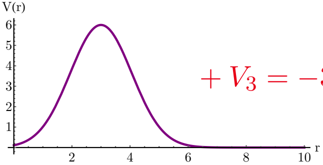
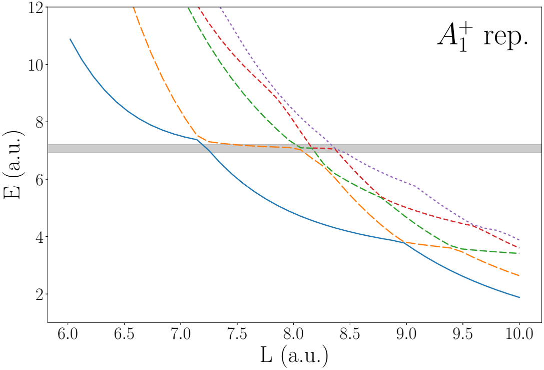


$+V_3 = -3.0$



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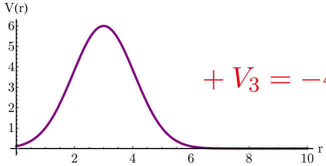
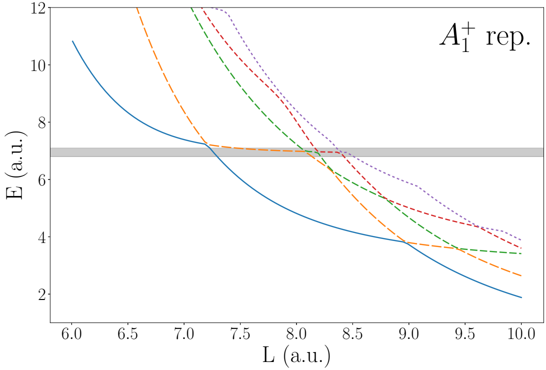


$+V_3 = -4.0$



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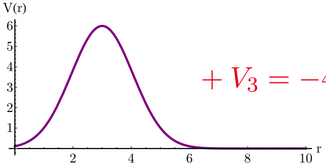

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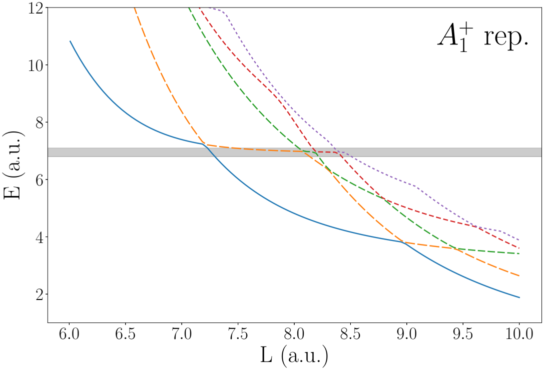
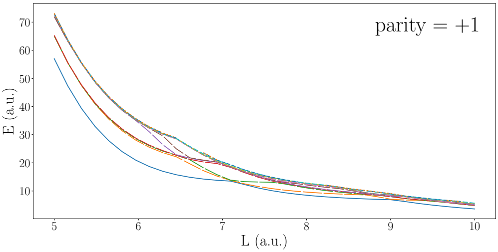
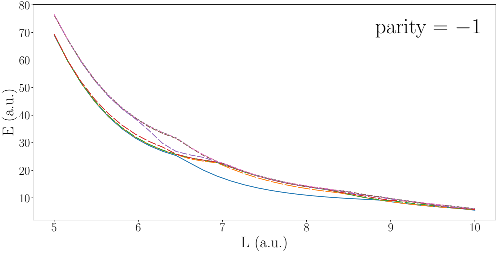


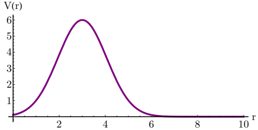
$\hookrightarrow$ **possible to move three-body resonance**

Four-body spectra (very preliminary)





four bosons



crossings need not be avoided!

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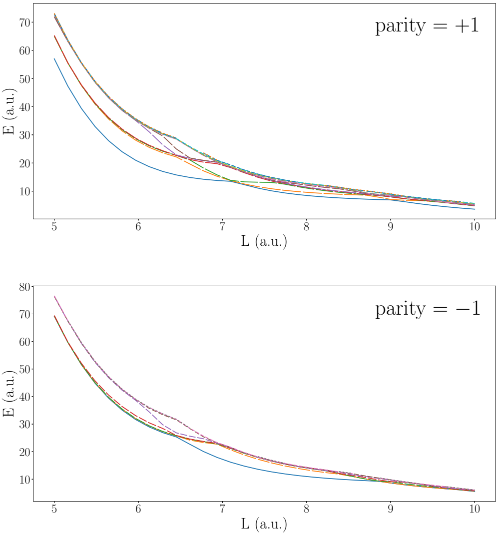

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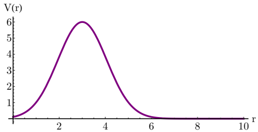

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— Thank you —