Generalized seniority: ground state and configuration mixing

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Outline

- Prof. Arima's works influence my works
- ground state: new algorithm for VAPNP+BCS
- configuration mixing $\begin{cases} \text{semi-magic nuclei} \\ \text{deformed nuclei} \end{cases}$

- My undergraduate project under Prof. Yu-Min Zhao: nucleon pair approximation

- IBM S,D bosons $\rightarrow$ S,D pairs of fermions

A. Arima, and F. Iachello, Phys. Rev. Lett. 35, 1069 (1975).

L. Y. Jia, H. Zhang, and Y. M. Zhao, Phys. Rev. C 75, 034307 (2007).

L. Y. Jia, H. Zhang, and Y. M. Zhao, Phys. Rev. C 76, 054305 (2007).

- My PhD project under Prof. Vladimir Zelevinsky: microscopic derivation of bosonic Hamiltonian by generalized density matrix method

- microscopic foundation of IBM $\rightarrow$ different ways of mapping

T. Otsuka, A. Arima, and F. Iachello, Nucl. Phys. A 309, 1 (1978).

L. Y. Jia, and V. G. Zelevinsky, Phys. Rev. C 84, 064311 (2011).

- seniority in a single j:

  $$P_j^\dagger = \sum_m a_{jm}^\dagger a_{j\tilde{m}}^\dagger$$

  G. Racah, Phys. Rev. 63, 367 (1943).

- seniority in several degenerate j:

  $$P^\dagger = \sum_j P_j^\dagger$$

  A. K. Kerman, Ann. Phys. 12, 300 (1961).

  A. Arima, and H. Kawarada, J. Phys. Soc. Japan 19, 1768 (1964).

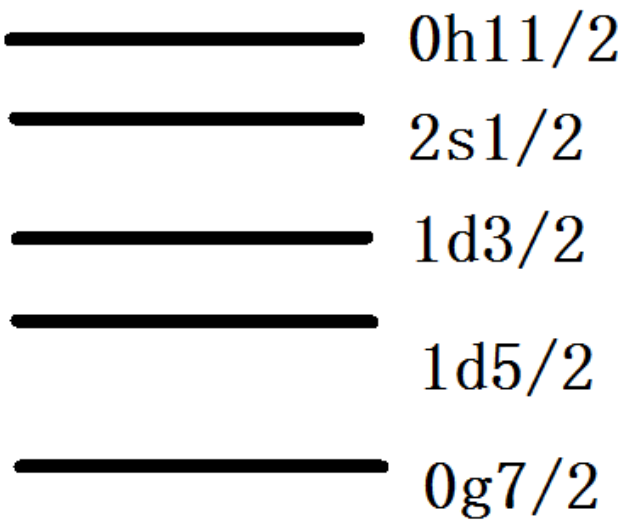
  A. Arima, and M. Ichimura, Progress of Theoretical Physics, 36, 296 (1966).

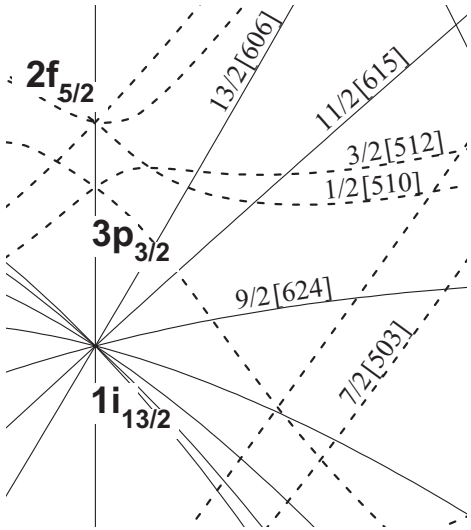
- generalized seniority:

  $$P^\dagger = \sum_j v_j P_j^\dagger$$

  I. Talmi, Nucl. Phys. A 172, 1 (1971).

Ground State





pairing gap: $\sim$ 2MeV

$\sim$ 1.5MeV

$$|\phi_N\rangle = (P^\dagger)^N|0\rangle$$

$$P^\dagger = \sum_\alpha v_\alpha P^\dagger_\alpha = \sum_\alpha v_\alpha a^\dagger_\alpha a^\dagger_{\tilde{\alpha}}$$

variation principle

New Algorithm: VAPNP + BCS

$$v_\alpha \quad \Rightarrow \quad \chi, \chi^{[\alpha]}, \chi^{[\alpha\beta]} \quad \text{(fast recursive formula)}$$

$$\Rightarrow \quad \text{average energy } \bar{E} \quad \Rightarrow \quad \text{gradient } \frac{\partial \bar{E}}{\partial v_\alpha} = 0$$

$$v_\alpha = \frac{\langle \phi_N^{[\alpha]} | H | \phi_N^{[\alpha]} \rangle - \bar{E}}{-N^2 (\sum_{\beta \neq \alpha} G_{\alpha\beta} v_\beta \chi_{N-1}^{[\alpha\beta]}) / \chi_N^{[\alpha]}} \quad \text{(new algorithm, no } \int \mathrm{d}\theta\text{)}$$

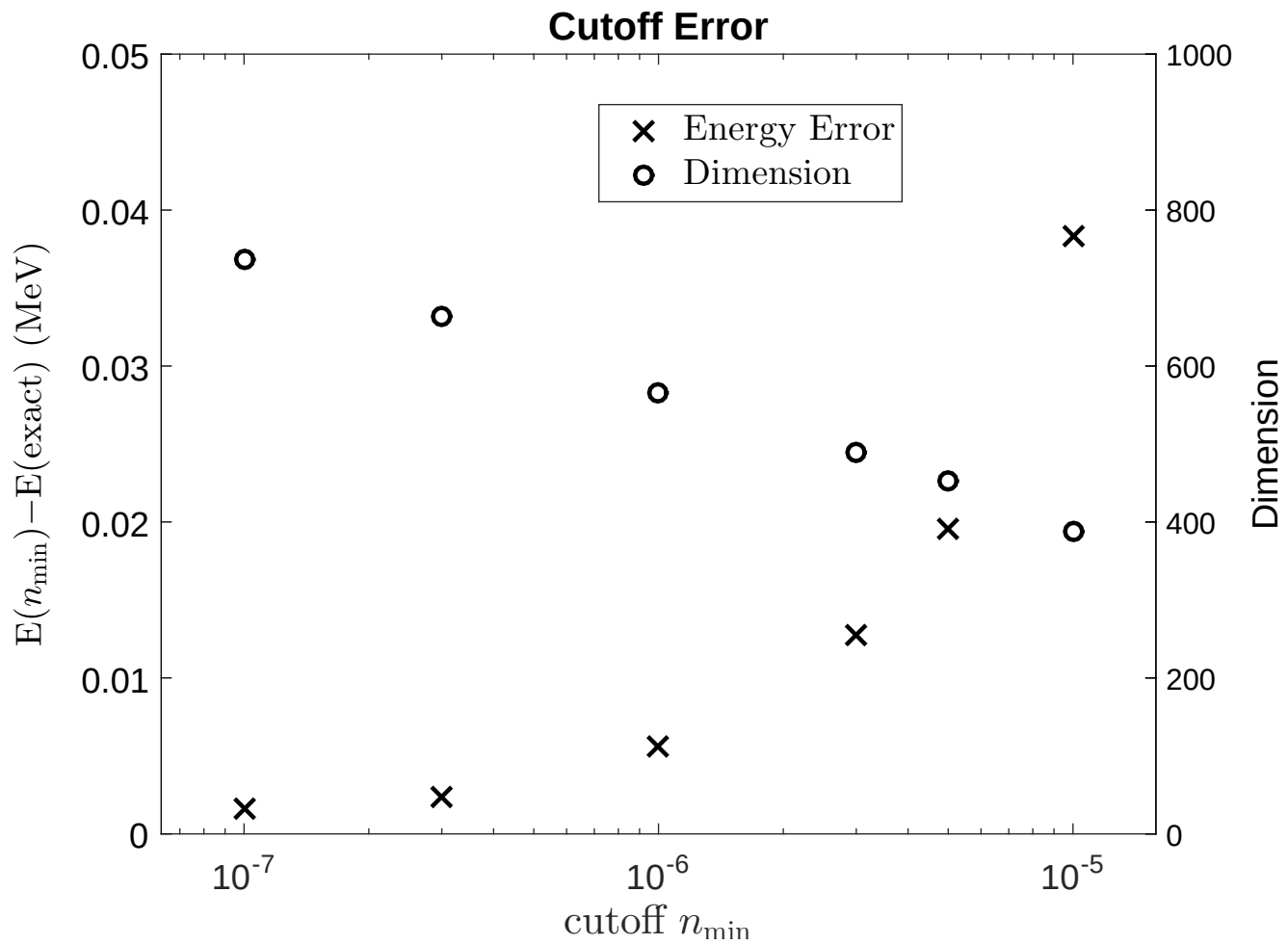
$\chi_N = \langle \phi_N | \phi_N \rangle$ is normalization.

$\chi^{[\alpha]}, \chi^{[\alpha\beta]}$ means Pauli-blocking.

$G_{\alpha\beta} \equiv V_{\alpha\tilde{\alpha}\tilde{\beta}\beta}$ is pairing matrix elements.

L. Y. Jia, arXiv:1808.03729 (2018).

$V_{\mathrm{low}-k}$ not diverge in pairing channel (Nilsson + VAPNP + BCS)

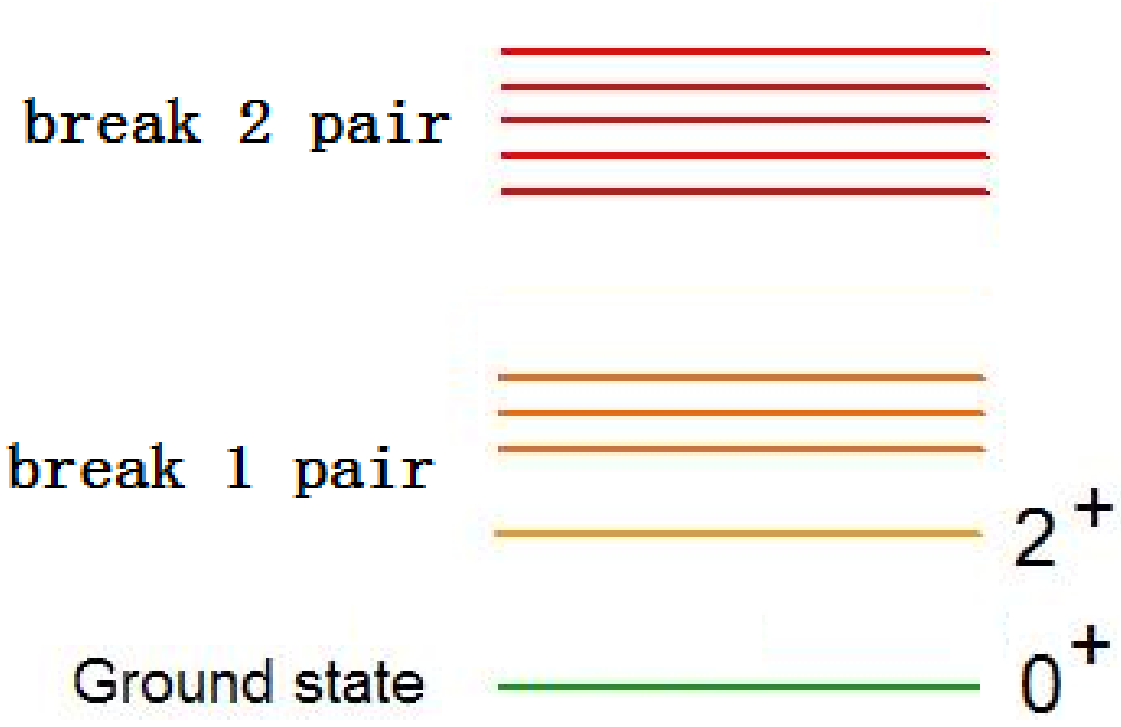


time $\sim$ 30 seconds: 15 oscillator shells, serial computing (single core) on laptop, converges to 3 keV error.

now working on ...

- VAPNP+HFB: gradient with respect to canonical basis change
- two different collective pairs: neutron-rich halo nuclei

Excited States

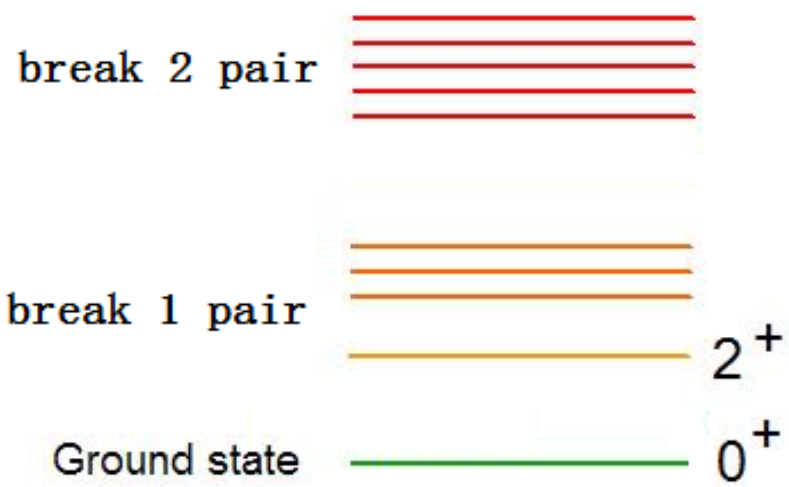


$a^\dagger a^\dagger a^\dagger a^\dagger (P^\dagger)^{N-2}|0\rangle$

$a^\dagger a^\dagger (P^\dagger)^{N-1}|0\rangle$

$(P^\dagger)^N|0\rangle$

Generalized Seniority Mixing



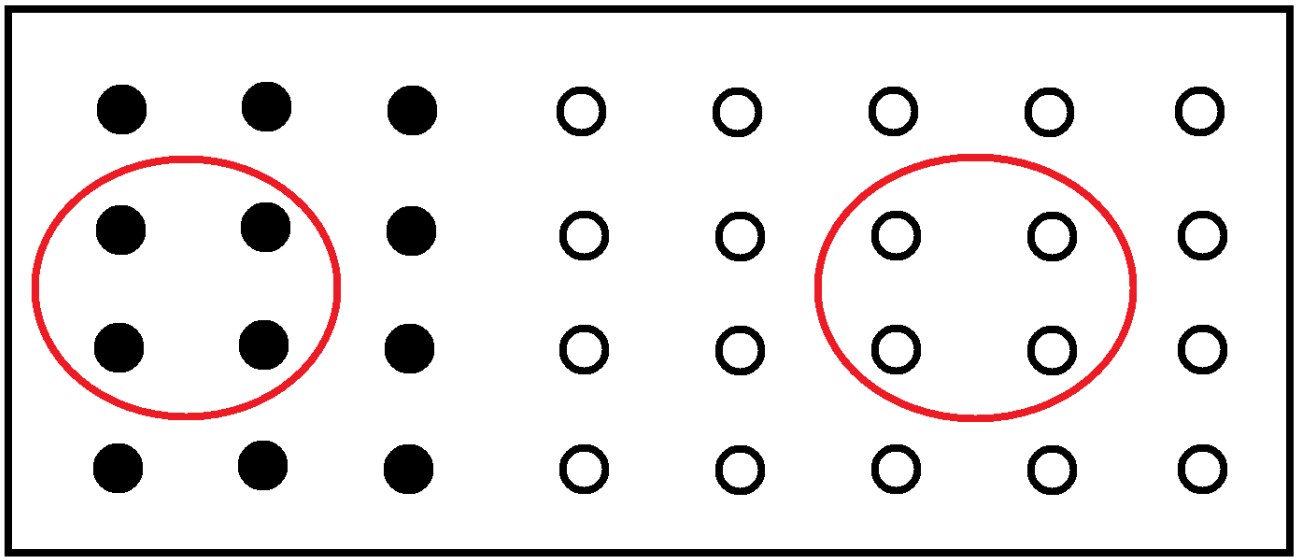
$$\underbrace{a^\dagger a^\dagger \ldots a^\dagger}_{S=2s}(P^\dagger)^{N-s}|0\rangle$$

$s \to N$, shell model

L. Y. Jia, J. Phys. G: Nucl. Part. Phys. 42, 115105 (2015).

Particle-Hole Symmetry

$$^{112}_{50}Sn_{62}$$

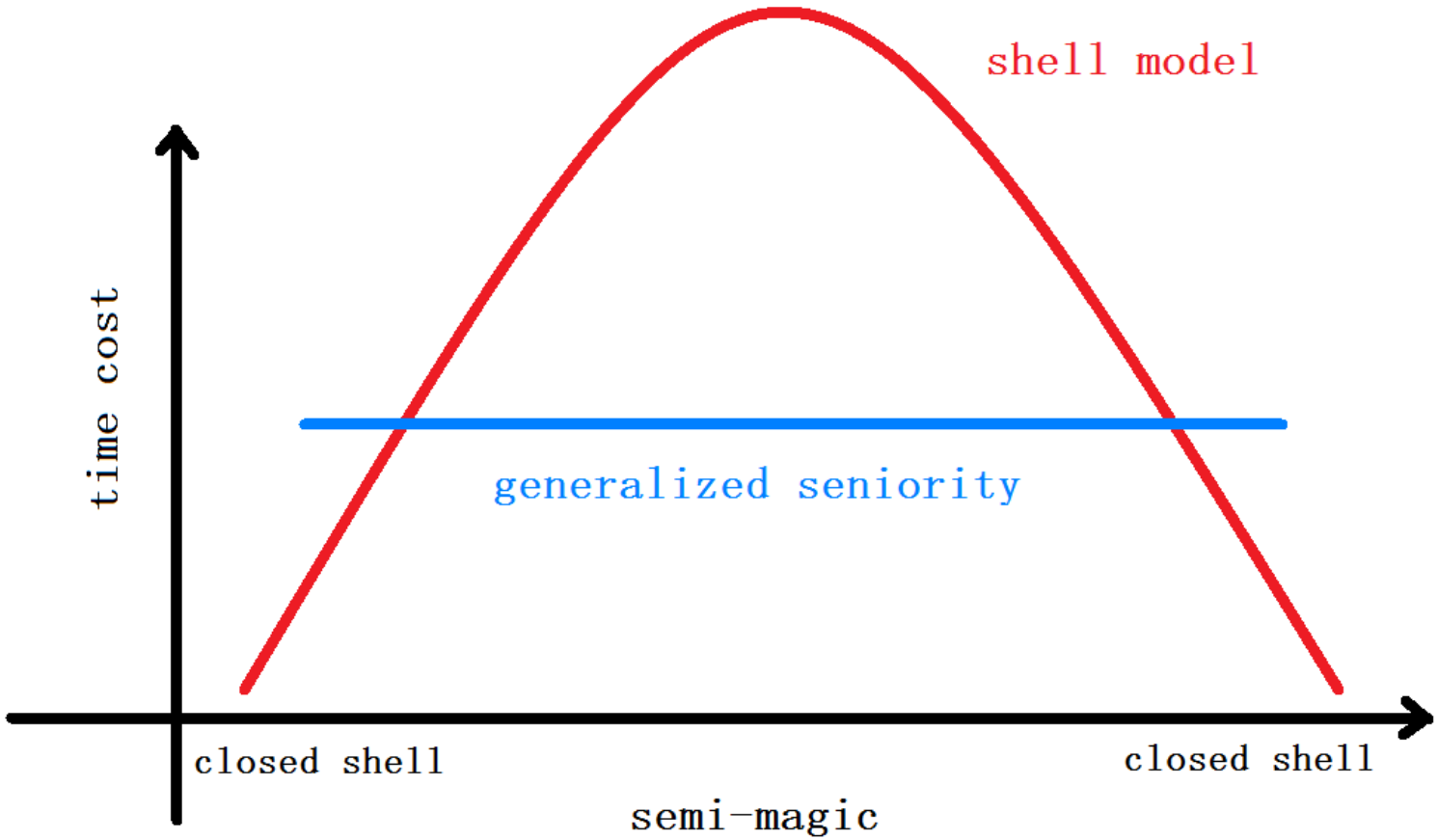


$$\underbrace{a^\dagger a^\dagger \ldots a^\dagger}_{S=2s}(P^\dagger)^{N-s}|0\rangle$$

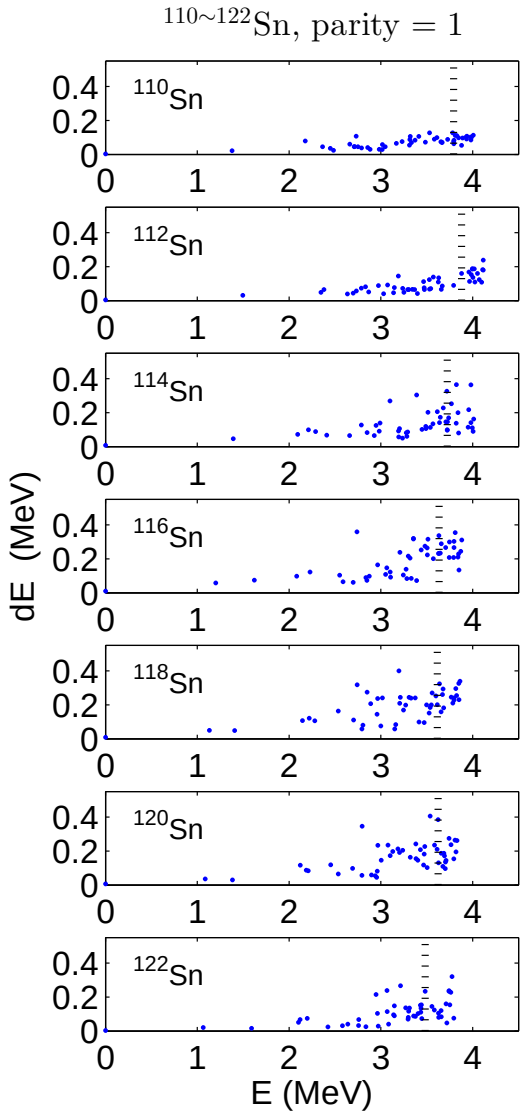
L. Y. Jia, Phys. Rev. C 93, 064307 (2016).

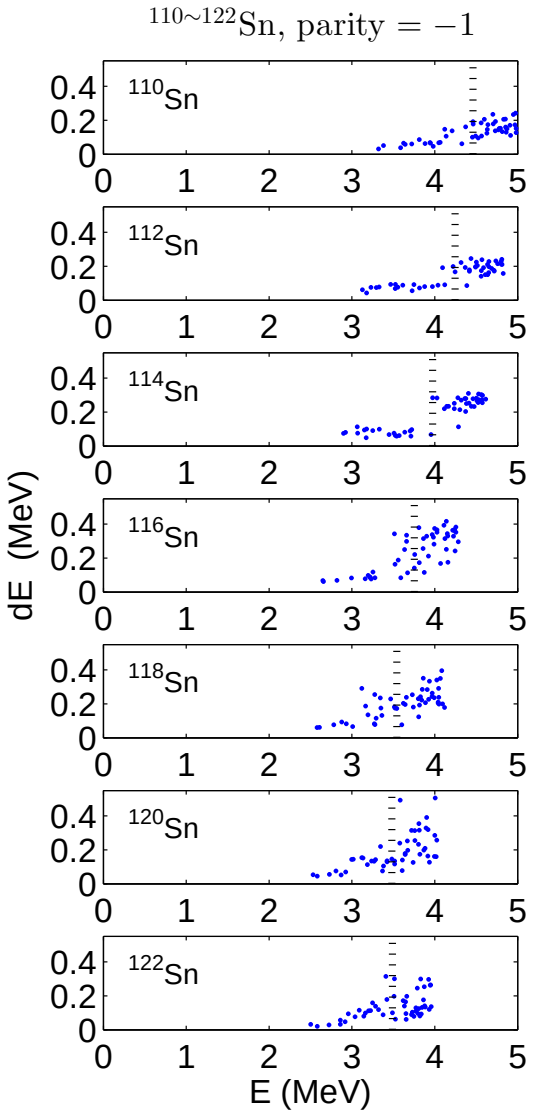
Semi-magic Nuclei

Speed


shell model
generalized seniority
time cost
closed shell
closed shell
semi-magic

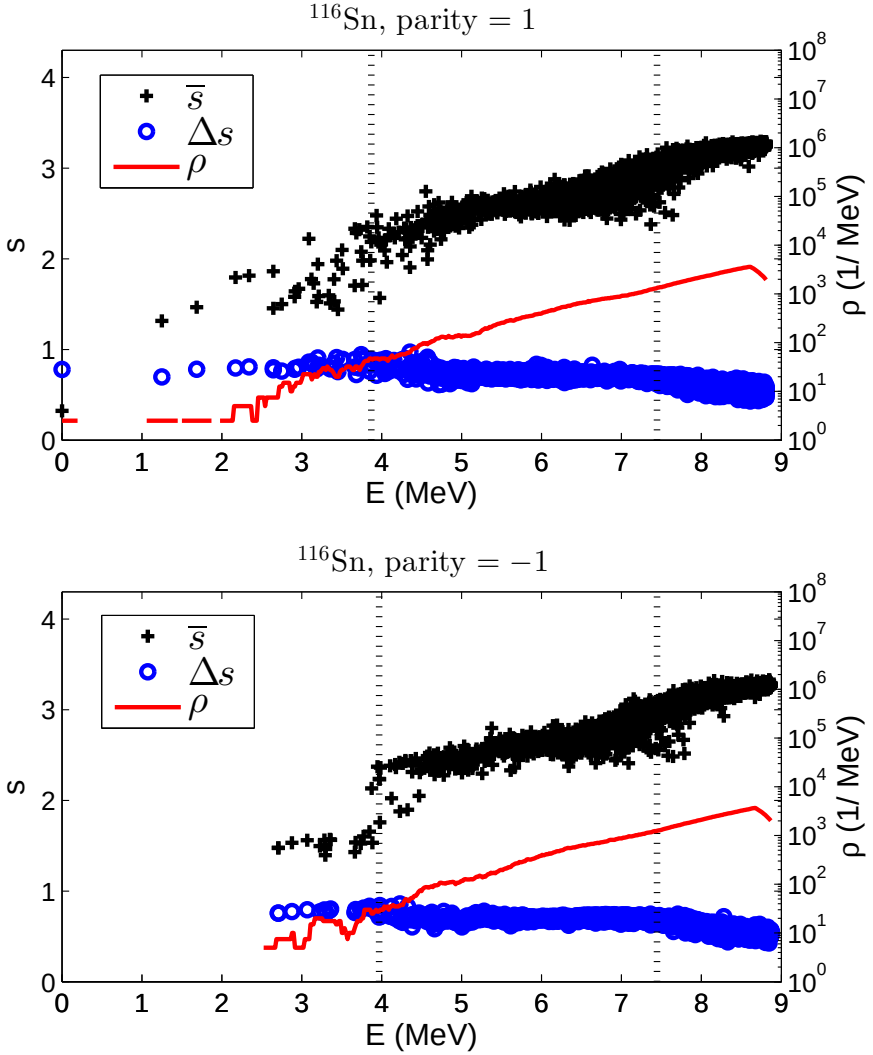
Accuracy





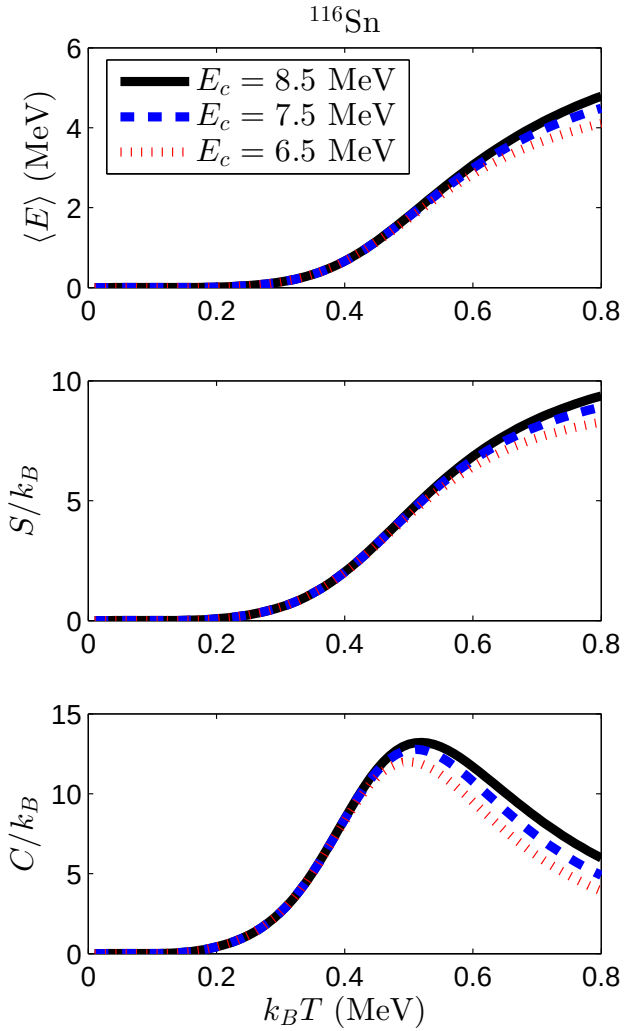
L. Y. Jia and Chong Qi, Phys. Rev. C 94, 044312 (2016).

^{116}Sn 10000 states



L. Y. Jia and Chong Qi, Phys. Rev. C 94, 044312 (2016).

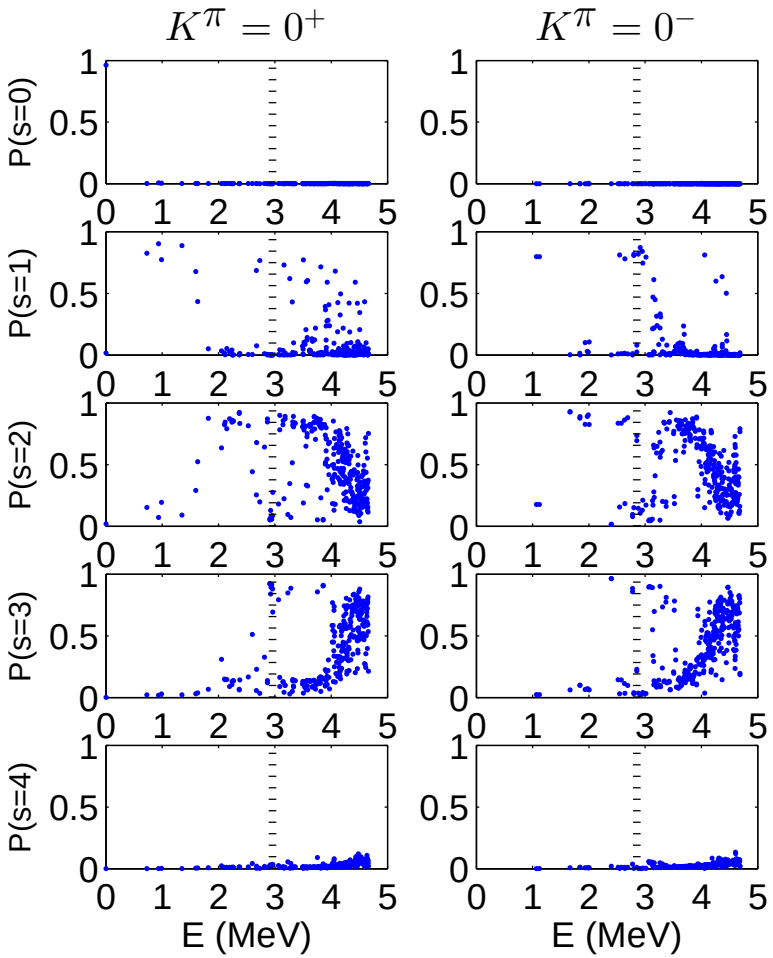
Thermal Properties



L. Y. Jia and Chong Qi, Phys. Rev. C 94, 044312 (2016).

Deformed Nuclei

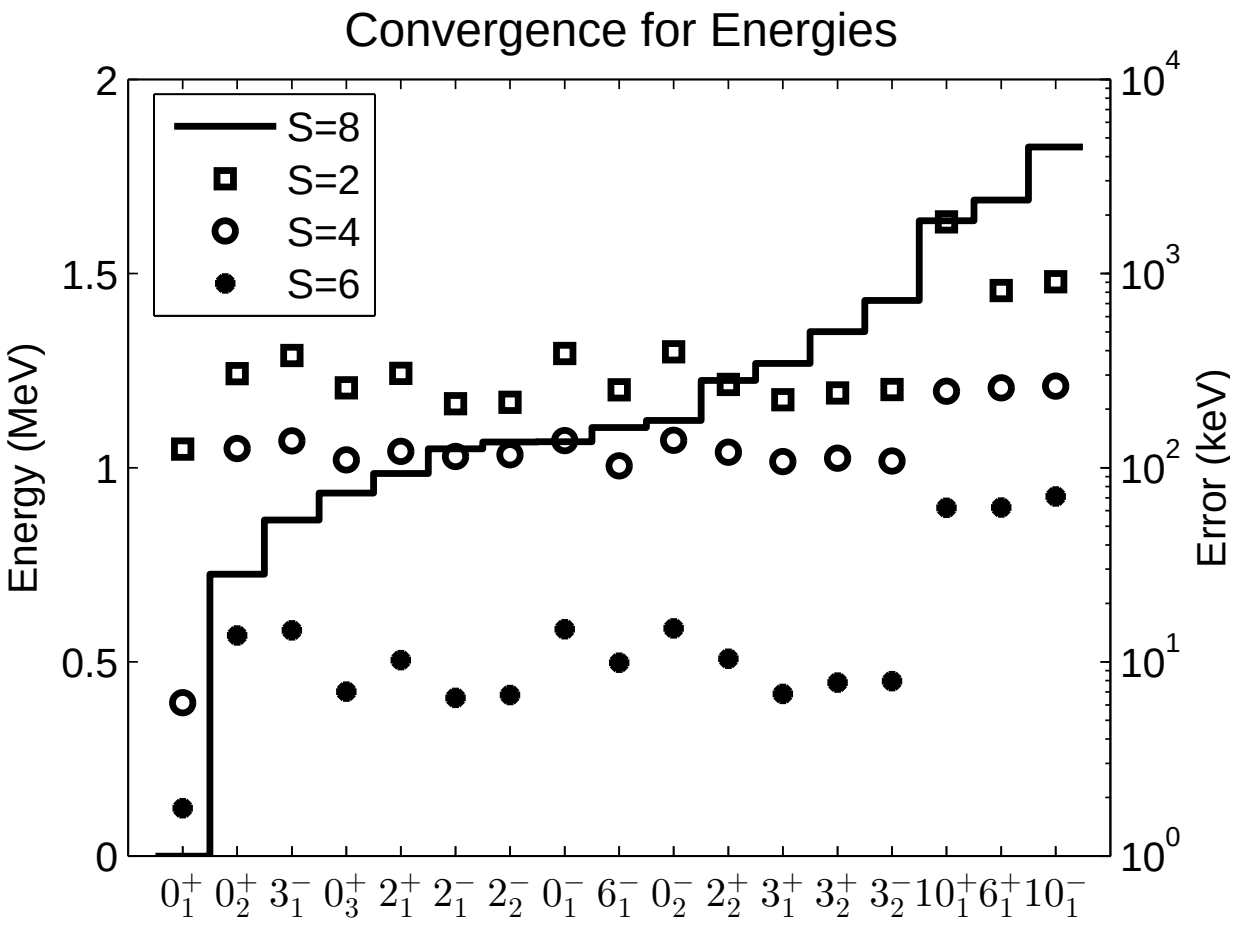
Nilsson basis ($^{158}_{64}Gd_{96}$, 600 intrinsic neutron states)



Converged using V_{lowk}

L. Y. Jia, Phys. Rev. C 96, 034313 (2017).

Nilsson basis ($^{158}_{64}Gd_{96}$, intrinsic neutron states)



L. Y. Jia, Phys. Rev. C 96, 034313 (2017).

Future Plan

- other truncations on top of generalized seniority
- β decay rates of (deformed) r-process nuclei
- $0\nu\beta\beta$ decay?

Thank you!