Bulk properties and collective excitations of spherical open-shell nuclei from chiral nuclear Hamiltonians

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Motivation

To investigate **ground-state** & **excited states** properties of **spherical open-shell nuclei** using basic many-body approximations in the context of **modern chiral interactions** [1].

- **Ground-state trends** in E_0, S_{2n} & Δ_{2n}?
- **Low- and high-energy spectroscopy**?
- Manifestation of **pairing properties**?

HFB & BMBPT

- Hartree-Fock-Bogoliubov mean-field (**HFB**) [2]

$$\begin{pmatrix} h-\lambda & \Delta \\ -\Delta^* & -(h-\lambda)^* \end{pmatrix} \begin{pmatrix} U_\mu \\ V_\mu \end{pmatrix} = E_\mu \begin{pmatrix} U_\mu \\ V_\mu \end{pmatrix}.$$

- Correlations - HFB is supplied by Bogoliubov Many-body Perturbation Theory (**BMBPT**) [3]

$$E^{(2)}_{\text{corr}} = -\frac{1}{4!} \sum_{\alpha,\beta,\gamma,\delta} \frac{H^{(40)}_{\alpha\beta\gamma\delta} H^{(04)}_{\gamma\delta\alpha\beta}}{E_{\alpha\beta\gamma\delta}}.$$

- Selected numerical results are displayed in Fig. 1.

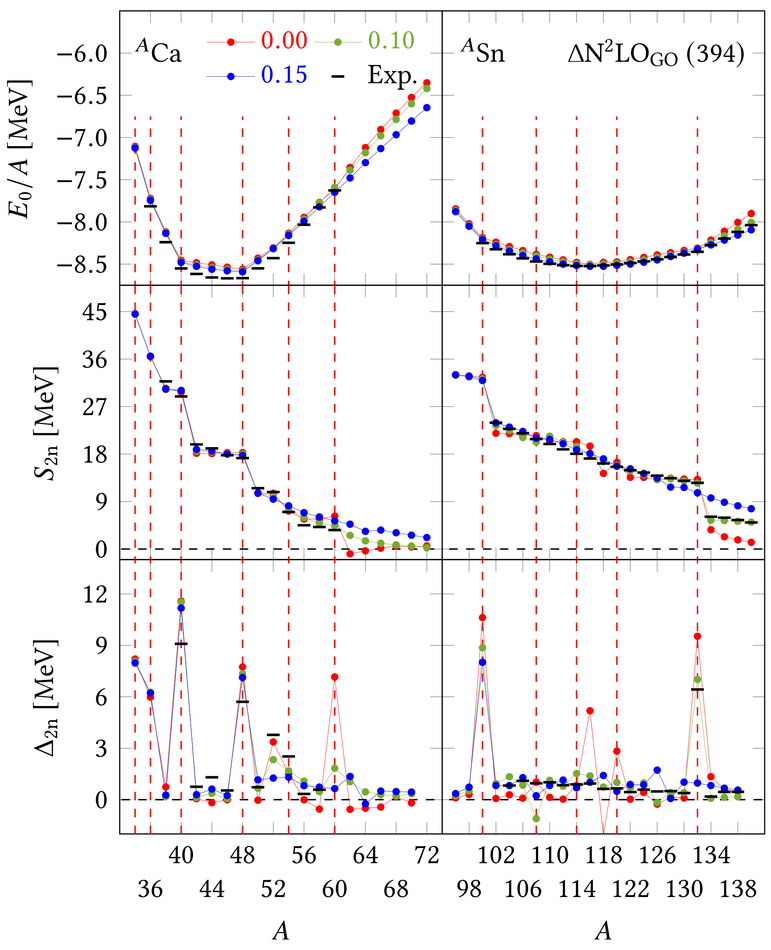


Figure 1: Ground-state systematics for HFB+BMBPT(2) for ^{A}Ca & ^{A}Sn with ΔN^{2}LO$_{\text{GO}}$ (394) interaction model. Different colors depict varying monopole 0^+ interaction enhancement G_n = 0.00, 0.10, 0.15 MeV, see further for explanation. Dashed-red lines (----) depict subshell-closed solutions.

- **Reasonable description** E_0 and S_{2n}, some difficulties with Δ_{2n}, similar for other models N^{3}LO$_{\text{Texas}}$, ΔN^{2}LO$_{\text{GO}}$ (450). Our findings in agreement with other works, e.g. [4].
- Problems with **stability of HFB** solutions (*weak pairing?*) & trends in **neutron rich systems**, little better with N^{3}LO$_{\text{Texas}}$.

- We have tried **enhancement of 0^+ interaction channel** with monopole pairing

$$V^{0+} \to V^{0+} - G_n \sum_{a,c} a^\dagger_a a^\dagger_{\bar{a}} a_{\bar{c}} a_c.$$

- **Small enhancement helps** stability, and pairing trends. Distribution of V^{0+} matrix element changes in Fig. 2. **Pairing is a fine effect.**

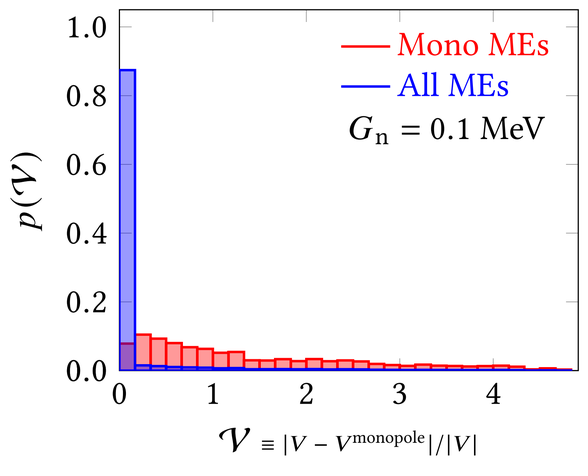


Figure 2: Distribution $p(\mathcal{V})$ of relative change of 0^+ interaction matrix elements $\mathcal{V}$ for full channel (*all matrix elements*) and pure monopole channel (*enhanced matrix elements*).

QTDA & QRPA

- Quasiparticle Random-Phase Approximation (Tamm-Dancoff Approximation) (**QRPA/QTDA**)

$$\begin{pmatrix} \mathbb{A} & \mathbb{B} \\ -\mathbb{B}^* & -\mathbb{A}^* \end{pmatrix} \begin{pmatrix} X^\nu \\ Y^\nu \end{pmatrix} = \omega_\nu \begin{pmatrix} X^\nu \\ Y^\nu \end{pmatrix}.$$

- First step to access **excited states**, i.e. with **2qp structure**, & related (*electromagnetic*) response

$$|\nu\rangle = Q^\dagger_\nu |0\rangle = \sum_{\alpha>\beta} \left(\alpha^\dagger_\alpha \alpha^\dagger_\beta X^\nu_{\alpha\beta} - \alpha_\alpha \alpha_\beta Y^\nu_{\alpha\beta}\right)|0\rangle.$$

Low-Energy Spectroscopy

- **Struggle with 2^+_1 levels**. **Collapsing QRPA** solutions, QTDA can reproduce level energies with enhanced pairing, see Fig. 3.
- Underlying **QBA is heavily questionable** (*similar with* 3^-_1), missing significant correlations?

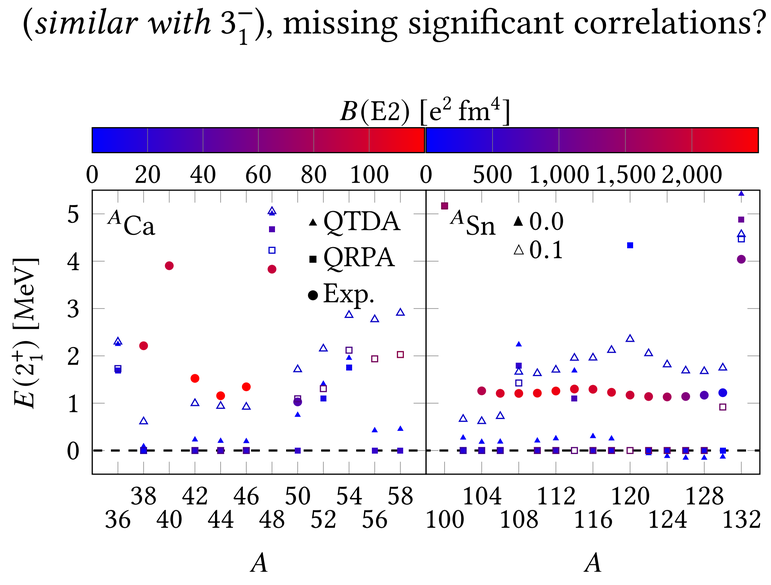


Figure 3: Systematics of $E(2^+_1)$ energies & associated $B(\text{E2}|2^+_1 \to 0^+_1)$ transitions in ^{A}Ca & ^{A}Sn chains with potential ΔN^{2}LO$_{\text{GO}}$ (394) for QRPA (■) & QTDA (▲), compared to known experimental values (●).

High-Energy Response

- In $^{\text{iv}}$E1 channel, we are interested in **GDR** & **PDR**. One can track the **effect of neutron addition**, results plotted in Figs. 4 & 5.
- High-energy response is **not plagued by near-ground-state instabilities**. **Compatible with available experimental data**.

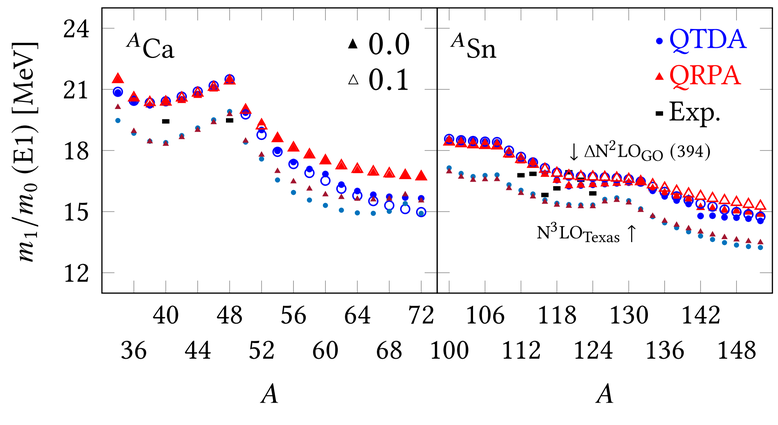


Figure 4: Evolution of E1 centroid m_0/m_1 in ^{A}Ca & ^{A}Sn calculated in QRPA & QTDA, using ΔN^{2}LO$_{\text{GO}}$ (394) & N^{3}LO$_{\text{Texas}}$ interactions, with (△) & without (▲) pairing enhancement.

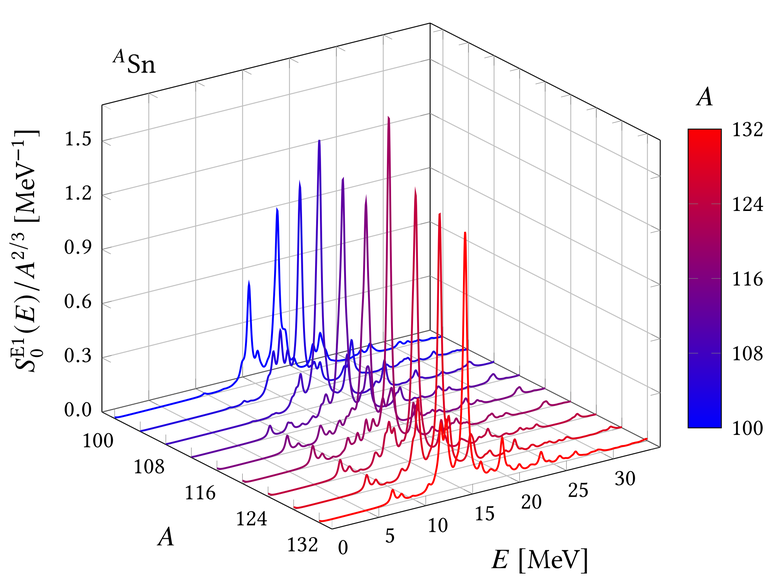


Figure 5: Systematic development of E1 strength function $S^{\text{E1}}_0(E)$ (Δ = 0.5 MeV) from QRPA along ^{A}Sn chain for interaction ΔN^{2}LO$_{\text{GO}}$ (394).

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