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Nuclear matrix element of $0\nu\beta\beta$ decay in the triaxial projected shell model

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Introduction

Neutrinoless double beta decay

- Neutrinoless double beta ($0\nu\beta\beta$) decay is a lepton-number violating process that is possible only if the neutrinos are Majorana particles.
- $0\nu\beta\beta$ decay is also related to the absolute mass-scale and thus, the hierarchy of neutrinos. Avignone RMP2008
- The lifetime of this process is: Engel RPP2017

$$[T_{1/2}^{0\nu}(0_i^+ \to 0_f^+)]^{-1} = G^{0\nu}|M^{0\nu}|^2\left(\frac{\langle m_{\beta\beta}\rangle}{m_e}\right)^2$$

- To determine the effective neutrino mass, reliable nuclear matrix element (NME) is required.

Status on NMEs of $0\nu\beta\beta$ decay

- Configuration interaction shell model (CISM) Menendez NPA2009, Horoi PRL2013
- Quasiparticle random phase approximation (QRPA) Simkovic PRC2013, Hyvarinen PRC2015
- The interacting Boson model (IBM) Barea PRC2015
- Density functional theory (DFT) + generator coordinate method (GCM) Song PRC2014, Yao PRC2015, Rodriguez PRL2010, Vaquero PRL2013
- Projected Hartree-Fock Bogoliubov (PHFB) Rath PRC2012, Rath PRC2013

In this presentation

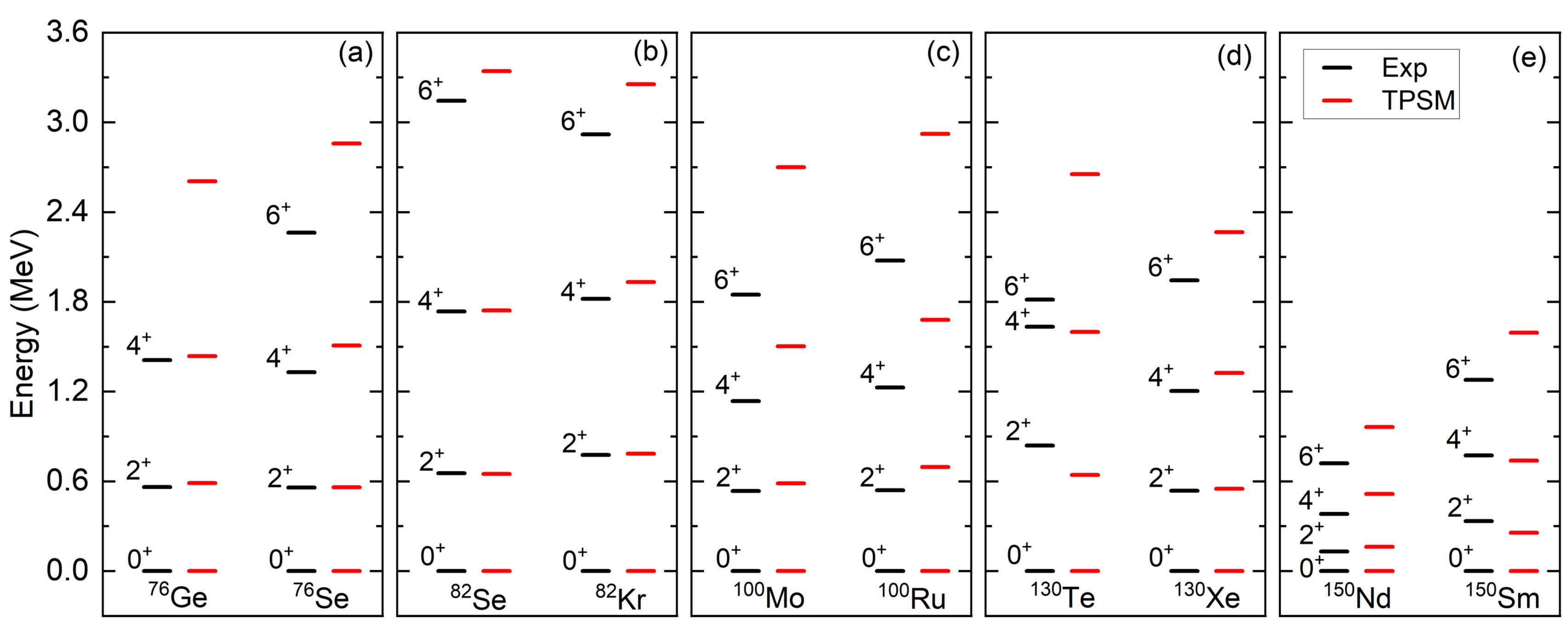
✓ The effects of triaxial deformation, quasiparticle configuration mixing, and the closure approximation on NMEs have been investigated within the triaxial projected shell model.

Numerical details

- Nuclei: ^{76}Ge, ^{82}Se, ^{100}Mo, ^{130}Te, ^{150}Nd
- Monopole pairing strength G_M^n=20/A, G_M^p = 30/A Singh EPJA 2007
- Quadrupole deformation β for nuclei ^{100}Mo, ^{130}Te, ^{150}Nd are taken from Singh EPJA 2007, and those for ^{76}Ge and ^{82}Se are calculated self-consistently by the covariant density functional theory.
- Nilsson parameters μ and κ are taken from reference Zhang PRC1989
- Quadrupole pairing strength $G_Q = 0.2 \times G_M$

Results and discussion

Energy spectra

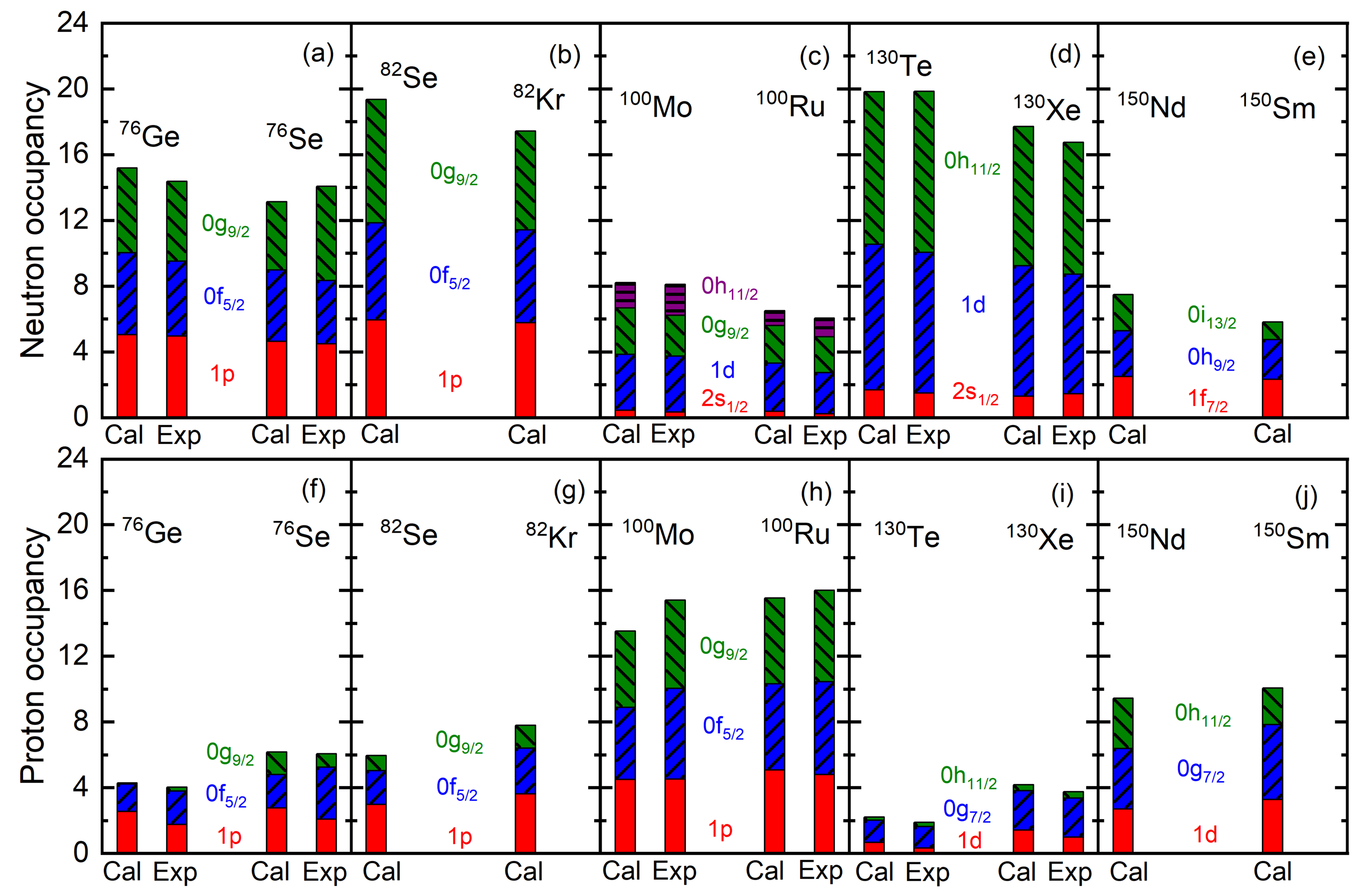


E2 transition probabilities

Mother	^{76}Ge	^{82}Se	^{100}Mo	^{130}Te	^{150}Nd
TPSM	0.218	0.199	0.584	0.269	3.018
Expt.	0.278	0.180	0.530	0.296	2.707
Daughter	^{76}Se	^{82}Kr	^{100}Ru	^{130}Xe	^{150}Sm
TPSM	0.304	0.210	0.457	0.496	2.321
Expt.	0.419	0.225	0.493	0.634	1.347

- The calculated energy spectra and $B(E2;0^+\to 2^+)$ values reproduce the experimental data well.
- The overestimation of $B(E2;0^+\to 2^+)$ value for ^{150}Sm might be associated with a slightly larger quadrupole deformation β.

Occupancies of single-particle orbits



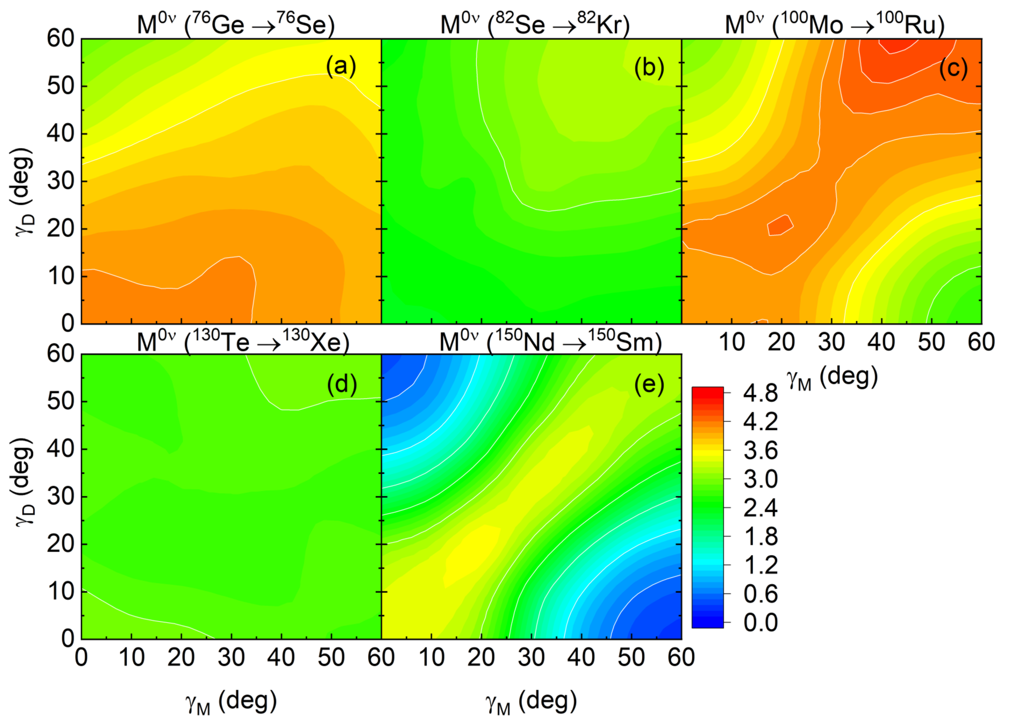
- The calculated occupancies of spherical single-particle orbits for both protons and neutrons reproduce the data well, which add confidence to the obtained wavefunctions.

Effects of configuration mixing on the NMEs

Decay process	TPSM				TPHFB				$\Delta M^{0\nu}$
	$M^{0\nu}$	$M_{GT}^{0\nu}$	$M_F^{0\nu}$	$M_T^{0\nu}$	$M^{0\nu\prime}$	$M_{GT}^{0\nu\prime}$	$M_F^{0\nu\prime}$	$M_T^{0\nu\prime}$	
^{76}Ge → ^{76}Se	3.17	2.67	-0.72	-0.01	3.37	2.84	-0.77	-0.01	0.20
^{82}Se → ^{82}Kr	2.59	2.16	-0.59	-0.02	2.78	2.32	-0.63	-0.02	0.19
^{100}Mo → ^{100}Ru	3.92	3.46	-0.78	-0.03	3.99	3.52	-0.79	-0.03	0.07
^{130}Te → ^{130}Xe	2.92	2.64	-0.56	-0.01	3.00	2.71	-0.58	-0.01	0.08
^{150}Nd → ^{150}Sm	3.29	2.89	-0.55	-0.02	3.44	3.02	-0.58	-0.02	0.15

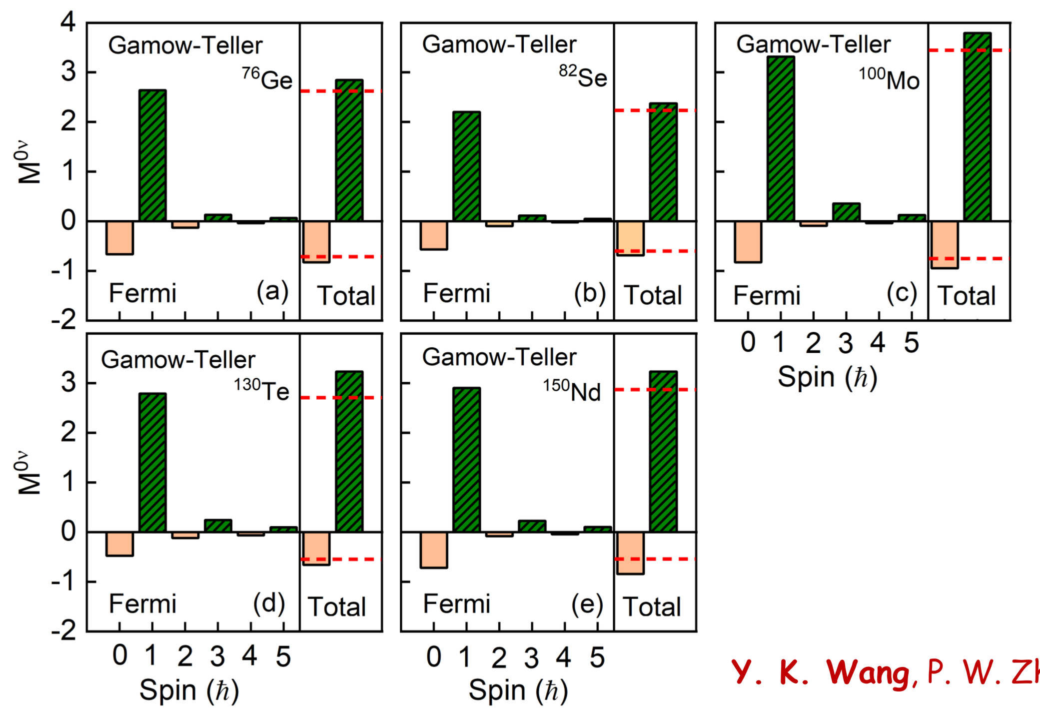
- The quasiparticle configuration mixing reduces the NMEs ranging from 2% to 7%.

Effects of triaxial deformation on the NMEs



- Varying γ from 0° to 60° for the mother and daughter nuclei, the NMEs change respectively by 41%, 17%, 68%, 14%, and 511%, for ^{76}Ge, ^{82}Se, ^{100}Mo, ^{130}Te, and ^{150}Nd.

Effects of closure approximation on the NMEs



- For nuclei ^{76}Ge, ^{82}Se, ^{100}Mo, ^{130}Te, and ^{150}Nd, the contribution of the odd-odd intermediate states increase respectively the values of the NMEs by 7%, 4%, 11%, 20%, and 14%.

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Summary

- The nuclear matrix elements of $0\nu\beta\beta$ decay for nuclei ^{76}Ge, ^{82}Se, ^{100}Mo, ^{130}Te, and ^{150}Nd are studied within the triaxial projected shell model.
- The low-lying spectra, the $B(E2;0^+\to 2^+)$ values, and the occupancies of single-particle orbits for nuclei under consideration are reproduced well.
- The effects of quasiparticle configuration mixing, the triaxial deformation, and the closure approximation on the nuclear matrix elements are studied in detail.