Double and single-β decays and nuclear structures in the mapped IBM

Kosuke Nomura

Hokkaido University

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Contents

- $\beta\beta$ decays, and the Interacting Boson Model
- Low-lying structures of even-even and odd-odd nuclei
- $2\nu\beta\beta$ decays
- Single-β decay of neutron-rich N~60 nuclei

Study of $\beta\beta$ decay

- Nature of neutrinos, test of fundamental symmetries, … neutrino-less $\beta\beta$ decay
- Experiments: GERDA, NEMO, KamLAND …
- Predicted nuclear matrix elements (NMEs) differ by a factor 2-3

Avignone et al., RMP (2008)
Agostini et al., RMP (2023)
Engel, Menendez, RPP (2017), etc.

Two-neutrino (2ν) $\beta\beta$ decay

- wealth of experimental data available
- needs calculation of the intermediate states (non-closure approx.)

Theoretical descriptions without the closure approx. by

- **Interacting Boson Model** — Yoshida-Iachello, PTEP (2013)
- QRPA — Suhonen-Civitarese, Phys. Rep.(1998)
  Pirinen-Suhonen PRC (2015)
  Simkovic, Smetana, Vogel, PRC (2018), etc.
- NSM — Caurier, Nowacki, Poves, IJMPE (2007)
  Yoshinaga et al., PTEP (2018)
  Coraggio et al., PRC (2019), etc.

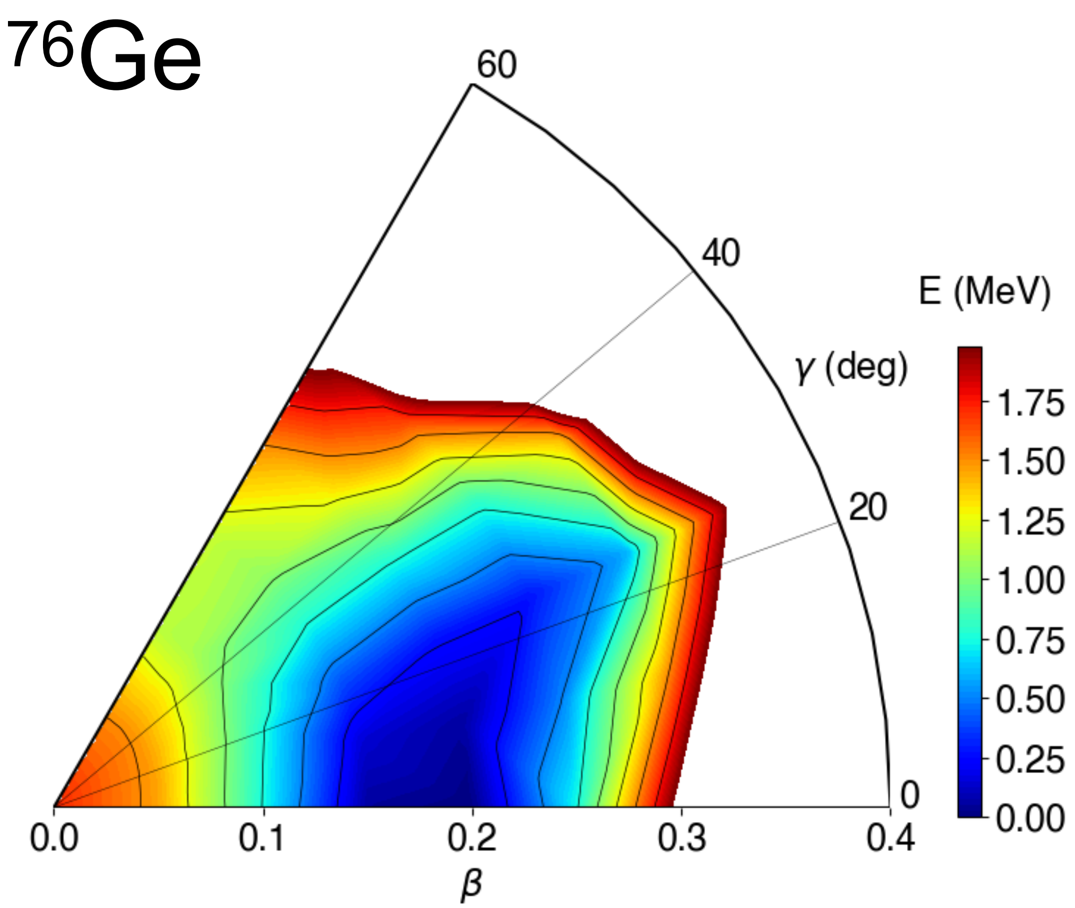
This work

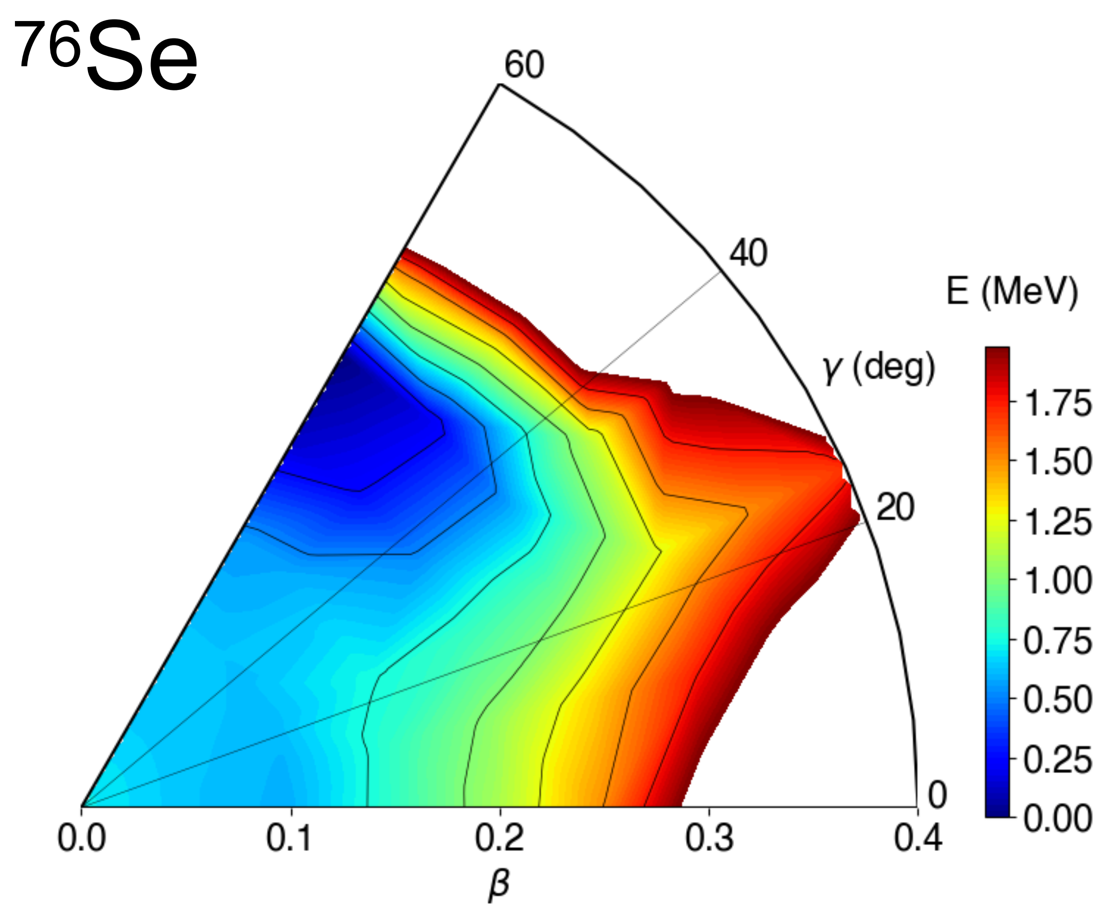
- Consistent description of nuclear structure, β, and $\beta\beta$ decays
- Framework: EDF-mapped IBM
- No closure approximation: calculations for odd-odd nuclei

K. Nomura, Phys. Rev. C 105 (2022) 044301
K. Nomura, arXiv: 2406.02986

K. Nomura, Phys. Rev. C 109 (2024) 034319
M. Homma, and K. Nomura, arXiv: 2404.14624, to appear in PRC

Potential energy surfaces

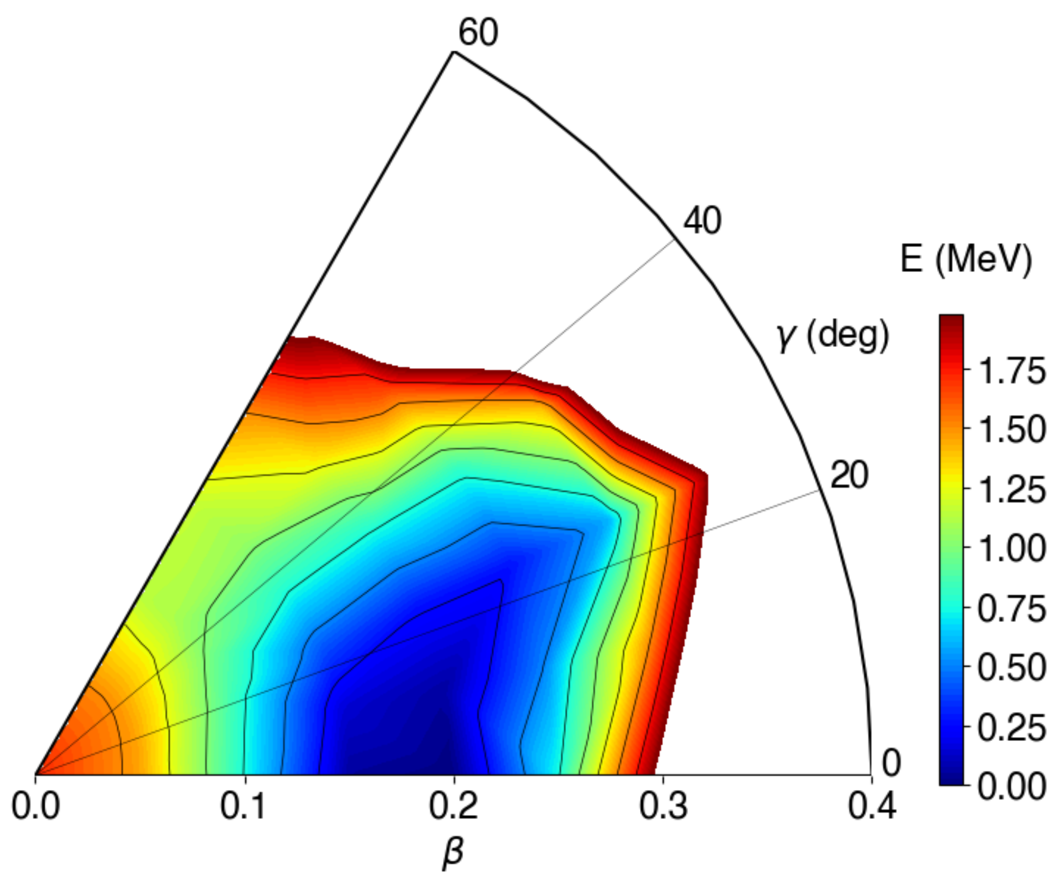


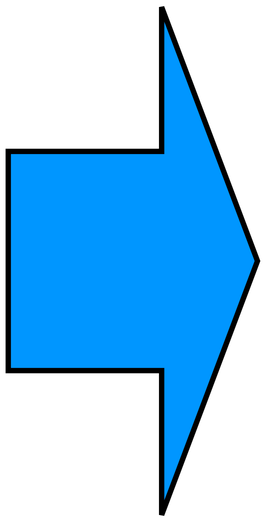


… calculated with the relativistic Hartree-Bogoliubov method with DD-PC1 energy density functional (EDF) and separable pairing

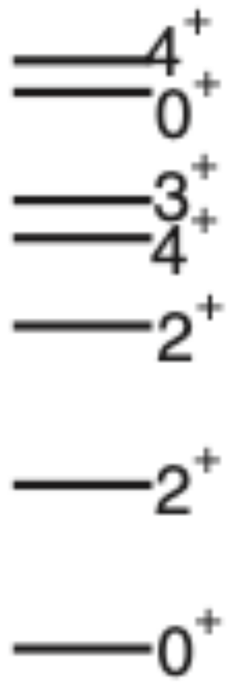
Computing energy spectra

Intrinsic frame





lab. frame



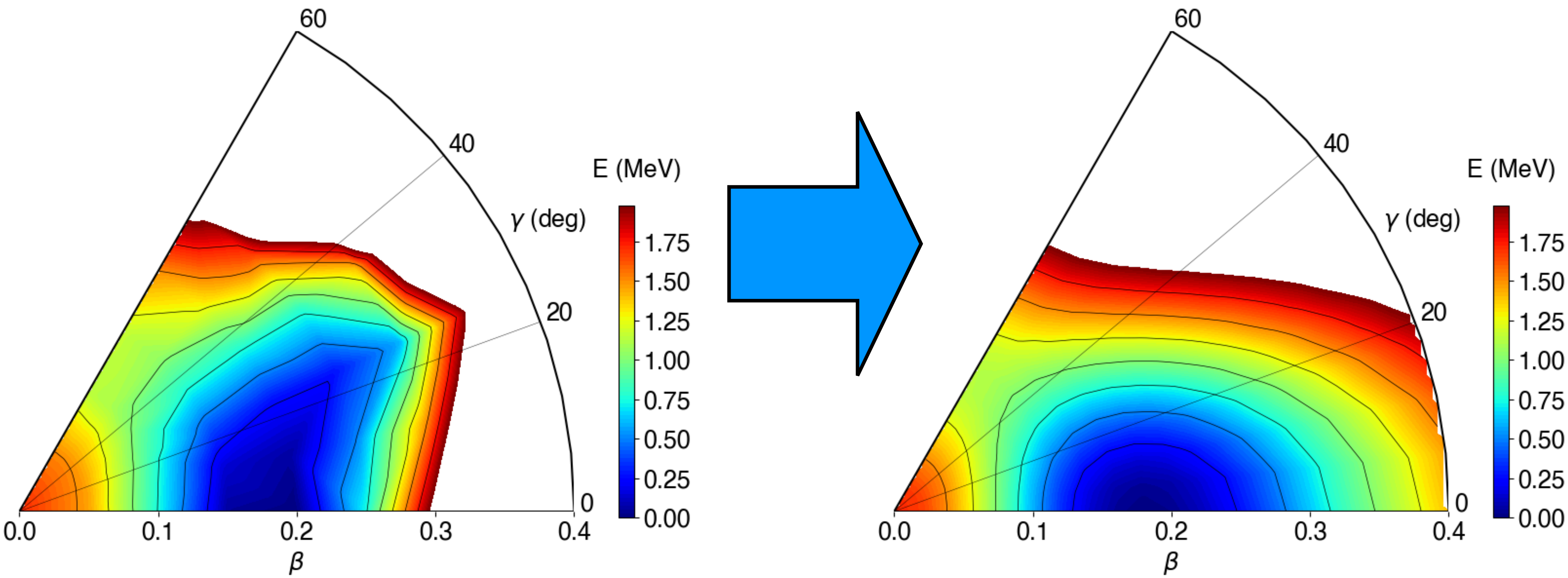
Beyond-mean-field treatments
- Symmetry projections, GCM
- Collective Hamiltonian
- Interacting Boson Model

Observables:
Excitation spectra, EM properties, β, $\beta\beta$ decay?

Mean-field to IBM

Fermionic

Bosonic



- SCMF energy surface is mapped onto that of the IBM
- Diagonalization of the mapped Hamiltonian yields energy spectra

KN et al. PRL101 (2008) 142501; PRC81 (2010) 044307

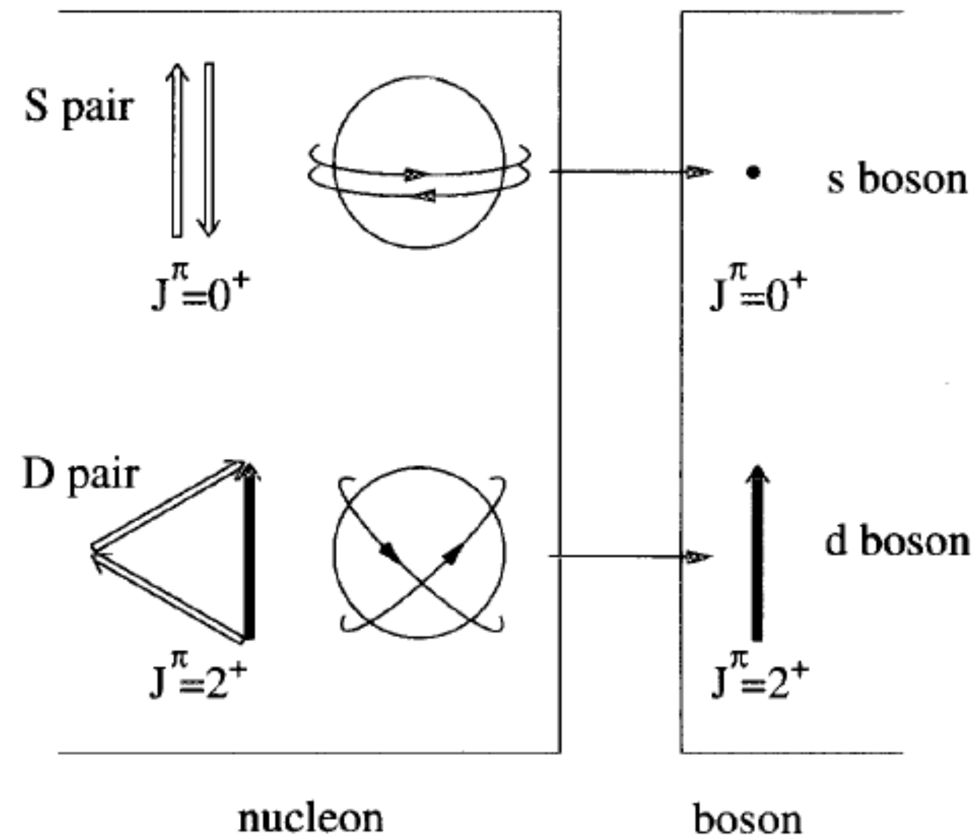
Interacting Boson Model (IBM)

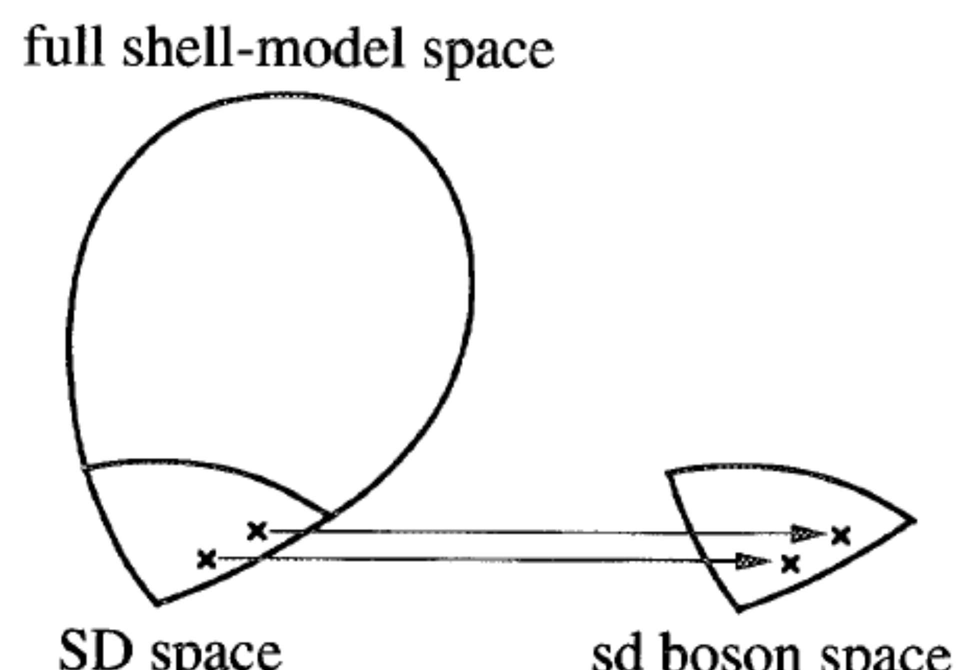
- Collective J=0+ and 2+ pairs of valence nucleons ↦ s, d bosons

- exactly solvable if the Hamiltonian has the dynamical symmetries U(5), SU(3), and O(6)

- Microscopic derivations from nucleonic degrees of freedom

Arima, Iachello (1975)
Otsuka, Arima, Iachello (1979)
Mizusaki, Otsuka (1997)
Nomura, Shimizu, Otsuka (2008)





Neutron-proton IBM (IBM-2)

- building blocks: (s_ν, s_π) and (d_ν, d_π) bosons

- Hamiltonian:

$$\boxed{\hat{H}_{\mathrm{IBM}} = \epsilon_d(\hat{n}_{d_\nu} + \hat{n}_{d_\pi}) + \kappa\,\hat{Q}_\nu \cdot \hat{Q}_\pi + \kappa' \hat{L} \cdot \hat{L}}$$

pairing-like (spherical driving) — quadrupole-quadrupole (deformation driving) — rotational term

$$\hat{Q}_\rho = s_\rho^\dagger \tilde{d}_\rho + d_\rho^\dagger s_\rho + \chi_\rho (d_\rho^\dagger \times \tilde{d}_\rho)^{(2)}$$

$$\hat{L} = \sqrt{10}[(d_\nu^\dagger \times \tilde{d}_\nu)^{(1)} + (d_\pi^\dagger \times \tilde{d}_\pi)^{(1)}]$$

… with 5 parameters

Geometry of the IBM

Energy surface:

$$E_{\mathrm{IBM}}(\beta,\gamma) = \langle \phi \,|\, \hat{H}_{\mathrm{IBM}} \,|\, \phi \rangle$$

… with boson coherent state

$$|\,\phi\rangle \propto \Pi_{\rho=\nu,\pi}\left[s^{\dagger}_{\rho} + \beta\cos\gamma d^{\dagger}_{\rho,0} + \frac{1}{\sqrt{2}}\beta\sin\gamma\left(d^{\dagger}_{\rho,+2} + d^{\dagger}_{\rho,-2}\right)\right]^{N_{\rho}} |\,0\rangle$$

Ginocchio-Kirson (1980)

IBM Hamiltonian is determined by

$$E_{\mathrm{SCMF}}(\beta,\gamma) \approx E_{\mathrm{IBM}}(\beta,\gamma)$$

KN et al. PRL101 (2008) 142501

Interacting Boson-Fermion-Fermion Model

$$\hat{H}_{\mathrm{IBFFM}} = \hat{H}_{\mathrm{IBM}} + \hat{H}_{\mathrm{F}} + \hat{V}_{\mathrm{BF}} + \hat{V}_{\nu\pi}$$

Single-fermion Hamiltonian

$$\hat{H}_{\mathrm{F}} = \sum_{j_\rho} \epsilon_{j_\rho} \hat{n}_{j_\rho}$$

Boson-fermion interactions

$$\hat{V}_{\mathrm{BF}} = \Gamma_0 \hat{V}_{\mathrm{dyn}} + \Lambda_0 \hat{V}_{\mathrm{exc}} + A_0 \hat{V}_{\mathrm{mon}}$$

dynamical (direct) term — exchange term — monopole term

neutron-proton interaction

$$\hat{V}_{\nu\pi} = 4\pi [v_{\mathrm{d}} + v_{\mathrm{ssd}} \boldsymbol{\sigma}_\nu \cdot \boldsymbol{\sigma}_\pi] \delta(\boldsymbol{r}) \delta(\boldsymbol{r}_\nu - r_0) \delta(\boldsymbol{r}_\pi - r_0) - \frac{1}{\sqrt{3}} v_{\mathrm{ss}} \boldsymbol{\sigma}_\nu \cdot \boldsymbol{\sigma}_\pi + v_{\mathrm{t}} \left[\frac{3(\boldsymbol{\sigma}_\nu \cdot \mathbf{r})(\boldsymbol{\sigma}_\pi \cdot \mathbf{r})}{r^2} - \boldsymbol{\sigma}_\nu \cdot \boldsymbol{\sigma}_\pi \right]$$

Iachello, Van Isacker, “The interacting boson-fermion model” (1991)

Boson-fermion interactions

$$\hat{V}^{\rho}_{\rm dyn} = \sum_{j_\rho j'_\rho} \gamma_{j_\rho j'_\rho} (a^\dagger_{j_\rho} \times \tilde{a}_{j'_\rho})^{(2)} \cdot \hat{Q}_{\rho'},$$

$$\hat{V}^{\rho}_{\rm exc} = -\left(s^\dagger_{\rho'} \times \tilde{d}_{\rho'}\right)^{(2)} \cdot \sum_{j_\rho j'_\rho j''_\rho} \sqrt{\frac{10}{N_\rho(2j_\rho+1)}} \beta_{j_\rho j'_\rho} \beta_{j''_\rho j_\rho} : \left[(d^\dagger_\rho \times \tilde{a}_{j''_\rho})^{(j_\rho)} \times (a^\dagger_{j'_\rho} \times \tilde{s}_\rho)^{(j'_\rho)}\right]^{(2)} : +({\rm H.c.}) \; ,$$

$$\hat{V}^{\rho}_{\rm mon} = \hat{n}_{d_\rho} \hat{n}_{j_\rho} \; ,$$

with (u,v)-dependent factors:

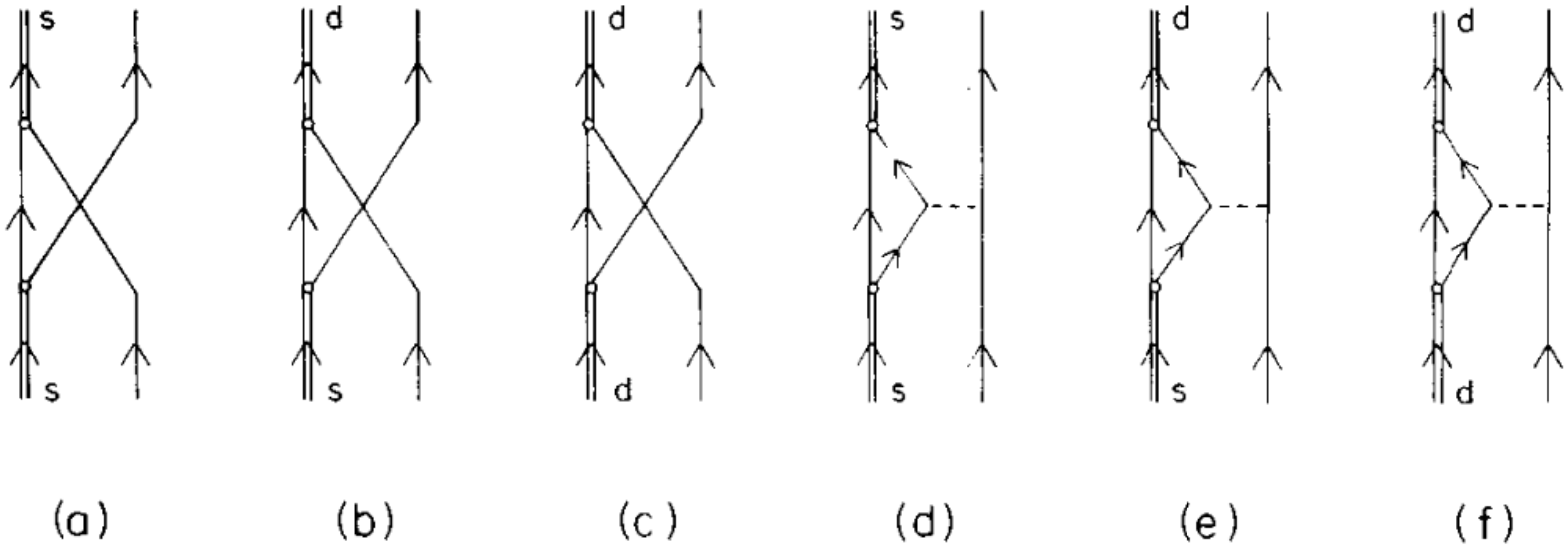
$$\gamma_{j_\rho j'_\rho} = (u_{j_\rho} u_{j'_\rho} - v_{j_\rho} v_{j'_\rho}) Q_{j_\rho j'_\rho}$$

$$\beta_{j_\rho j'_\rho} = (u_{j_\rho} v_{j'_\rho} + v_{j_\rho} u_{j'_\rho}) Q_{j_\rho j'_\rho}$$

… derived within the generalized seniority

e.g., Schoten, PPNP (1985)

Boson-fermion interactions



exchange terms

direct terms

Building the IBFFM Hamiltonian

$$\hat{H}_{\mathrm{IBFFM}} = \hat{H}_{\mathrm{IBM}} + \hat{H}_{\mathrm{F}} + \hat{V}_{\mathrm{BF}} + \hat{V}_{\nu\pi}$$

mapping the PES

spherical s.p. e. (ϵ_j)

occupation probabilities v_j^2 at spherical configuration

Microscopic input from EDF

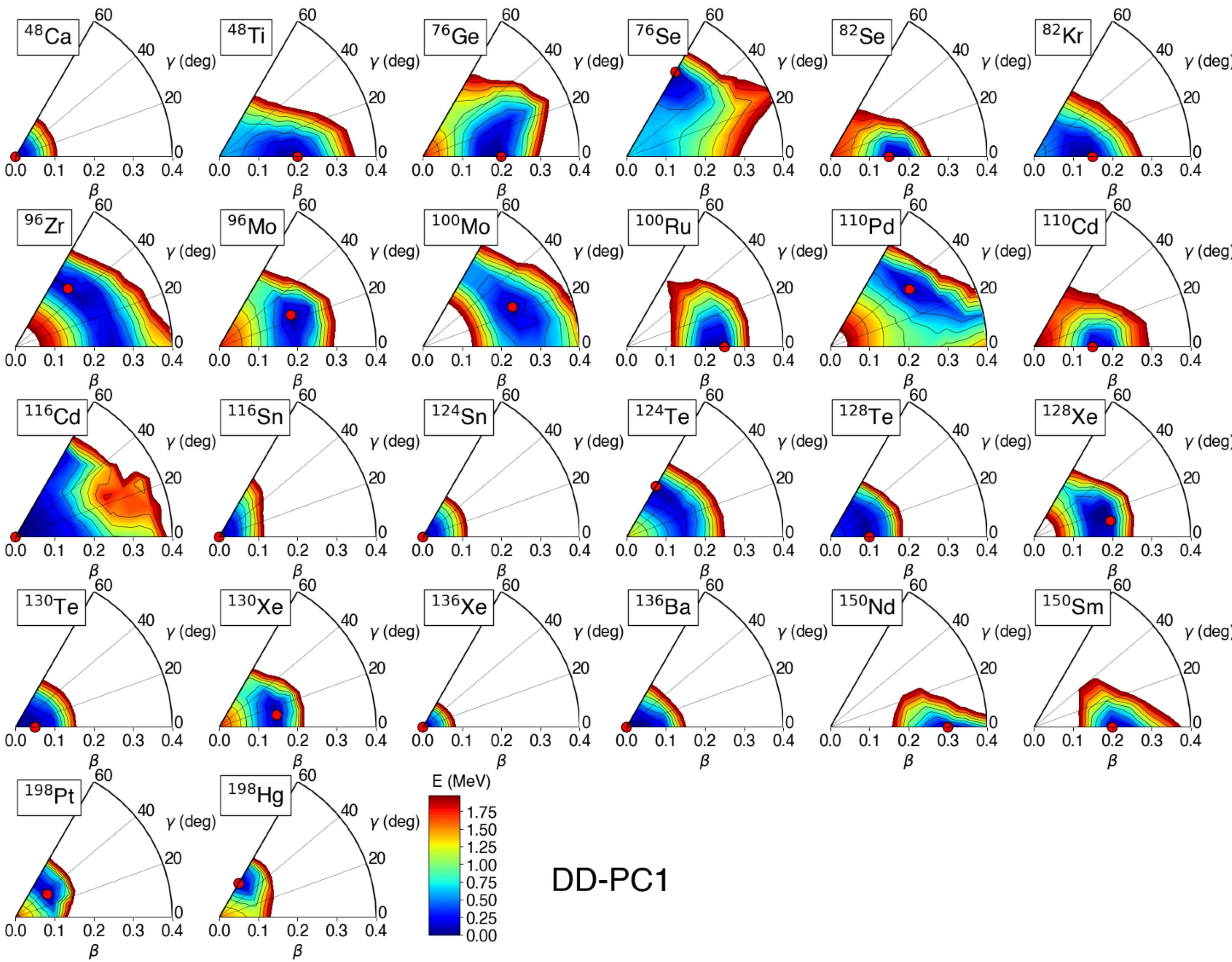
… 3 strength parameters for $\hat{V}_{\mathrm{BF}}$ fitted for each nucleus (odd-N, odd-Z, and parity)

… 4 strength parameters for $\hat{V}_{\nu\pi}$ fitted for each odd-odd nucleus

- IBFM: KN et al. PRC93 (2016) 054305
- IBFFM-2: KN et al., PRC99 (2019) 034308

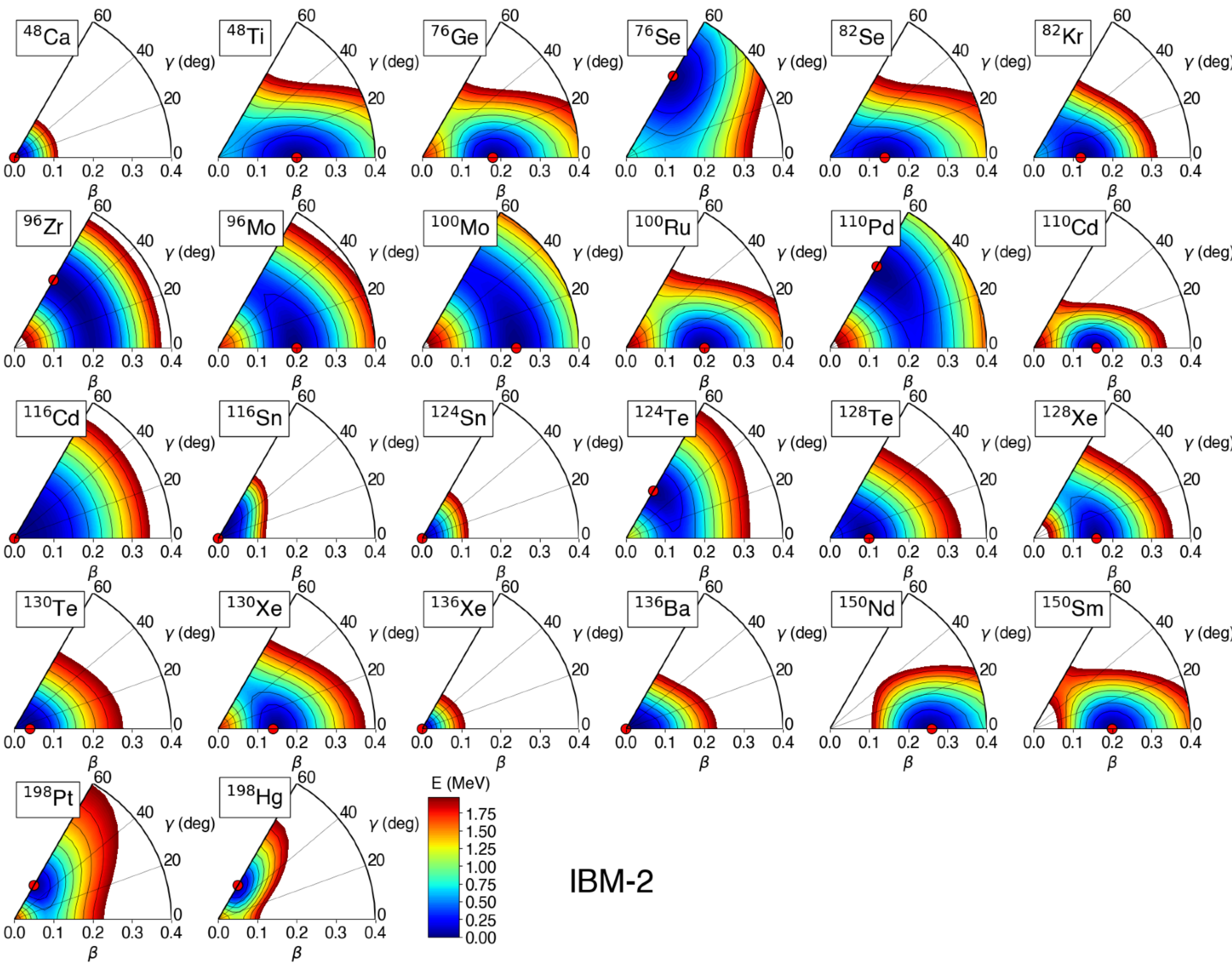
Low-lying structure

EDF PESs for even-even nuclei



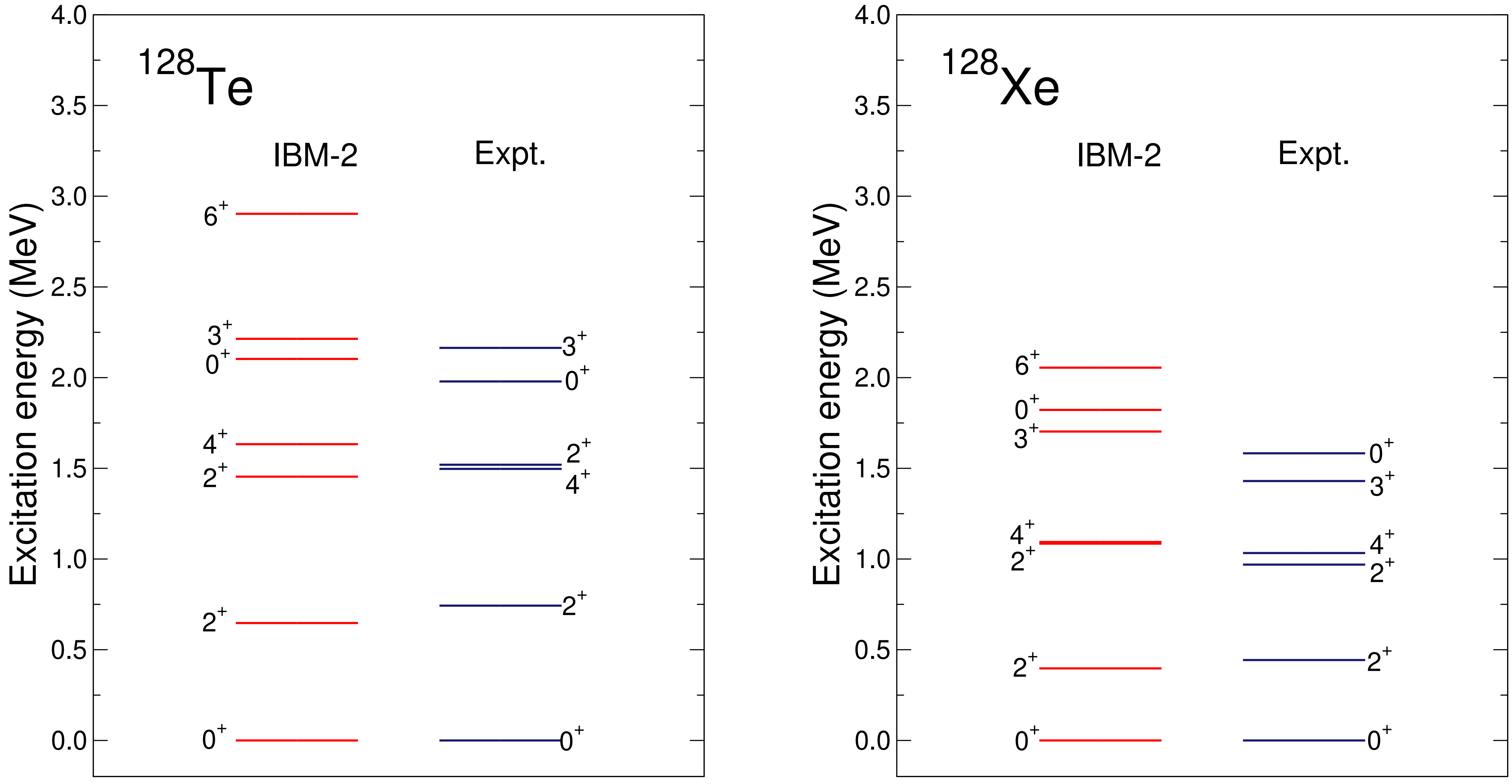
DD-PC1

IBM PESs

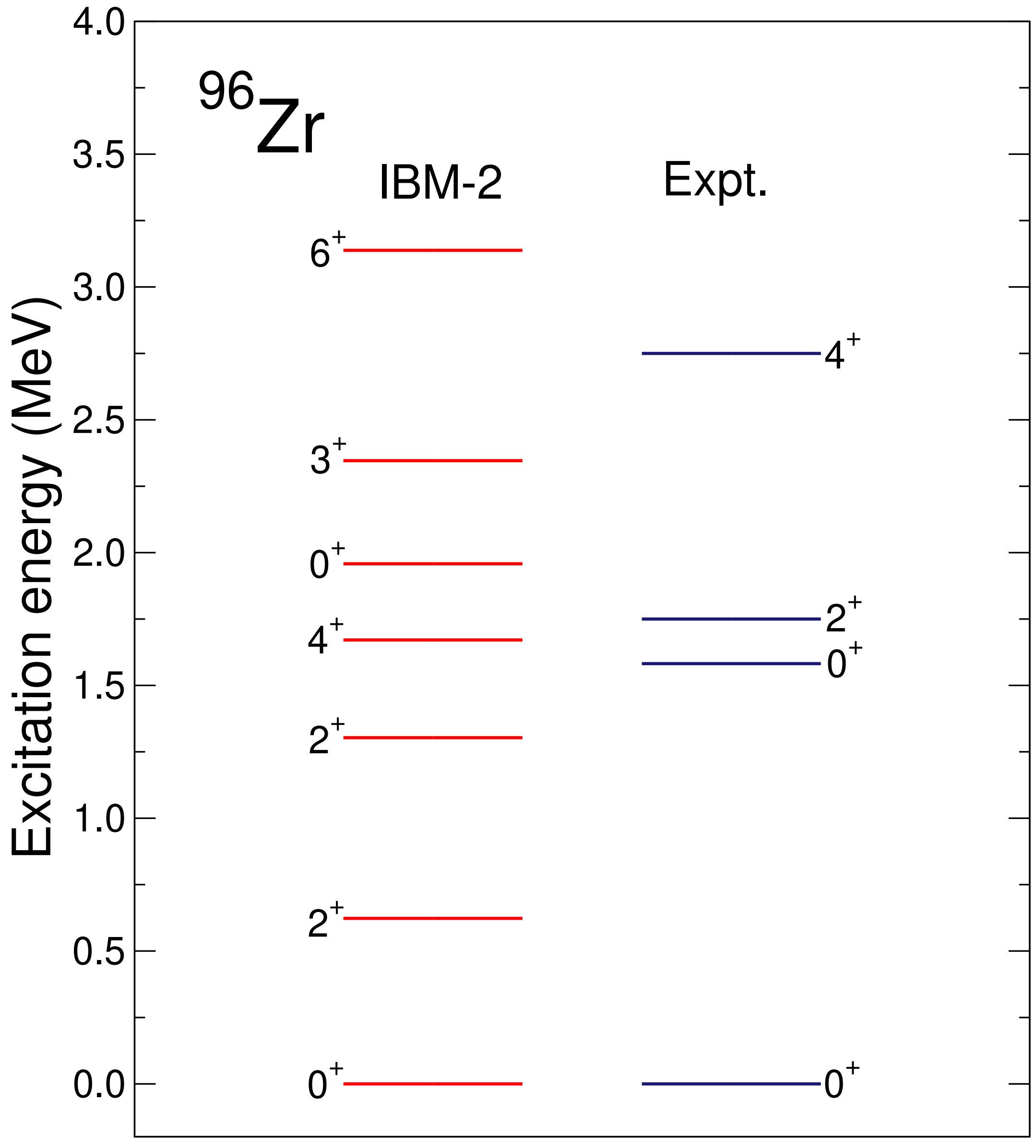


IBM-2

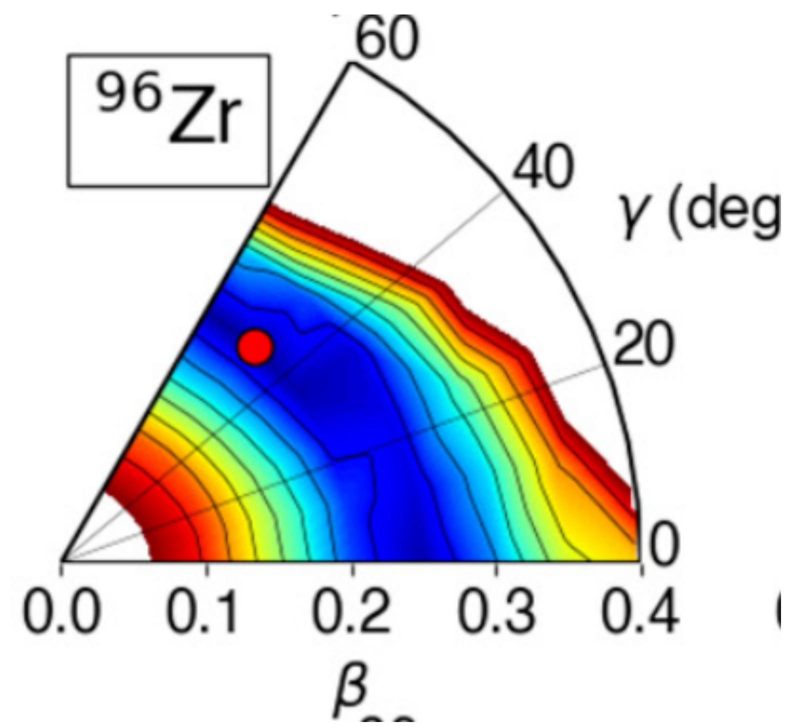
^{128}Te and ^{128}Xe spectra



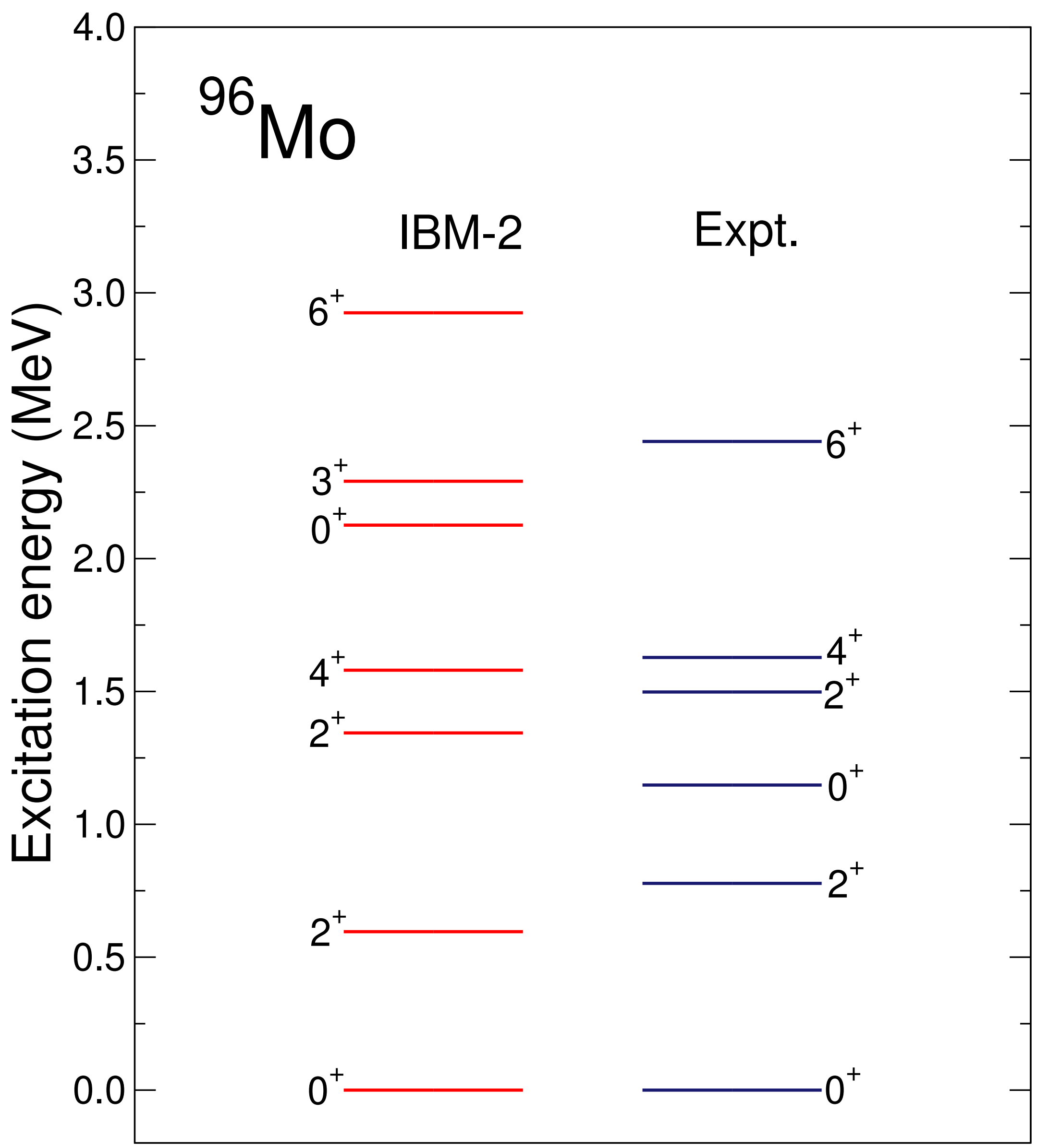
^{96}Zr spectrum



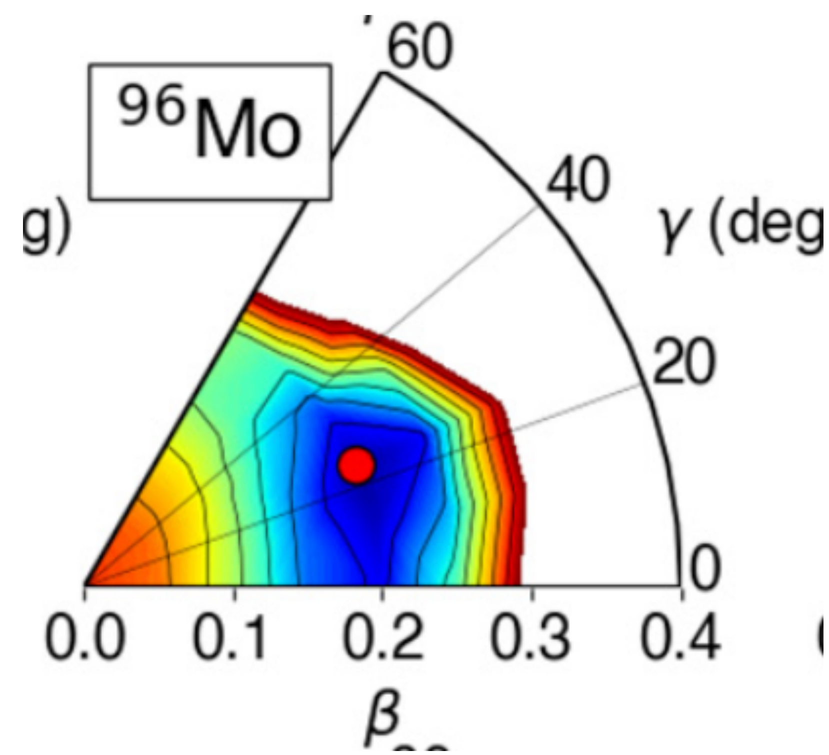
… unable to reproduce N=56 sub-shell effects



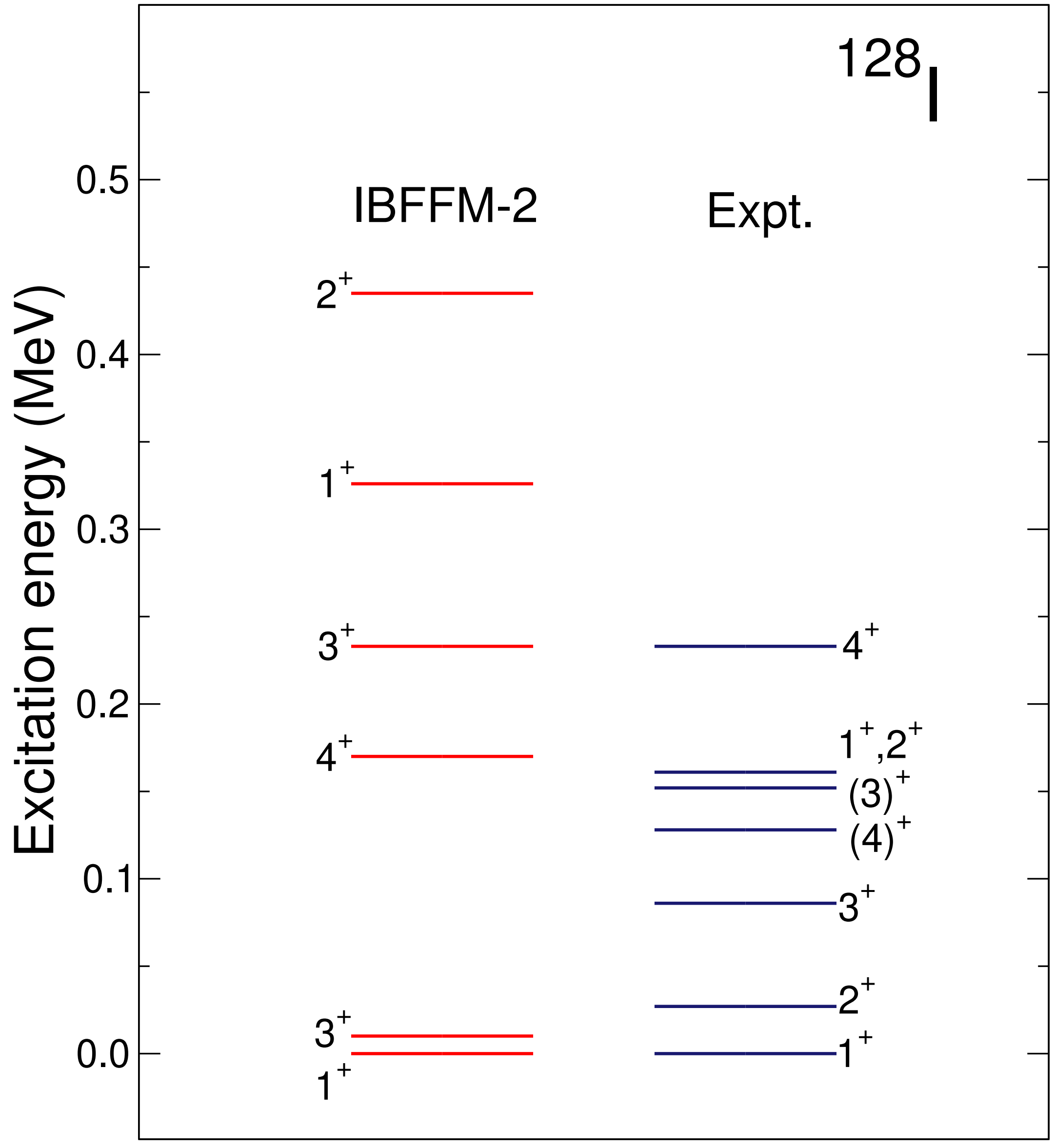
^{96}Mo spectrum

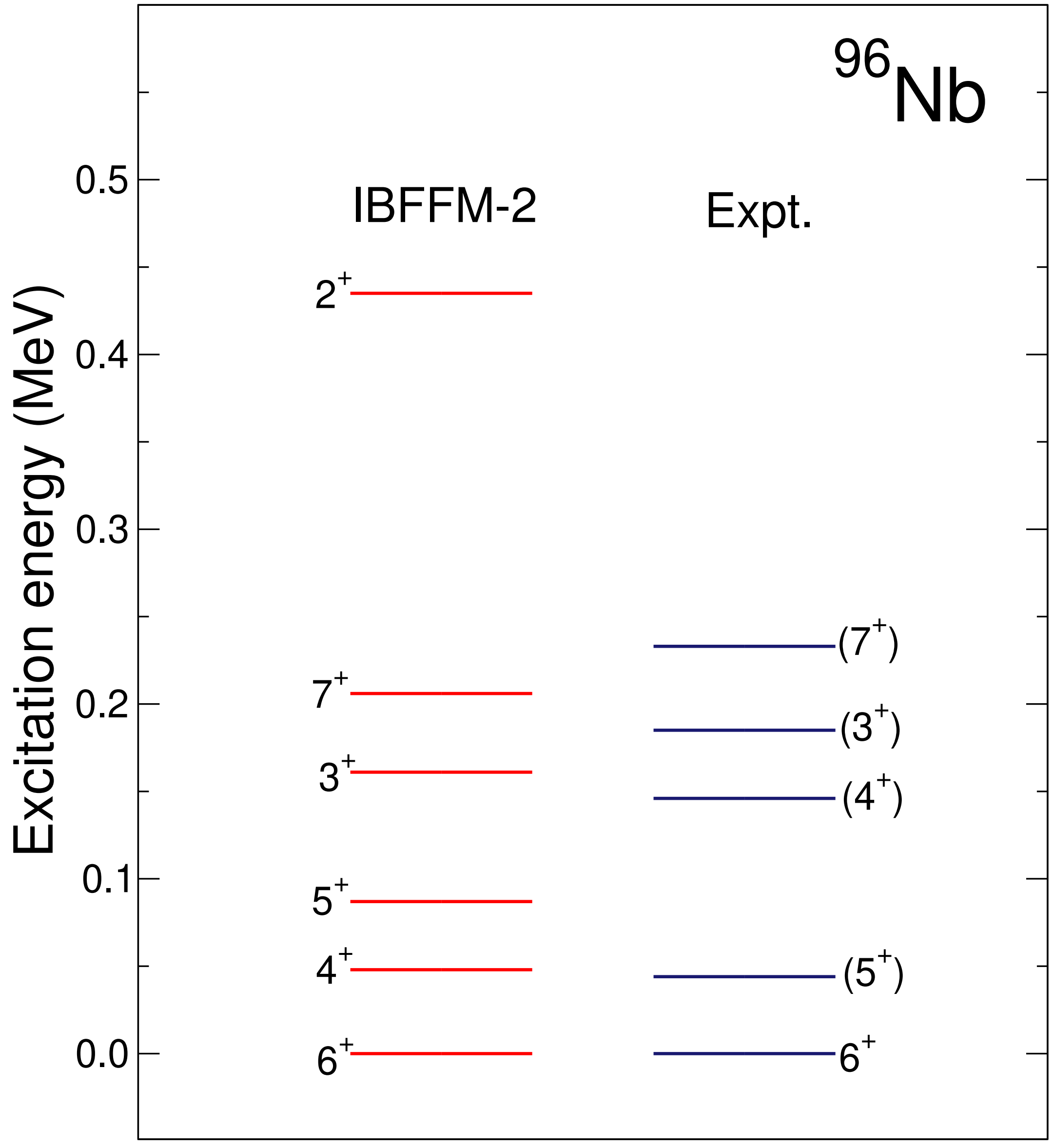


… overestimates the 0_2^+ level: a common problem of the mapped IBM

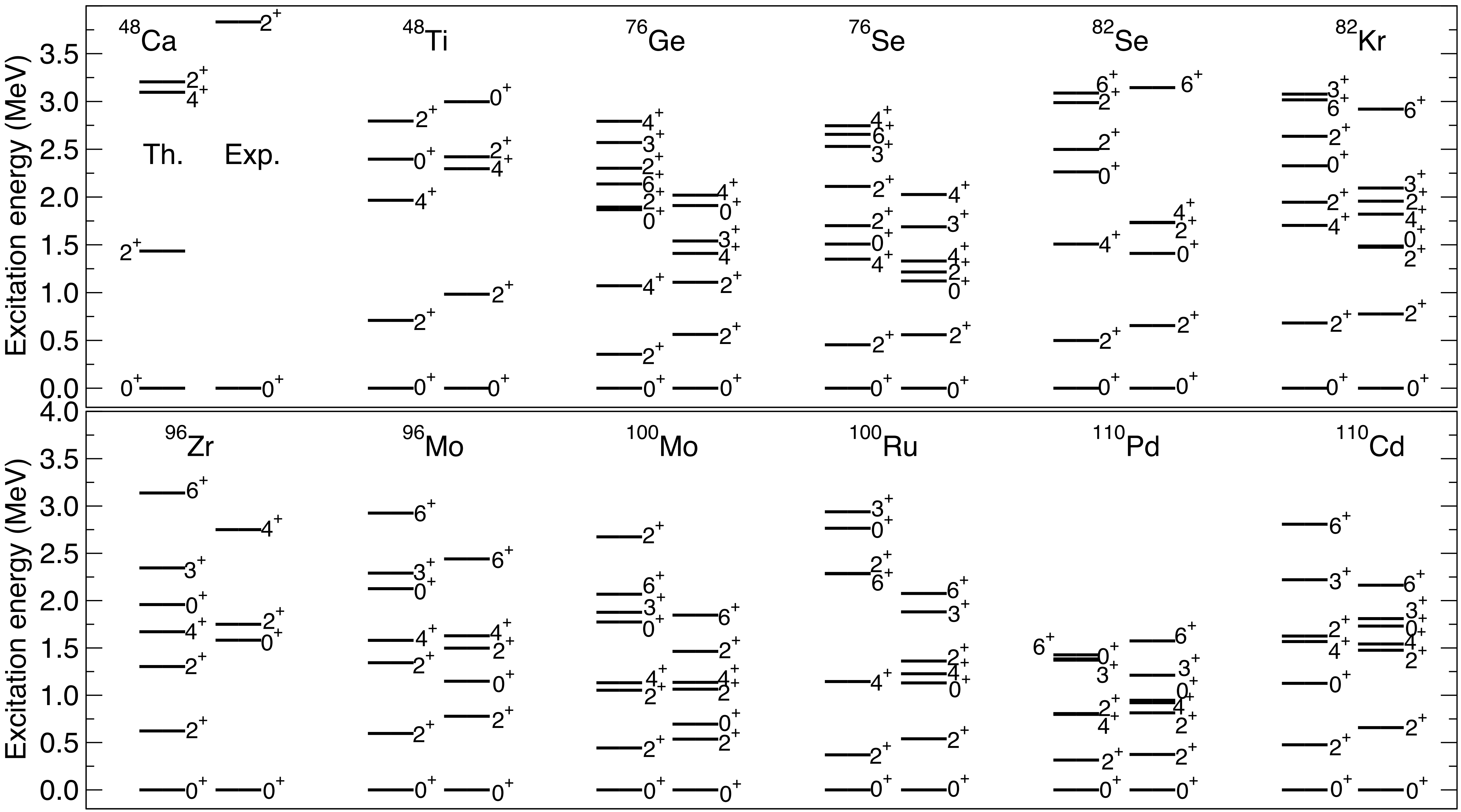


Energy spectra of odd-odd nuclei

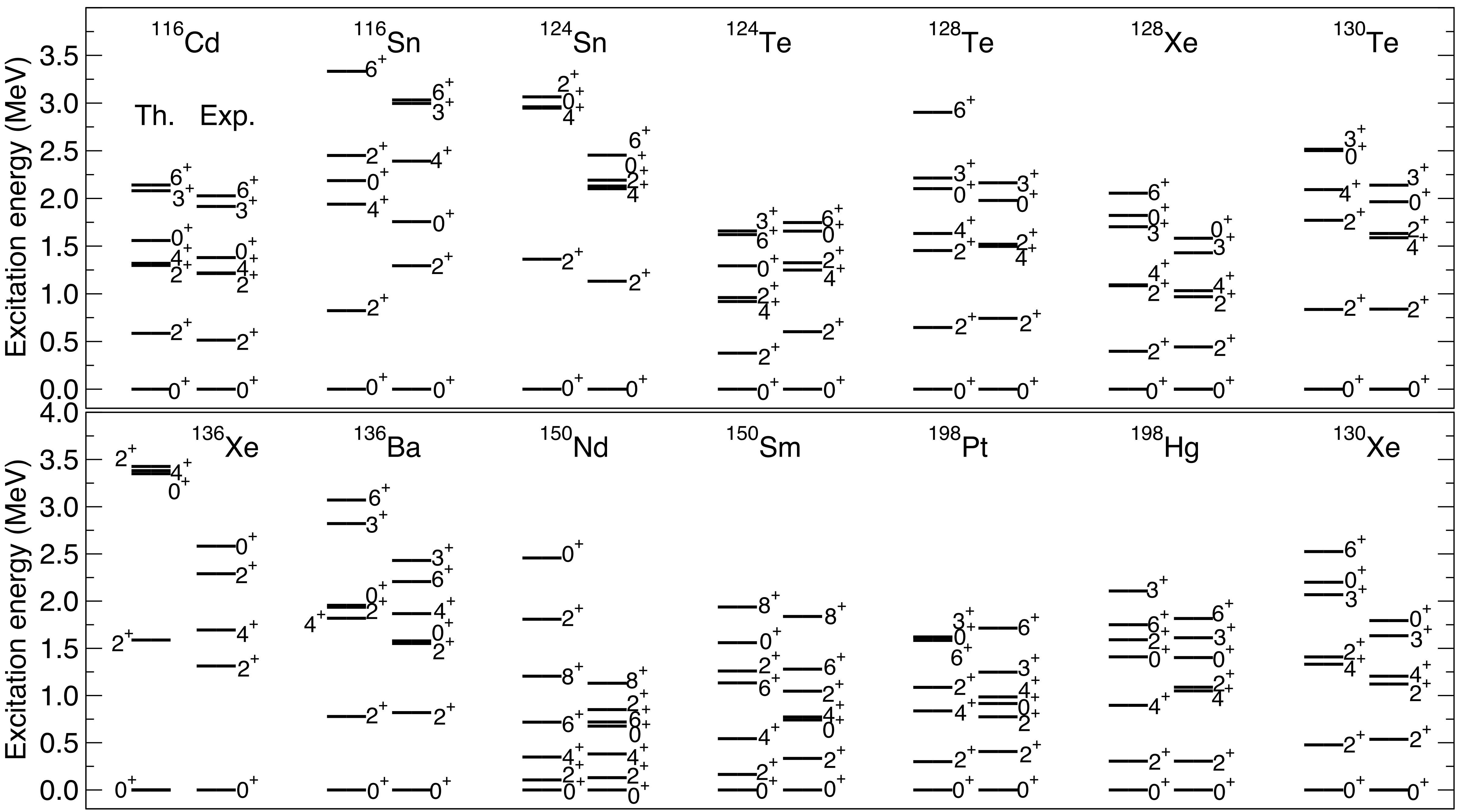




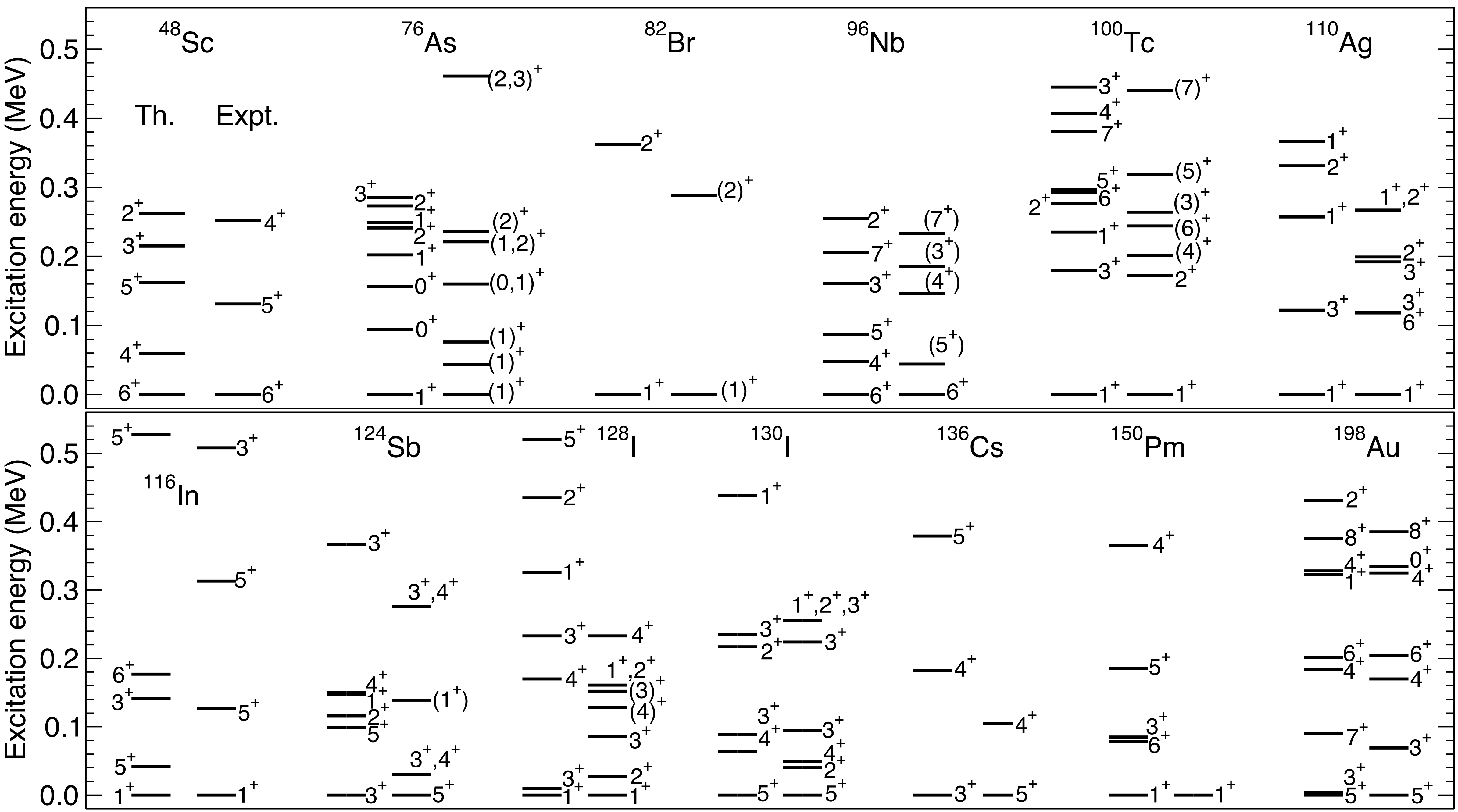
Energy spectra of even-even nuclei



Energy spectra of even-even nuclei



Energy spectra of odd-odd nuclei



$2\nu\beta\beta$ decay

Calculation of NME

$$M_{2\nu} = g_A^2 \cdot m_e c^2 \left[M_{2\nu}^{GT} - \left(\frac{g_V}{g_A} \right)^2 M_{2\nu}^{F} \right],$$

$$M_{2\nu}^{GT} = \sum_N \frac{\langle 0_F^+ \| t^+ \sigma \| 1_N^+ \rangle \langle 1_N^+ \| t^+ \sigma \| 0_{1,I}^+ \rangle}{E_N - E_I + \frac{1}{2}(Q_{\beta\beta} + 2m_e c^2)},$$

$$M_{2\nu}^{F} = \sum_N \frac{\langle 0_F^+ \| t^+ \| 0_N^+ \rangle \langle 0_N^+ \| t^+ \| 0_{1,I}^+ \rangle}{E_N - E_I + \frac{1}{2}(Q_{\beta\beta} + 2m_e c^2)},$$

GT and Fermi operators

$$t^{\pm} \longmapsto \hat{T}^{F} = \sum_{j_\nu j_\pi} \eta^{F}_{j_\nu j_\pi} \left(\hat{P}_{j_\nu} \times \hat{P}_{j_\pi} \right)^{(0)},$$

$$t^{\pm}\sigma \longmapsto \hat{T}^{GT} = \sum_{j_\nu j_\pi} \eta^{GT}_{j_\nu j_\pi} \left(\hat{P}_{j_\nu} \times \hat{P}_{j_\pi} \right)^{(1)},$$

with $\hat{P}_j$ given as one of

$$A^{\dagger}_{j_\rho m_\rho} = \zeta_{j_\rho} a^{\dagger}_{j_\rho m_\rho} + \sum_{j'_\rho} \zeta_{j_\rho j'_\rho} s^{\dagger}_\rho \left(\tilde{d}_\rho \times a^{\dagger}_{j'_\rho} \right)^{(j_\rho)}_{m_\rho}$$

$$B^{\dagger}_{j_\rho m_\rho} = \theta_{j_\rho} s^{\dagger}_\rho \tilde{a}_{j_\rho m_\rho} + \sum_{j'_\rho} \theta_{j_\rho j'_\rho} \left(d^{\dagger}_\rho \times \tilde{a}_{j'_\rho} \right)^{(j_\rho)}_{m_\rho}$$

and their H.C.

(u,v)-dependent forms

Dellagiacoma-Iachello (1989), etc.

Coefficients

$$\zeta_{j_\rho} = u_{j_\rho} \frac{1}{K'_{j_\rho}},$$

$$\zeta_{j_\rho j'_\rho} = -v_{j_\rho} \beta_{j'_\rho j_\rho} \sqrt{\frac{10}{N_\rho (2j_\rho + 1)}} \frac{1}{K K'_{j_\rho}},$$

$$\theta_{j_\rho} = \frac{v_{j_\rho}}{\sqrt{N_\rho}} \frac{1}{K''_{j_\rho}},$$

$$\theta_{j_\rho j'_\rho} = u_{j_\rho} \beta_{j'_\rho j_\rho} \sqrt{\frac{10}{2j_\rho + 1}} \frac{1}{K K''_{j_\rho}}.$$

with factors

$$K = \left(\sum_{j_\rho j'_\rho} \beta^2_{j_\rho j'_\rho} \right)^{1/2},$$

$$K'_{j_\rho} = \left[1 + 2\left(\frac{v_{j_\rho}}{u_{j_\rho}}\right)^2 \frac{\langle (\hat{n}_{s_\rho} + 1)\hat{n}_{d_\rho} \rangle_{0_1^+}}{N_\rho (2j_\rho + 1)} \frac{\sum_{j'_\rho} \beta^2_{j'_\rho j_\rho}}{K^2} \right]^{1/2},$$

$$K''_{j_\rho} = \left[\frac{\langle \hat{n}_{s_\rho} \rangle_{0_1^+}}{N_\rho} + 2\left(\frac{u_{j_\rho}}{v_{j_\rho}}\right)^2 \frac{\langle \hat{n}_{d_\rho} \rangle_{0_1^+}}{2j_\rho + 1} \frac{\sum_{j'_\rho} \beta^2_{j'_\rho j_\rho}}{K^2} \right]^{1/2},$$

… (u,v) amplitudes provided by the DFT

$Q_{\beta\beta}$ values

$$Q_{\beta\beta} = 2(m_n - m_p - m_e)c^2 + E^I_{\rm gs} - E^F_{\rm gs}$$

- $Q_{\beta\beta,\rm th}$: calculated by using the IBM eigenenergy: $E_{\rm gs} = E_{\rm IBM}(0^+_1) + E_0$
- $Q_{\beta\beta,\rm ex}$: experimental value

… 1~2 MeV difference

Nucleus	$Q_{\beta\beta,\rm th}$ (MeV)	$Q_{\beta\beta,\rm ex}$ (MeV)
^{48}Ca	1.8479	4.2681
^{76}Ge	0.8831	2.0391
^{82}Se	1.6356	2.9979
^{96}Zr	4.1285	3.3560
^{100}Mo	2.8338	3.0344
^{110}Pd	2.9081	2.0171
^{116}Cd	6.1166	2.8135
^{124}Sn	−0.3795	2.2927
^{128}Te	−0.1784	0.8680
^{130}Te	1.4466	2.5290
^{136}Xe	0.0989	2.4579
^{150}Nd	3.3123	3.3714
^{198}Pt	1.2895	1.0503

GT and Fermi matrix elements

	0_1^+				0_2^+			
	$M_{2\nu}^{GT}$		$M_{2\nu}^{F}$		$M_{2\nu}^{GT}$		$M_{2\nu}^{F}$	
Decay	$Q_{\beta\beta,\mathrm{th}}$	$Q_{\beta\beta,\mathrm{ex}}$	$Q_{\beta\beta,\mathrm{th}}$	$Q_{\beta\beta,\mathrm{ex}}$	$Q_{\beta\beta,\mathrm{th}}$	$Q_{\beta\beta,\mathrm{ex}}$	$Q_{\beta\beta,\mathrm{th}}$	$Q_{\beta\beta,\mathrm{ex}}$
$^{48}Ca \to {}^{48}Ti$	0.060	0.042	0.024	0.016	0.325	0.066	−0.142	−0.075
$^{76}Ge \to {}^{76}Se$	0.040	0.034	−0.007	−0.007	0.097	0.078	−0.085	−0.069
$^{82}Se \to {}^{82}Kr$	−0.060	-0.045	0.017	0.015	0.124	0.070	−0.081	−0.064
$^{96}Zr \to {}^{96}Mo$	0.139	0.154	−0.001	−0.001	0.053	0.063	−0.000	−0.000
$^{100}Mo \to {}^{100}Ru$	0.513	0.483	−0.000	−0.000	−0.007	−0.020	0.000	0.000
$^{110}Pd \to {}^{110}Cd$	0.071	0.080	0.000	0.000	−0.052	−0.062	0.000	0.000
$^{116}Cd \to {}^{116}Sn$	0.148	0.275	0.001	0.001	0.032	−0.037	−0.001	−0.001
$^{124}Sn \to {}^{124}Te$	0.123	0.074	−0.054	−0.045	0.345	−0.066	0.016	0.012
$^{128}Te \to {}^{128}Xe$	−0.139	−0.102	0.006	0.005	0.108	0.032	0.002	0.002
$^{130}Te \to {}^{130}Xe$	−0.041	−0.037	0.025	0.022	0.043	0.037	−0.019	−0.017
$^{136}Xe \to {}^{136}Ba$	−0.173	−0.102	0.028	0.028	−2.807	0.010	0.009	0.001
$^{150}Nd \to {}^{150}Sm$	−0.375	−0.369	0.000	0.000	−0.414	−0.390	−0.000	−0.000
$^{198}Pt \to {}^{198}Hg$	−0.016	−0.016	0.001	0.001	−0.008	−0.010	−0.000	−0.000

Results are similar between $Q_{\beta\beta,\mathrm{th}}$ and $Q_{\beta\beta,\mathrm{ex}}$ for the $0_1^+ \to 0_1^+$ decay, and significantly different for the $0_1^+ \to 0_2^+$ decay

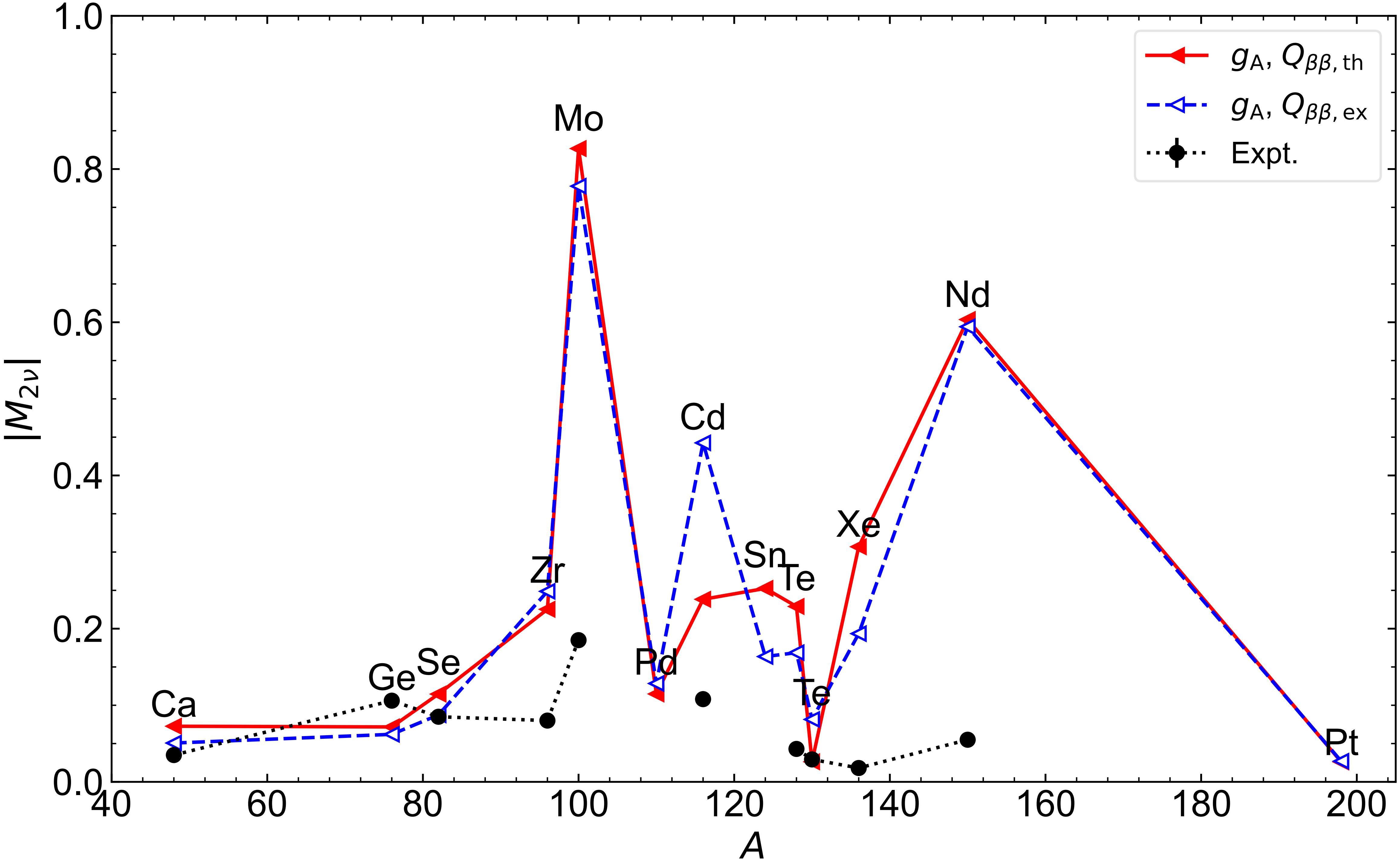
Isospin symmetry breaking

$$\chi_F(0^+) = M^{\mathrm{F}}_{2\nu} / M^{\mathrm{GT}}_{2\nu}$$

	$Q_{\beta\beta,\mathrm{th}}$	
Nucleus	$\chi_F(0_1^+)$	$\chi_F(0_2^+)$
^{48}Ca	0.401	−0.435
^{76}Ge	−0.179	−0.874
^{82}Se	−0.287	−0.650
^{96}Zr	−0.006	−0.003
^{100}Mo	−0.000	−0.005
^{110}Pd	0.000	−0.000
^{116}Cd	0.004	−0.021
^{124}Sn	−0.443	0.046
^{128}Te	−0.040	0.016
^{130}Te	−0.104	−0.093
^{136}Xe	−0.163	−0.003
^{150}Nd	−0.001	0.000
^{198}Pt	−0.060	0.036

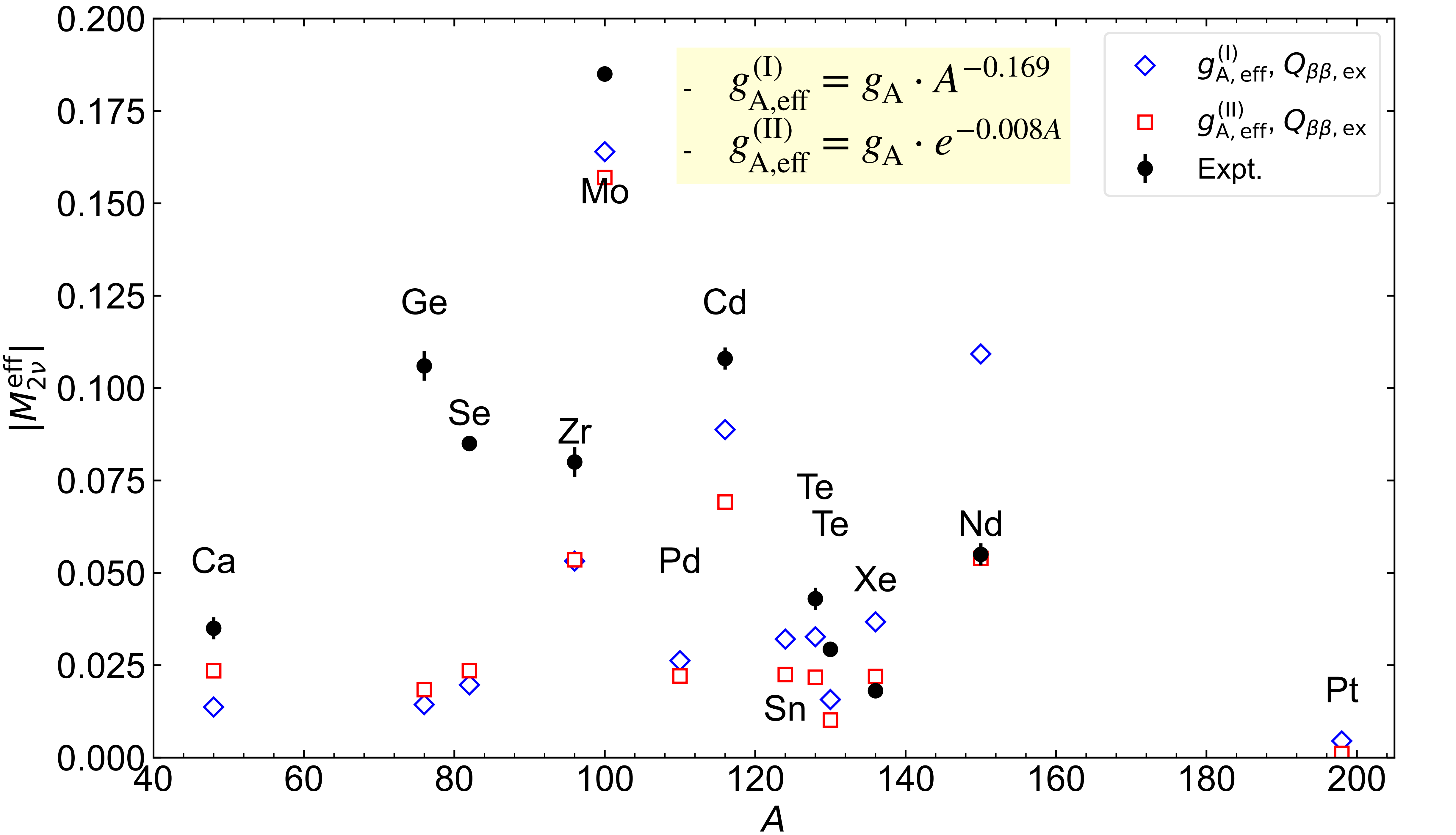
… appears when the protons and neutrons are in the same shells

NMEs

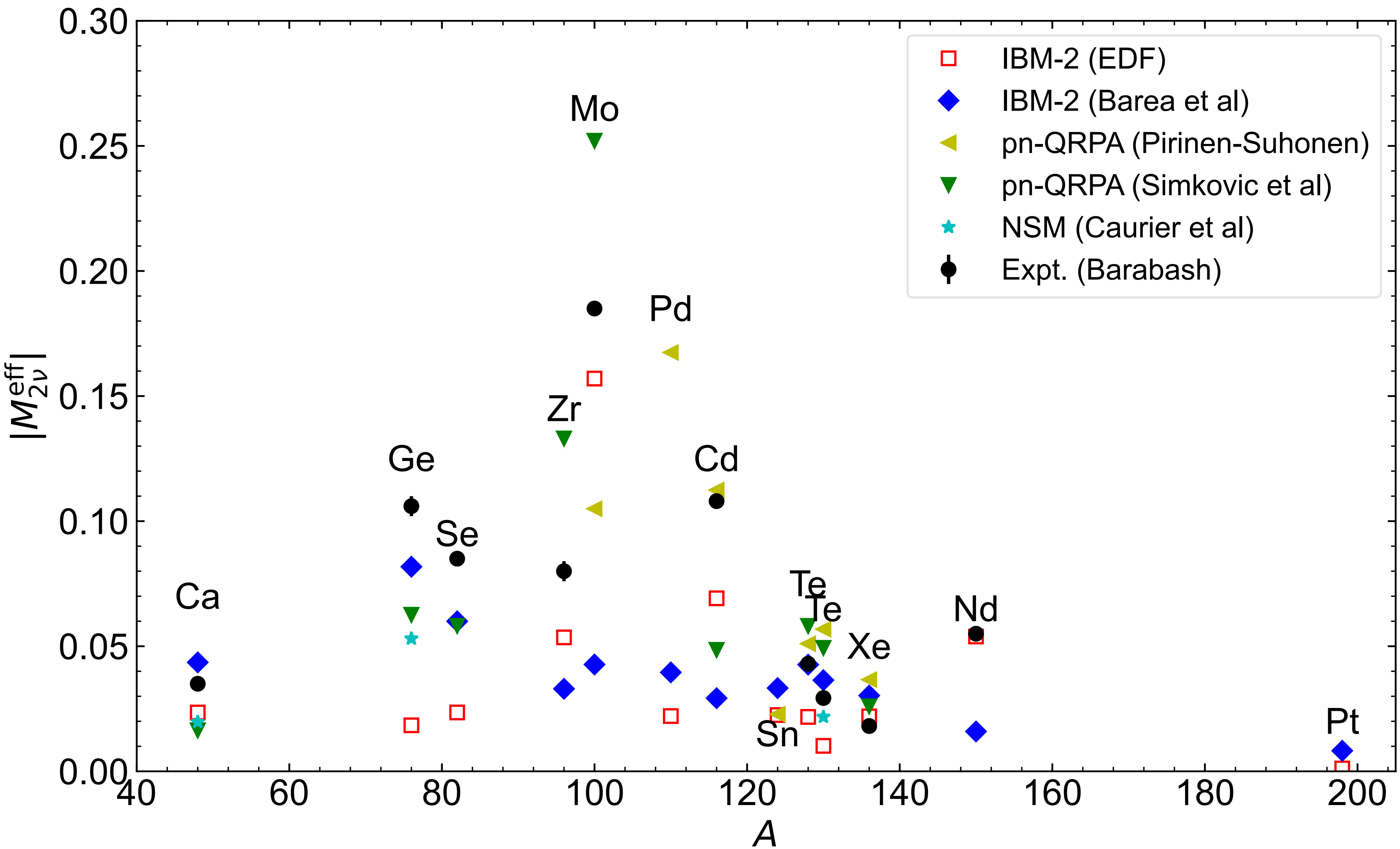


g_A, $Q_{\beta\beta,\mathrm{th}}$
g_A, $Q_{\beta\beta,\mathrm{ex}}$
Expt.
Mo
Nd
Cd
Xe
Sn
Te
Zr
Pd
Se
Ge
Ca
Te
Pt
$|M_{2\nu}|$
A
1.0
0.8
0.6
0.4
0.2
0.0
40
60
80
100
120
140
160
180
200

Effective NMEs



Comparison with other predictions



Half-lives

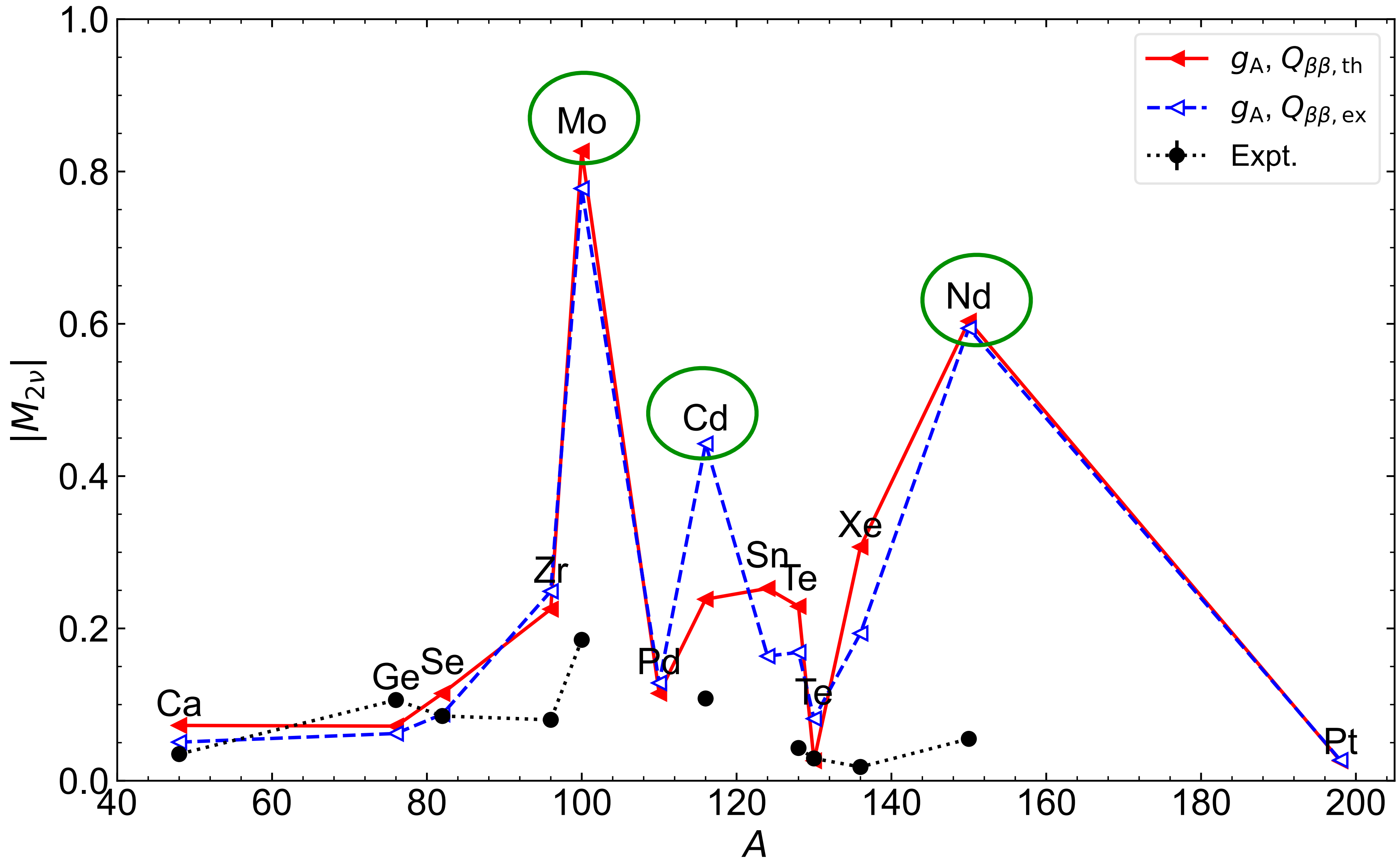
Decay	$\tau_{1/2}^{(2\nu)}$ (yr), with $Q_{\beta\beta,\mathrm{ex}}$			
	g_A	$g_{A,\mathrm{eff}}^{(I)}$	$g_{A,\mathrm{eff}}^{(II)}$	Expt. [12]
$^{48}\mathrm{Ca} \to {}^{48}\mathrm{Ti}$	2.50×10^{19}	3.43×10^{20}	1.16×10^{20}	$5.3^{+1.2}_{-0.8} \times 10^{19}$
$^{76}\mathrm{Ge} \to {}^{76}\mathrm{Se}$	5.39×10^{21}	1.01×10^{23}	6.14×10^{22}	$(1.88 \pm 0.08) \times 10^{21}$
$^{82}\mathrm{Se} \to {}^{82}\mathrm{Kr}$	8.20×10^{19}	1.61×10^{21}	1.13×10^{21}	$(0.87^{+0.02}_{-0.01}) \times 10^{20}$
$^{96}\mathrm{Zr} \to {}^{96}\mathrm{Mo}$	2.37×10^{18}	5.19×10^{19}	5.12×10^{19}	$(2.3 \pm 0.2) \times 10^{19}$
$^{100}\mathrm{Mo} \to {}^{100}\mathrm{Ru}$	5.00×10^{17}	1.12×10^{19}	1.23×10^{19}	$(7.06^{+0.15}_{-0.13}) \times 10^{18}$
$^{100}\mathrm{Mo} \to {}^{100}\mathrm{Ru}(0_2^+)$	1.59×10^{22}	3.57×10^{23}	3.90×10^{23}	$6.7^{+0.5}_{-0.4} \times 10^{20}$
$^{110}\mathrm{Pd} \to {}^{110}\mathrm{Cd}$	4.40×10^{20}	1.06×10^{22}	1.49×10^{22}	
$^{116}\mathrm{Cd} \to {}^{116}\mathrm{Sn}$	1.85×10^{18}	4.59×10^{19}	7.56×10^{19}	$(2.69 \pm 0.09) \times 10^{19}$
$^{124}\mathrm{Sn} \to {}^{124}\mathrm{Te}$	6.76×10^{19}	1.76×10^{21}	3.57×10^{21}	
$^{128}\mathrm{Te} \to {}^{128}\mathrm{Xe}$	1.31×10^{23}	3.48×10^{24}	7.86×10^{24}	$(2.25 \pm 0.09) \times 10^{24}$
$^{130}\mathrm{Te} \to {}^{130}\mathrm{Xe}$	9.85×10^{19}	2.65×10^{21}	6.31×10^{21}	$(7.91 \pm 0.21) \times 10^{20}$
$^{136}\mathrm{Xe} \to {}^{136}\mathrm{Ba}$	1.86×10^{19}	5.16×10^{20}	1.45×10^{21}	$(2.18 \pm 0.05) \times 10^{21}$
$^{150}\mathrm{Nd} \to {}^{150}\mathrm{Sm}$	7.78×10^{16}	2.30×10^{18}	9.45×10^{18}	$(9.34 \pm 0.65) \times 10^{18}$
$^{150}\mathrm{Nd} \to {}^{150}\mathrm{Sm}(0_2^+)$	5.84×10^{17}	1.73×10^{19}	7.10×10^{19}	$1.2^{+0.3}_{-0.2} \times 10^{20}$
$^{198}\mathrm{Pt} \to {}^{198}\mathrm{Hg}$	8.95×10^{22}	3.20×10^{24}	5.09×10^{25}	

$$\left[\tau_{1/2}^{(2\nu)}\right]^{-1} = G_{2\nu} |M_{2\nu}|^2$$

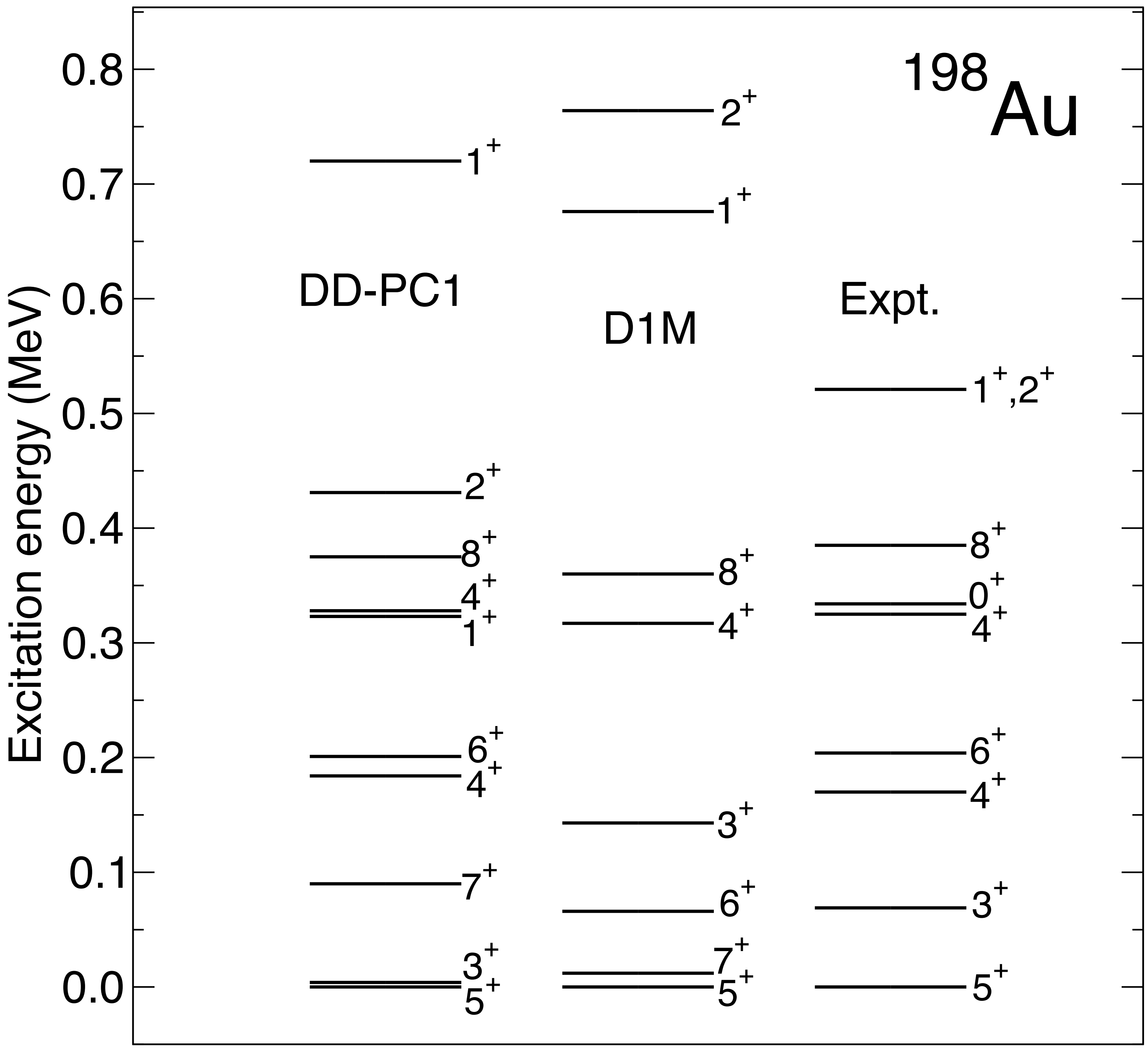
Phase-space factor: Kotila-Iachello (2012)
Experiment: Barabash, Universe (2020)

Source of uncertainties

- SCMF: choice of the EDF, pairing properties, … etc.
- IBM/IBFFM: Hamiltonian, model space, … etc.



Sensitivity to the EDFs



… from the mapped IBM using the Gogny-D1M EDF.

Sensitivity to the EDFs

	0_1^+			0_2^+		
EDF	$M_{2\nu}^{\mathrm{GT}}$	$M_{2\nu}^{\mathrm{F}}$	$\lvert M_{2\nu}\rvert$	$M_{2\nu}^{\mathrm{GT}}$	$M_{2\nu}^{\mathrm{F}}$	$\lvert M_{2\nu}\rvert$
DD-PC1	−0.016	0.001	0.026	−0.008	−0.000	0.012
D1M	−0.074	0.000	0.120	−0.034	−0.000	0.054

larger $|M_{2\nu}|$ with Gogny EDF

Pairing interaction in the SCMF

… separable pairing force of finite range

Tian, Ma, Ring (2009)

$$V(\mathbf{r}_1, \mathbf{r}_2, \mathbf{r}'_1, \mathbf{r}'_2) = -V\delta(\mathbf{R} - \mathbf{R}')P(\mathbf{r})P(\mathbf{r}')\frac{1}{2}(1 - P^\sigma),$$

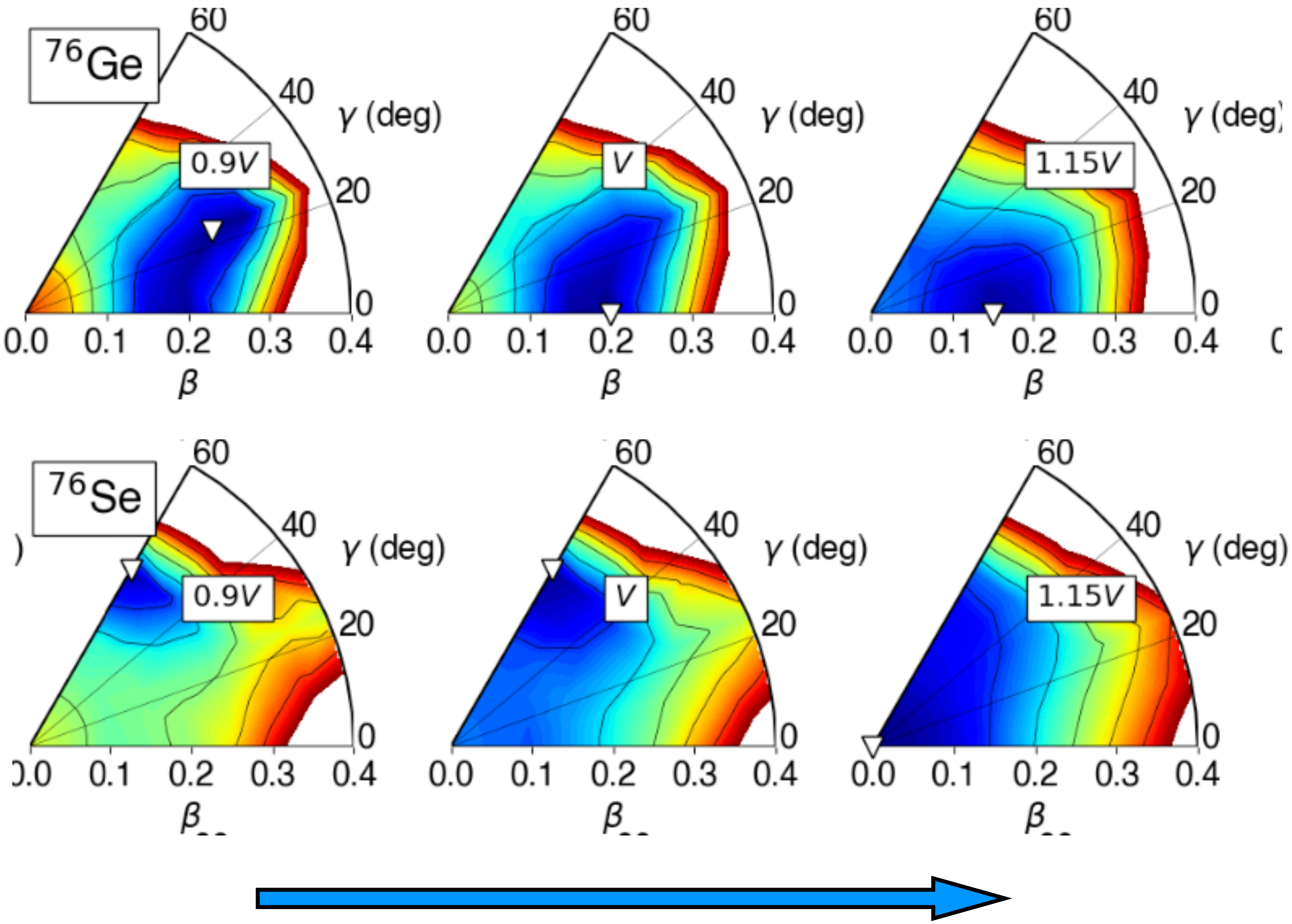
$$P(\mathbf{r}) = \frac{1}{(4\pi a^2)^{3/2}} e^{-\mathbf{r}^2/4a^2}$$

… strength V=728 MeV fm3 fit to Gogny D1S pairing gap

compare results with the pairing strength

- 10 % reduced
- default
- 15 % enhanced

Sensitivity to the pairing strength



increased pairing strength favors less pronounced deformation

Influence on IBM parameters

IBM-2 Hamiltonian:

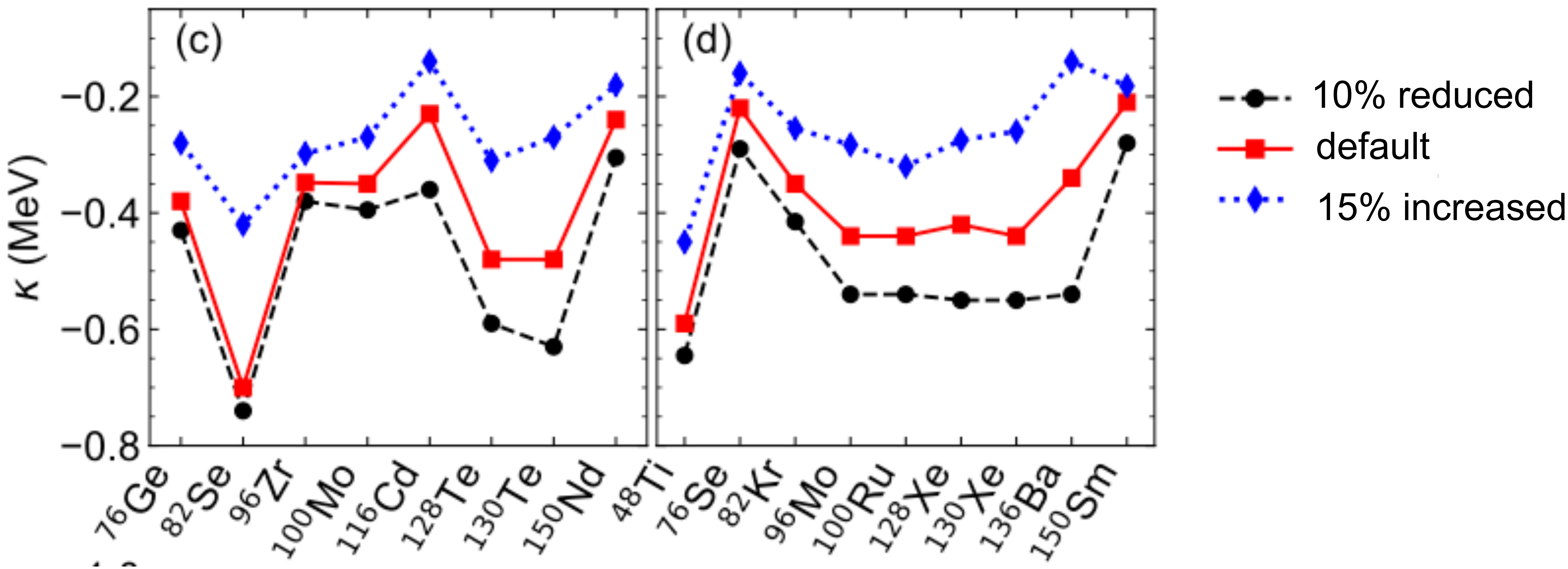
$$\hat{H}_{\text{IBM}} = \epsilon_d (\hat{n}_{d_\nu} + \hat{n}_{d_\pi}) + \kappa \hat{Q}_\nu \cdot \hat{Q}_\pi + \kappa' \hat{L} \cdot \hat{L}$$

pairing-like (spherical driving)

quadrupole-quadrupole (deformation driving)

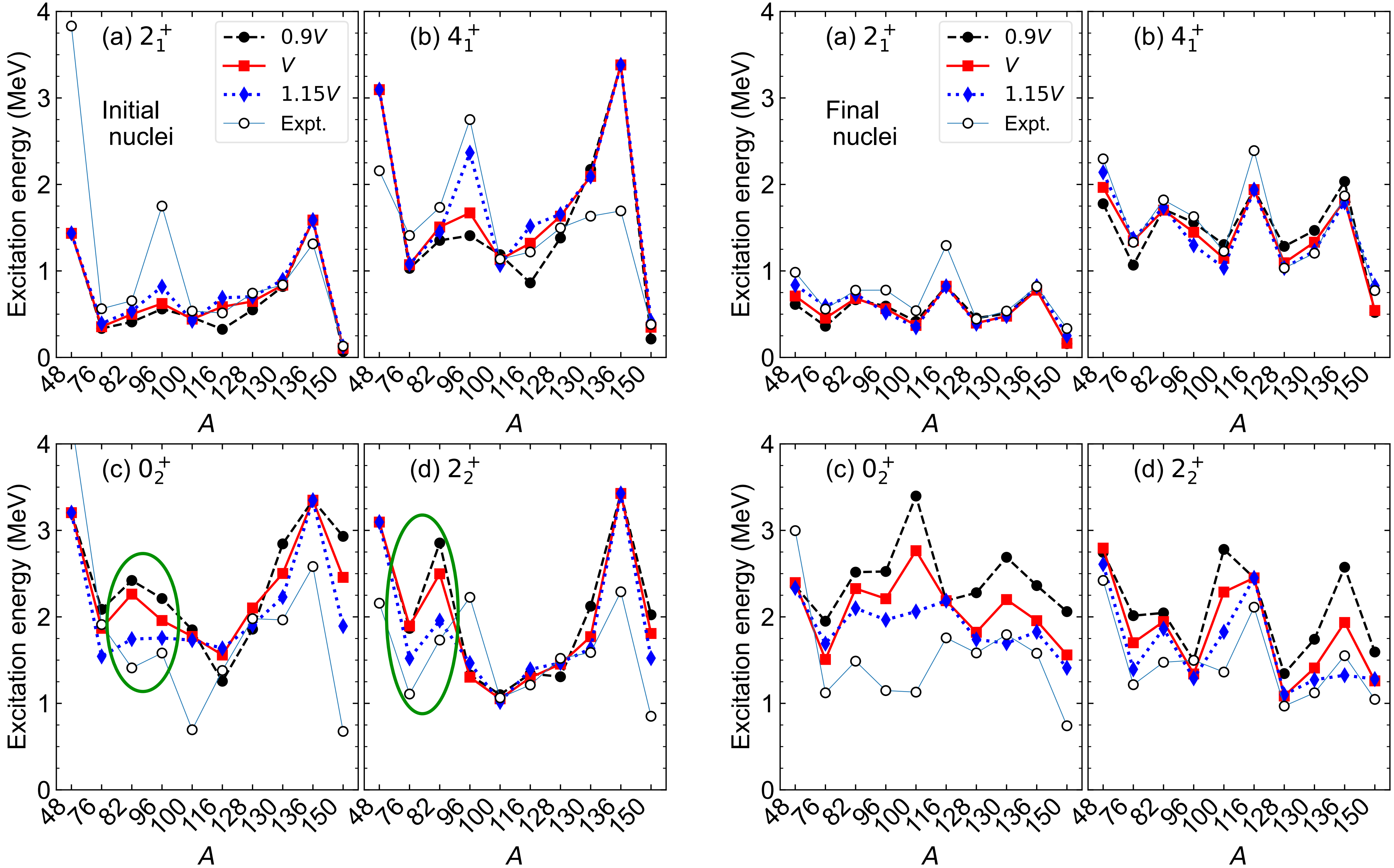
… disagreement with the 0_2^+ states is due to a too large QQ strength, as the SCMF PES exhibits a too pronounced deformation

Derived QQ strength



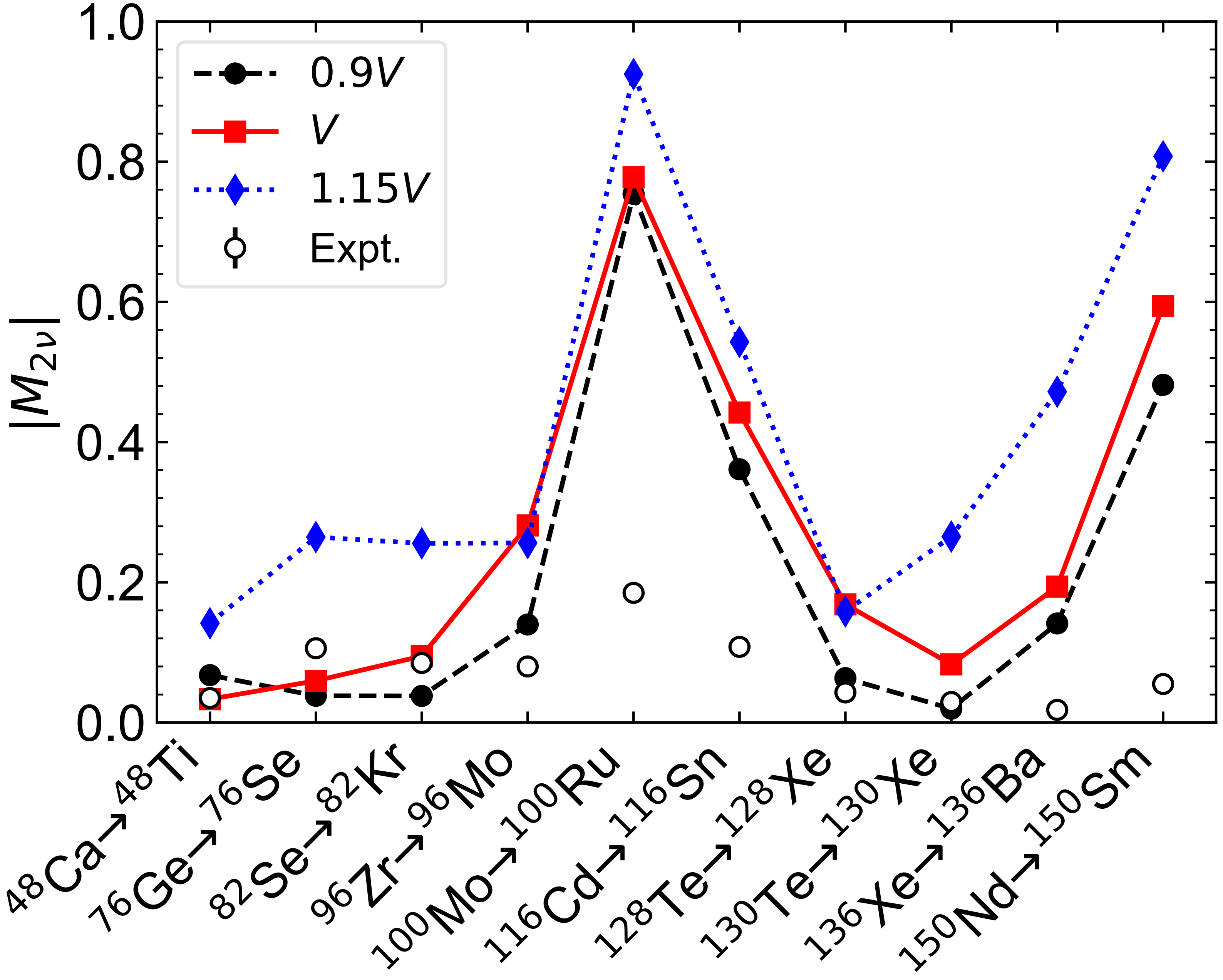
… QQ strength reduced with the enhanced pairing

Impacts on energy spectra

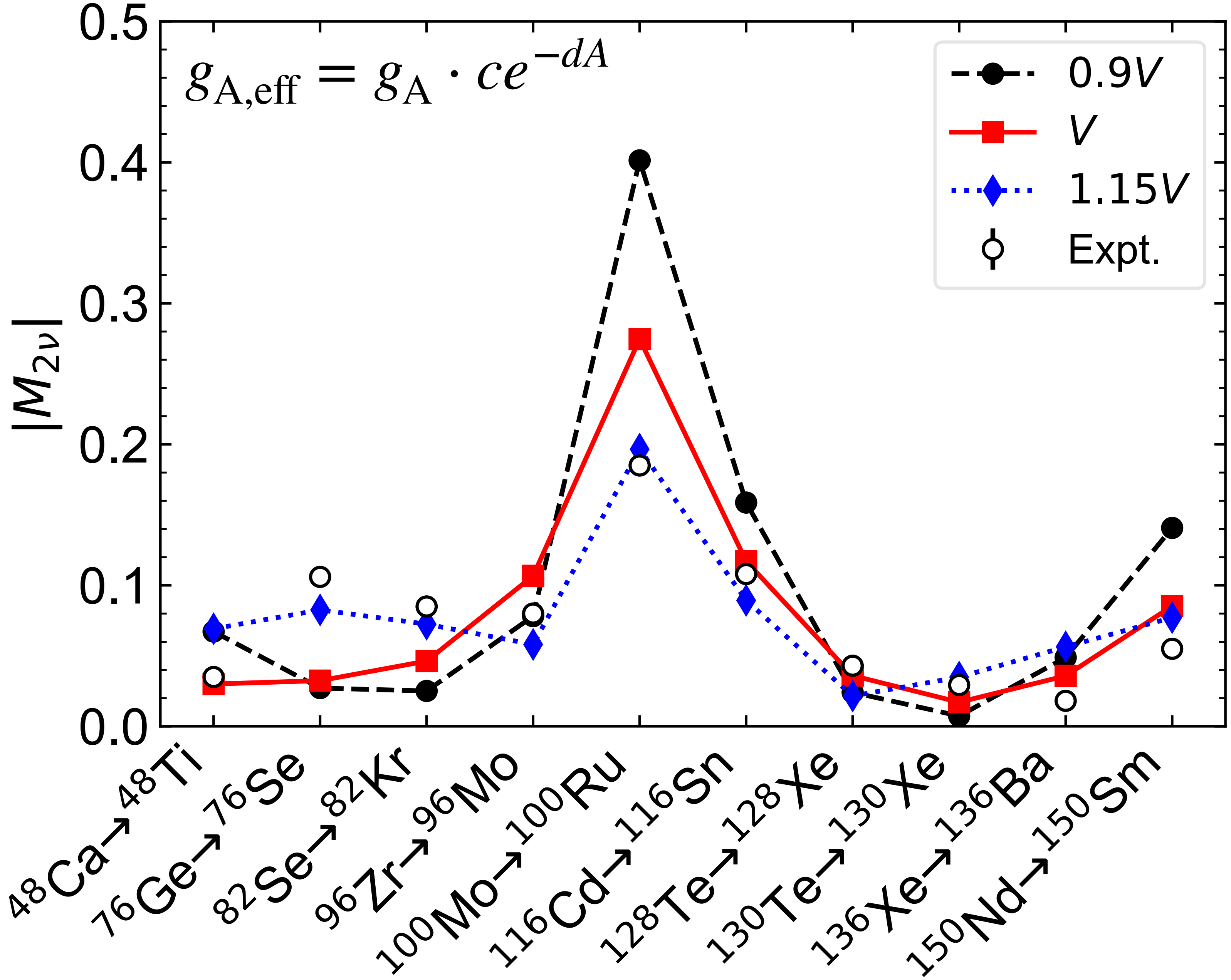


0_2^+ and 2_2^+ energy levels are lowered with the increased (+15%) pairing

Unquenched NMEs

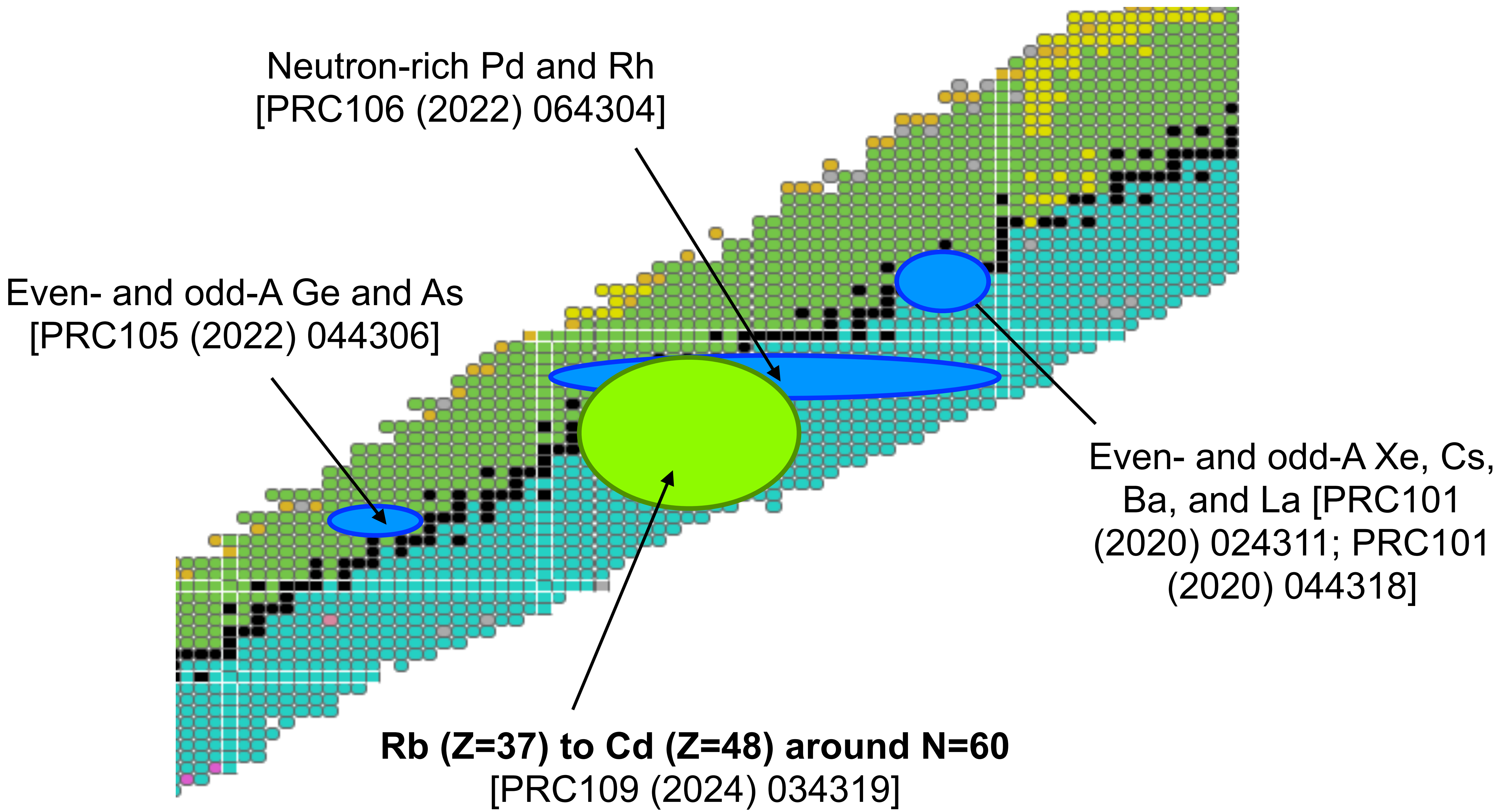


Effective NMEs

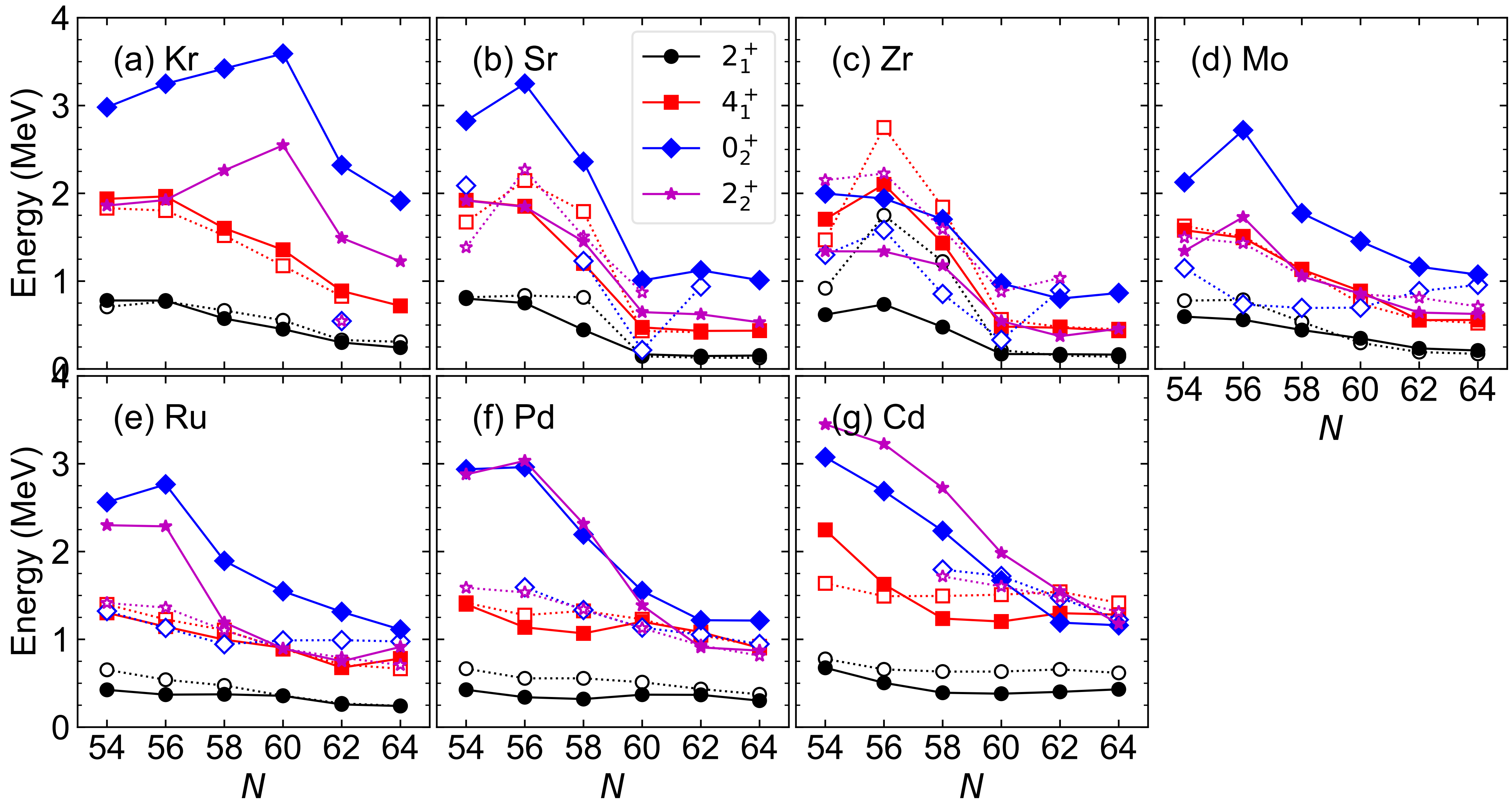


Single β decay

Mapped IBM applied to β decay

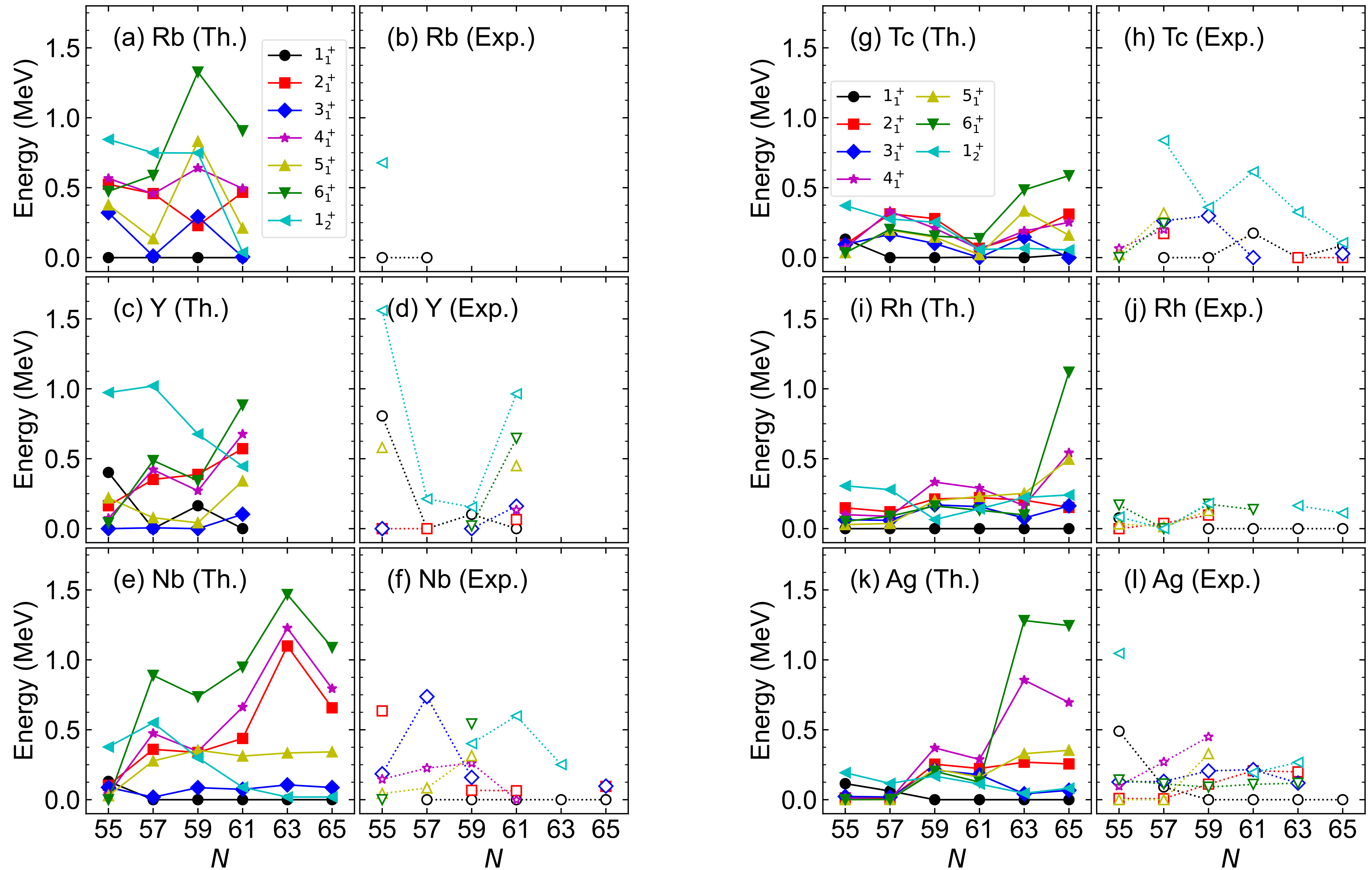


Energy spectra of even-even nuclei

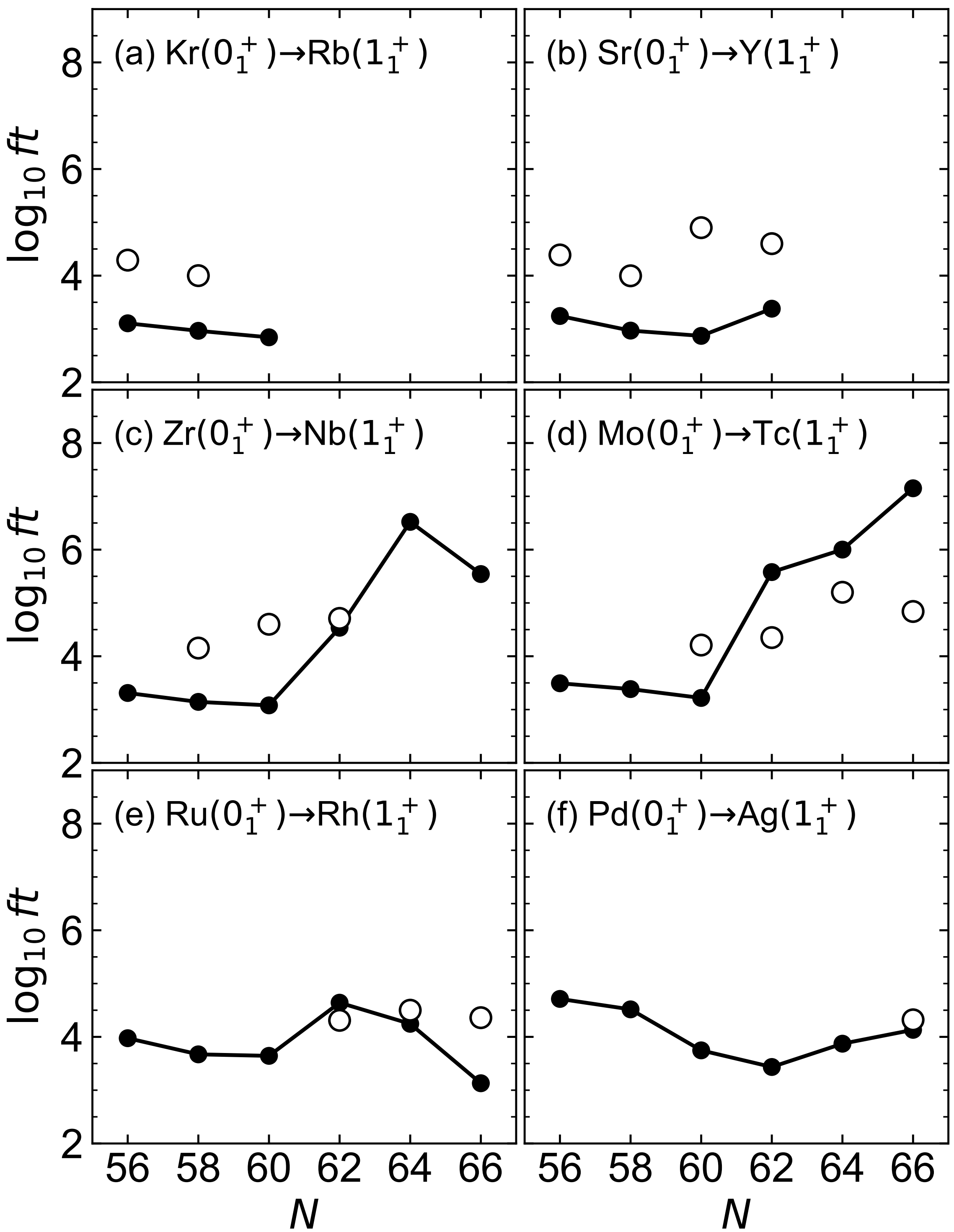


mapped IBM results based on the DD-PC1 EDF

Energy spectra of odd-odd nuclei



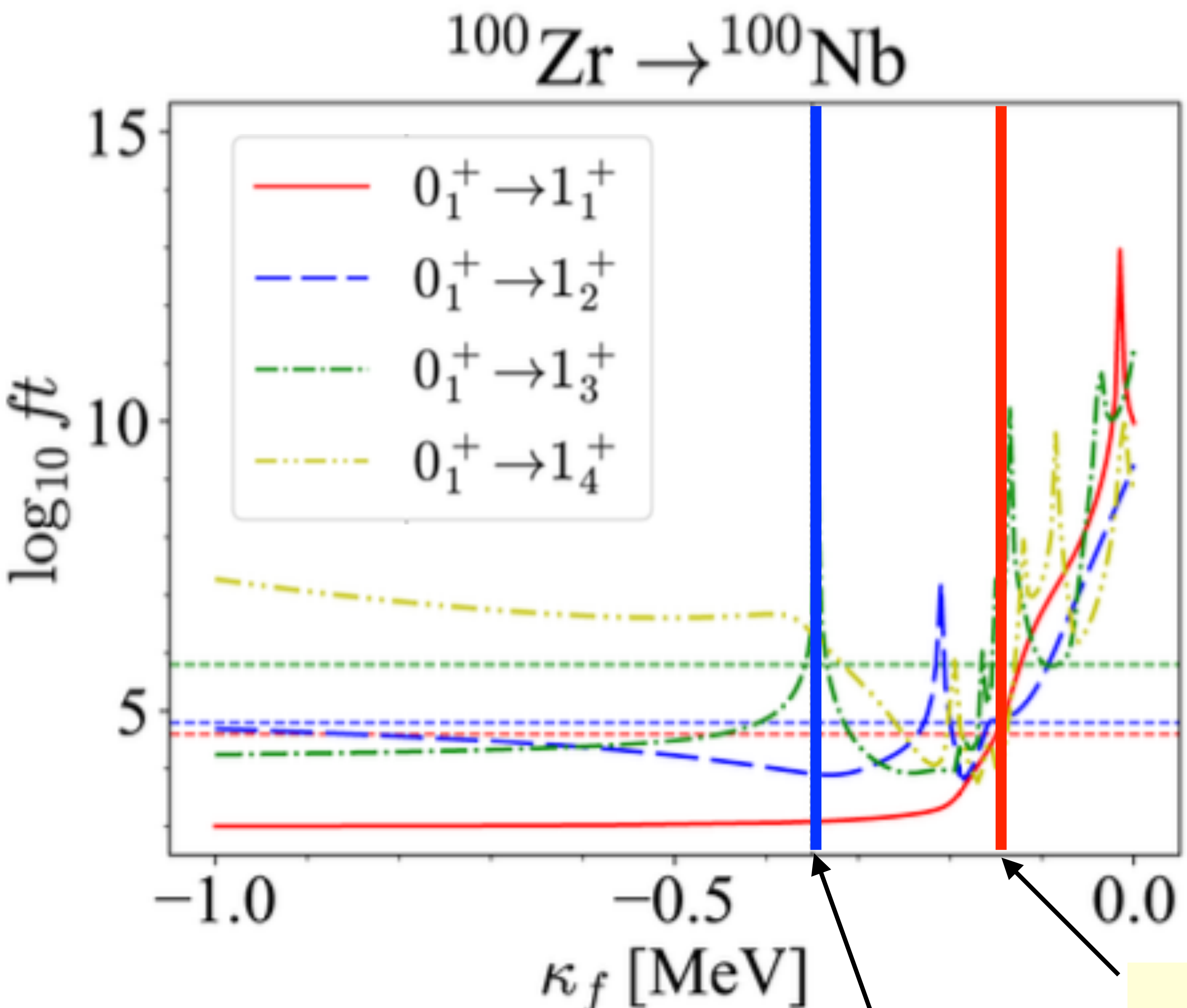
β^- decay log(ft)



Significant change of log(ft) around N=60, reflecting a shape phase transition

Phys. Rev. C 109 (2024) 034319

log(ft) as a constraint to IBM-2



derived value from the mapping

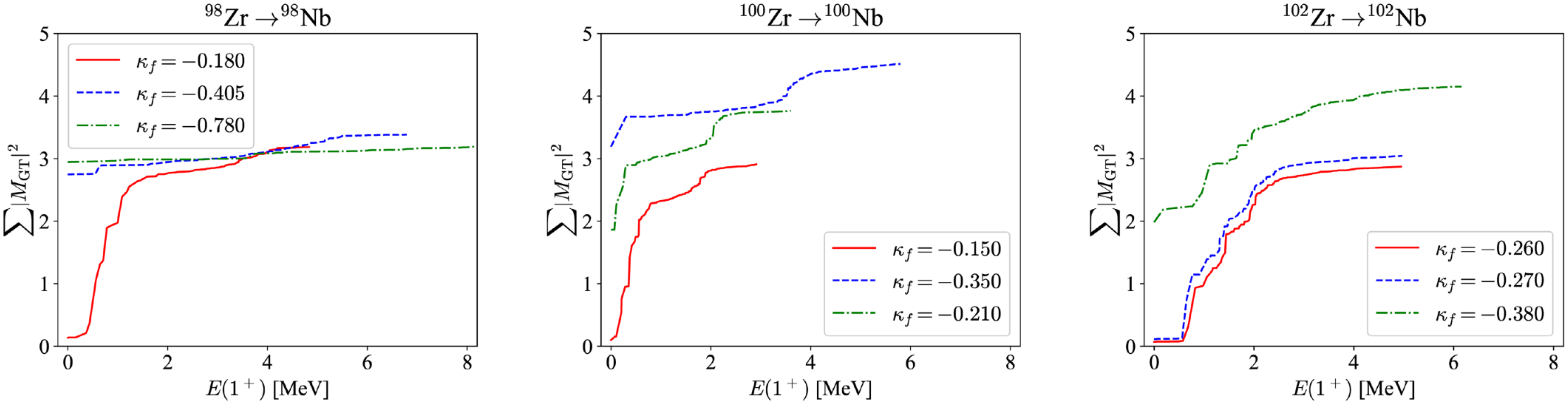
value required to reproduce experimental log(ft)

… QQ strength κ_f for the IBFFM-2 should be reduced by ~50%

M. Homma, K.N., arXiv: 2404.14624

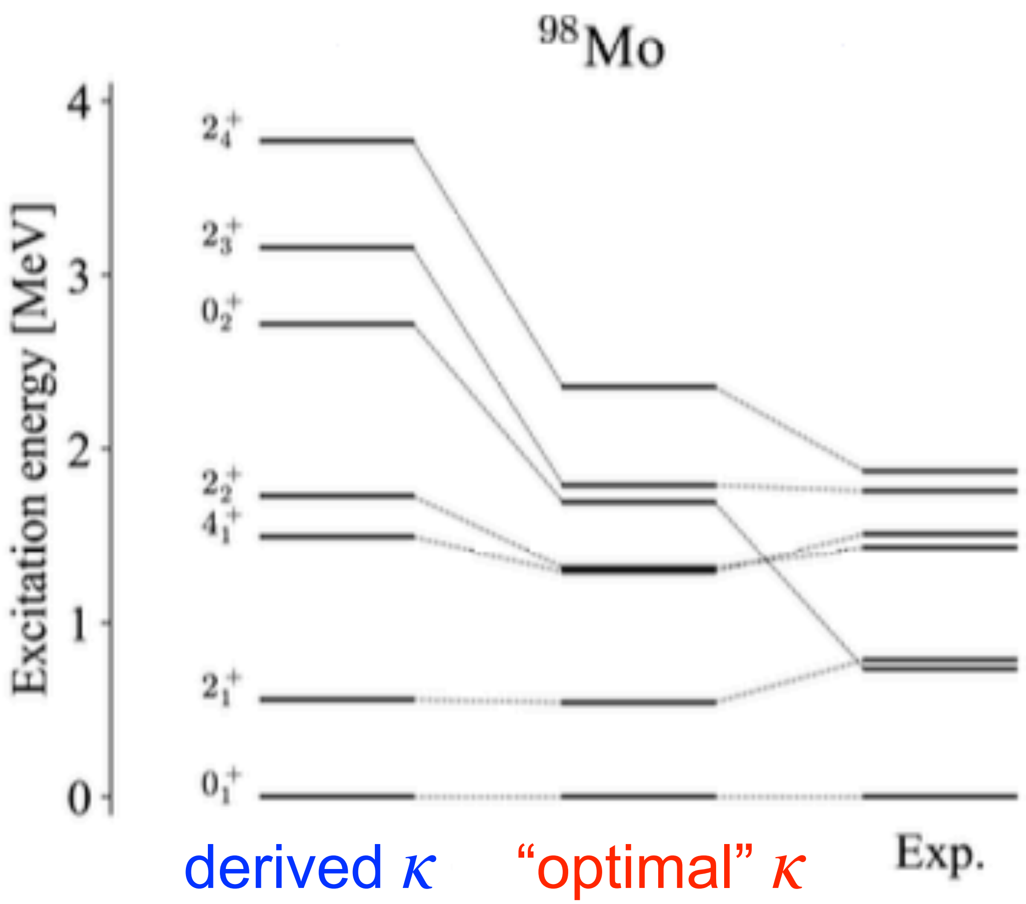
GT running sums

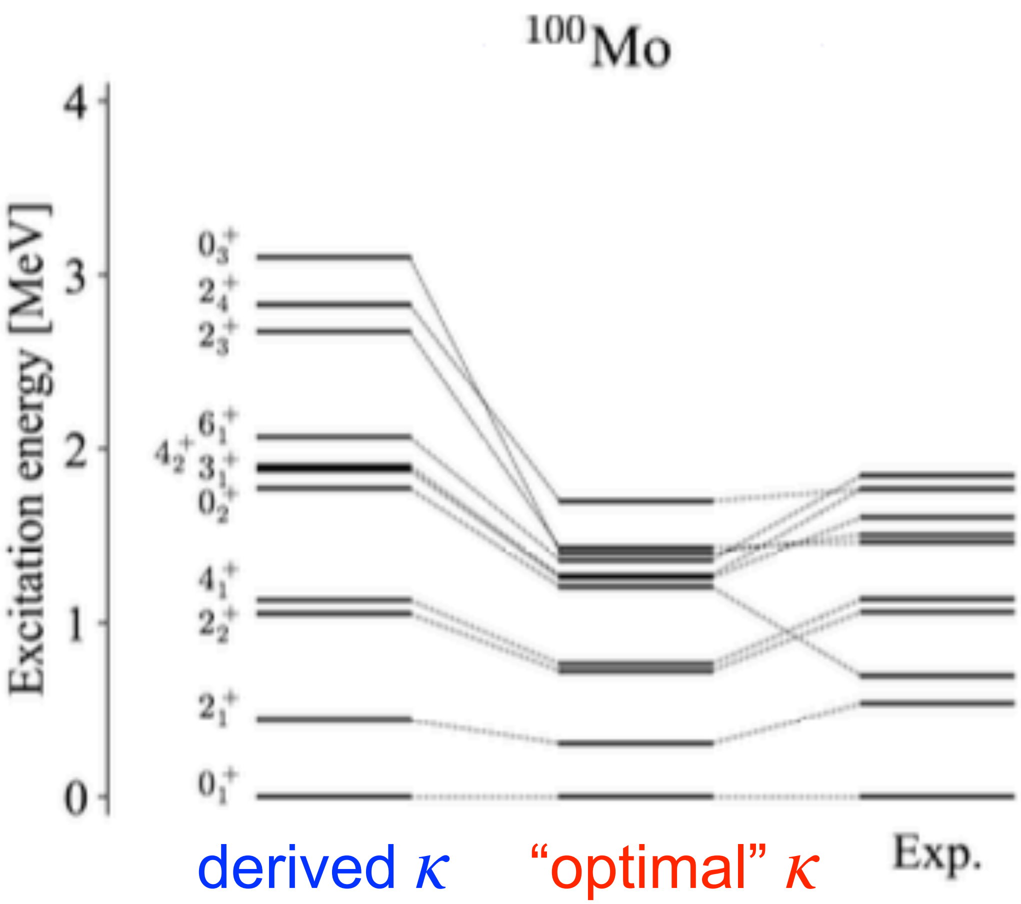
— "optimal" QQ strength



… reduced QQ strength giving smaller GT matrix element for neutron-rich Zr

Comparisons of spectra





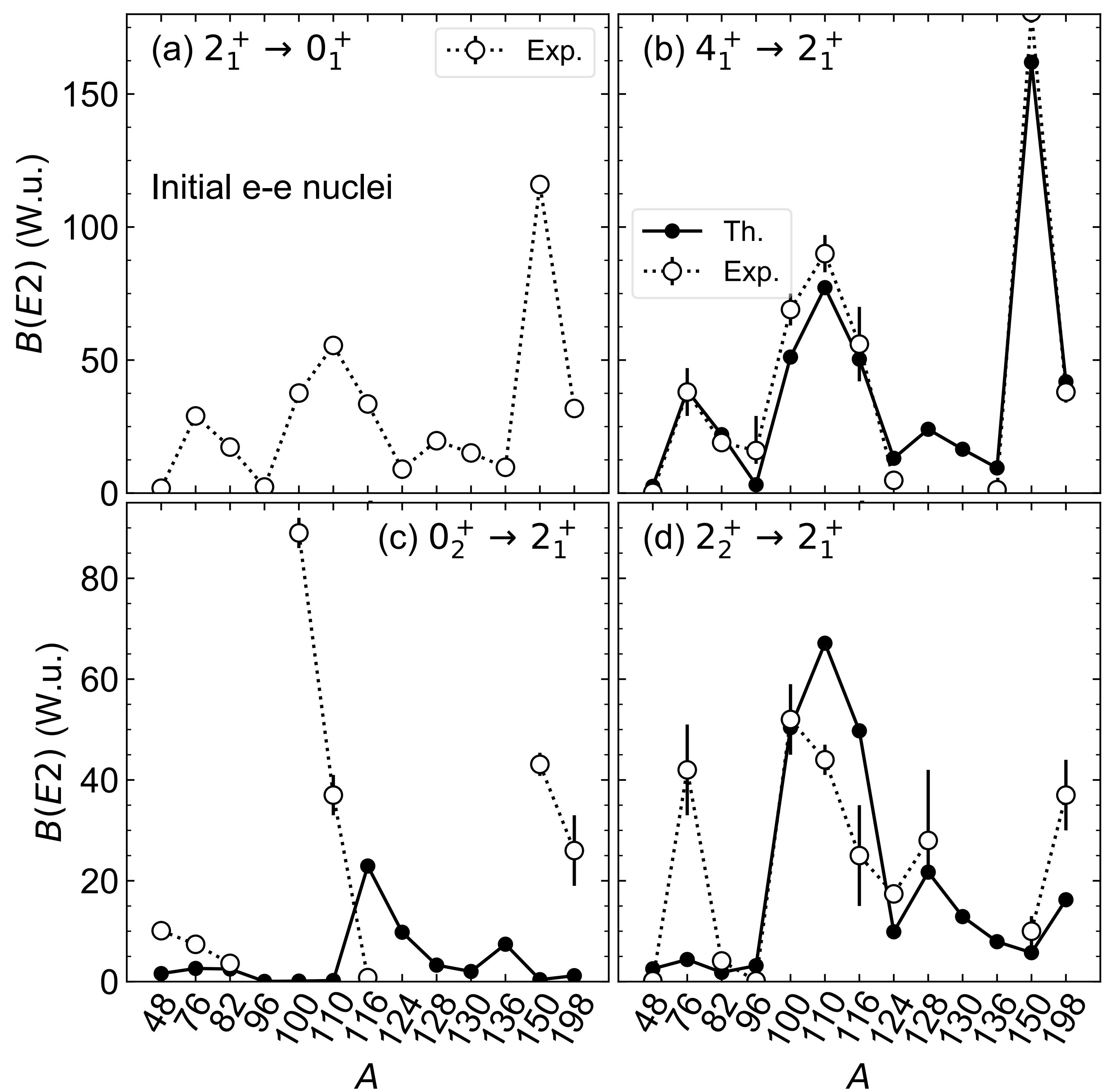
improvement over the mapped IBM-2 results for ^{A}Mo (= ^{A}Nb + p - n)

Summary

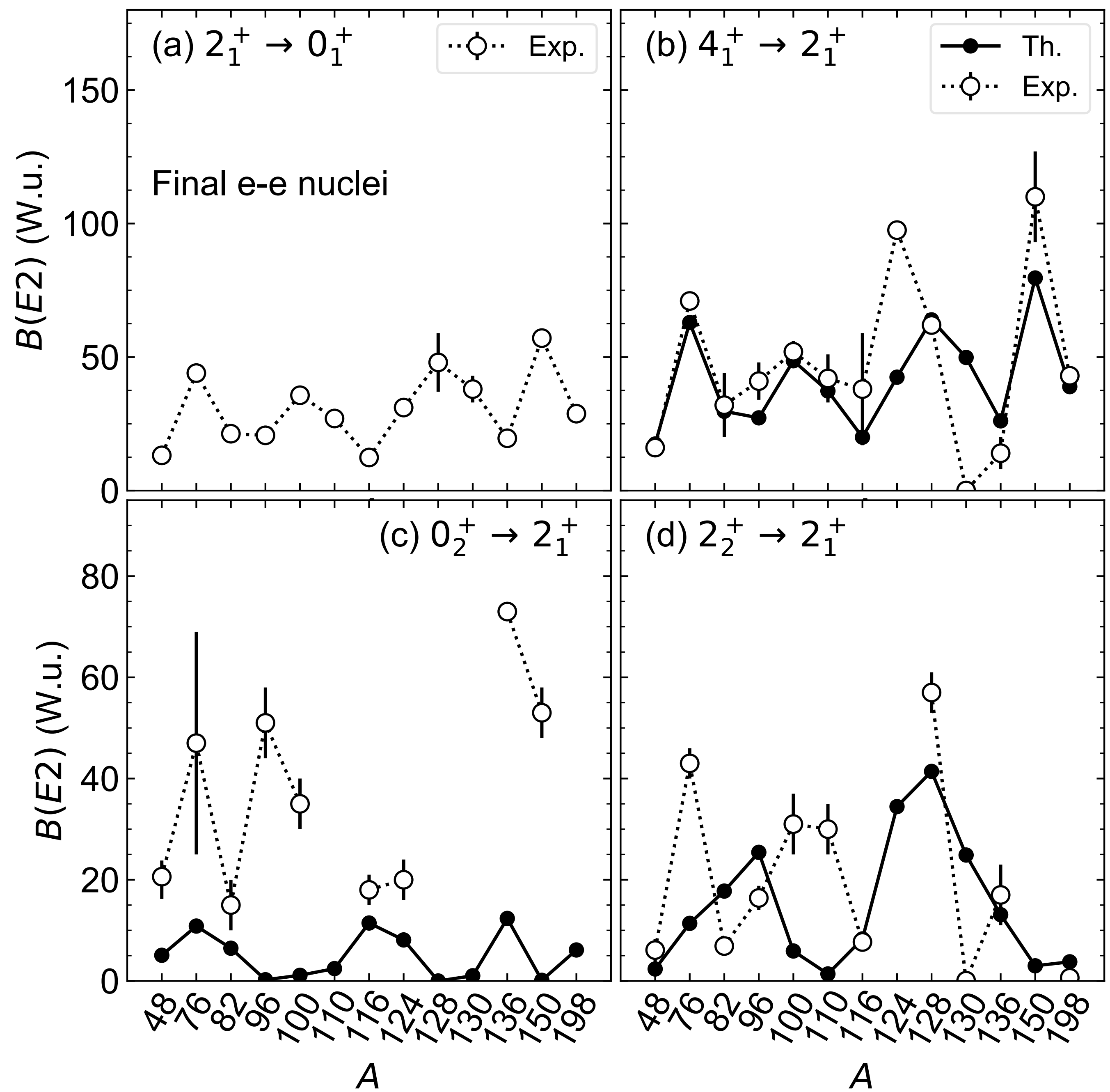
- Consistent description of low-lying states and $2\nu\beta\beta$ NME
- Further improvements by assessing model deficiency, coupling to higher-order deformations, shape coexistence…?
- Extension to the 0ν mode is in progress

Thank you

B(E2)s of parent nuclei



B(E2)s of daughter nuclei



NMEs

Decay	$Q_{\beta\beta,\text{th}}$			$Q_{\beta\beta,\text{ex}}$			
	$\lvert M_{2\nu}\rvert$	$\lvert M_{2\nu}^{(\text{I})}\rvert$	$\lvert M_{2\nu}^{(\text{II})}\rvert$	$\lvert M_{2\nu}\rvert$	$\lvert M_{2\nu}^{(\text{I})}\rvert$	$\lvert M_{2\nu}^{(\text{II})}\rvert$	$\lvert M_{2\nu}^{\text{eff}}\rvert$ [12]
^{48}Ca $\to$ ^{48}Ti	0.073	0.020	0.034	0.051	0.014	0.024	0.035 ± 0.003
^{76}Ge $\to$ ^{76}Se	0.072	0.017	0.021	0.062	0.014	0.018	0.106 ± 0.004
^{82}Se $\to$ ^{82}Kr	0.115	0.026	0.031	0.087	0.020	0.024	0.085 ± 0.001
^{96}Zr $\to$ ^{96}Mo	0.225	0.048	0.048	0.249	0.053	0.054	0.088 ± 0.004
^{100}Mo $\to$ ^{100}Ru	0.827	0.174	0.167	0.778	0.164	0.157	0.185 ± 0.002
^{100}Mo $\to$ ^{100}Ru(0_2^+)	0.011	0.002	0.002	0.032	0.007	0.007	0.151 ± 0.004
^{110}Pd $\to$ ^{110}Cd	0.115	0.023	0.020	0.128	0.026	0.022	
^{116}Cd $\to$ ^{116}Sn	0.238	0.048	0.037	0.443	0.089	0.069	0.108 ± 0.003
^{124}Sn $\to$ ^{124}Te	0.253	0.050	0.035	0.164	0.032	0.022	
^{128}Te $\to$ ^{128}Xe	0.229	0.044	0.030	0.169	0.033	0.022	0.043 ± 0.003
^{130}Te $\to$ ^{130}Xe	0.091	0.017	0.011	0.081	0.016	0.010	0.0293 ± 0.0009
^{136}Xe $\to$ ^{136}Ba	0.307	0.058	0.035	0.194	0.037	0.022	0.0181 ± 0.0006
^{150}Nd $\to$ ^{150}Sm	0.604	0.111	0.055	0.594	0.109	0.054	0.055 ± 0.003
^{150}Nd $\to$ ^{150}Sm(0_2^+)	0.666	0.122	0.060	0.629	0.116	0.057	0.044 ± 0.005
^{198}Pt $\to$ ^{198}Hg	0.026	0.004	0.001	0.027	0.005	0.001	

data: Barabash, Universe (2020)