

Octupole vibrations in super heavy nuclei and K mixing for isomeric states within the QRPA formalism

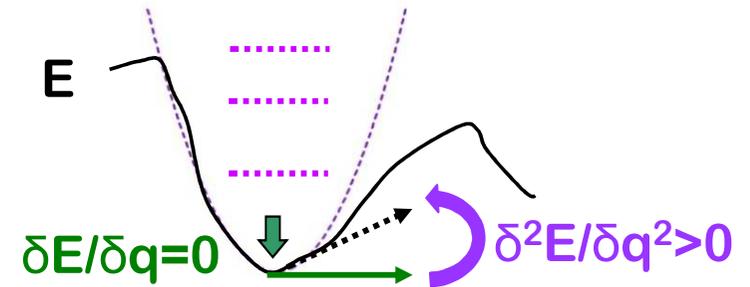
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The QRPA methods describe nuclear excited states for all multipoles and both parities whatever the intrinsic deformation of the ground state.

Quadrupole, octupole and higher multipolarities can be obtained even on top of spherical HFB calculations. But standard QRPA approaches don't describe rotational motion.

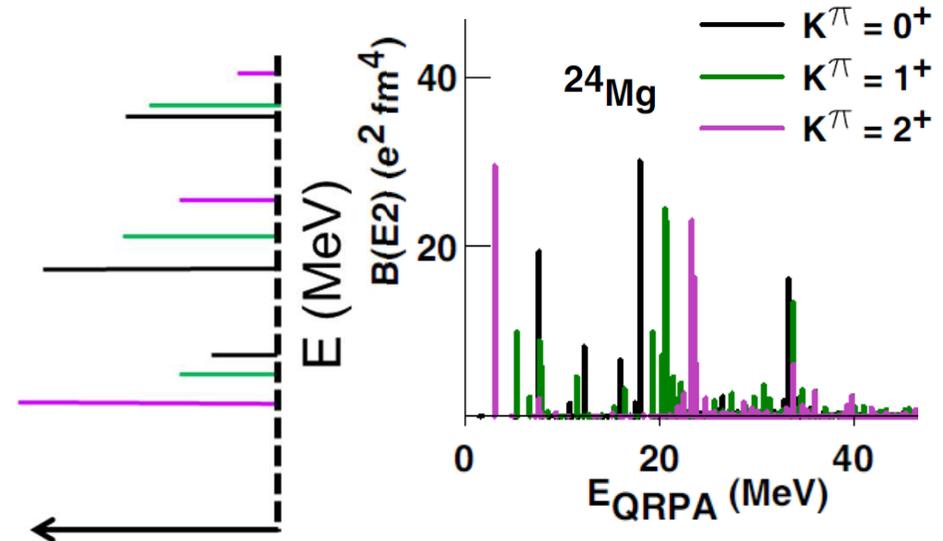
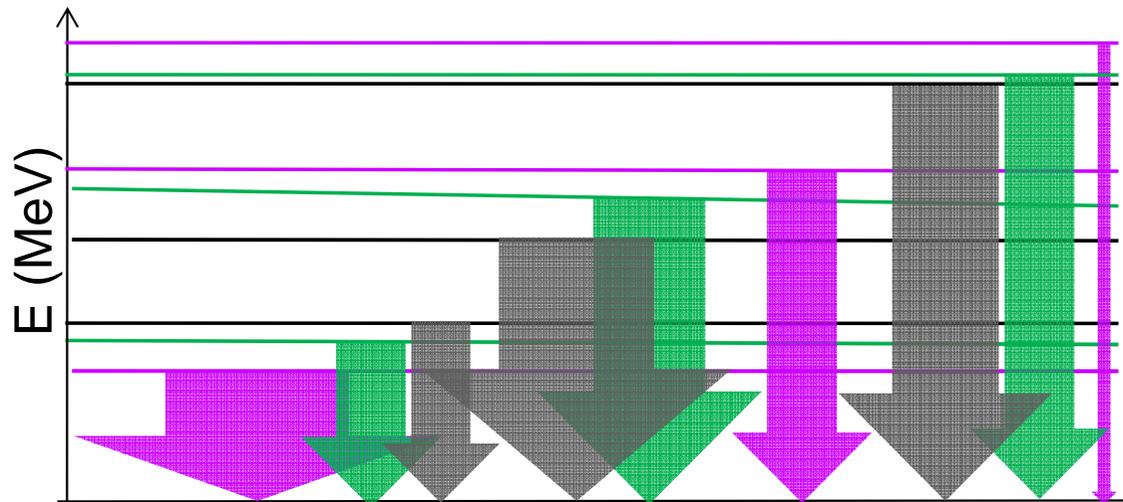
Main approximation:

Linear response, i.e. harmonic potential approximation



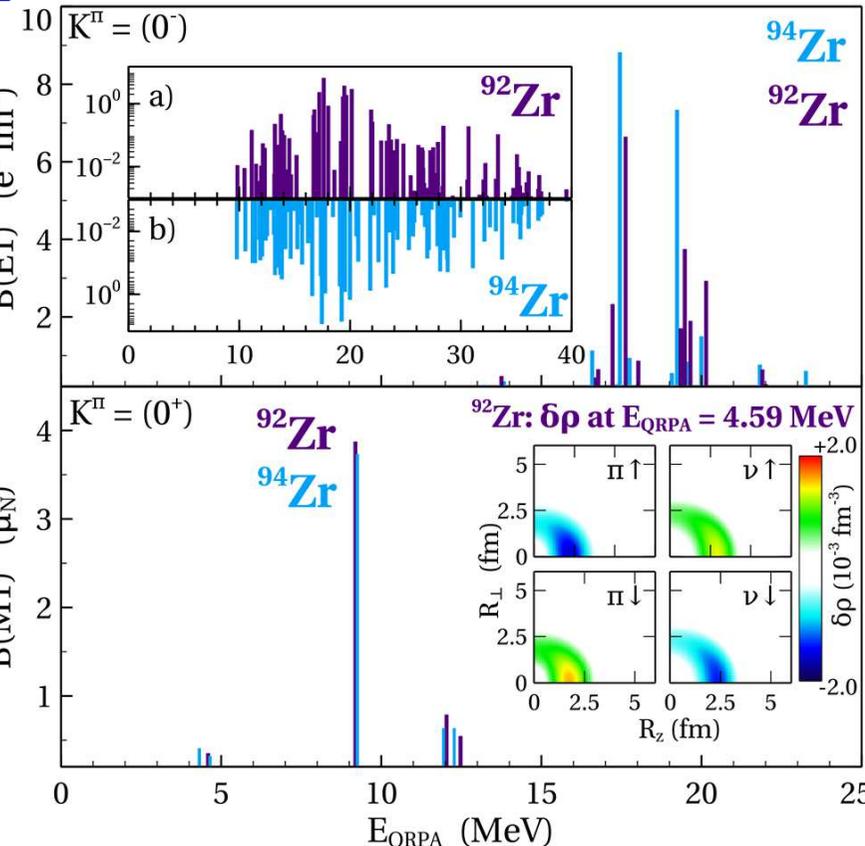
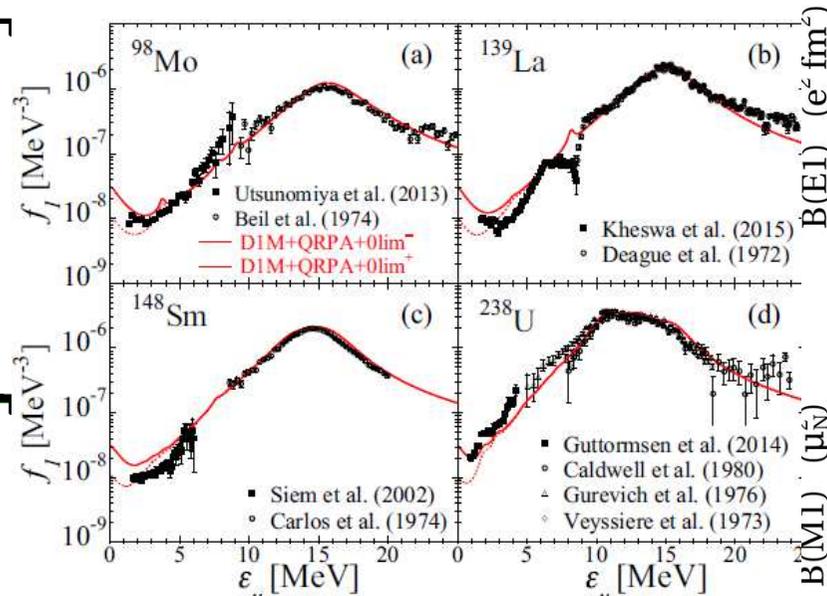
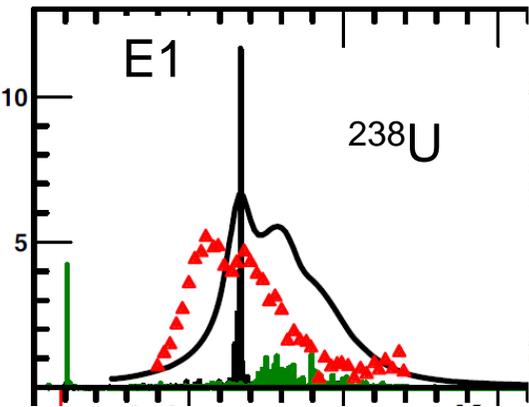
The present QRPA approach (ISAAC code) using matrix representation allows to provide excited state wave functions, excitation energies and transitions (probabilities and densities) from the GS for deformed nuclei with axial symmetry.

And the results ?

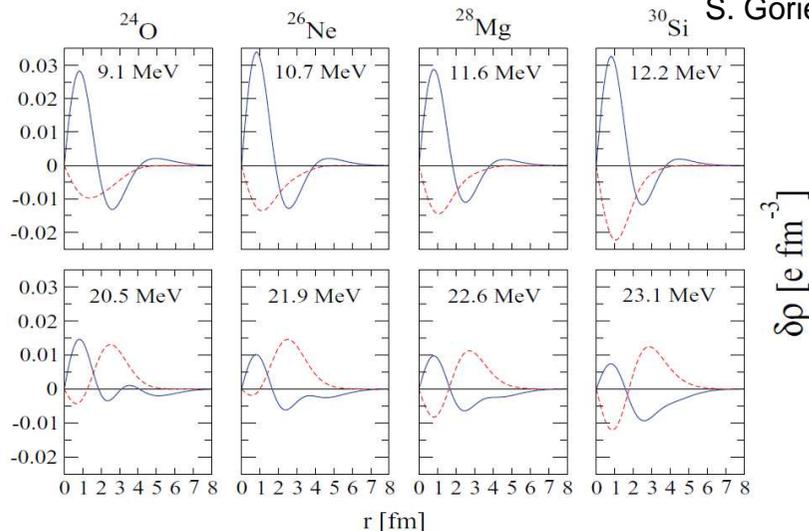


Usual application: Giant and pygmy resonances, γ strength functions

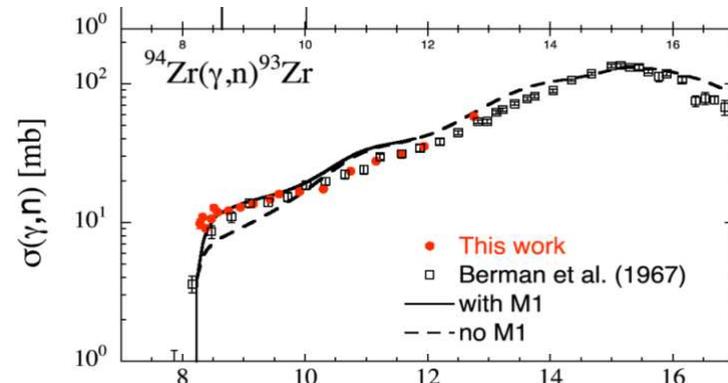
S. Péru et al, PRC 83, 014314 (2011)



S. Goriely et al, PRC98,014327 (2018)



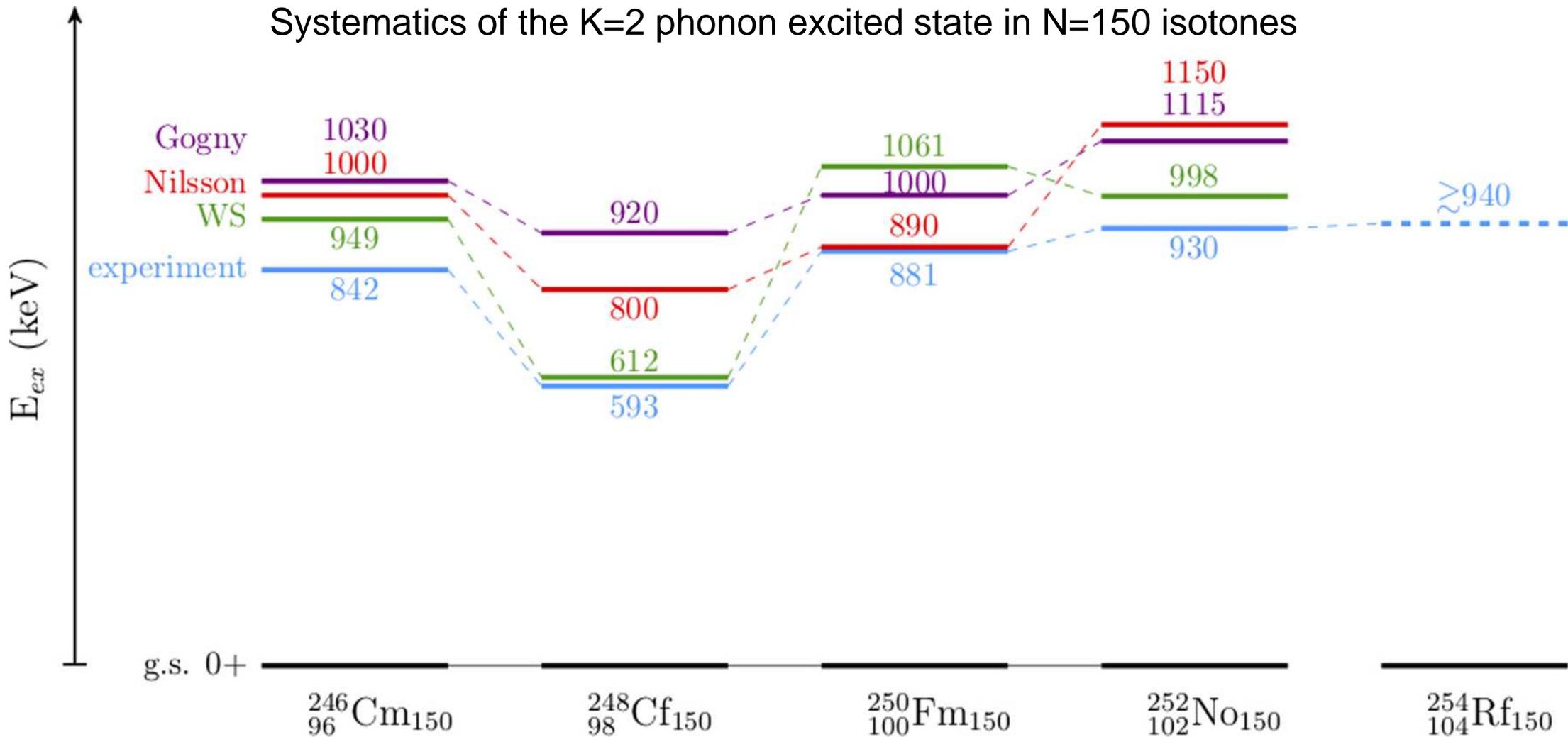
M. Martini et al, PRC 83, 034309 (2011)



H.Utsunomia et al, PRL 100, 162502 (2008)

I. Deloncle et al, EPJA 53 : 170 (2017)

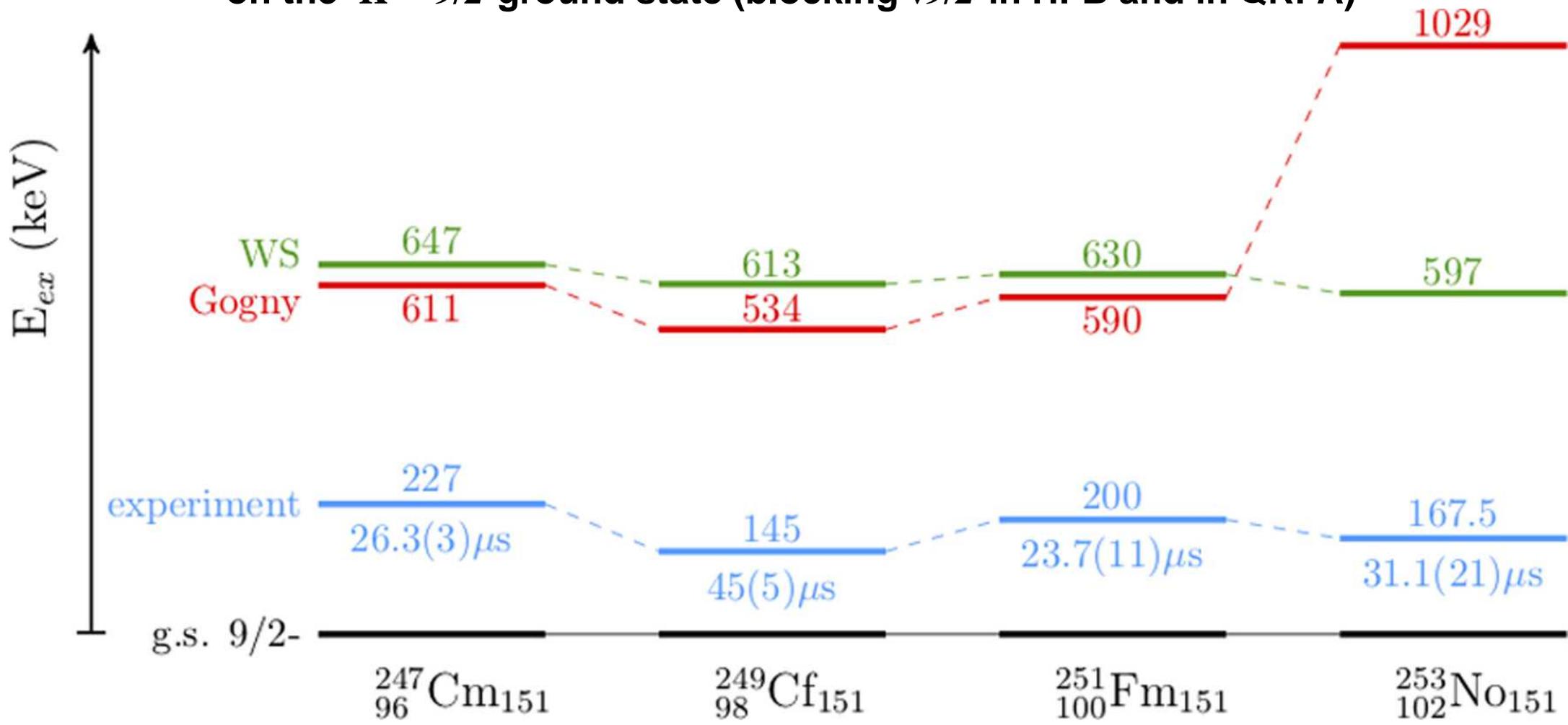
Another usual application: low energy spectroscopy for even-even nuclei



K. Rezyunkina et al, Physical Review C 97, 054332 (2018)

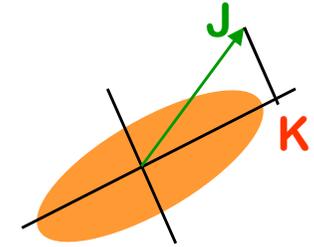
Other application: low energy spectroscopy for odd nuclei

QRPA $J^\pi = 5/2^+$ state is defined as a phonon $K^\pi = -2^-$ on the $K^\pi = -9/2^-$ ground state (blocking $\nu 9/2^-$ in HFB and in QRPA)



K. Rezyunkina et al, Physical Review C 97, 054332 (2018)

Transition probabilities within axially-symmetric deformed QRPA



Restoration of rotational symmetry for even-even deformed nuclei:

$$|JM(K)\rangle = \frac{\sqrt{2J+1}}{4\pi} \int d\Omega D_{MK}^J(\Omega) R(\Omega) |\theta_K\rangle + (-)^{J-K} D_{M-K}^J(\Omega) R(\Omega) |\bar{\theta}_K\rangle$$

$$Q_{\lambda\mu} \propto \mu_N \sum_i^A r^\lambda Y_{\lambda\mu}(\theta, \phi)$$

$$T_{\lambda\mu} = \mu_N \sum_i^A \left(g_{s_i} \vec{s}_i + \frac{2}{\lambda+1} g_{l_i} \vec{l}_i \right) \cdot \vec{v} (r^\lambda Y_{\lambda\mu}(\theta, \phi))$$

In intrinsic frame

$$r^\lambda Y_{\lambda\mu} = \sum_{\nu=-\lambda}^{\lambda} D_{\mu\nu}^\lambda r^\lambda Y_{\lambda\nu}(\theta, \phi)$$

$J^\pi = 3^-$ and $K = 2$

$$\langle \tilde{0} | E_3 | J = 3, K = 2 \rangle = \sqrt{7} \begin{pmatrix} 0 & 3 & 3 \\ 0 & -2 & 2 \end{pmatrix}^2 \langle 0 | \widehat{Q}_{32} | \theta_{K=2} \rangle = \frac{1}{\sqrt{7}} \langle 0 | \widehat{Q}_{32} | \theta_{K=2} \rangle$$

$J^\pi = 2^-$ and $K = 2$

$$\langle \tilde{0} | M_2 | J = 2, K = 2 \rangle = \sqrt{5} \begin{pmatrix} 0 & 2 & 2 \\ 0 & -2 & 2 \end{pmatrix}^2 \langle 0 | \widehat{T}_{22} | \theta_{K=2} \rangle = \frac{1}{\sqrt{5}} \langle 0 | \widehat{T}_{22} | \theta_{K=2} \rangle$$

First $K^\pi = 2^-$ ($J^\pi = 3^-$) vibrational states in $N=150$ isotones

Nucleus	$E_{\text{Exp.}}$ keV	E_{D1M} keV	$B(E3)$ Exp. W.u.	$B(E3)$ D1M W.u.	% π	% ν
^{246}Cm	842	1030	10,6	10,2	28	72
^{248}Cf	593	920		11,0	34	66
^{250}Fm	881	1000		10,0	28	72
^{252}No	930	1115		8,3	18	82

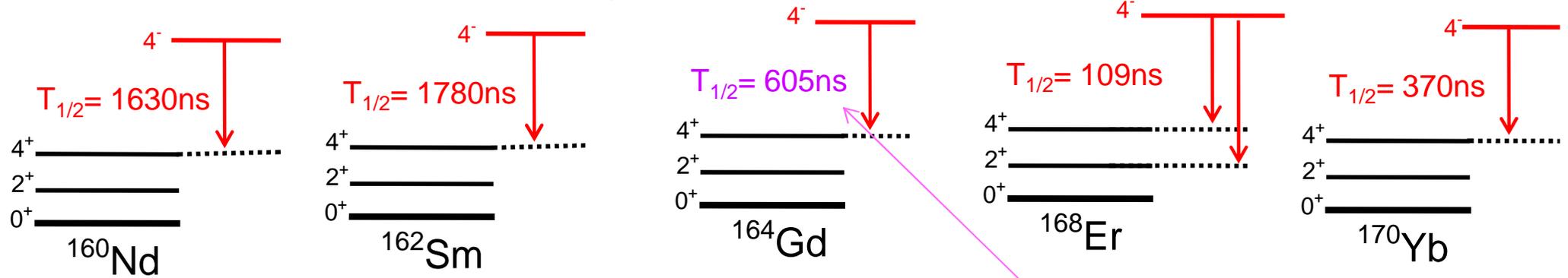
First $J^\pi = 5/2^+$ vibrational states in $N=151$ isotones

Nucleus	$E_{\text{Exp.}}$ keV	E_{D1M} keV	$B(E3)$ Exp. W.u.	$B(E3)$ D1M W.u.	% π	% ν
^{247}Cm	227	611	7.3(21)	9,8	15	85
^{249}Cf	145	534	10(4)	11,1	18	82
^{251}Fm	200	590	18(6)	9,2	13	87
^{253}No	168	(1029)	13(8)			

K. Rezyunkina et al, Physical Review C 97, 054332 (2018)

Unusual application: 4^- isomers in N=100 isotones

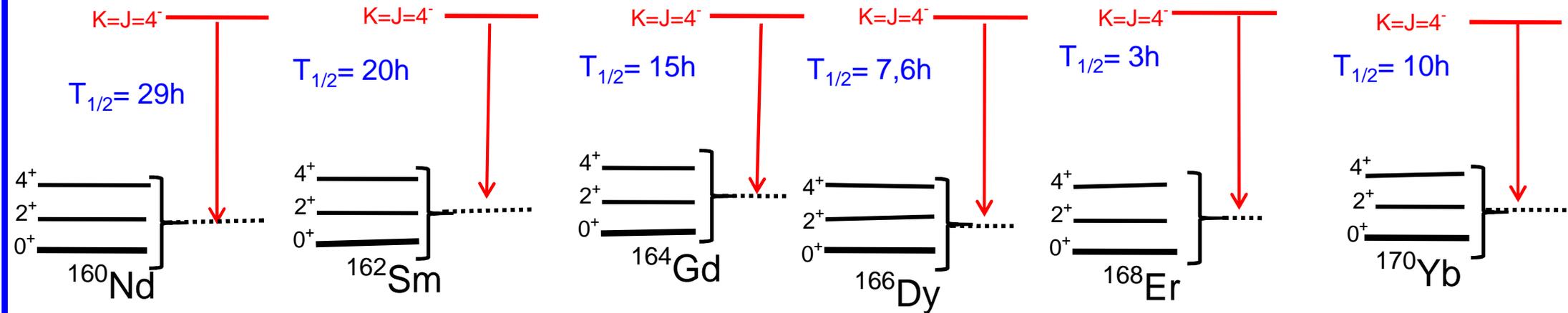
Experimental half-lives



The $4^- \rightarrow 4^+$ transition is expected to be E1

Laurent Gaudefroy, CEA, DAM, DIF
Spontaneous fission of ^{252}Cf

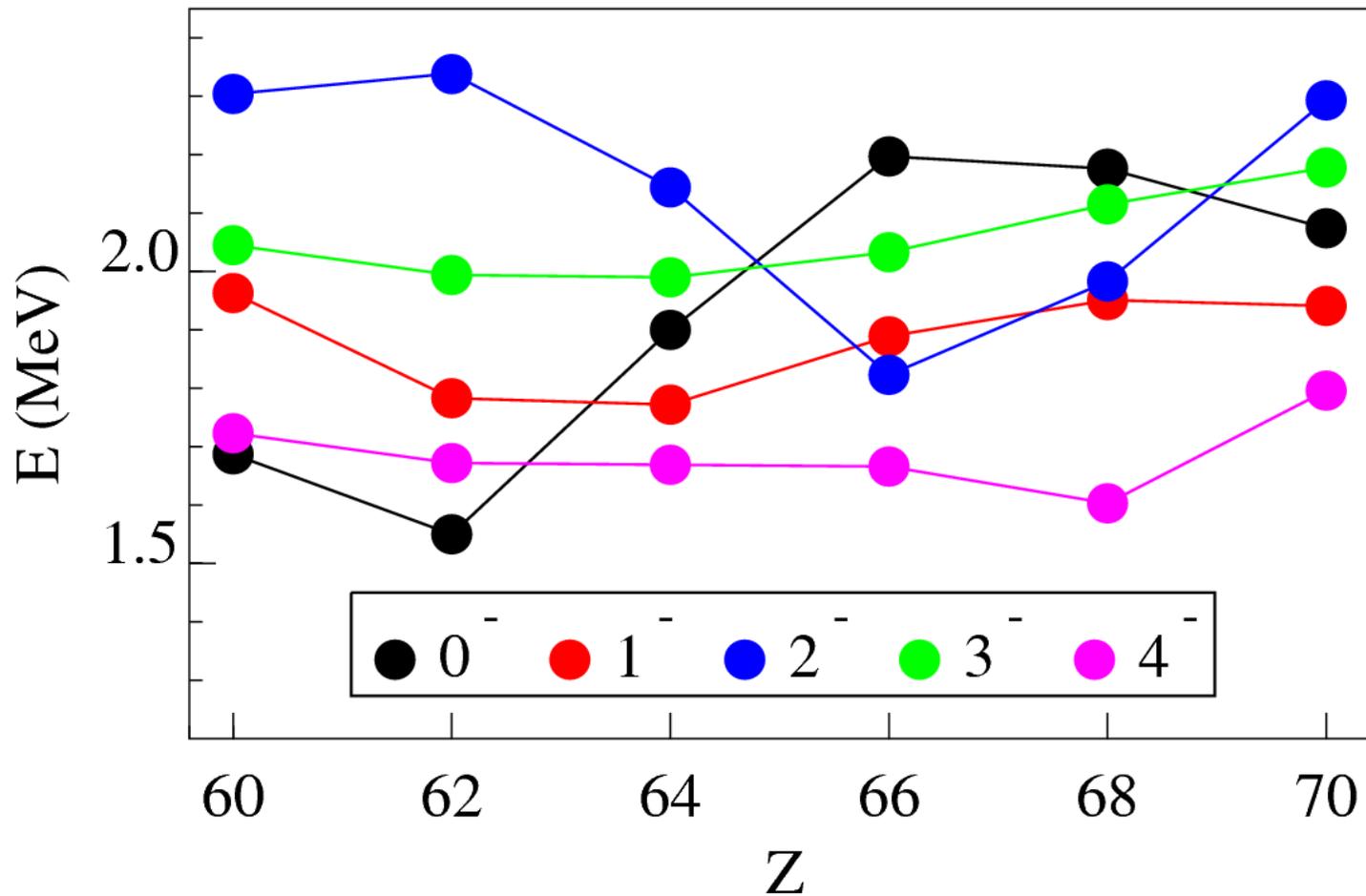
HFB+QRPA in axial symmetry with D1M Gogny force for $K^\pi = 4^-$



Only M4 and E5 transitions are allowed $\leftarrow \lambda \geq K=4$

→ $J = 4^-$ isomers in $N=100$ isotones are not $K = 4$ states

First $J^\Pi = 4^-$ excited state obtained for each K bloc with D1M HFB+QRPA;



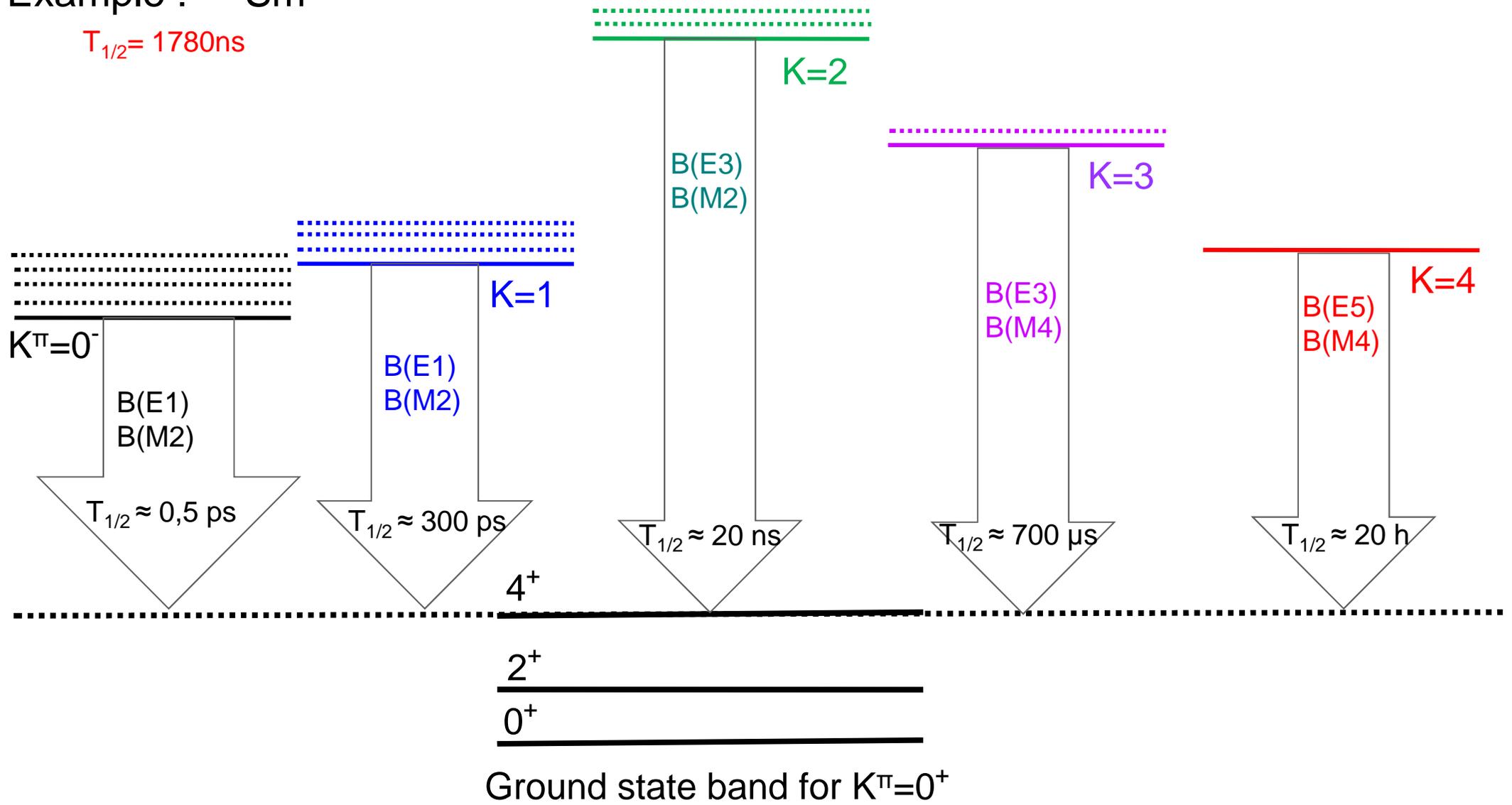
For rotational states

$$E_J = \frac{\hbar}{2I} (J(J+1) - K^2)$$

L. Gaudefroy, S. Péru, et al, PRC97,064317 (2018)

Example : ^{162}Sm

$T_{1/2} = 1780\text{ns}$

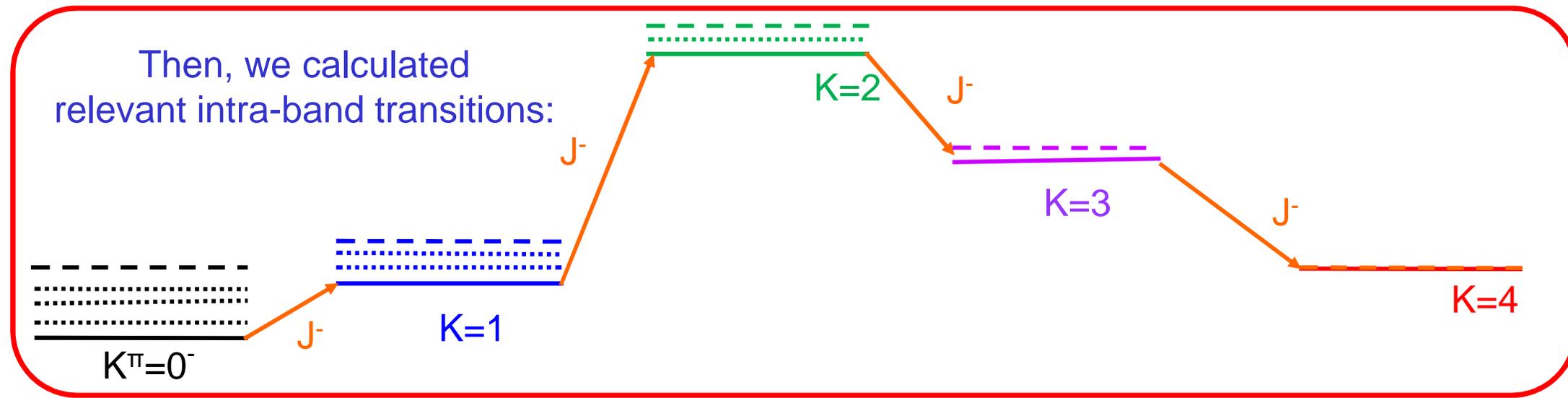
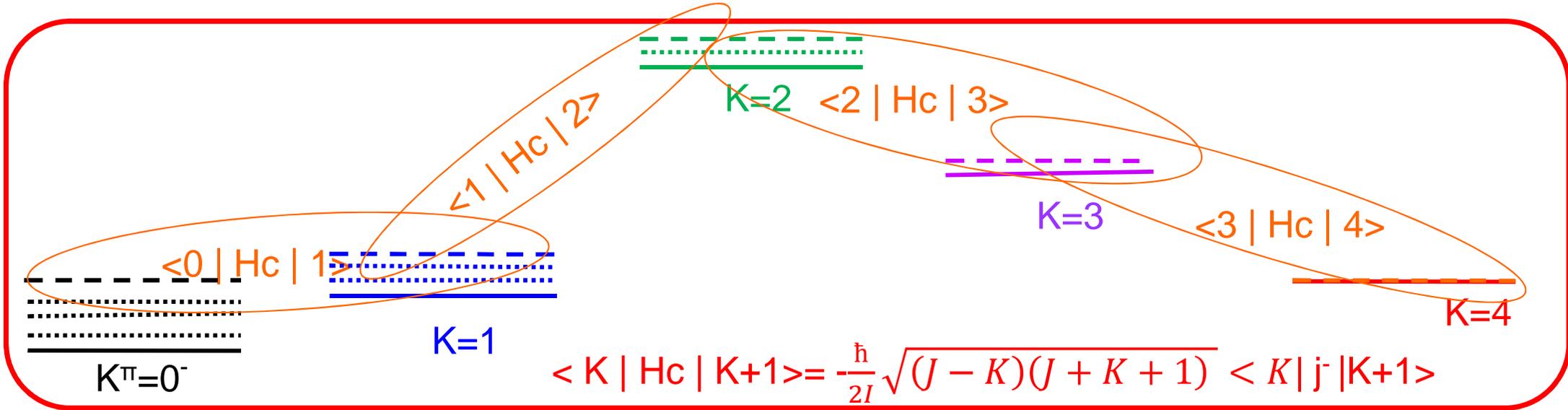


No calculated half-lives reproduce the experimental one!

How to fix it?

K-mixing with Coriolis effect and j_{\pm} operators,

i.e. to calculate transitions between QRPA excited states, in order to fill a coupling matrix :



L. Gaodefroy, S. Péru, et al, PRC97,064317 (2018)

mixing	^{160}Nd	^{162}Sm	^{164}Gd	^{166}Dy	^{168}Er	^{170}Yb	^{172}Hf
K=0	0,0000	0,0000	0,0005	0,0000	0,0002	0,0015	0,0026
K=1	0,0001	0,0001	0,0004	0,0022	0,0021	0,0011	0,0509
K=2	0,0171	0,0178	0,0236	0,0048	0,0069	0,0500	0,0086
K=3	0,0005	0,0005	0,0005	0,0324	0,0329	0,0108	0,0017
K=4	0,9998	0,9998	0,9997	0,9995	0,9994	0,9987	0,9987

T $\frac{1}{2}$ ns	^{160}Nd	^{162}Sm	^{164}Gd	^{166}Dy	^{168}Er	^{170}Yb	^{172}Hf
Exp.	1670(210)	1780(70)	605(30)	?	109(7)	370(15)	~1
QRPA	6970	11105	3980	285	365	260	1,5
QRPA/Exp.	4,17	6,24	6,57	?	3,35	0,703	1,5

Unitary factor for 3 orders of magnitude

Main mode of decay	^{160}Nd	^{162}Sm	^{164}Gd	^{166}Dy	^{168}Er	^{170}Yb	^{172}Hf
	E3	E3	E3, E1	E1	E1	E1, E3	E1

To summarize

Qualitative description of octupole low-lying states in super-heavy nuclei, for even and for odd particle numbers.

K-mixing of QRPA states provides a good description of J=4 isomers in N=100 isotones

Perspectives:

Enlarge the QRPA description of spectroscopy for low energy transitions.

For example $2^+_2 \rightarrow 2^+_1$ et $4^+_1 \rightarrow 2^+_1$

