Octupole excitation in super heavy nuclei and J=4 isomeric states in N=100 isotones described by the same QRPA approach

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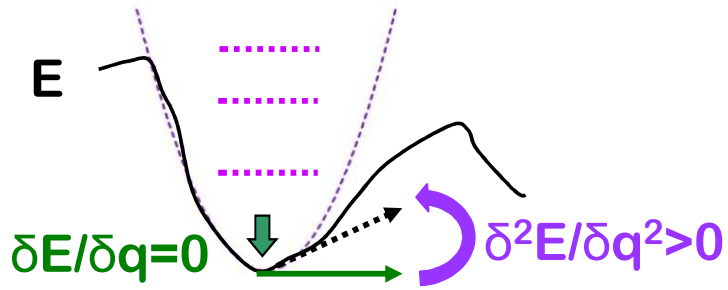
The QRPA methods describe nuclear excited states for all multipoles and both parities whatever the intrinsic deformation of the ground state.

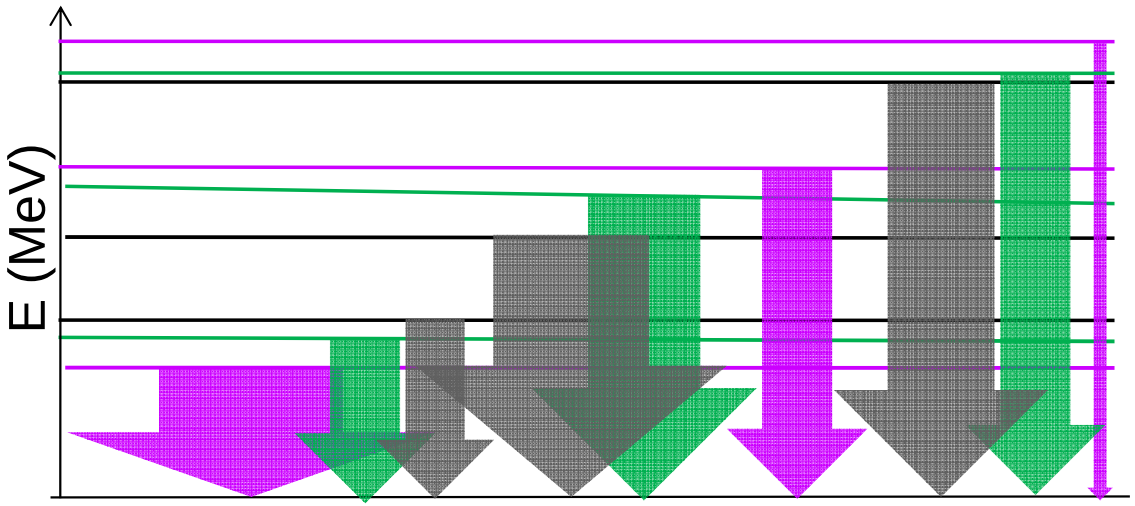
Quadrupole, octupole and higher multipolarities can be obtained even on top of spherical HFB calculations.
But standard QRPA approaches don't describe rotational motion.

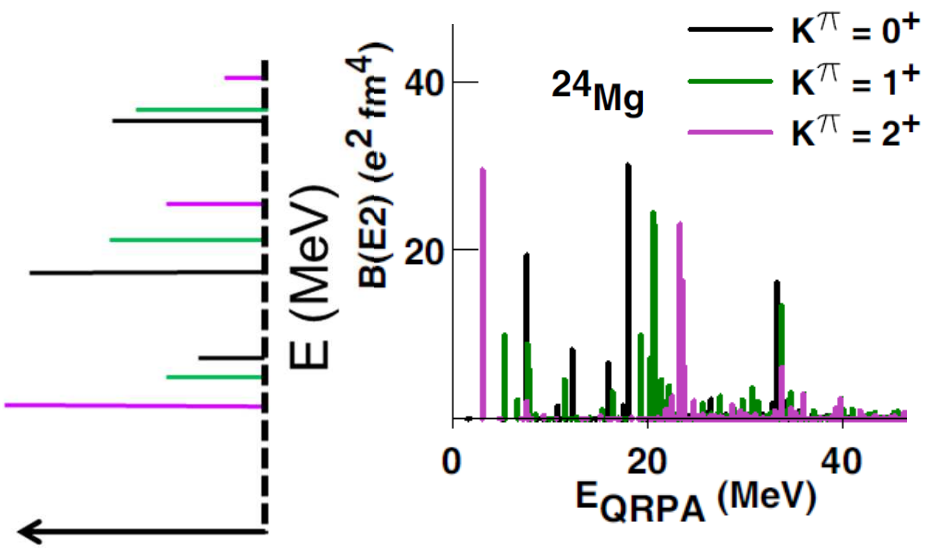


Main approximation:
Linear response, i.e. harmonic potential approximation

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.

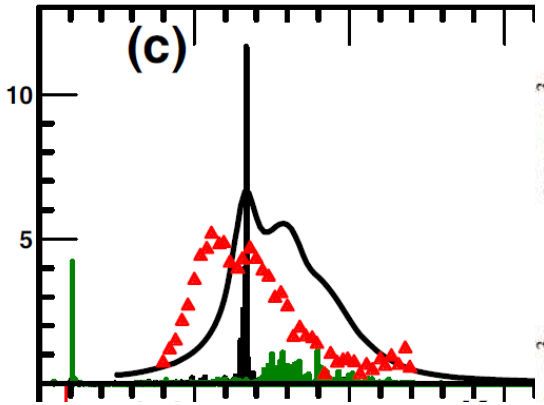
And the results ?

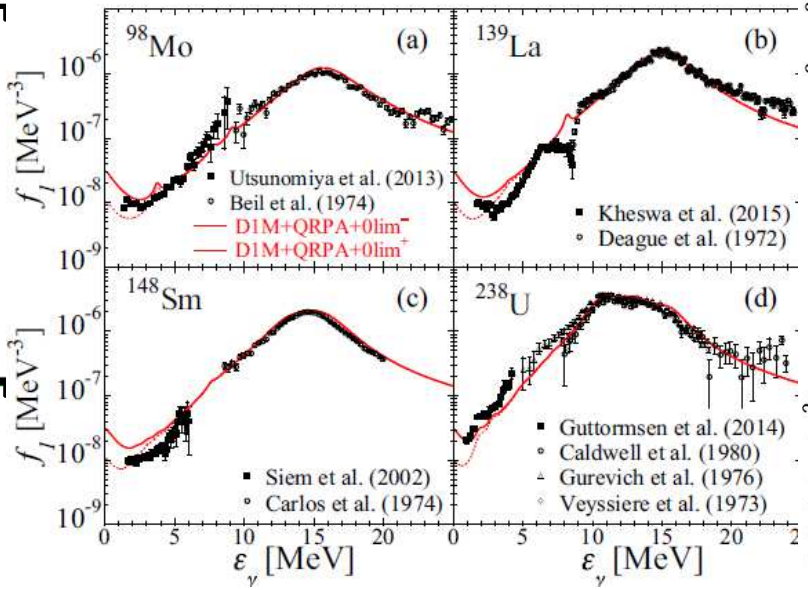




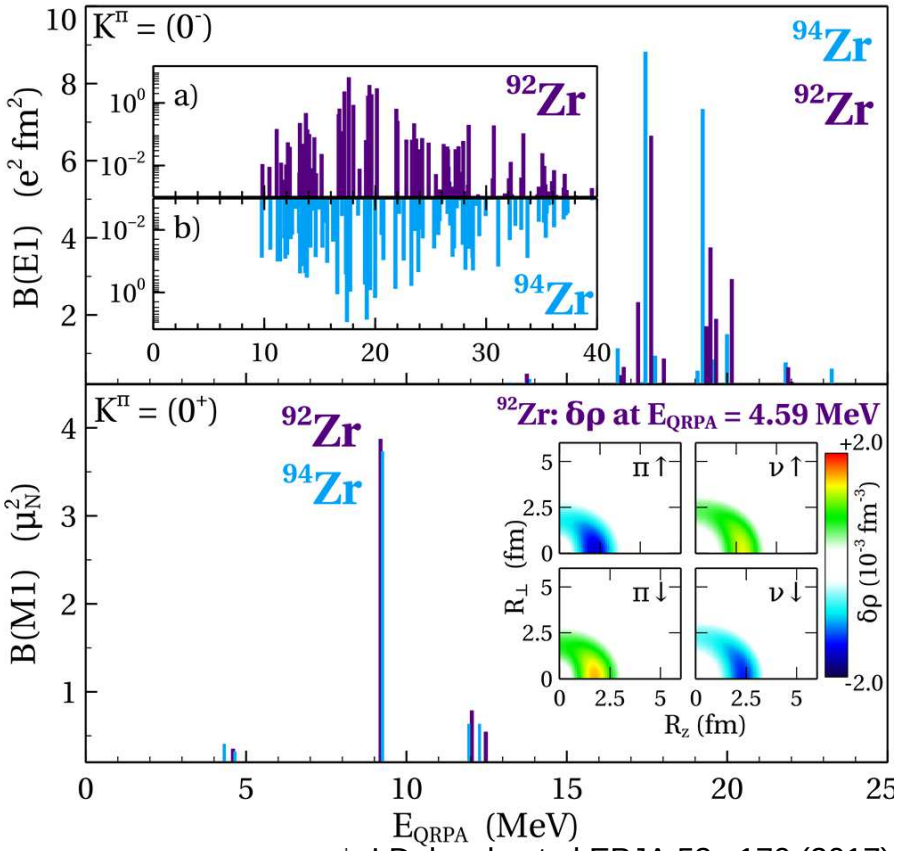
Usual application: Giant and pygmy resonances, γ strength functions

S. Péru et al, PRC 83, 014314 (2011)



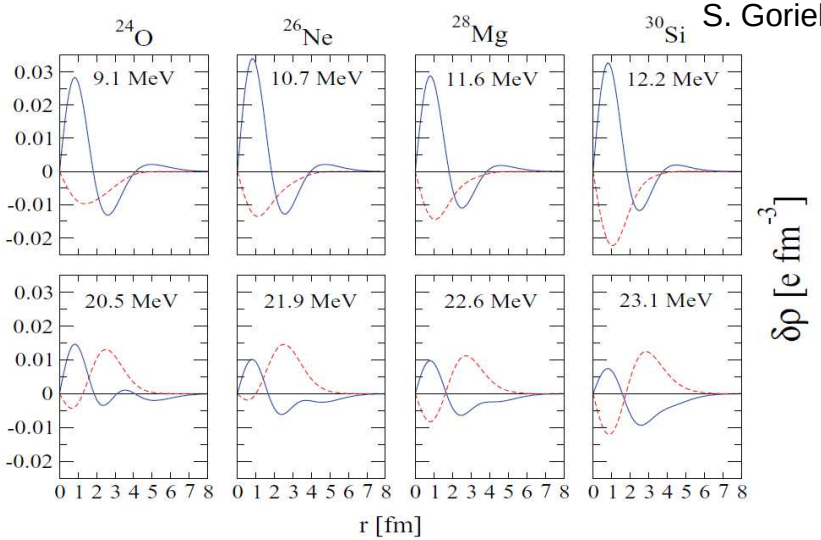


S. Goriely et al, PRC98,014327 (2018)

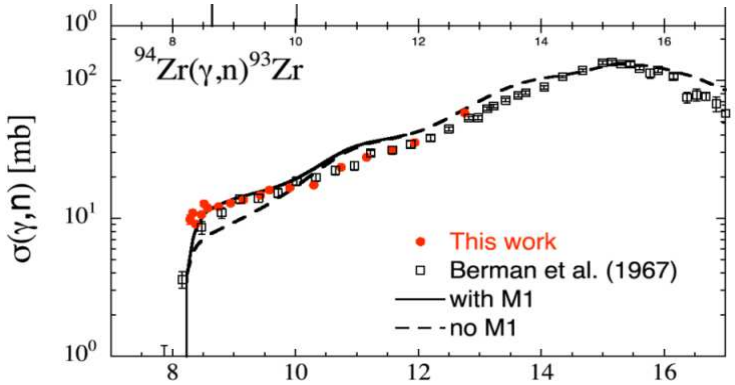


I.Deloncle et al,EPJA 53 : 170 (2017)

Some results of ISAAC with D1M or D1S



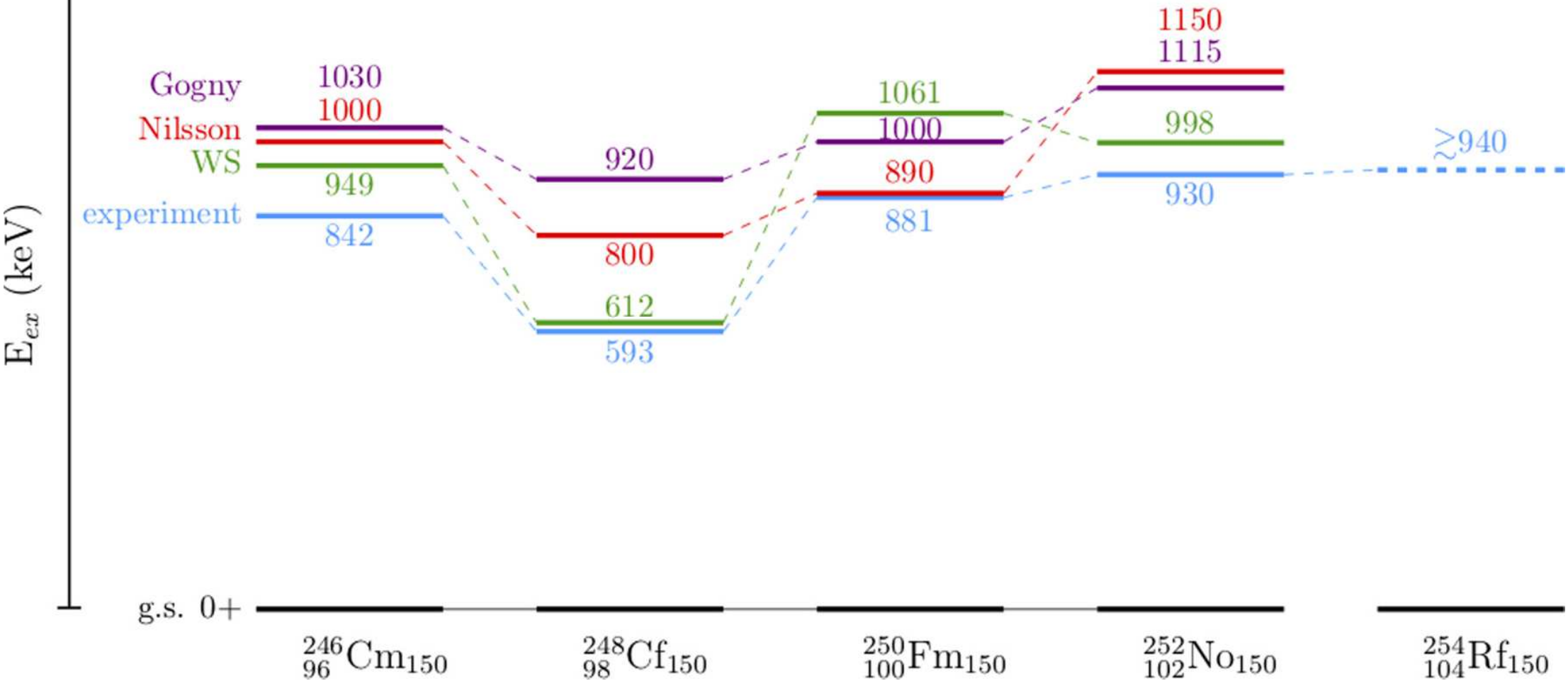
M. Martini et al, PRC 83, 034309 (2011)



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

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

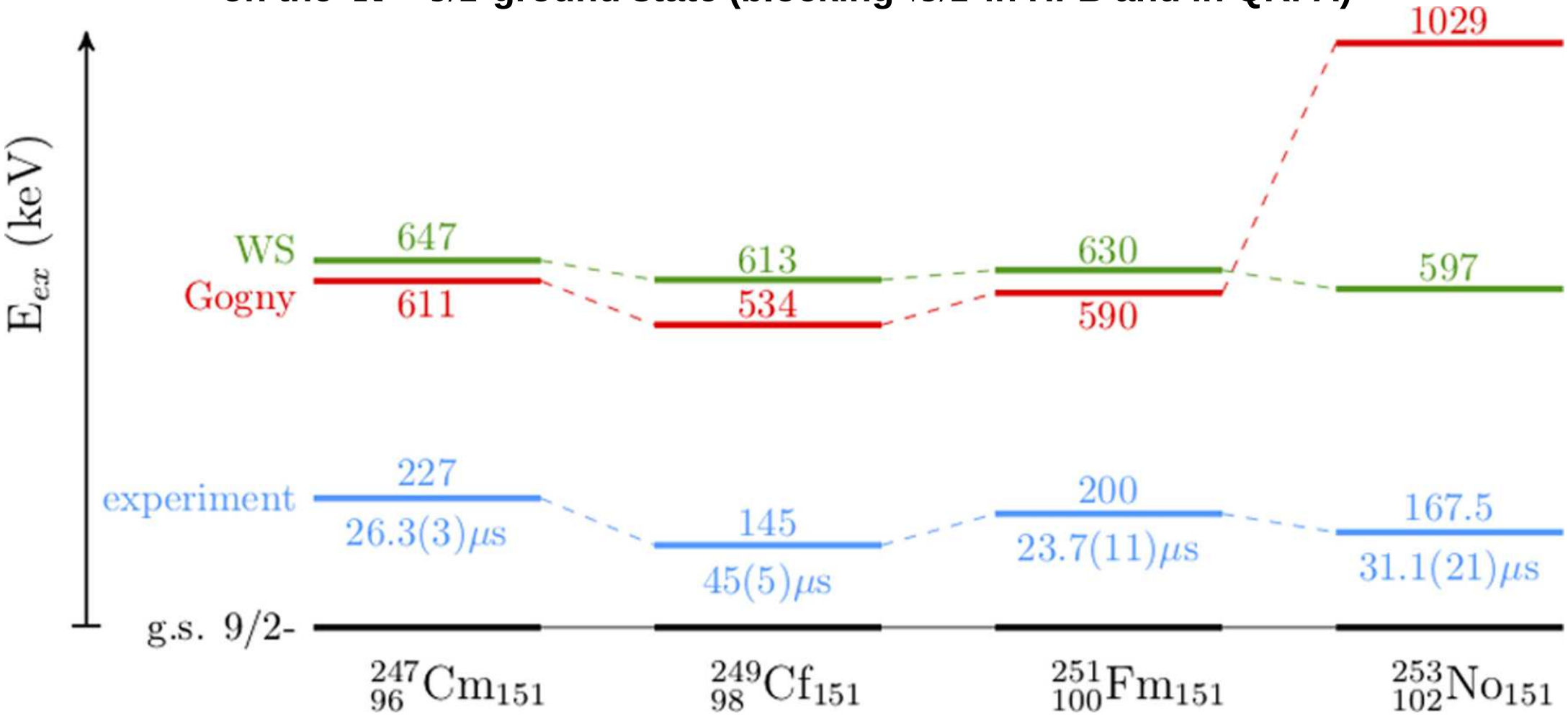
Systematics of the K=2 phonon excited state in N=150 isotones



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

First K^{π} =2^- (J^{π} = 3^-) vibrational states in N=150 isotones

Nucleus	$E_{Exp.}$ 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^{π} = $5/2^+$ vibrational states in N=151 isotones

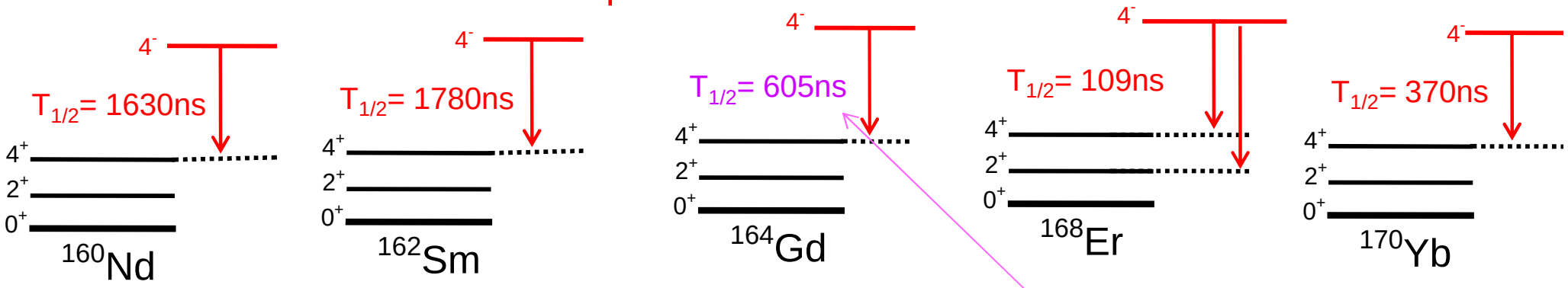
Nucleus	$E_{Exp.}$ keV	E_{D1M} keV	B(E3) Exp. W.u.	B(E3) D1M W.u.	% π	% ν
^{247}Cm	227	611	7.3(21)	9,8	15	85
^{249}Cf	145	534	10(4)	11,1	18	82
^{251}Fm	200	590	18(6)	9,2	13	87
^{253}No	168	(1029)	13(8)			

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

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

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

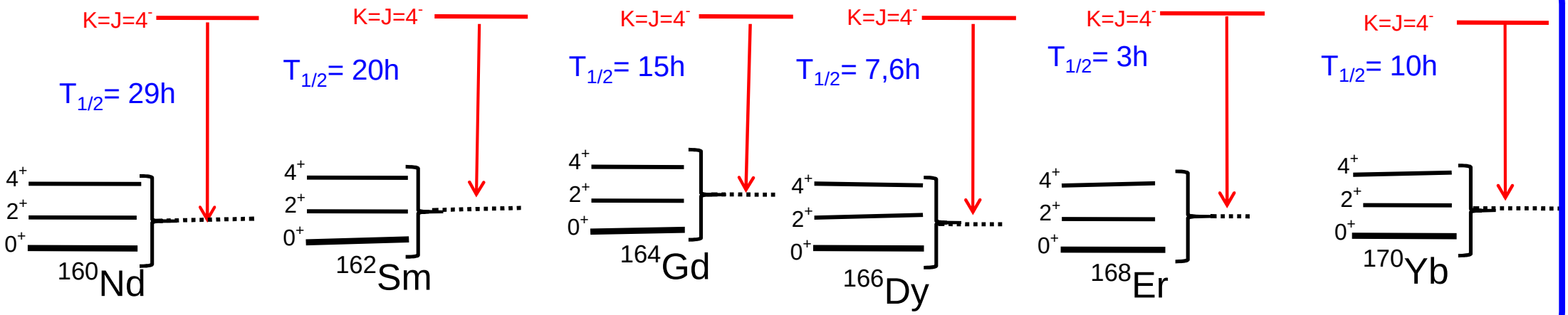
Experimental half-lives



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

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

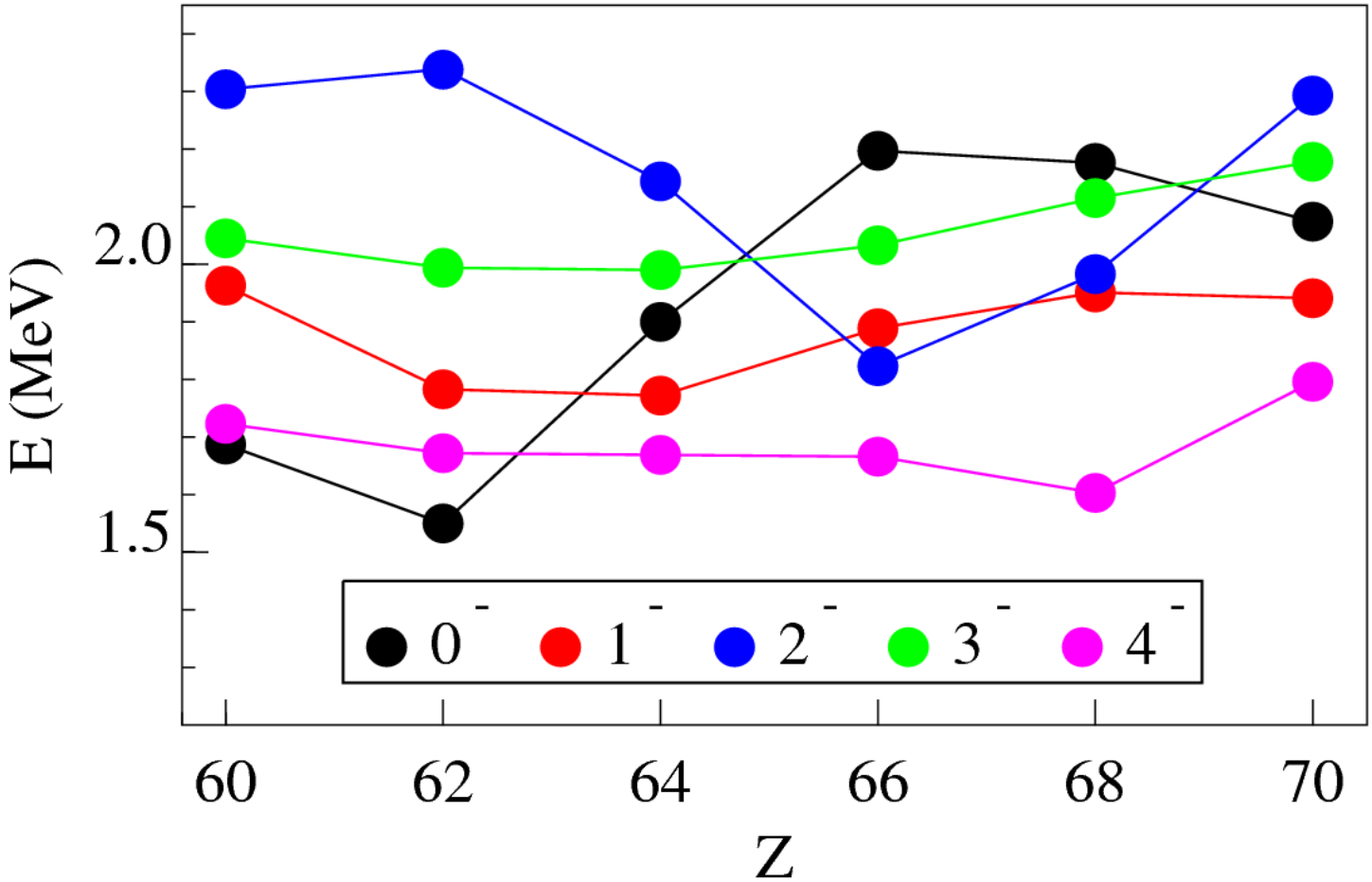
HFB+QRPA in axial symmetry with D1M Gogny force for $K^{\pi} = 4^-$



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

➔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;



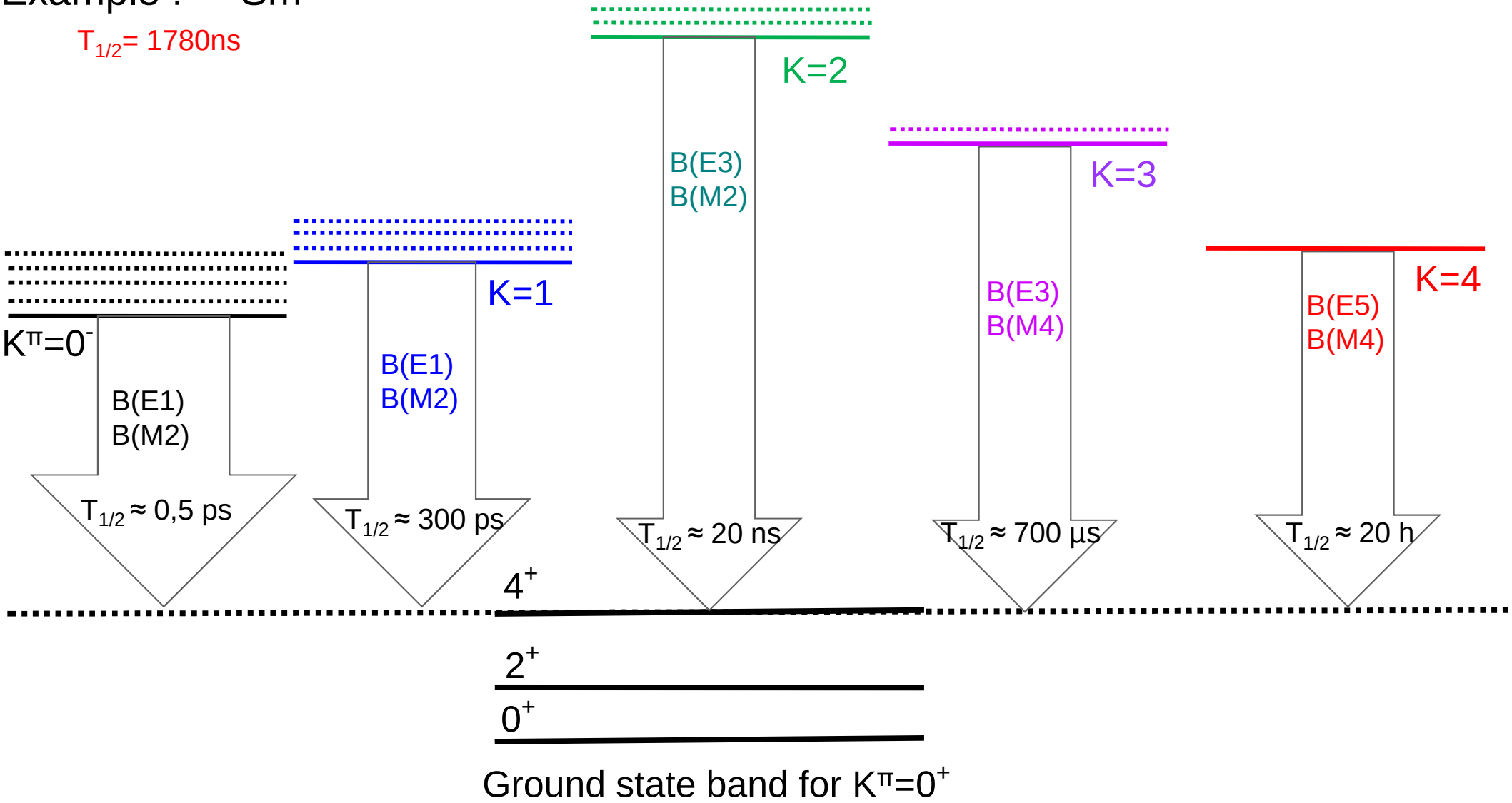
For rotational states

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

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

Example : ^{162}Sm

$T_{1/2}$= 1780ns



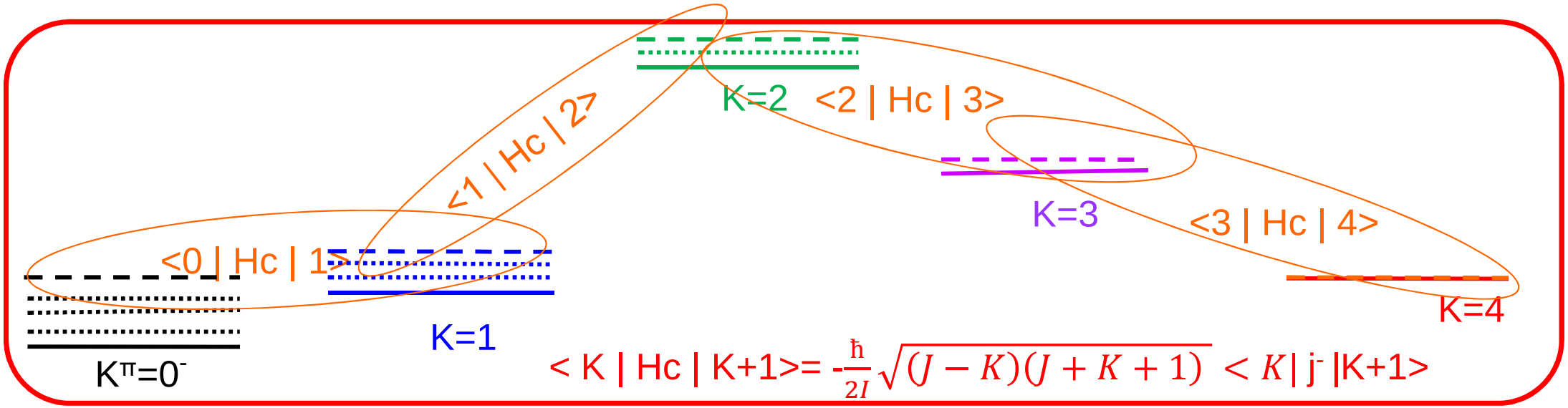
Ground state band for $K^{\pi}=0^{+}$

No calculated half-lives reproduce the experimental one!

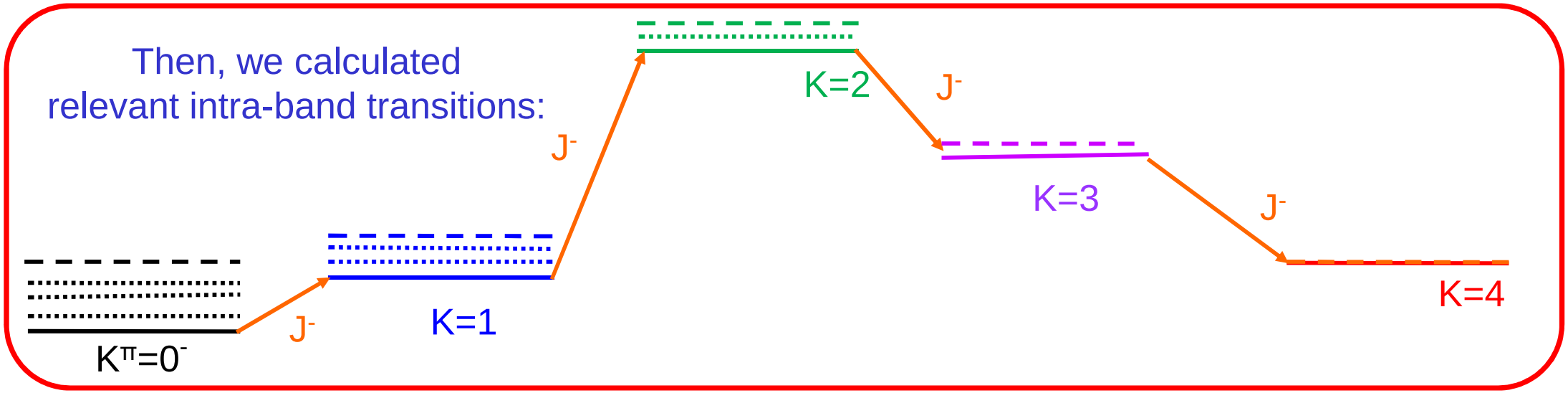
How to fix it?

K-mixing with Coriolis effect and j± operators,

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



$$< K \mid Hc \mid K+1 > = -\frac{\hbar}{2I}\sqrt{(J-K)(J+K+1)} < K \mid j^{-} \mid K+1 >$$



L. Gaudefroy, 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 ½ 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 $4^+_1 \rightarrow 2^+_1$