9th international workshop: Quantum Phase Transitions in Nuclei and Many-body Systems

Shape coexistence and collective low-spin states in ^{112,114}Sn

(Lifetime measurements with SONIC@HORUS)

M. Spieker *et al.*, PRC **97**, 054319 (2018)

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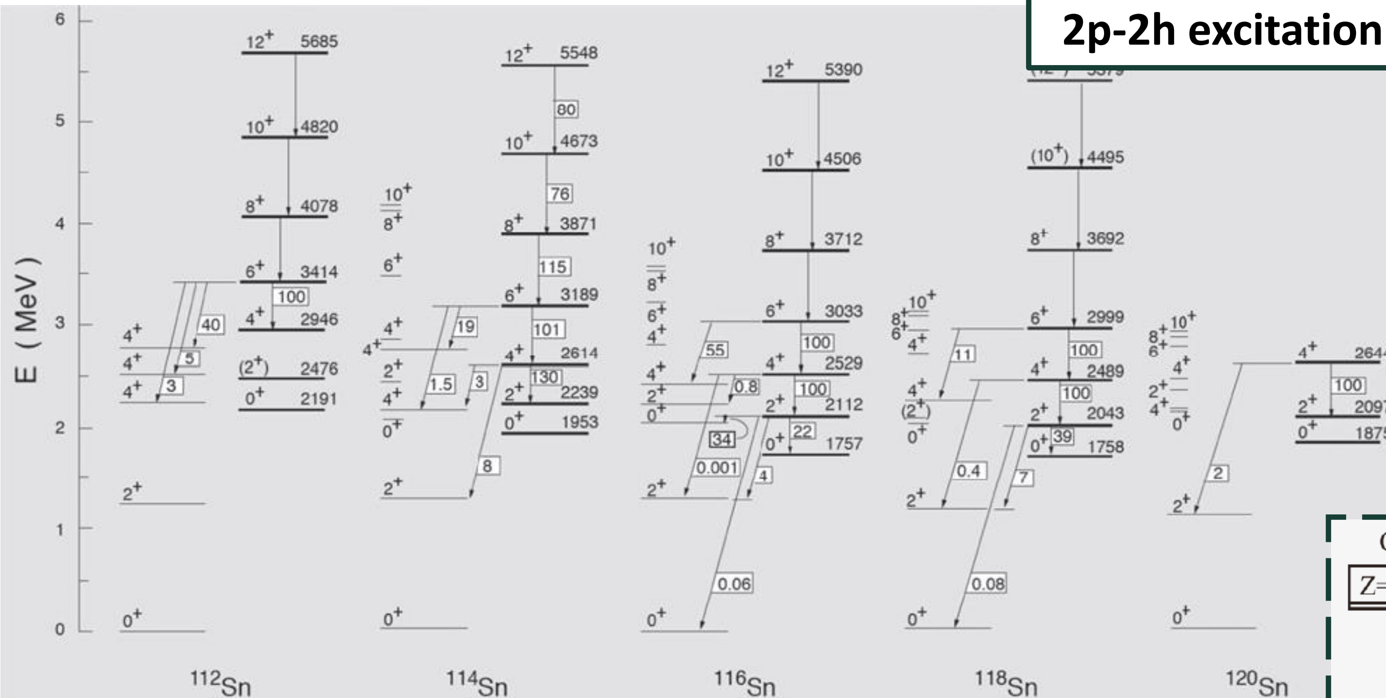
Bonn-Cologne Graduate School of Physics and Astronomy

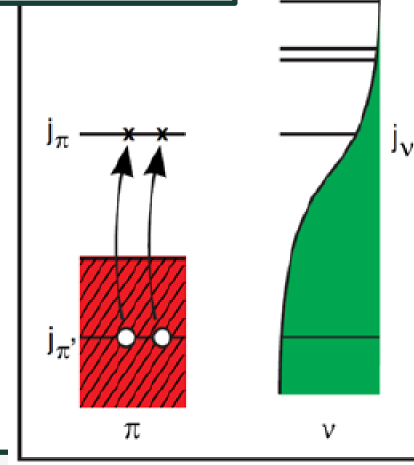
NSCL

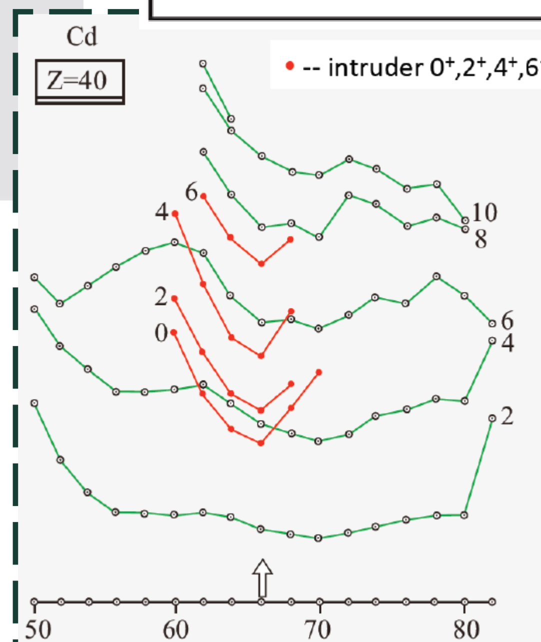
supported by DFG (ZI 510/7-1)

Shape coexistence in Z = 50 region



2p-2h excitation across Z = 50





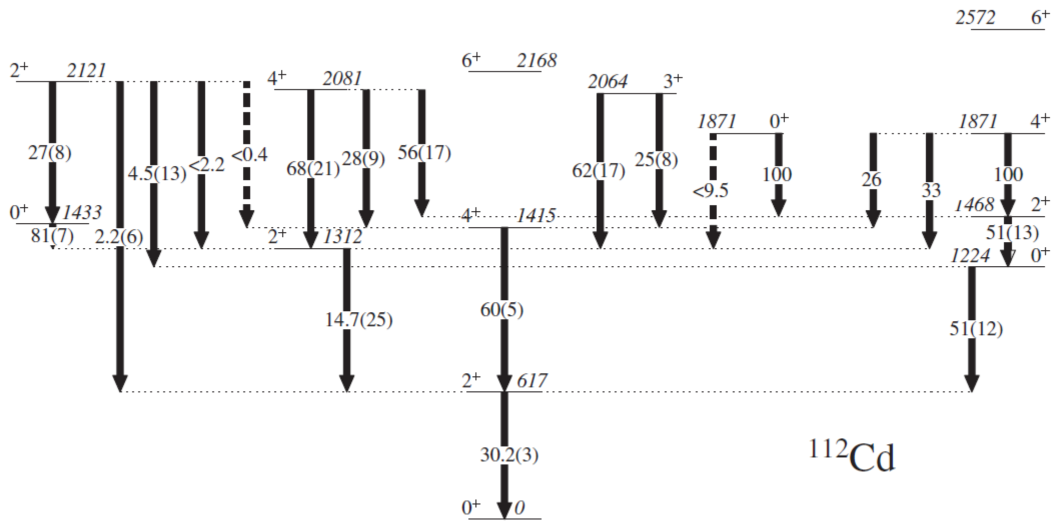
"additional" states observed

→ attributed to 2p-2h excitations across the Z = 50 shell closure, i.e. Pd isotopes as "inert core"

Figures:
P.E. Garrett, SSNET17
D. Rowe and J.L. Wood, *Models of Nuclear Structure: Foundational Models* (World Scientific, Singapore, 2010)

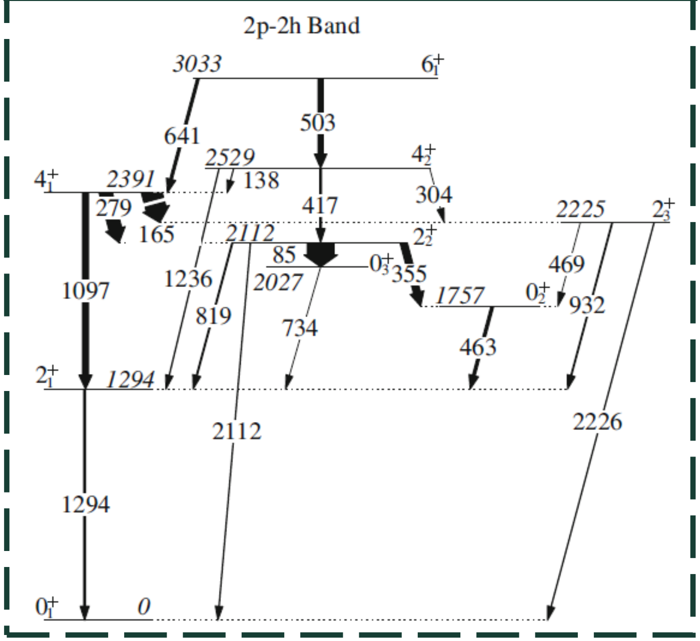
Shape coexistence in Z = 50 region

Quasi-rotational structure of Cd isotopes and mixing between the different configurations
(are there “true“ vibrational states at all?)



P.E. Garrett and J.L. Wood, J. Phys. G **37**, 064028 (2010)

^{116}Sn – Is the 3rd 0$^+$ bandhead?



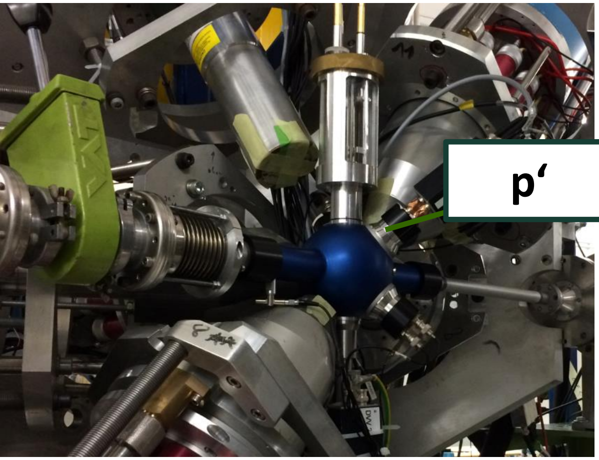
J.L. Pore *et al.*, EPJA **52**, 27 (2017)

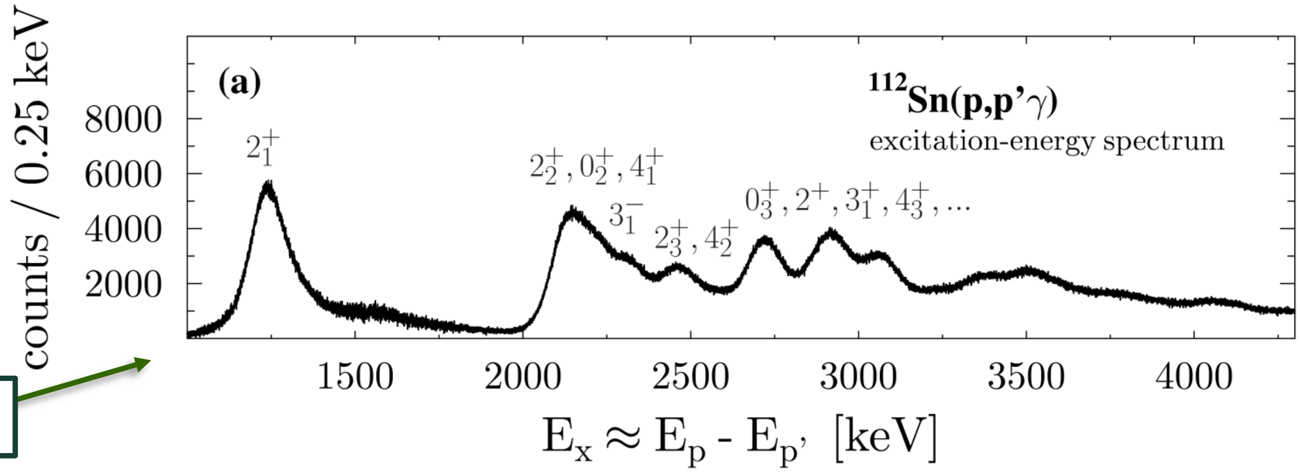
Experimental requirements:

- Selective probe needed to excite those low-spin states (non-Yrast)
- Small γ-decay branching ratios need to be detected
- Lifetimes and multipole-mixing ratios need to be measured for the determination of reduced transition strengths

(p,p’γ) DSA coincidence technique

SONIC@HORUS





(p,p‘γ) DSA coincidence technique: A. Hennig *et al.*, NIM **794**, 171 (2015)

SONIC@HORUS (UoC, Germany): S.G. Pickstone *et al.*, NIM **875**, 104 (2017)

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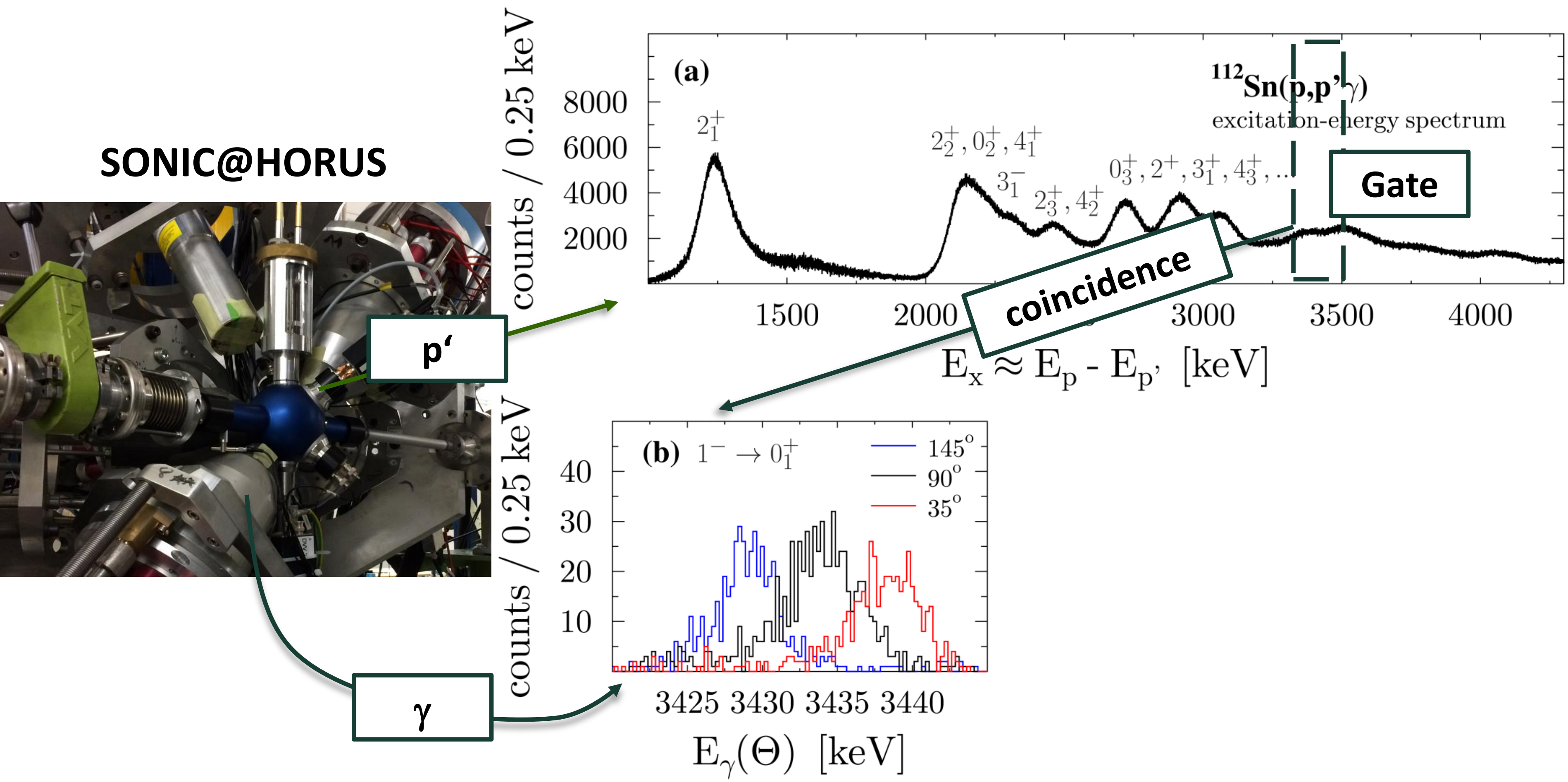
SONIC@HORUS



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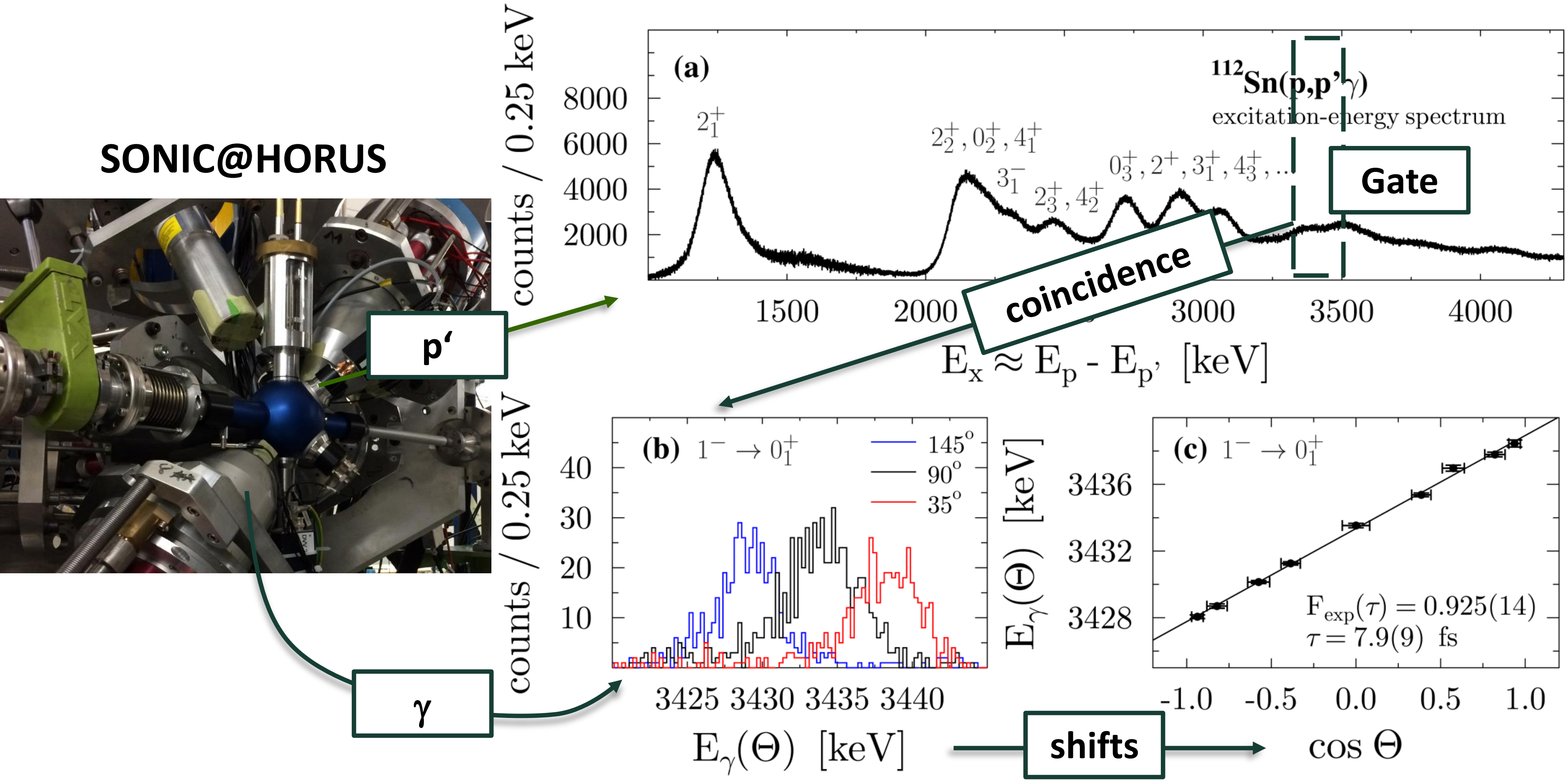

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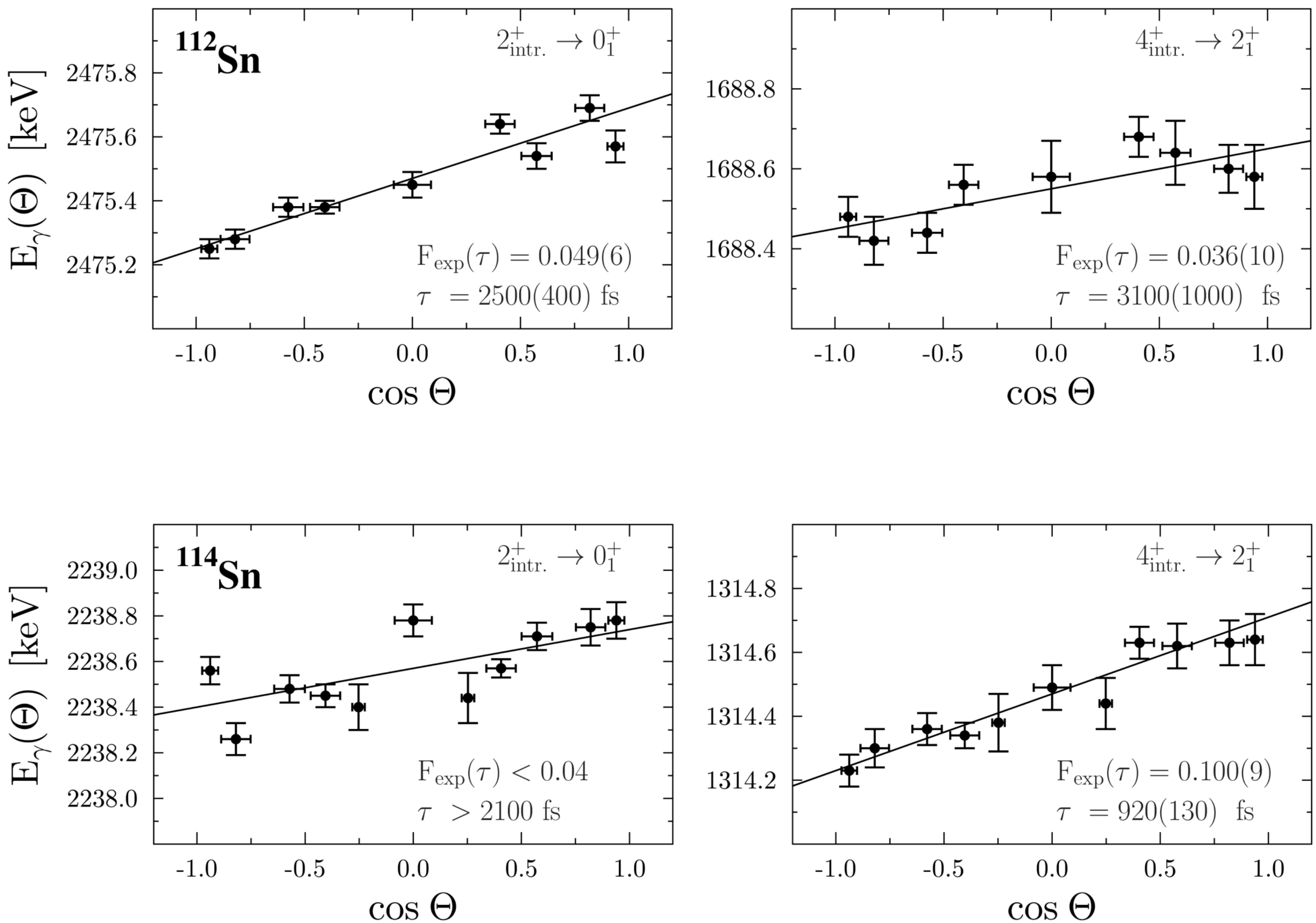
Lifetimes of intruder states in ^{112,114}Sn



γ-decay behavior of the states of interest

^{112}Sn

E_x [keV]	J_i^π	J_f^π	E_γ [keV]	I_γ [%]
1256.5(2)	2_1^+	0_1^+	1256.5(2)	100
2150.5(3)	2_2^+	0_1^+	2150.5(2)	20(3)
	2_2^+	2_1^+	893.9(2)	100
2190.5(2)	0_2^+	2_1^+	934.0(2)	100
2247.0(3)	4_1^+	2_1^+	990.47(10)	100
2353.7(2)	3_1^-	2_1^+	1097.2(2)	100
2475.5(2)	2_3^+	0_1^+	2475.5(2)	100
	2_3^+	2_1^+	1218.9(2)	36(5)
	2_3^+	0_2^+	284.9(2)	0.70(10)
2520.5(2)	4_2^+	2_1^+	1264.0(2)	100
		[⋮]		
2945.0(7)	4^+	2_1^+	1688.5(2)	100
	4^+	2_2^+	794.2(2)	5.4(10)
	4^+	4_1^+	697.9(2)*	<1.5
	4^+	2_3^+	469.5(2)	18(3)
	4^+	4_2^+	424.6(3)*	4.9(9)
	4^+	6_1^+	396.4(4)*	2.3(5)
	4^+	4^+	161.4(2)*	9(2)

^{114}Sn

E_x [keV]	J_i^π	J_f^π	E_γ [keV]	I_γ [%]
1299.7(2)	2_1^+	0_1^+	1299.7(2)	100
1952.9(2)	0_2^+	2_1^+	653.2(2)	100
2155.9(2)	0_3^+	2_1^+	856.2(2)	100
2187.3(3)	4_1^+	2_1^+	887.6(2)	100
2238.6(2)	2_2^+	0_1^+	2238.5(2)	100
	2_2^+	2_1^+	938.9(2)	81(12)
	2_2^+	0_2^+	286.5(10)	0.9(3)
2274.5(2)	3_1^-	2_1^+	974.8(2)	100
2420.5(2)	0_4^+	2_1^+	1120.8(2)	100
2453.8(2)	2_3^+	0_1^+	2453.7(2)	28(4)
	2_3^+	2_1^+	1154.0(2)	100
	2_3^+	2_2^+	215.4(4)	1.3(3)
2514.4(2)	3_1^+	4_1^+	327.1(2)	100
2613.7(4)	4_2^+	2_1^+	1314.5(2)	100
	4_2^+	4_1^+	426.0(4)	1.6(6)
	4_2^+	2_2^+	375.2(3)	1.8(6)

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* New γ-decay branching

^{114}Sn

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"intruder" states

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0^+@2617 keV ⋮

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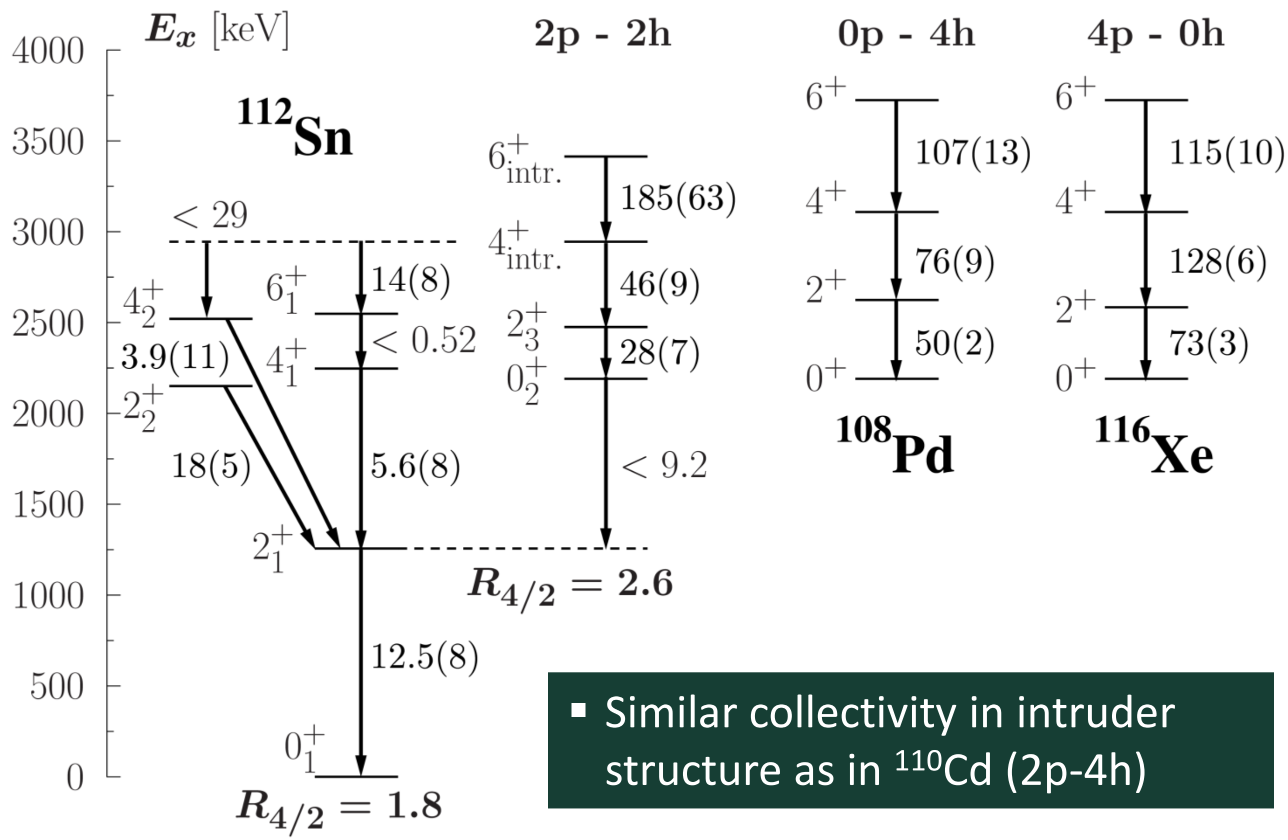
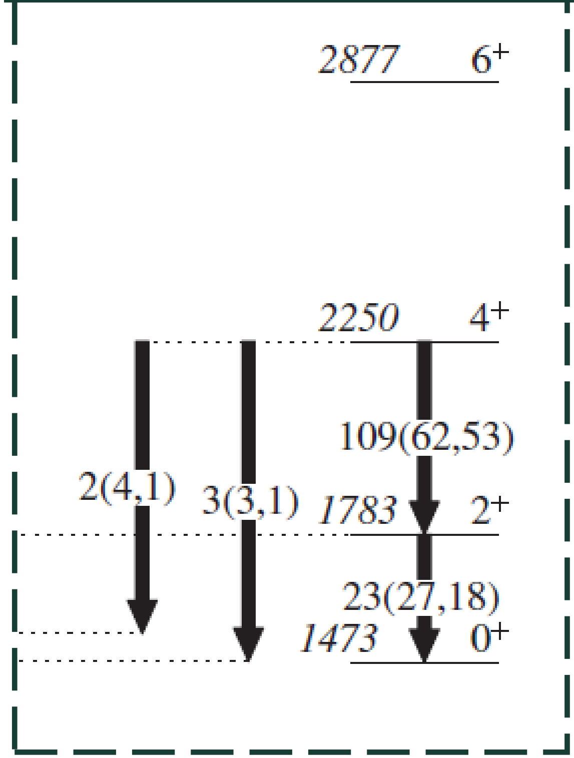
“intruder” states

Shape coexistence in ^{112}Sn



- Similar collectivity in intruder structure as in ^{110}Cd (2p-4h)

^{110}Cd P.E. Garrett and J.L. Wood, J. Phys. G 37, 064028 (2010)



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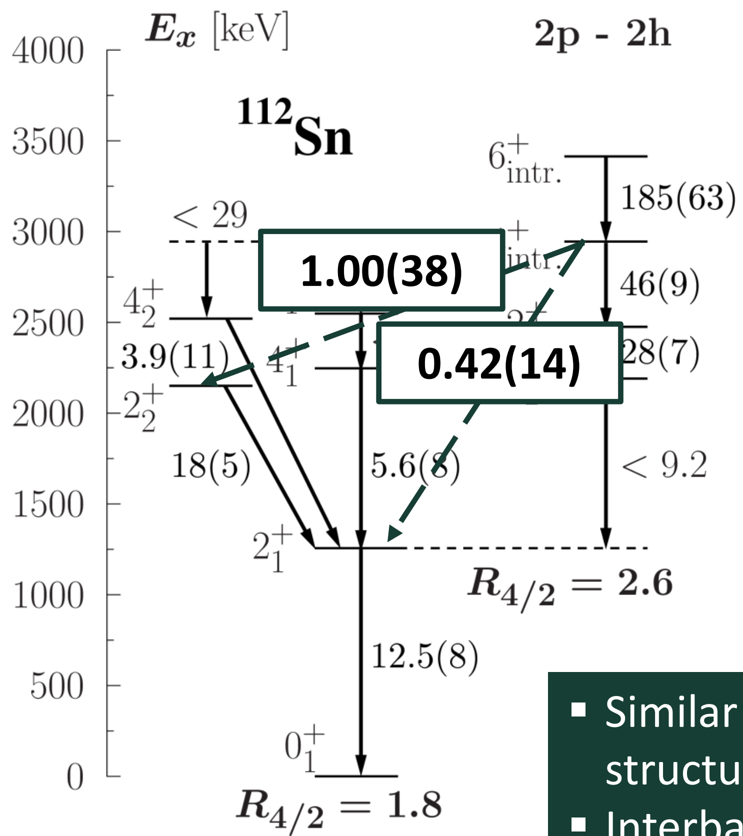
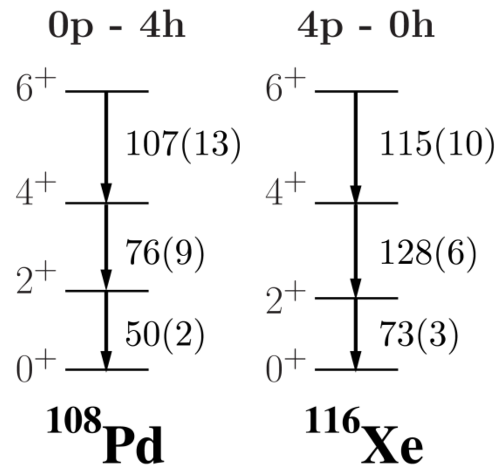
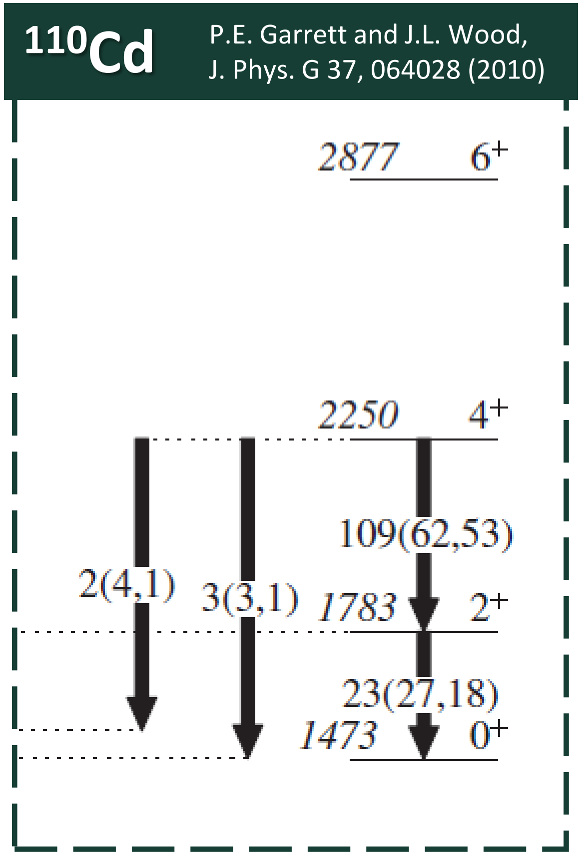
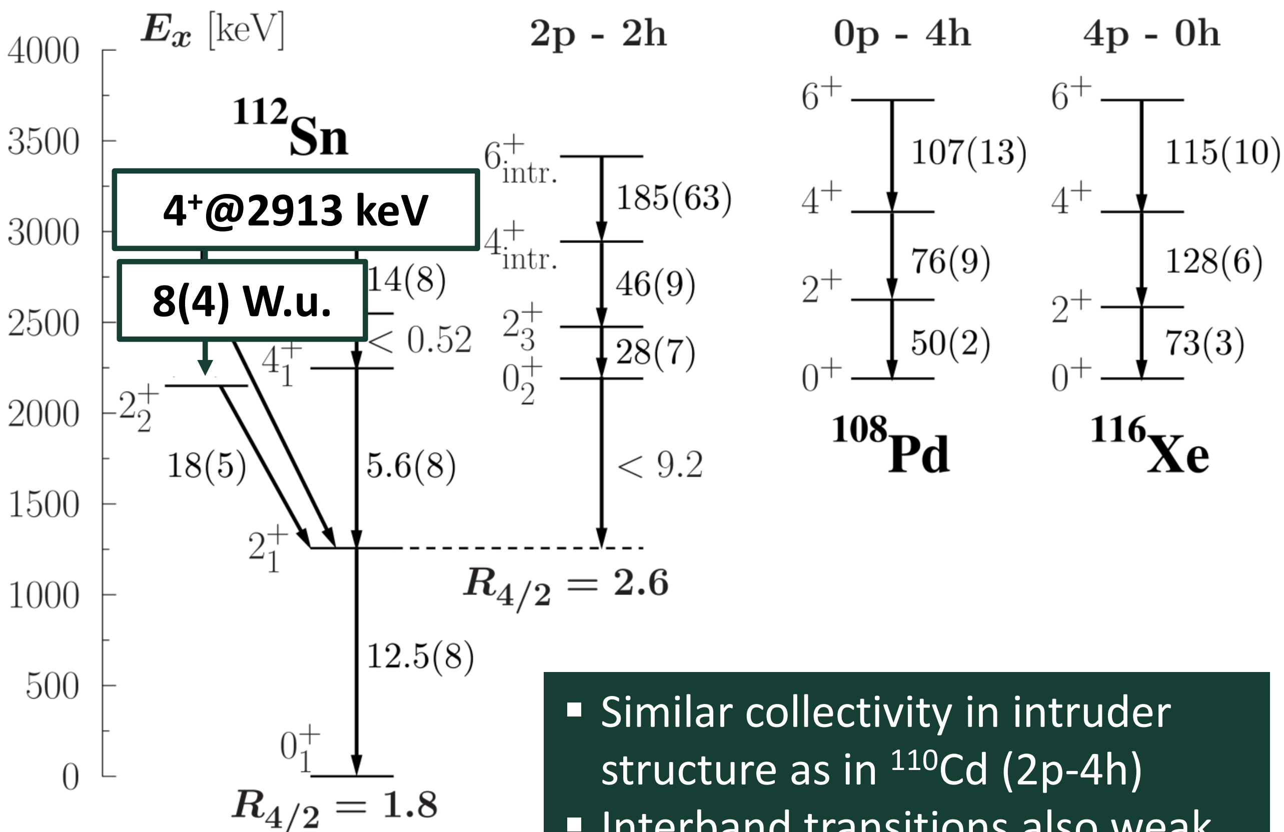


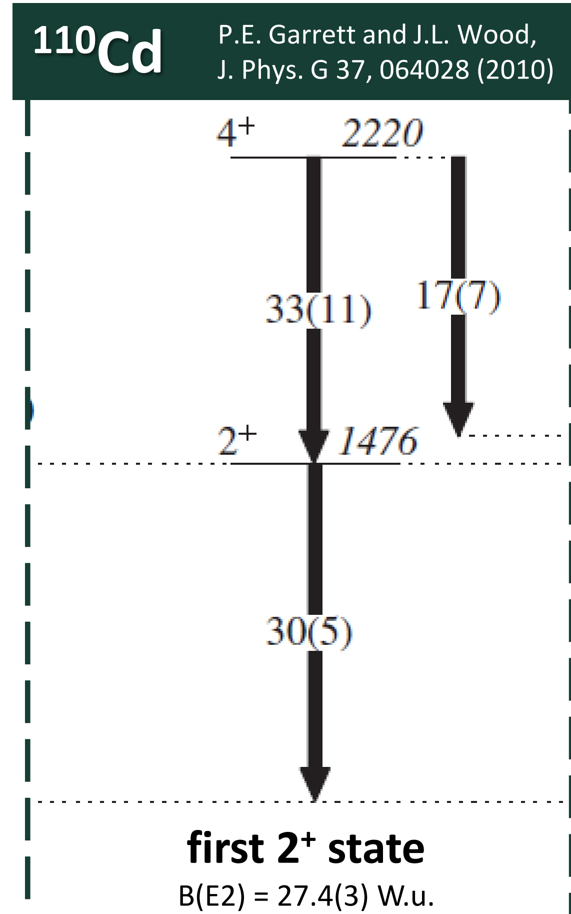




- Similar collectivity in intruder structure as in ^{110}Cd (2p-4h)
- Interband transitions also weak

Shape coexistence in ^{112}Sn





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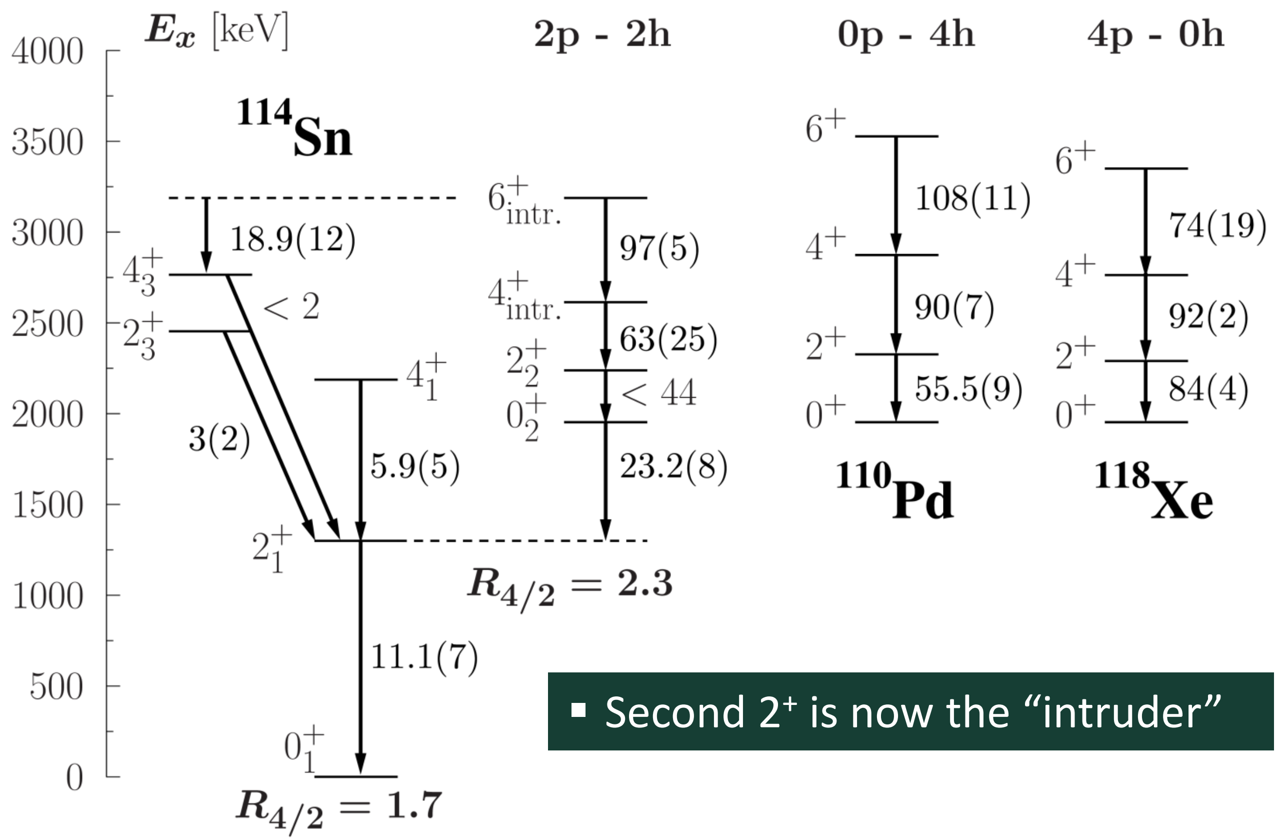
- Interband transitions also weak
- Quasi-rotational structure of Cd isotopes was proposed

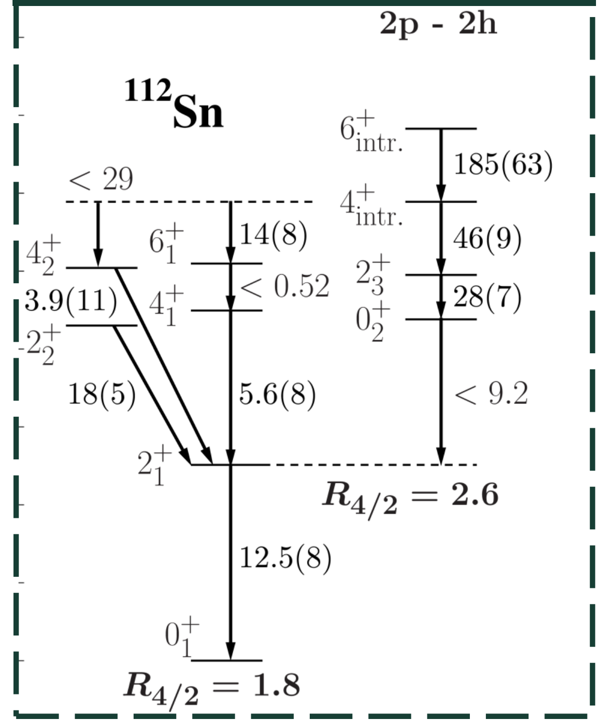
“Quasi-rotational structure“ already existent at higher energies in Sn isotopes?

Shape coexistence in ^{114}Sn



- Second 2⁺ is now the "intruder"

^{112}Sn



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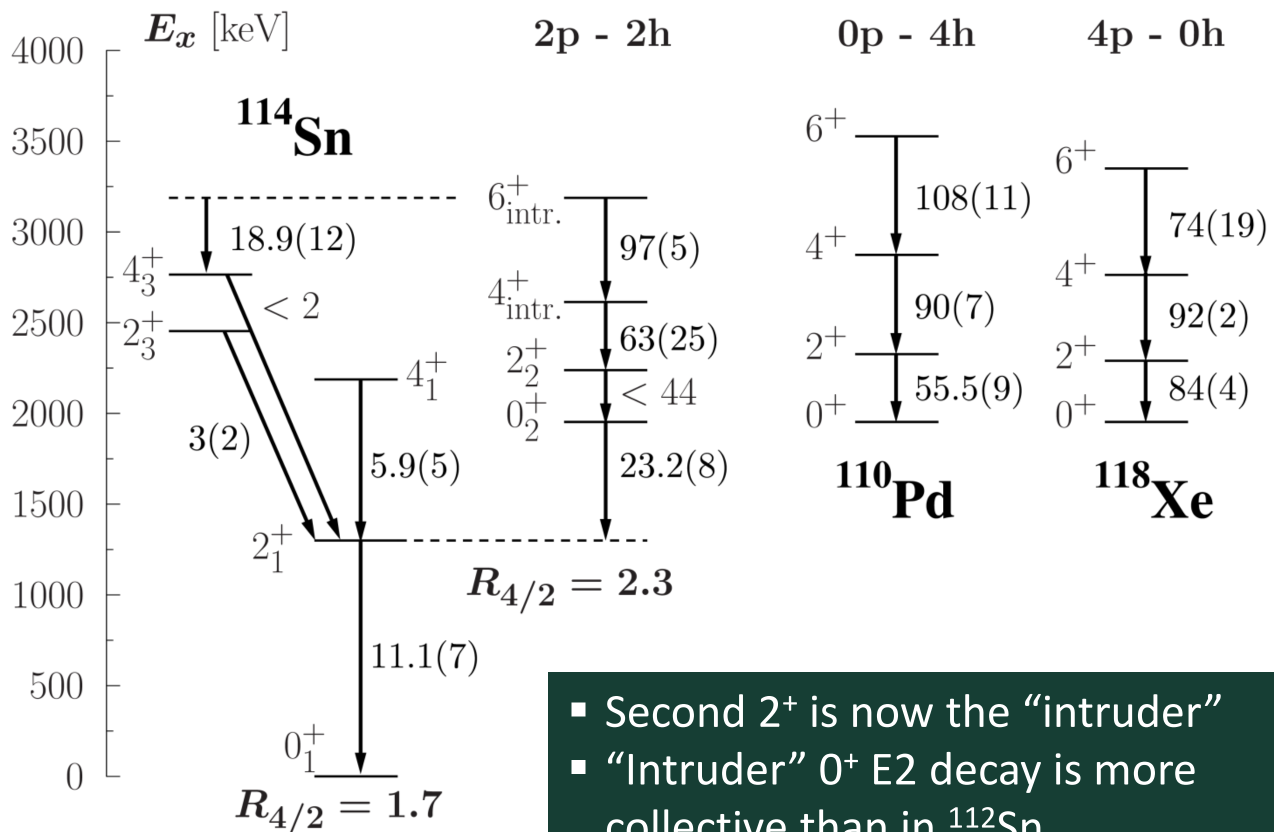
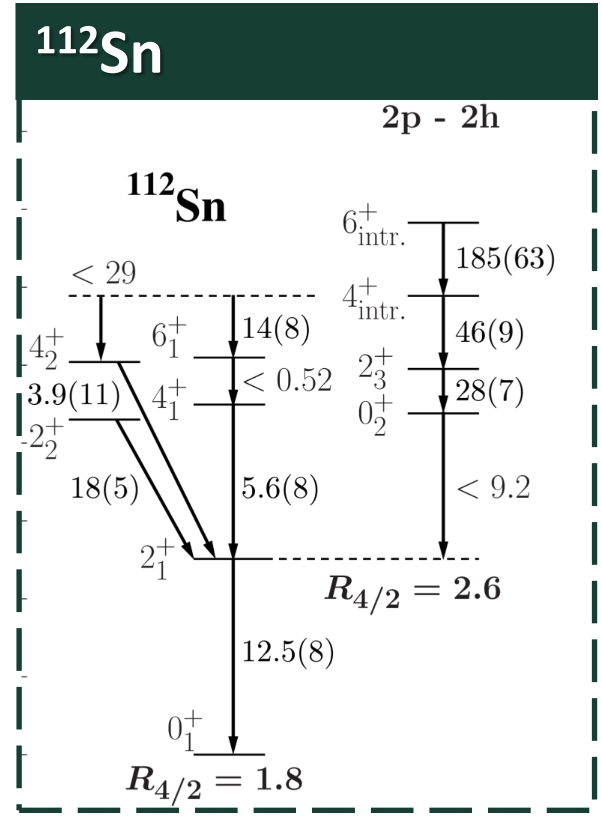


- Second 2$^+$ is now the "intruder"
- "Intruder" 0$^+$ E2 decay is more collective than in ^{112}Sn



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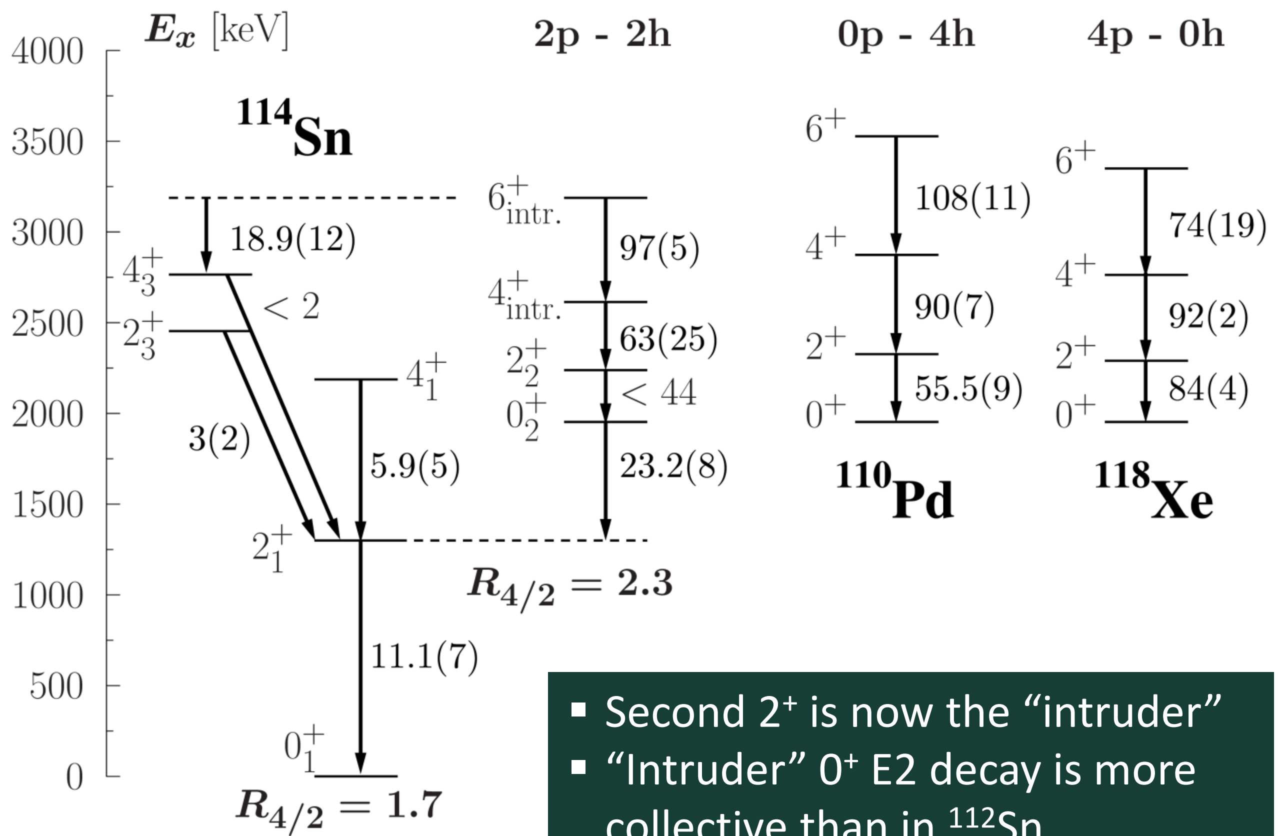

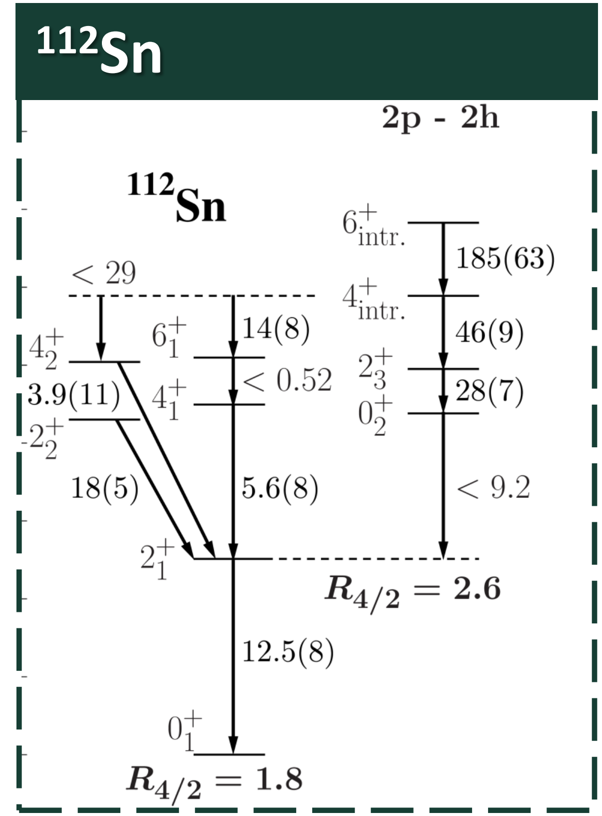

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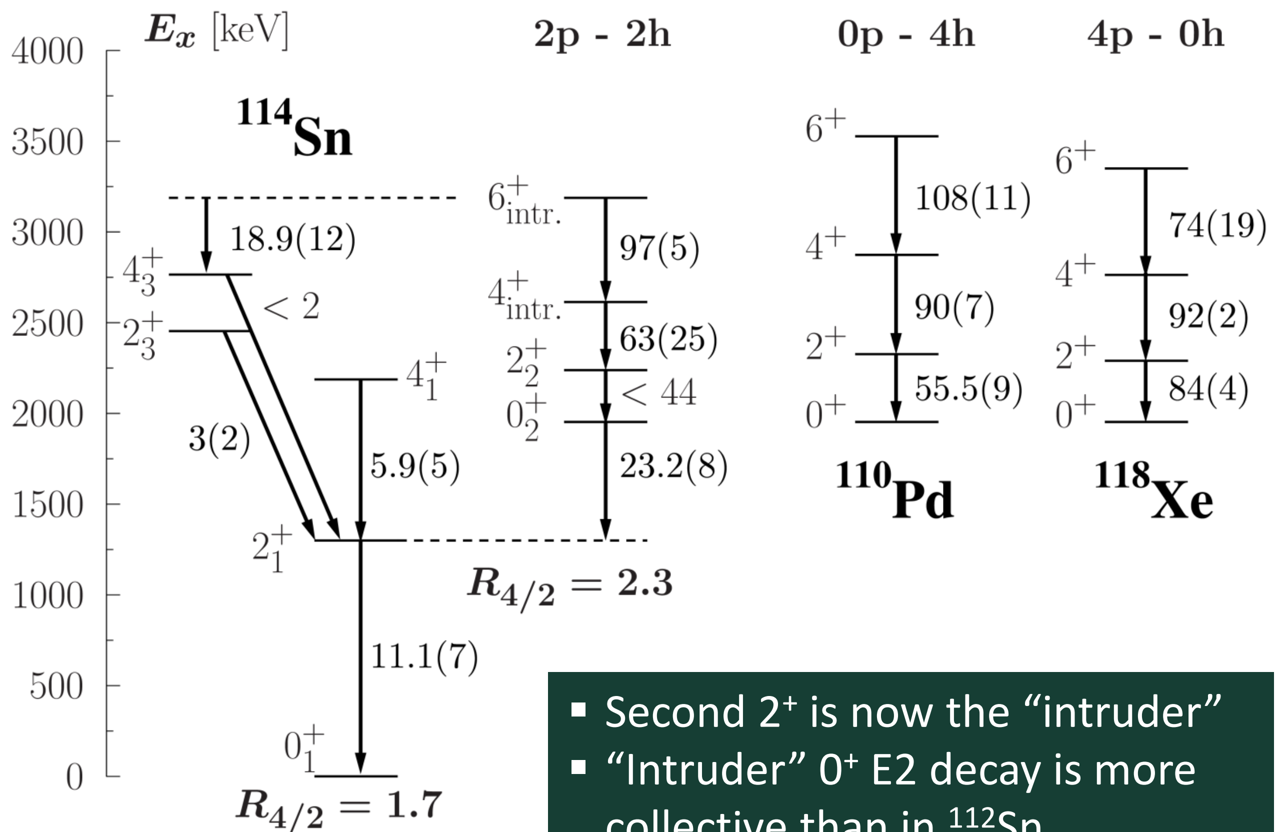
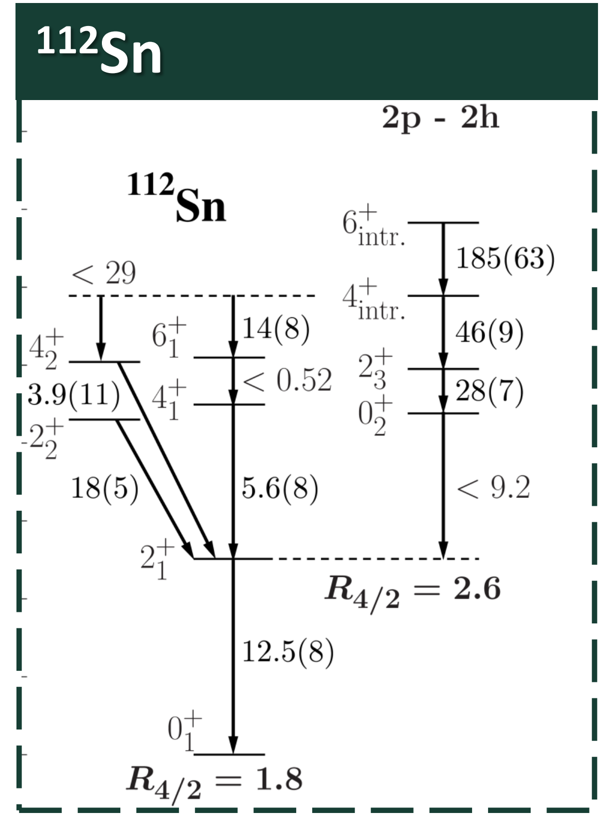
Shape coexistence in ^{114}Sn





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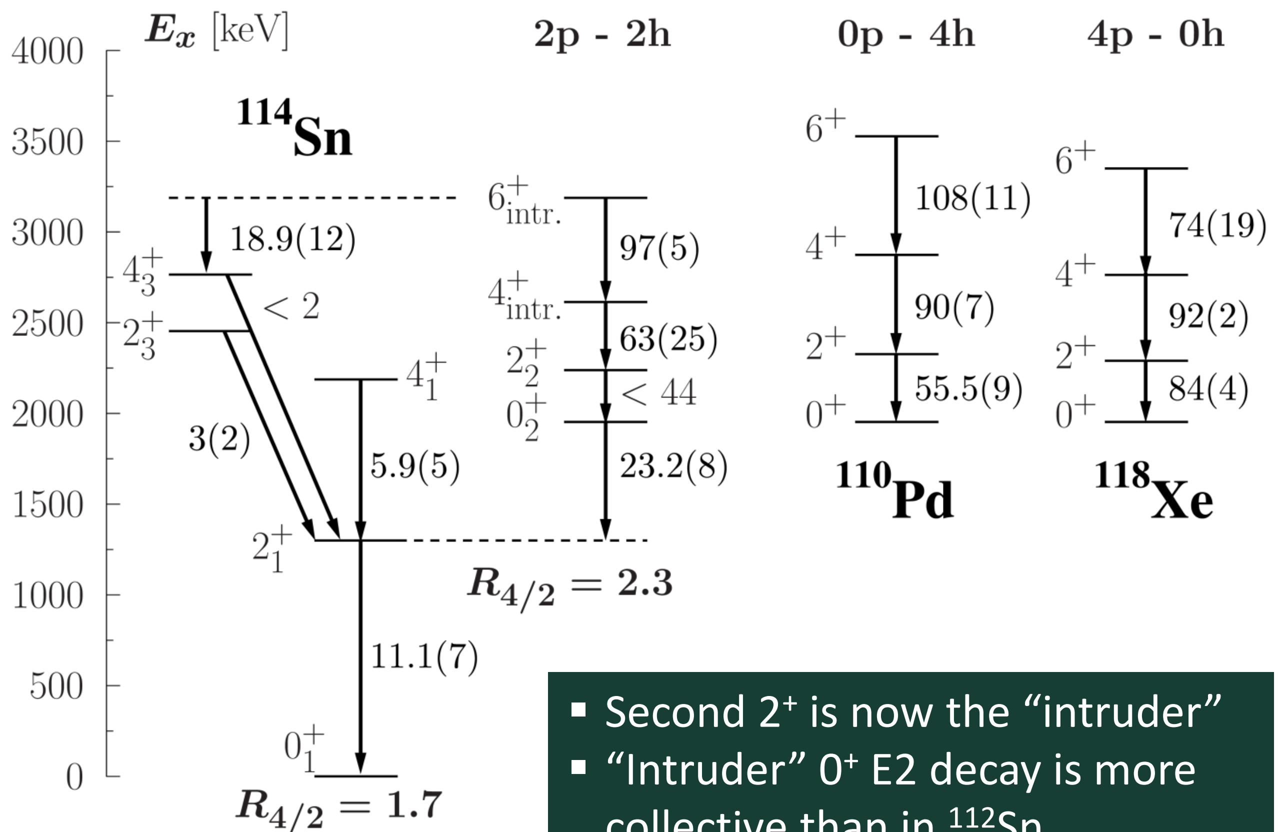
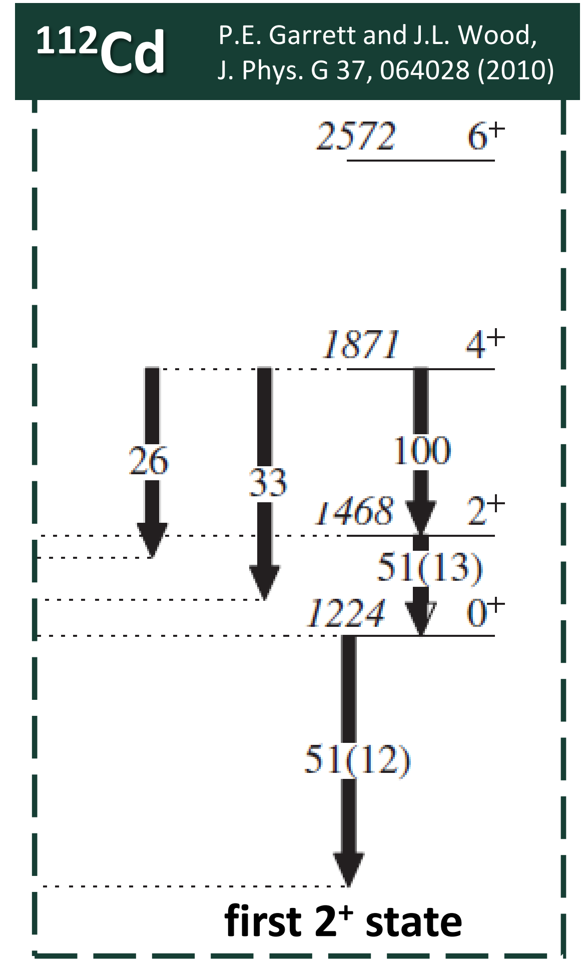
Influence of underlying single-particle structure or overall structure change?

Different influence of neutron single-particle states?

Shape coexistence in ^{114}Sn





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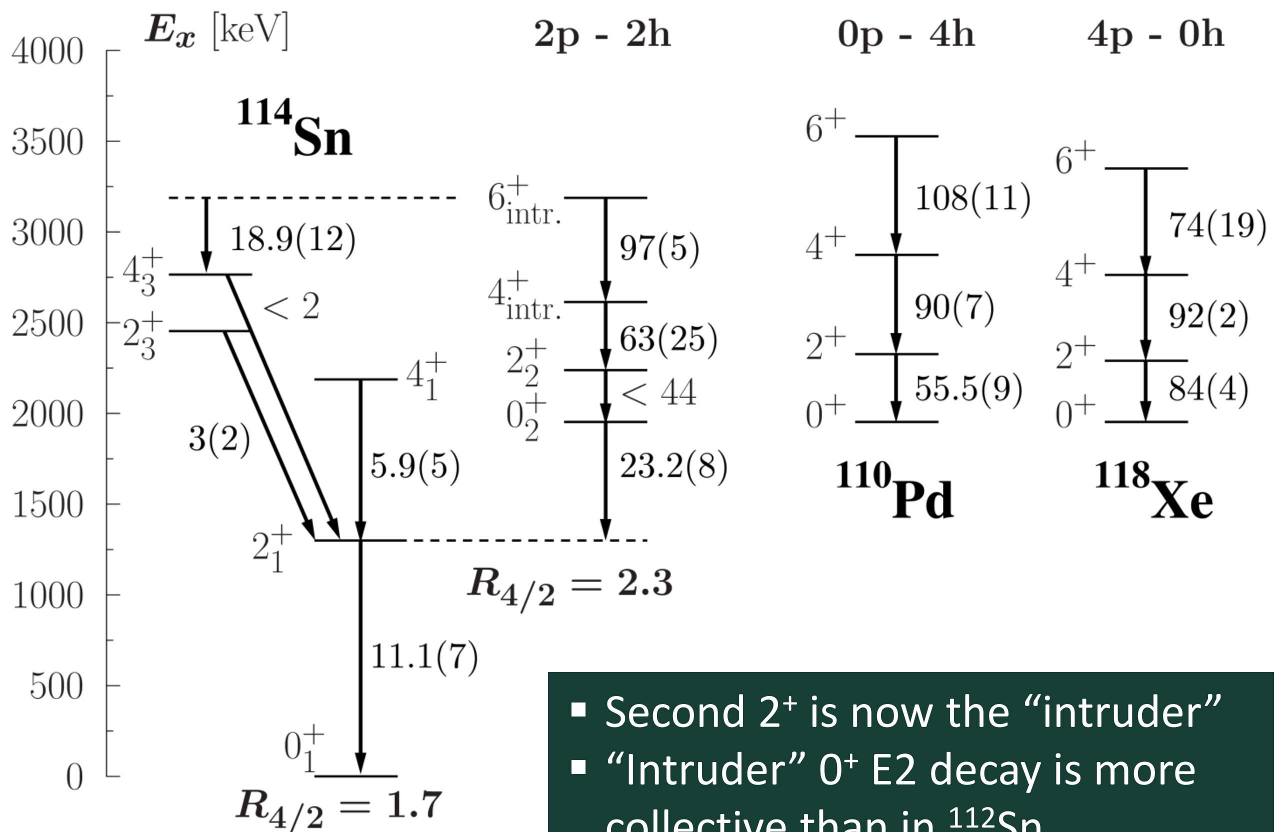

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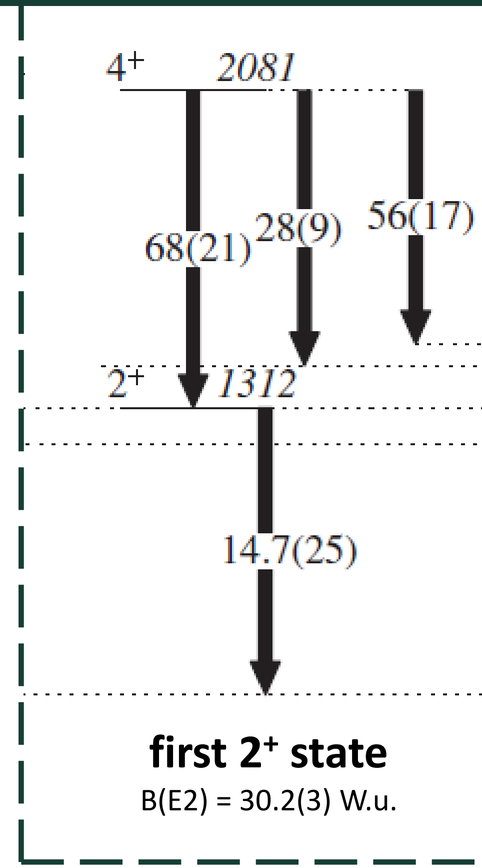
^{112}Cd P.E. Garrett and J.L. Wood, J. Phys. G 37, 064028 (2010)



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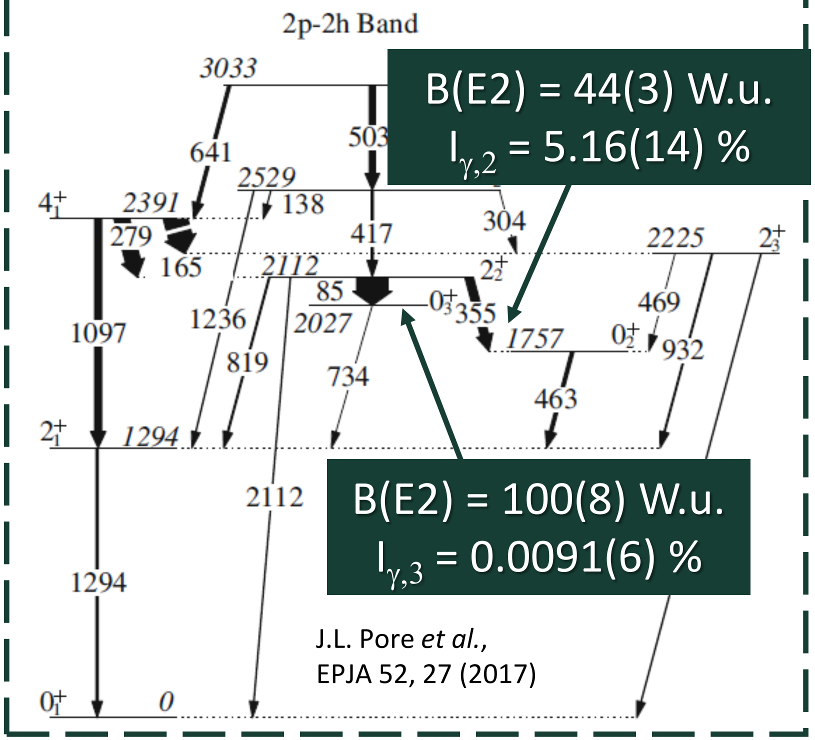
Shape coexistence in ^{114}Sn

Comparison to IBM-2 mixing calculations
(assuming ^{110}Pd to cause intruder structure)

J_i^π	E_x [MeV]	$E_{x,\mathrm{IBM}}$ [MeV]	J_f^π	$B(E2)_{\mathrm{exp.}}\downarrow$ [W.u.]	$B(E2)_{\mathrm{IBM}}\downarrow$ [W.u.]
normal configuration					
2_1^+	1.30	1.30	0_1^+	11.1(7)	11
4_1^+	2.19	2.28	2_1^+	5.9(5)	19
0_2^+	1.95	1.99	2_1^+	23.2(8)	21
2_3^+	2.45	2.54	0_1^+	0.023(9)	0.004
			2_1^+	3(2)	17
			2_2^+	-	8
intruder configuration					
0_3^+	2.16	2.15	2_1^+	≤ 5	2
2_2^+	2.24	2.46	0_1^+	≤ 0.12	0.04
			2_1^+	≤ 8	2
			0_2^+	≤ 44	31
			0_3^+	-	27
4_2^+	2.61	3.00	2_1^+	6.6(10)	0.2
			4_1^+	1.6(10)	0.06
			2_2^+	62(25)	85
6^+	3.19	3.63	4_1^+	1.68(9)	1.5
			4_2^+	97(5)	93
			4_3^+	18.9(12)	0.7

^{116}Sn – Is 3rd 0$^+$ bandhead?



J.L. Pore *et al.*,
EPJA 52, 27 (2017)

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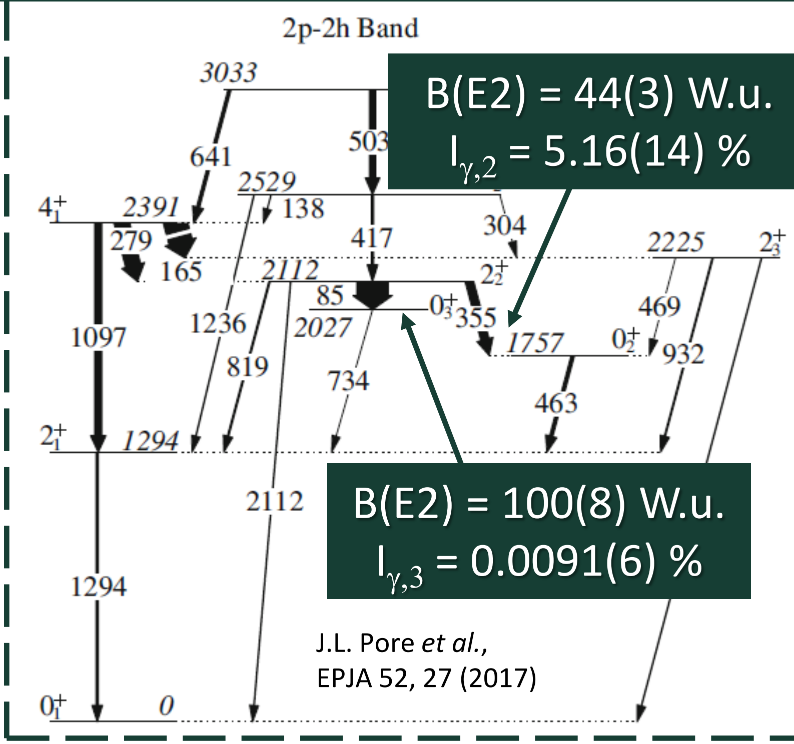
J_i^π	E_x [MeV]	$E_{x,\mathrm{IBM}}$ [MeV]	J_f^π	$B(E2)_{\mathrm{exp.}}\downarrow$ [W.u.]	$B(E2)_{\mathrm{IBM}}\downarrow$ [W.u.]
		normal configuration			
2_1^+	1.30	1.30	0_1^+	11.1(7)	11
4_1^+	2.19	2.28	2_1^+	5.9(5)	19
0_2^+	1.95	1.99	2_1^+	23.2(8)	21
2_3^+	2.45	2.54	0_1^+	0.023(9)	0.004
			2_1^+	3(2)	17
			2_2^+	-	8
		intruder configuration			
0_3^+	2.16	2.15			
2_2^+	2.24	2.46			
			0_2^+	≤ 44	31
			0_3^+	-	27
4_2^+	2.61	3			
			2_2^+	62(25)	85
6^+	3.19	3.63	4_1^+	1.68(9)	1.5
			4_2^+	97(5)	93
			4_3^+	18.9(12)	0.7

$I_{\gamma,2}$ = 0.9(3) % (Exp.)
$I_{\gamma,3} \approx$ 0.002 % (IBM)

B(E2) = 55.5(9) W.u. in ^{110}Pd

^{116}Sn – Is 3rd 0$^+$ bandhead?



B(E2) = 44(3) W.u.
$I_{\gamma,2}$ = 5.16(14) %

B(E2) = 100(8) W.u.
$I_{\gamma,3}$ = 0.0091(6) %

J.L. Pore *et al.*,
EPJA 52, 27 (2017)

Shape coexistence in ^{114}Sn

Comparison to IBM-2 mixing calculations

(assuming ^{110}Pd to cause intruder structure)

J_i^π	E_x [MeV]	$E_{x,\mathrm{IBM}}$ [MeV]	J_f^π	$B(E2)_{\mathrm{exp.}}\downarrow$ [W.u.]	$B(E2)_{\mathrm{IBM}}\downarrow$ [W.u.]
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6^+	3.19	3.63	4_1^+	1.68(9)	
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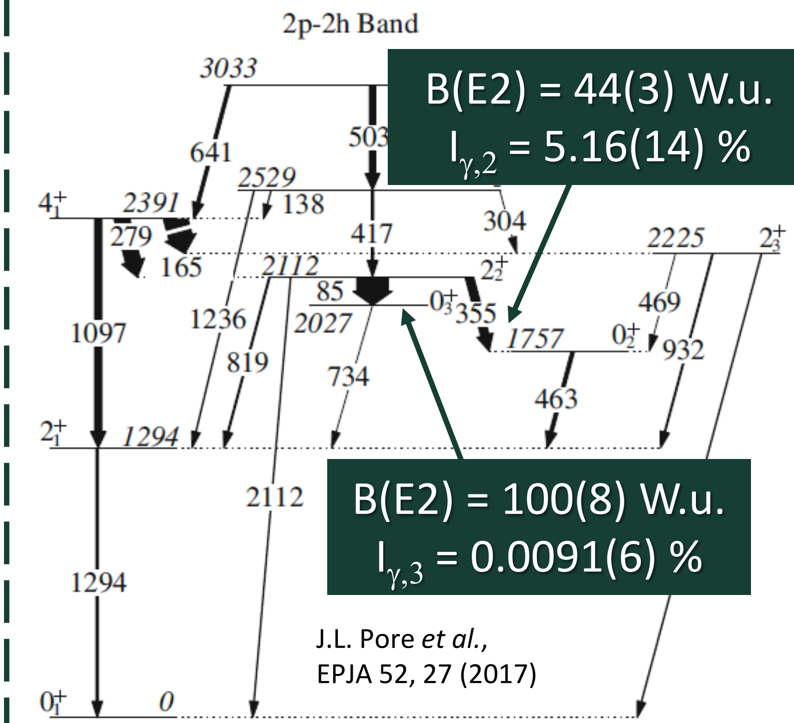

B(E2) = 44(3) W.u.
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B(E2) = 100(8) W.u.
$I_{\gamma,3}$ = 0.0091(6) %

J.L. Pore *et al.*,
EPJA 52, 27 (2017)

B(E2) = 40(7) W.u. in ^{112}Pd

How could this large B(E2) in ^{116}Sn be explained?

Shape coexistence in ^{114}Sn

Comparison to IBM-2 mixing calculations
(assuming ^{110}Pd to cause intruder structure)

J_i^π	E_x [MeV]	$E_{x,\mathrm{IBM}}$ [MeV]	J_f^π	$B(E2)_{\mathrm{exp.}}\downarrow$ [W.u.]	$B(E2)_{\mathrm{IBM}}\downarrow$ [W.u.]
normal configuration					
2_1^+	1.30	1.30	0_1^+	11.1(7)	11
4_1^+	2.19	2.28	2_1^+	5.9(5)	19
0_2^+	1.95	1.99	2_1^+	23.2(8)	21
2_3^+	2.45	2.54	0_1^+	0.023(9)	0.004
			2_1^+	3(2)	17
			2_2^+	-	8
intruder configuration					
0_3^+	2.16	2.15			
2_2^+	2.24	2.46			
			0_2^+	≤ 44	31
			0_3^+	-	27
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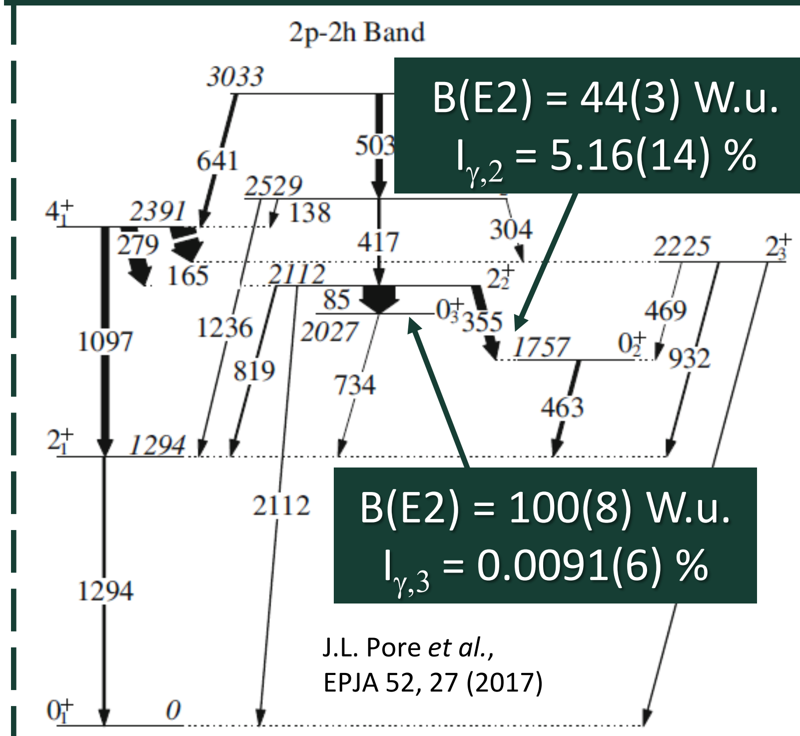
			2_2^+	62(25)	85
6^+	3.19	3.63	4_1^+	1.68(9)	
			4_2^+	97(5)	
			4_3^+	18.9(12)	0.7

$I_{\gamma,2}$ = 0.9(3) % (Exp.)
$I_{\gamma,3}$ ≈ 0.002 % (IBM)

B(E2) = 55.5(9) W.u. in ^{110}Pd

^{116}Sn – Is 3rd 0$^+$ bandhead?



B(E2) = 44(3) W.u.
$I_{\gamma,2}$ = 5.16(14) %

B(E2) = 100(8) W.u.
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J.L. Pore *et al.*,
EPJA 52, 27 (2017)

B(E2) = 40(7) W.u. in ^{112}Pd

How could this large B(E2) in ^{116}Sn be explained?

B(E2) = 101(5) W.u. in ^{120}Xe

Summary

- **SONIC@HORUS** to determine lifetimes and γ-decay behavior of low-spin states via (p,p'γ) DSA coincidence technique

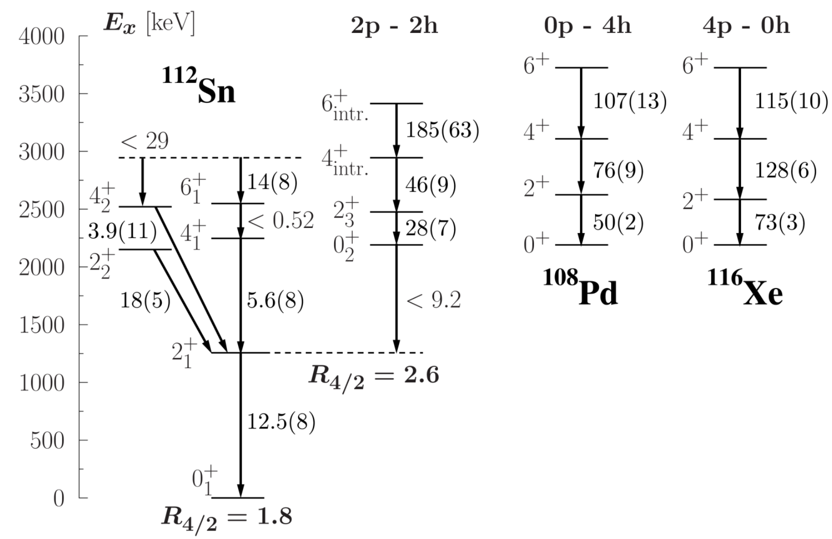
  [A. Hennig *et al.*, NIM **794**, 171 (2015)]

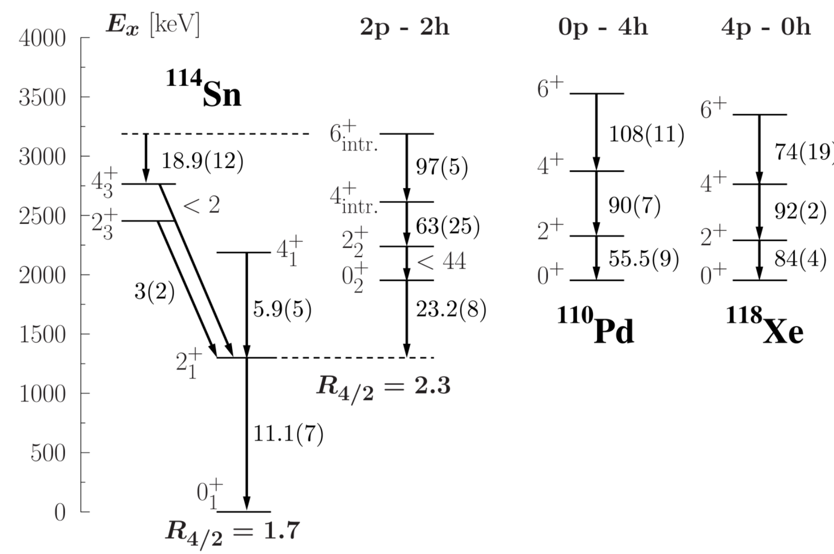
  [S.G. Pickstone *et al.*, NIM **875**, 104 (2017)]

- **Collectivity of low-spin "intruder" states** studied in ^{112,114}Sn

- **Mixing hypothesis between normal and intruder configuration** tested via schematic IBM-2 mixing calculations

- No clear hints at quadrupole multiphonon structures in ^{112,114}Sn





[M. Spieker *et al.*, PRC **97**, 054319 (2018)]

Universität zu Köln

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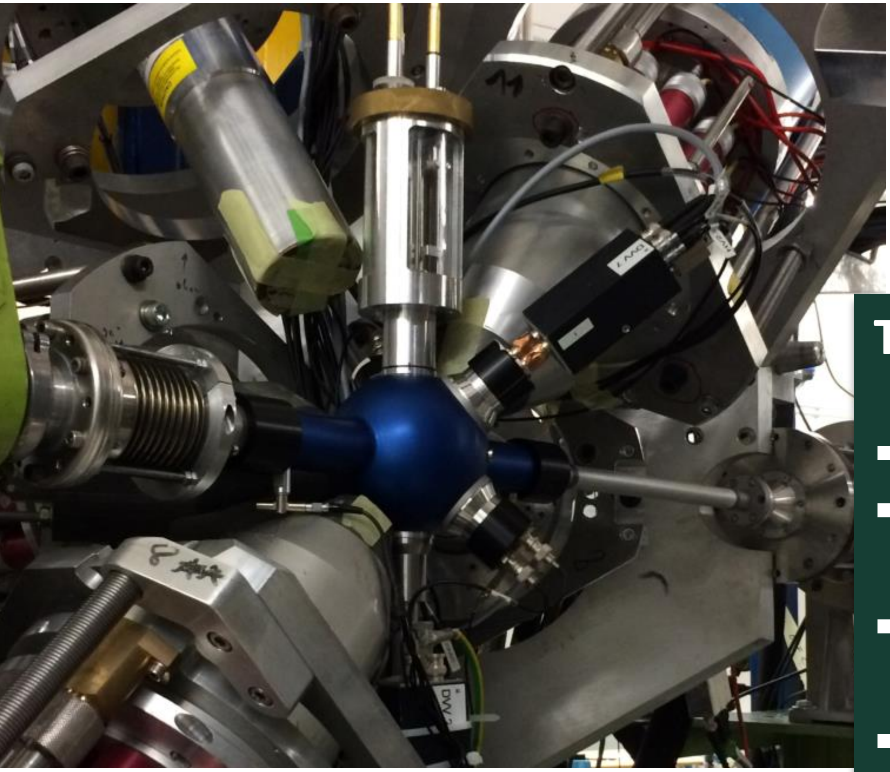
back-up

(p,p'γ) DSA coincidence technique

Determination of γ-energy centroid shifts due to Doppler effect with SONIC@HORUS at UoC (Cologne, Germany)



$$E_\gamma(\Theta,t) = E_\gamma^0\left(1 + F(\tau)\frac{v_0}{c}\cos\Theta\right)$$

The (p,p'γ) DSA coincidence technique

- Lifetimes from 10 fs to 1 ps can be measured
- Feeding from higher-lying states excluded due to pγ coincidences (excitation gate)
- γ-decay branching can be measured
  $\rightarrow$ Partial decay widths accessible
- Dozens of lifetimes in one experiment!
- J = 0 – 6 are excited with (p,p') at E_p = 8 MeV

(p,p'γ) DSA coincidence technique: A. Hennig *et al.*, NIM **794**, 171 (2015)

SONIC@HORUS (UoC, Germany): S.G. Pickstone *et al.*, NIM **875**, 104 (2017)

(p,p’γ) DSA coincidence technique

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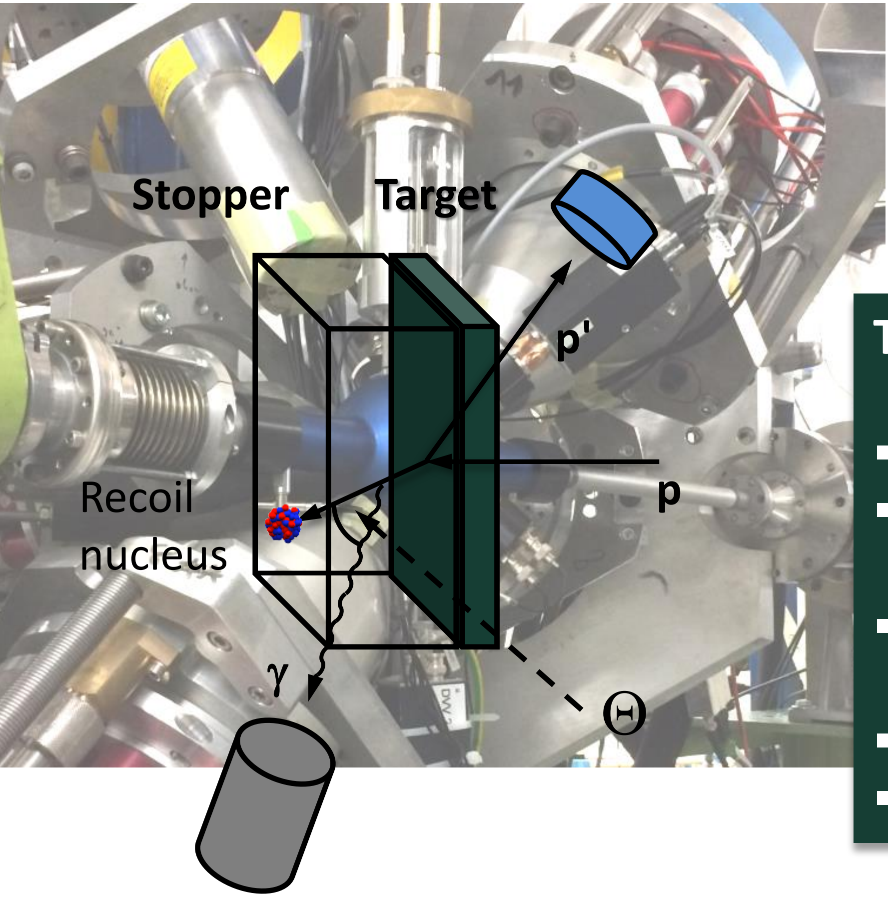

$$E_\gamma(\Theta,t) = E_\gamma^0 \left(1 + F(\tau)\frac{v_0}{c}\cos\Theta\right)$$

The (p,p‘γ) DSA coincidence technique

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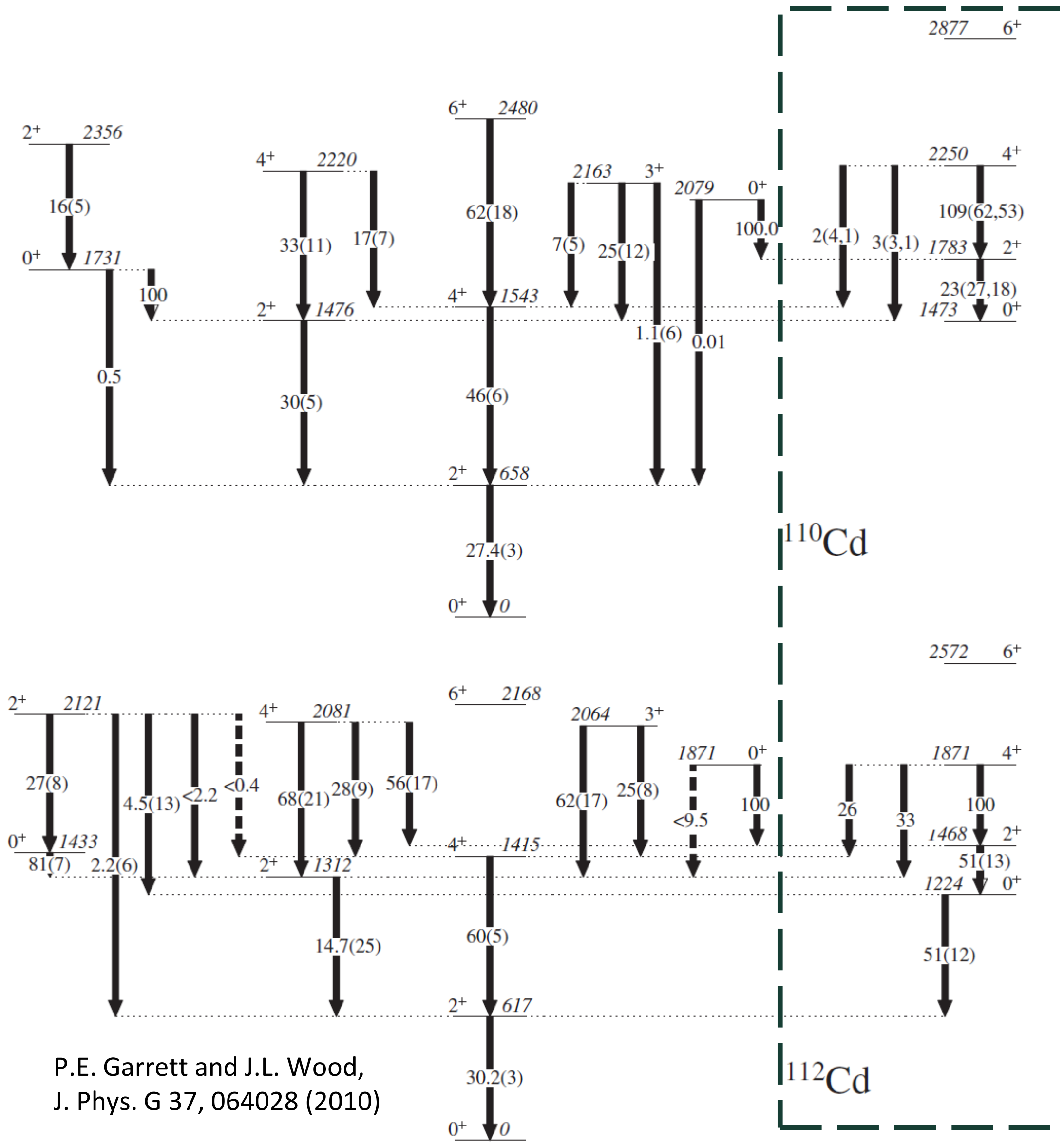
(p,p‘γ) DSA coincidence technique: A. Hennig *et al.*, NIM **794**, 171 (2015)

SONIC@HORUS (UoC, Germany): S.G. Pickstone *et al.*, NIM **875**, 104 (2017)

Shape coexistence in Cd isotopes



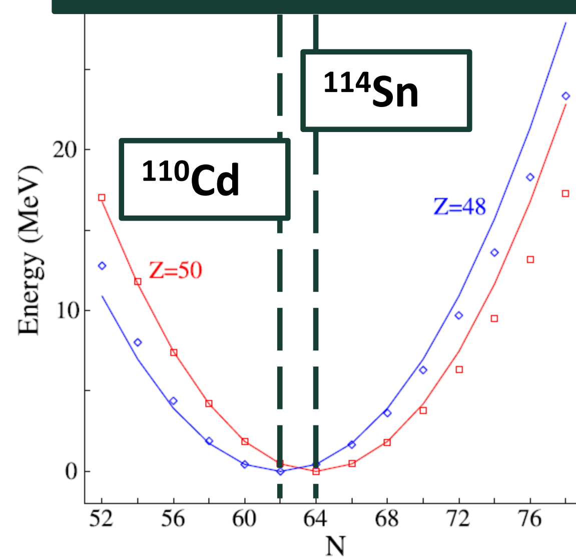
P.E. Garrett and J.L. Wood,
J. Phys. G 37, 064028 (2010)

Shape coexistence in ^{110,112}Cd (Z = 48, N = 62, 64)

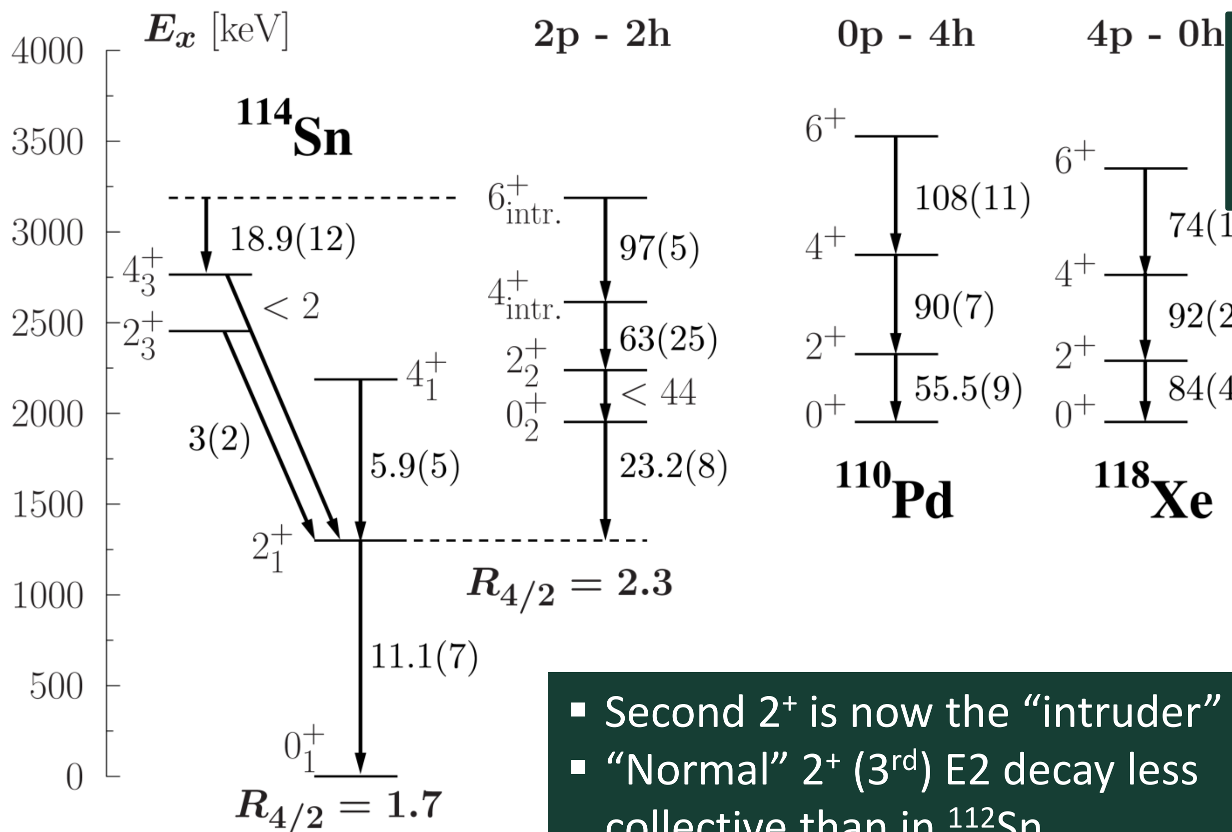
- "additional" states observed
→ attributed to 2p-4h excitations across the Z = 50 shell closure, i.e. Pd isotopes as "inert core"

P.E. Garrett, J. Phys. G 43, 084002 (2016)

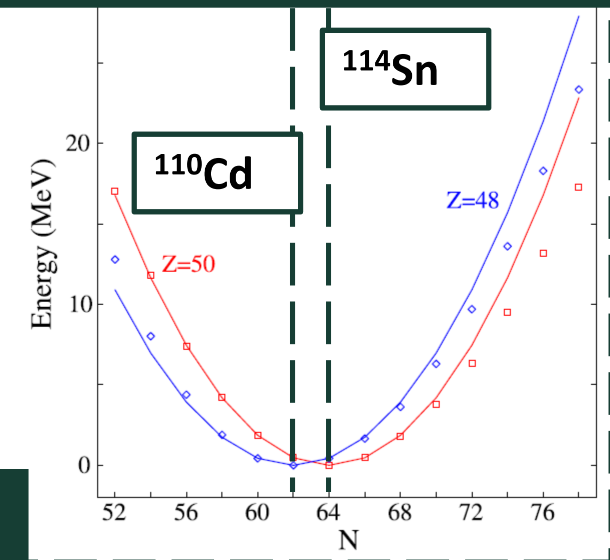
Ground-state energies compared to Pairing rotor model



Shape coexistence in ^{114}Sn



Ground-state energies compared to Pairing rotor model



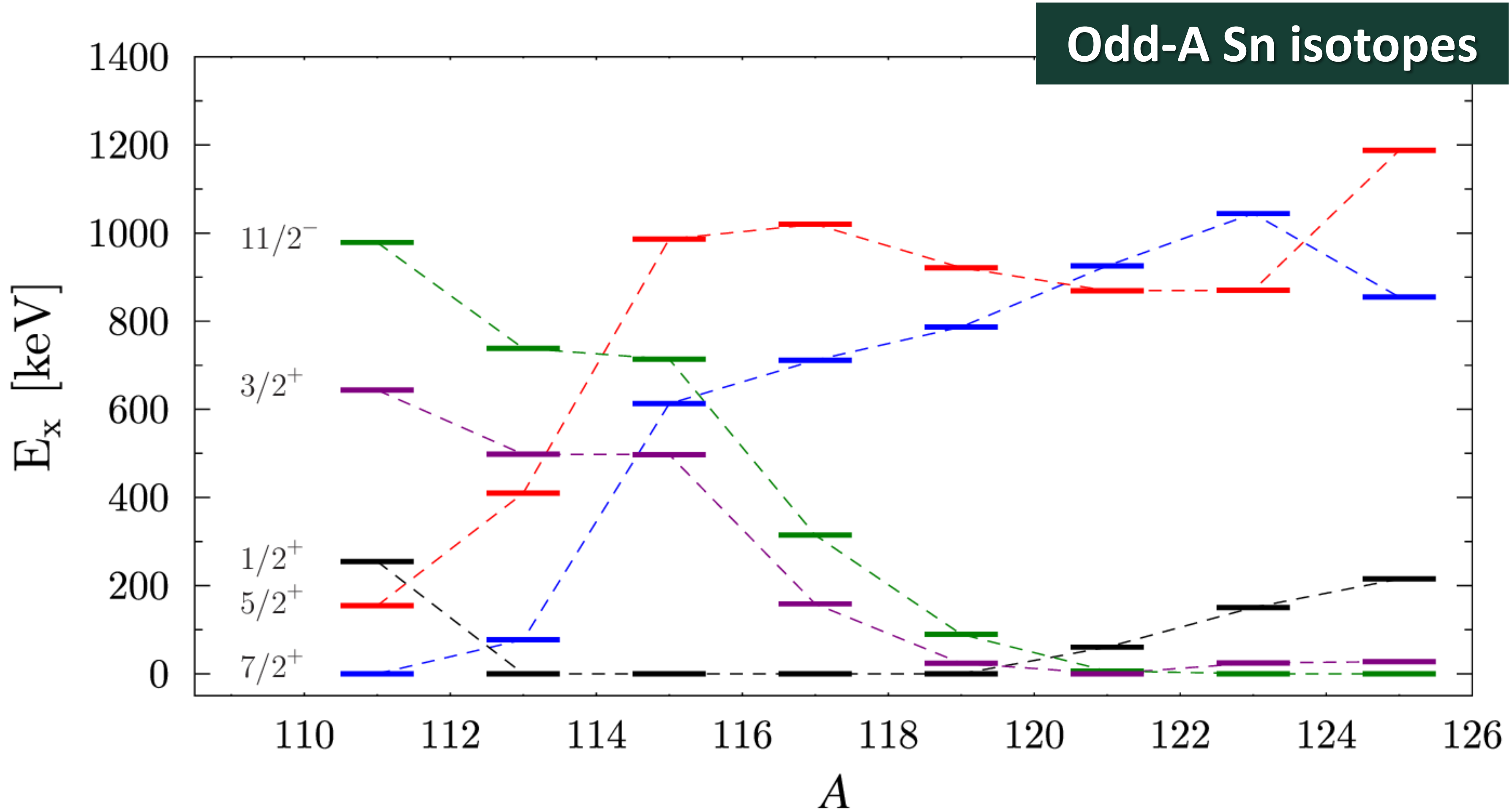
P.E. Garrett, J. Phys. G 43, 084002 (2016)

- Second 2$^+$ is now the "intruder"
- "Normal" 2$^+$ (3rd) E2 decay less collective than in ^{112}Sn
- "Intruder" 0$^+$ E2 decay is more collective than in ^{112}Sn

Influence of underlying single-particle structure or overall structure change?

Different influence of neutron single-particle states?

Neutron single-particle structure



Are there quadrupole multiphonon states?

J_i^π	E_x [keV]	J_f^π	$B(E2)_{\text{exp.}}$ [W.u.]
	^{112}Sn		
0^+	2617.4(3)	2_1^+	≤ 2
		2_2^+	≤ 7
2^+	2720.6(2)	0_1^+	≤ 0.02
		2_1^+	$0.06^{+0.08}_{-0.01}$
		2_2^+	≤ 4.3
		0_2^+	3.3(12)
3^+	2755.2(3)	2_1^+	≤ 0.004
		2_2^+	≤ 12
		4_1^+	≤ 45
		4_2^+	≤ 0.2
4^+	2783.5(2)	2_1^+	5.1(6)
		4_1^+	≤ 35
	^{114}Sn		
4^+	2859.2(5)	2_1^+	2.8(4)
		4_1^+	≤ 10
		2_2^+	< 5
		2_3^+	< 46
2^+	2943.4(2)	0_1^+	< 0.001
		2_1^+	≤ 0.3
		0_2^+	≤ 0.4
		2_2^+	≤ 0.9
		0_4^+	≤ 1.6
		2_3^+	≤ 5.2
0^+	3028.0(2)	2_1^+	1.7(7)
		2_2^+	1.4(10)
		2_3^+	16(8)

^{124}Sn

D. Bandyopadhyay *et al.*, NPA **747**, 206 (2005)

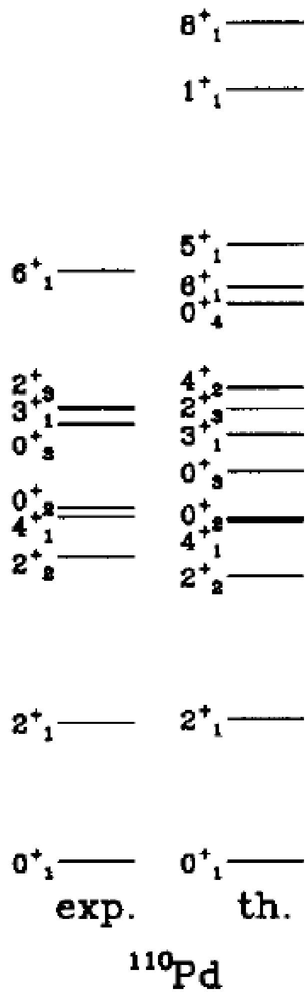
J_i^π [$\hbar$]	J_f^π [$\hbar$]	Exp [W.u.]
2_1^+	0_1^+	9.0[a]
4_1^+	2_1^+	4.8[a]
2_2^+	2_1^+	< 9.3
2_2^+	0_1^+	< 0.004
0_2^+	2_1^+	< 8.3
0_3^+	2_2^+	< 78
0_3^+	2_1^+	< 1.6
2_3^+	2_2^+	$4.4^{+0.2}_{-4.4}$
2_3^+	2_1^+	$0.12^{+0.13}_{-0.07}$
2_3^+	0_1^+	$0.028^{+0.008}_{-0.007}$
6_1^+	4_1^+	< 90
3_1^+	4_2^+	< 46[b]
3_1^+	4_1^+	< 5
3_1^+	2_2^+	< 67[b]
3_1^+	2_1^+	< 0.3
4_3^+	4_2^+	$3.1^{+14}_{-3.1}$
4_3^+	4_1^+	$4.2^{+0.2}_{-0.2}$
4_3^+	2_1^+	$0.27^{+0.21}_{-0.19}$

[a] Calculated using the halflives from Ref. [14].
[b] Calculated using mixing ratios from the present work and from Ref. [20].

IBM-2 calculations

Table IV. Comparison of the normal and intruder configurations identified experimentally and the predictions of the *sd* IBM-2 with mixing in ^{114}Sn. The parameters for the intruder configuration were adopted from Ref. [53], i.e. ^{110}Pd. The parameters for the normal configuration in ^{114}Sn were adopted from Ref. [54] but slightly changed, i.e. $C_{0\nu} = -0.55$, $C_{2\nu} = 0$, and $C_{4\nu} = -0.31$. The mixing parameters α and β were kept at 0.2 and 0, respectively. Δ, i.e. the relative energy shift between the normal and intruder configurations was set to 2.78 MeV. The parameters of the $E2$ operator were also slightly changed to $e_\nu = 0.07\,\mathrm{eb}^2$, $e_\pi = 0.105\,\mathrm{eb}^2$ and $e_2/e_0 = 1.43$. The experimental $B(E2; 2^+_1 \to 0^+_1)$ value is taken from Ref. [35]. For a description of the Hamiltonian, the $E2$ operator and their parameters see, *e.g.*, Refs. [53, 55].

J^π_i	E_x [MeV]	$E_{x,\mathrm{IBM}}$ [MeV]	J^π_f	$B(E2)_{\mathrm{exp.}}\downarrow$ [W.u.]	$B(E2)_{\mathrm{IBM}}\downarrow$ [W.u.]
normal configuration					
2^+_1	1.30	1.30	0^+_1	11.1(7)	11
4^+_1	2.19	2.28	2^+_1	5.9(5)	19
0^+_2	1.95	1.99	2^+_1	23.2(8)	21
2^+_3	2.45	2.54	0^+_1	0.023(9)	0.004
			2^+_1	3(2)	17
			2^+_2	-	8
intruder configuration					
0^+_3	2.16	2.15	2^+_1	≤ 5	2
2^+_2	2.24	2.46	0^+_1	≤ 0.12	0.04
			2^+_1	≤ 8	2
			0^+_2	≤ 44	31
			0^+_3	-	27
4^+_2	2.61	3.00	2^+_1	6.6(10)	0.2
			4^+_1	1.6(10)	0.06
			2^+_2	62(25)	85
6^+	3.19	3.63	4^+_1	1.68(9)	1.5
			4^+_2	97(5)	93
			4^+_3	18.9(12)	0.7



Hamiltonian:

$$H = \epsilon_\pi n_{d_\pi} + \epsilon_\nu n_{d_\nu} + \kappa Q_\pi \cdot Q_\nu + M_{\pi\nu} + V_{\pi\pi} + V_{\nu\nu}$$

Parts of Hamiltonian:

$$Q_\rho = (d^\dagger \times s + s^\dagger \times \tilde{d})^{(2)}_\rho + \chi_\rho (d^\dagger \times \tilde{d})^{(2)}_\rho, \qquad \rho = \pi, \nu\,,$$

$$M_{\pi\nu} = \frac{1}{2}\xi_2 (s^\dagger_\nu \times d^\dagger_\pi - d^\dagger_\nu \times s^\dagger_\pi)^{(2)} \cdot (s_\nu \times \tilde{d}_\pi - \tilde{d}_\nu \times s_\pi)^{(2)} + \sum_{k=1,3} \xi_k (d^\dagger_\nu \times d^\dagger_\pi)^{(k)} \cdot (\tilde{d}_\pi \times \tilde{d}_\nu)^{(k)}$$

(κ and ξs are 0 for ^{114}Sn)

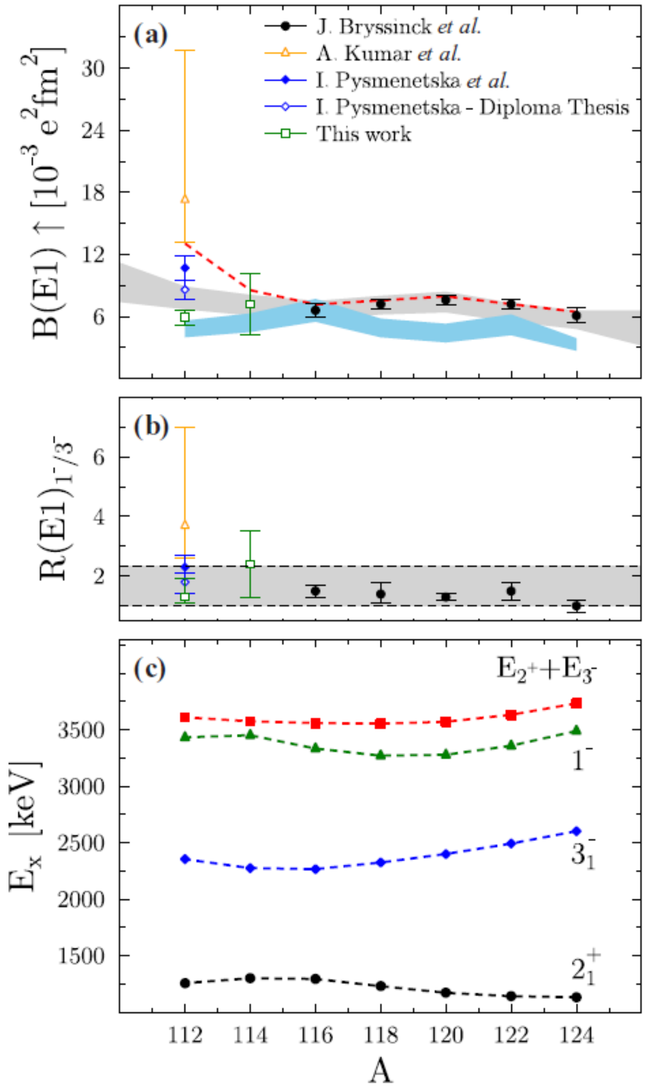
$$V_{\rho\rho} = \sum_{L=0,2,4} \frac{1}{2} c^\rho_L (d^\dagger_\rho \times d^\dagger_\rho)^{(L)} \cdot (\tilde{d}_\rho \times \tilde{d}_\rho)^{(L)}, \qquad \rho = \pi, \nu$$

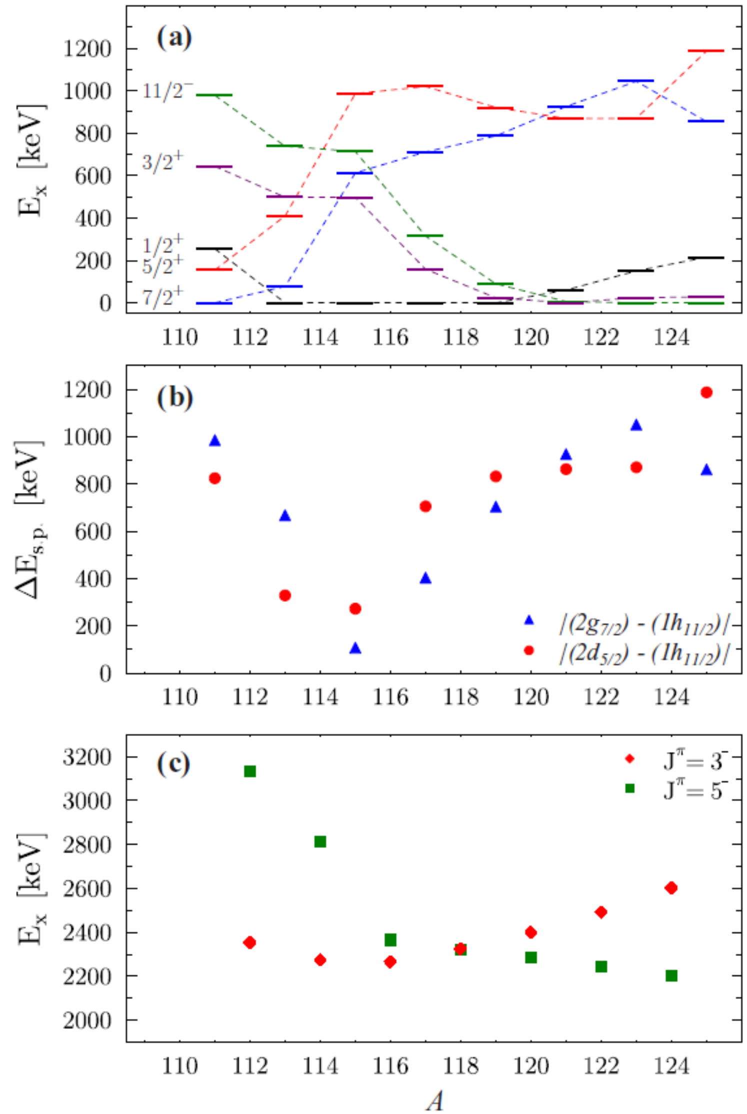
Mixing part:

$$H_{\mathrm{mix}} = \alpha (s^\dagger_\pi s^\dagger_\pi + s_\pi s_\pi)^{(0)} + \beta (d^\dagger_\pi d^\dagger_\pi + \tilde{d}_\pi \tilde{d}_\pi)^{(0)}$$

^{110}Pd: K.H. Kim *et al.*, NPA **604**, 163 (1996)

Quadrupole-octupole coupled states





^{112}Sn: Quadrupole-octupole coupled states

E_x [keV]	J^π	J^π_f	E_f [keV]	E_γ [keV]	I_γ	$B(E1)\downarrow$ [mW.u.]	$B(E2)\downarrow$ [W.u.]
1256.5(2)	2^+_1	0^+_1	0	1256.5(2)	1		12.5(7)[a]
2353.7(2)	3^-_1	2^+_1	1256.5(2)	1097.2(2)	1	1.13(8)	
3383.3(2)	3^-	2^+_1	1256.5(2)	2126.8(2)	0.85(2)	0.120(9)	
		2^+_2	2150.5(3)	1232.9(2)	0.041(9)	0.030(7)	
		$(2^+,3,4^+)$	2917.0(2)	466.5(2)	0.11(2)	1.5(2)	
3396.6(2)	$2^{(-)}$	2^+_1	1256.5(2)	2139.9(2)	0.057(13)	0.005(2)	
		2^+_2	2150.5(2)	1246.1(2)	0.64(3)	0.30(9)	
		3^-_1	2353.7(2)	1042.4(2)	0.27(5)		9^{+3}_{-7}
		2^+_4	2720.6(2)	675.8(2)	0.039(9)	0.11(5)	
3433.4(2)	$1^{(-)}$	0^+_1	0	3433.4(2)	1	1.31(15)	
3497.9(2)	5^-	3^-_1	2353.7(2)	1144.2(2)	0.70(4)		29(13)
		4^+_2	2520.5(2)	977.1(2)	0.27(6)	0.39(18)	
		4^+	2783.5(2)	714.7(3)	$\leqslant$0.03	$\leqslant$0.19	
3553.2(2)	$(3)^-$	2^+_1	1256.5(2)	2296.8(2)	0.83(3)	0.06(2)	
		3^+_1	2755.2(3)	797.7(3)	0.17(3)	0.30(10)	
3827.1(3)	$(1^-,2^+)$	0^+_1	0	3827.1(2)	0.58(3)	0.040(5)	
		2^+_1	1256.5(2)	2570.8(2)	0.29(5)	0.066(11)	
		3^-_1	2353.7(2)	1473.0(7)	0.13(3)		4.5(11)
3984.7(3)	$(1^-,2^+)$	0^+_1	0	3984.7(3)	0.79(2)	0.08(2)	
		3^-_1	2353.7(2)	1630.0(3)	0.14(2)		5(2)
		2^+_3	2475.5(2)	1507.8(4)	0.07(2)	0.137(95)	

^{114}Sn: Quadrupole-octupole coupled states

E_x [keV]	J^π	J^π_f	E_f [keV]	E_γ [keV]	I_γ	$B(E1)\downarrow$ [mW.u.]	$B(E2)\downarrow$ [W.u.]
1299.7(2)	2^+_1	0^+_1	0	1299.7(2)	1		11.1(7)[a]
2274.5(2)	3^-_1	2^+_1	1299.7(2)	974.8(2)	1	0.65(8)	
2814.6(2)	5^-_1	4^+_1	2187.3(3)	627.4(2)	0.88(2)	$\leqslant$0.77	
		3^-_1	2274.5(2)	539.9(2)	0.12(3)		$\leqslant$38
2904.9(3)	3^-	2^+_1	1299.7(2)	1605.1(4)	0.026(5)	0.0030(14)	
		4^+_1	2187.3(3)	717.3(2)	0.77(2)	0.7(3)	
		3^+_1	2514.4(2)	390.2(2)	0.20(3)	1.6(7)	
		4^+_2	2613.7(4)	290.3(4)	0.011(4)	0.21(12)	
3225.1(2)	3^-	2^+_1	1299.7(2)	1925.4(2)	0.920(14)	0.11(2)	
		2^+_3	2453.8(2)	771.4(4)	0.019(7)	0.04(2)	
		3^-	2904.9(3)	319.9(4)	0.061(13)		
3397.3(2)	3^-	2^+_1	1299.7(2)	2097.6(2)	0.31(5)	0.06(2)	
		2^+_2	2238.6(2)	1158.3(2)	0.13(2)	0.14(6)	
		3^-_1	2274.5(2)	1122.0(4)	0.44(2)		3^{+11}_{-3}
		2^+_3	2453.8(2)	943.2(2)	0.12(2)	0.24(10)	
3452.1(2)	(1^-)	0^+_1	0	3452.1(2)	1	1.6(7)	
3483.9(4)	$(1^-,2^+)$	2^+_1	1299.7(2)	2184.1(2)	0.671(13)	0.06(2)	
		0^+_3	2155.9(2)	1327.7(3)[b]	0.094(14)	0.037(11)	
		3^-_1	2274.5(2)	1209.0(2)	0.235(14)		5.2(13)
3514.1(3)	3^-	2^+_1	1299.7(2)	2214.4(2)	0.76(3)	0.14(6)	
		4^+_1	2187.4(3)	1327.0(4)[c]	0.07(2)	0.06(3)	
		2^+_2	2238.6(2)	1275.0(3)	0.17(3)	0.17(8)	
3524.4(2)	3^-	2^+_1	1299.7(2)	2224.5(3)	0.55(3)	0.023(17)	
		4^+_1	2187.3(3)	1158.3(2)	0.15(3)	0.028(22)	
		3^-_1	2274.5(2)	1122.0(4)	0.13(2)		1.2(10)
		2^+_3	2453.8(2)	943.2(2)	0.17(3)	0.08(6)	
3610.2(4)	$5^{(-)}$	4^+_1	2187.3(3)	1422.9(3)	1	1.0(3)	
3650.3(3)	$(1^-,2^+)$	0^+_1	0	3650.1(3)	0.44(3)	0.012(4)	
		2^+_1	1299.7(2)	2350.3(3)	0.11(2)	0.011(5)	
		0^+_3	2155.9(2)	1493.7(3)	0.09(2)	0.04(2)	
		3^-_1	2274.5(2)	1374.6(2)	0.36(6)		6(2)