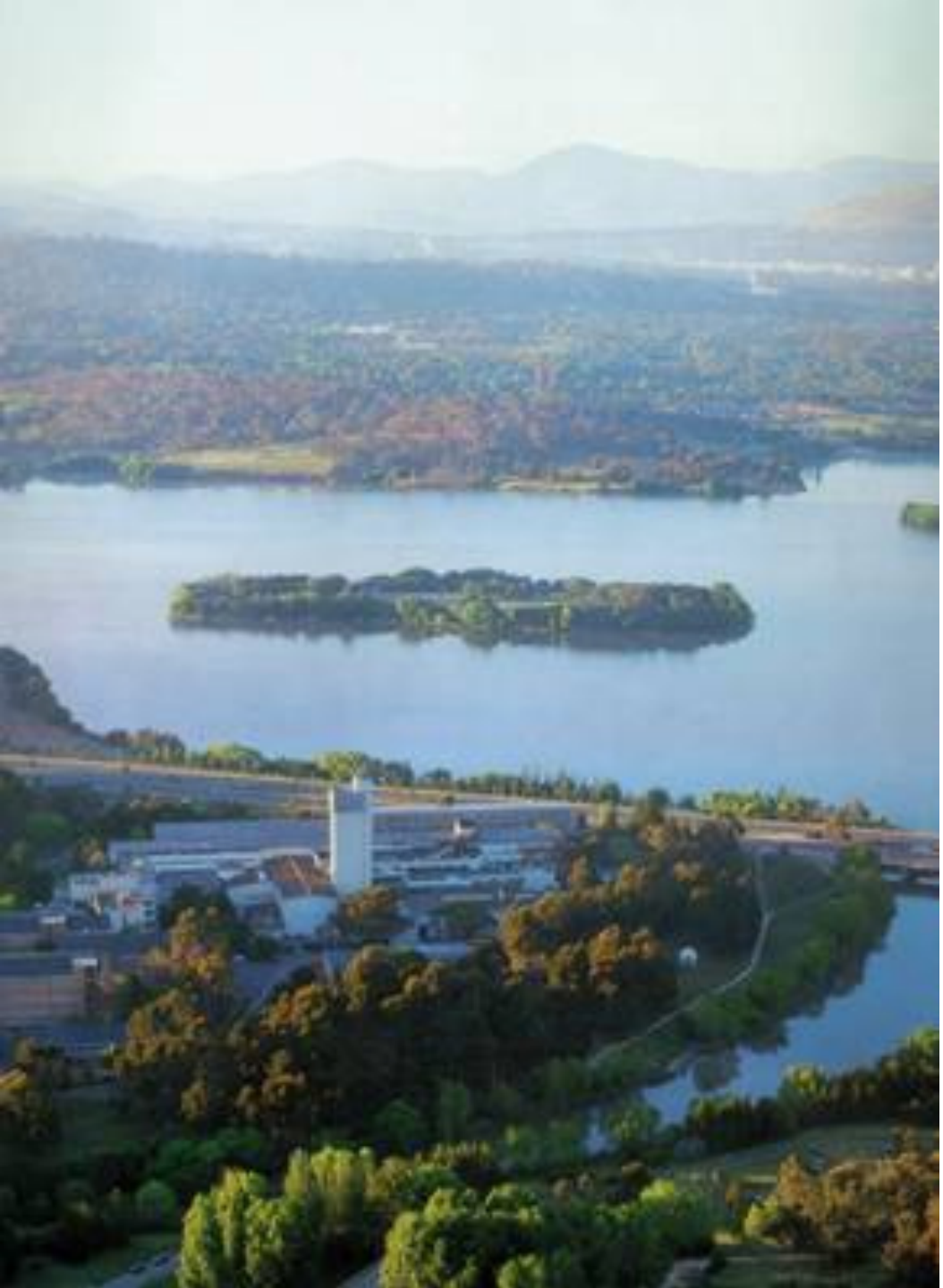

Triaxiality and the changing nature of K-isomers in tungsten nuclei between A=182 and A=190

Greg Lane

THE AUSTRALIAN NATIONAL UNIVERSITY

Principal Collaborators

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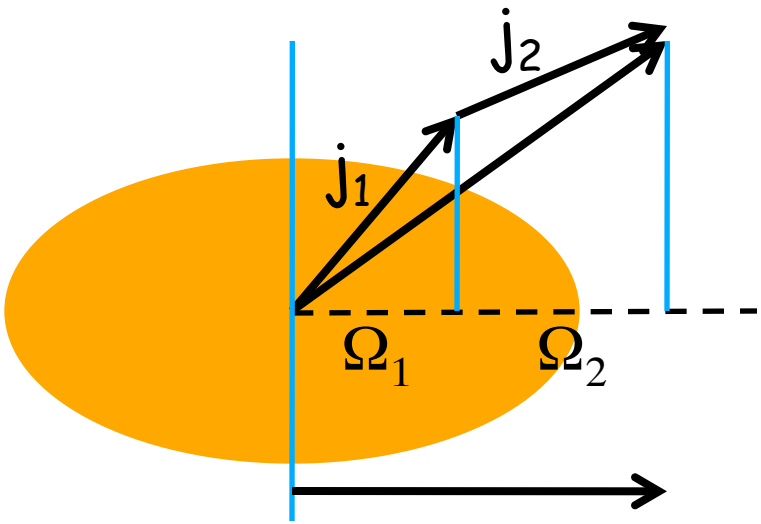
Lowell: Partha Chowdhury

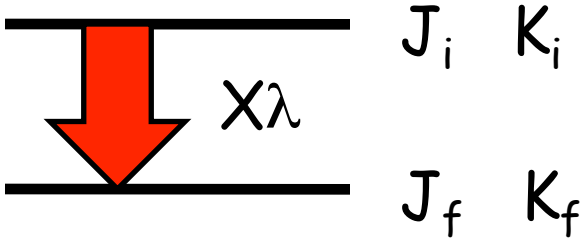
Peking: Furong Xu

K - A "Good" Quantum Number?

Sum projections of individual nucleons



$K = \Omega_1 + \Omega_2$



$\lambda \geq |J_i - J_f|$ yes

$\lambda \geq |K_i - K_f|$ Sort of

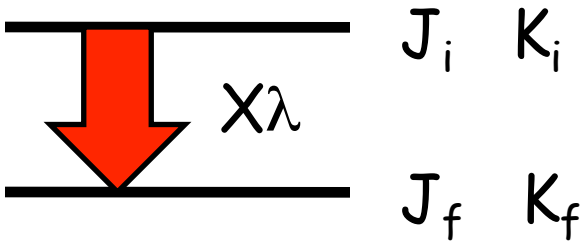
Transition of multipolarity-λ can only change the K projection by at most λ.

Axially deformed nucleus $\Rightarrow$ symmetry axis.

Projection K is a hidden quantum number.

The shortfall is the degree of "forbiddenness" $\nu = \Delta K - \lambda$.

K-hindered transitions



Forbiddenness $\nu = \Delta K - \lambda$

Hindrance $f = \tau_\gamma / \tau_W$

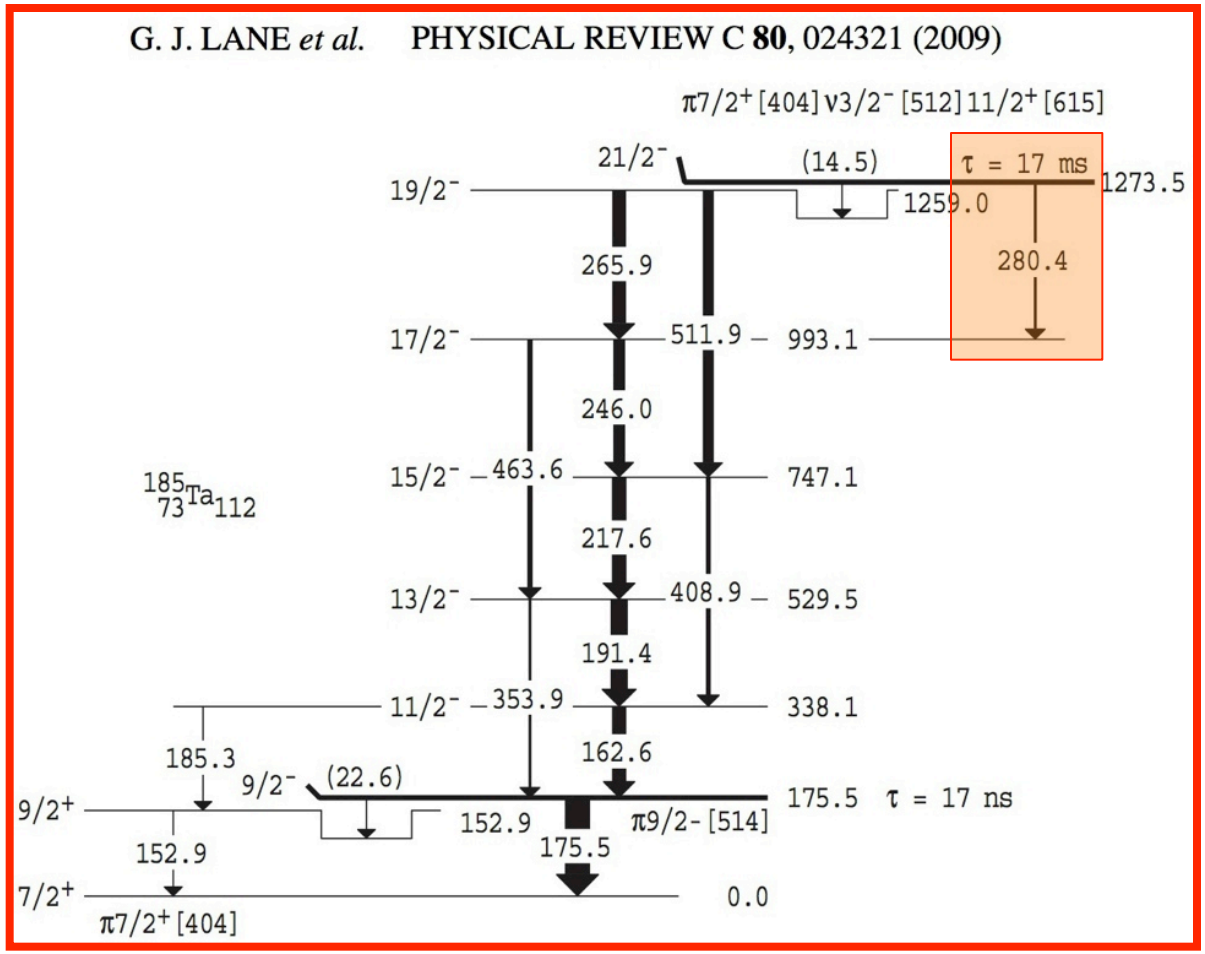
Reduced hindrance $f_\nu = f^{1/\nu}$

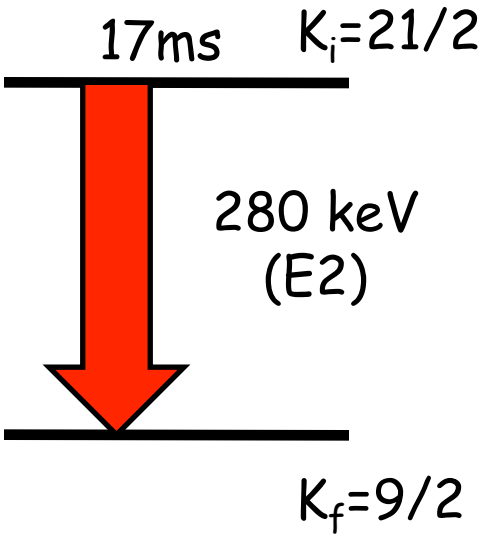
"Weisskopf" estimate

Remember this!

Typically $f_\nu = 30 - 300$

K-isomers





Forbiddenness is

$$\nu = \Delta K - \lambda$$
$$= (21/2-9/2) - 2$$
$$= 4$$

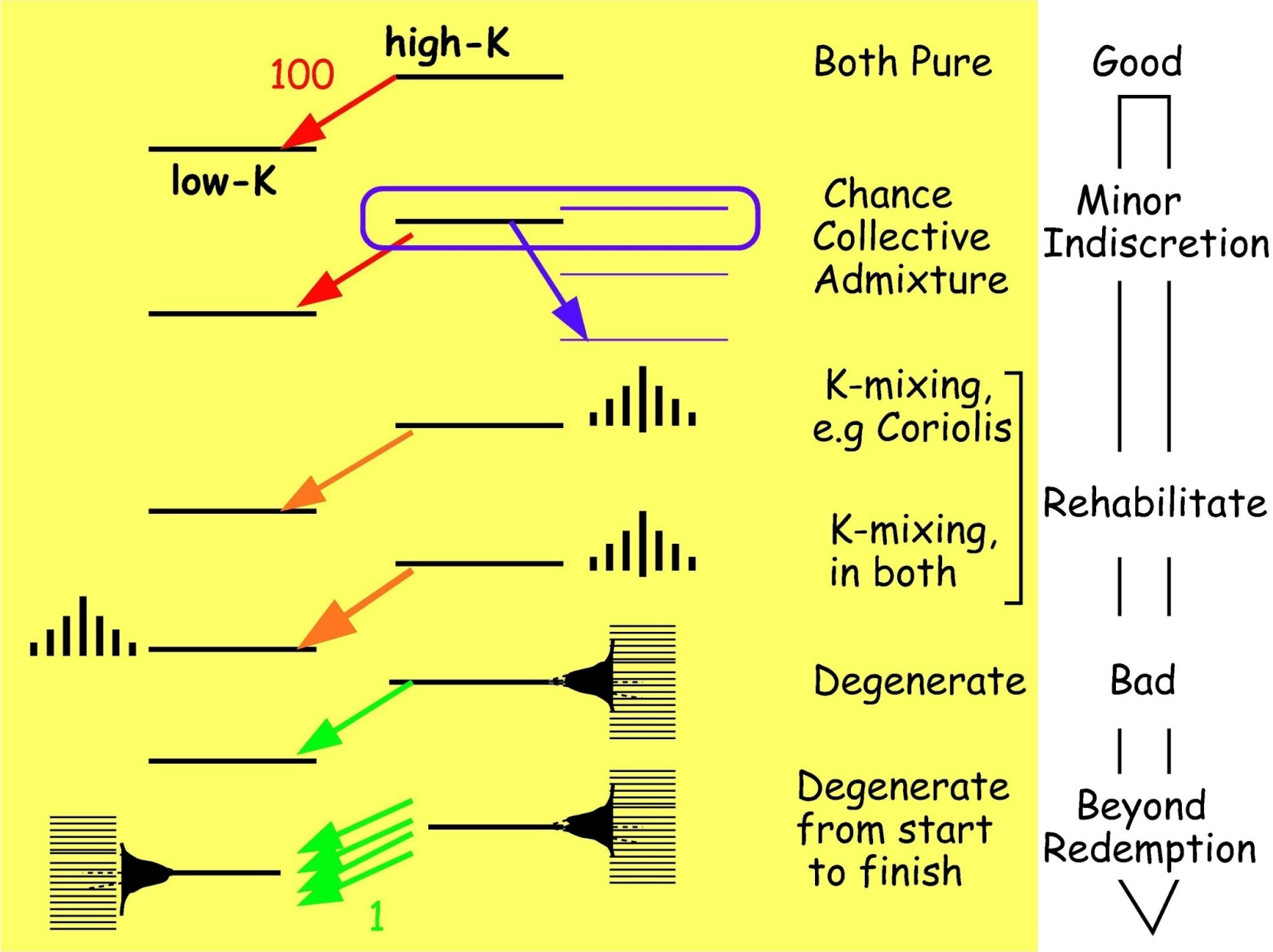
"Normal" 280.4 keV E2 should have τ~7ns

τ~17ms ➔ Hindrance, f~10^8

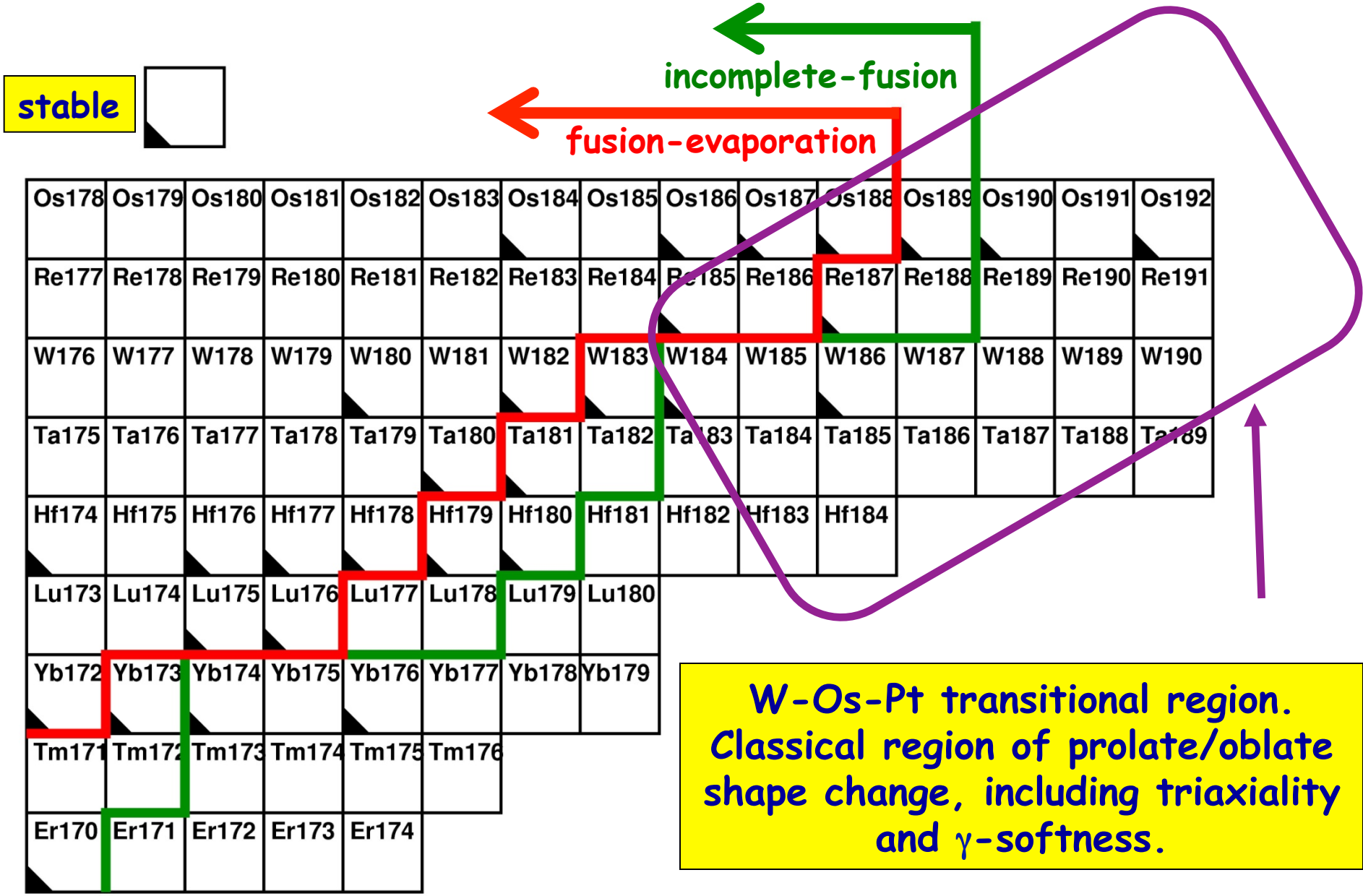
Hence reduced hindrance, f_ν = 71

A "good" K-isomer

Good-K vs Bad-K – as viewed by George Dracoulis



Transitional behaviour

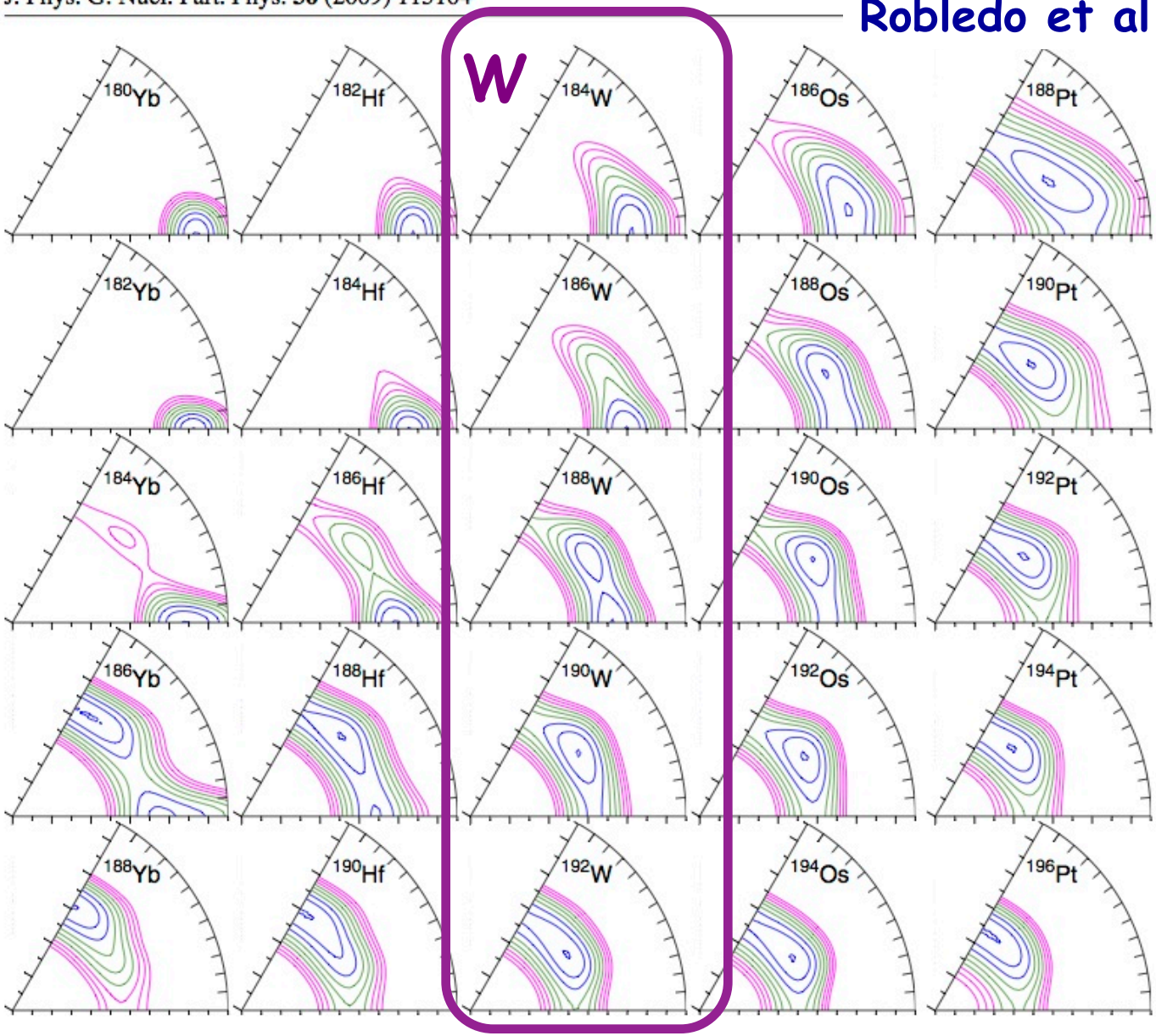


W-Os-Pt transitional region. Classical region of prolate/oblate shape change, including triaxiality and γ-softness.

Transitional behaviour – HFB calculations

J. Phys. G: Nucl. Part. Phys. **36** (2009) 115104

Robledo et al



N=110

N=112

N=114

N=116

N=118

Experimental program

- Four Gammasphere experiments at Argonne
- Deep-inelastic collisions with pulsed ^{136}Xe beams.
- Neutron-rich nuclei in A=180 to A=190 region.
- Thick targets
  - ^{170}Er, ^{174}Yb, ^{175}Lu, ^{176}Lu, ^{185}Re, ^{186}W, ^{187}Re and ^{192}Os.
- γ-γ-γ-time: 1/825 ns pulsing
- γ-γ-clock: 10/40μs, 20/60μs, 100/400μs, 1/4ms, 10/40ms, 100/400ms, 1/4s slow chopping.

  - neutron-rich nuclei are only weakly populated
  - huge backgrounds
    - many (many!) products
    - intense target excitation

Requires Gammasphere and time correlations to pull them out.

Results summary – part 1

Ta173	Ta174	Ta175	Ta176	Ta177	Ta178	Ta179 49/2+ 76ns	Ta180	Ta181	Ta182
Hf172	Hf173	Hf174	Hf175	Hf176	Hf177	Hf178	Hf179	Hf180	Hf181
Lu171	Lu172	Lu173	Lu174 26– 350ns 21+ 41ns 13+ 360ns	Lu175 51/2+ 55us 37/2– 58ns 27/2– 50ns	Lu176	Lu177 39/2– 8us 33/2+ 900ns 25/2+ 90ns	Lu178 25– 1.5us 16+ 104ns 13– 45ns	Lu179	Lu180
Yb170	Yb171	Yb172	Yb173	Yb174 23– 41ns 14+ 80ns 7– 370ns	Yb175 37/2+ 230ns 33/2+ 17ns 27/2– 500us	Yb176 23 1.5us 15+ 104ns 12– 45ns	Yb177 15/2– 50ns	Yb178 15 5ns 8– 4ns 5– 200ns	Yb179 29/2 ~1us 25/2– ~60ns
Tm169	Tm170	Tm171 19/2+ 2.1us	Tm172 7+ 232us	Tm173 33/2+ 250ns 19/2+ ~1us	Tm174 ~100 us	Tm175 21/2+ >10us 15/2– 45ns	Tm176		
Er168	Er169	Er170	Er171	Er172 6+ >1us	Er173	Er174 8– >8us	Er175		

New isomers

Results summary – part 2

	Os184	Os185	Os186	Os187	Os188	Os189	Os190	Os191	Os192
	Re183	Re184	Re185 25/2+ 290ns 19/2– 8ns 15/2– 2ns	Re186	Re187 19/2+ 170ns	Re188	Re189	Re190	Re191
W181	W182	W183	W184 16+ 270ns	W185 35/2+ 1.8us	W186 16+ >4ms 7– 26us	W187	W188 158ns	W189	W190 240us 158ns
Ta180	Ta181	Ta182	Ta183	Ta184	Ta185 21/2– 17ms 9/2– 17ns	Ta186	Ta187		
Hf179	Hf180	Hf181	Hf182	Hf183	Hf184				
Lu178 25– 1.5us 16+ 104ns 13– 45ns	Lu179	Lu180 9– 2.3ms	Lu181	Lu182	Lu183				

New isomers / spectroscopy

Overall goal and some caveats

Overall goal:

- Observe whether an increase in triaxiality across the tungsten isotopes affects the K-hindered transitions.

Other factors:

- Changing deformation ➔ different configurations ➔ configuration dependent transition strengths?
- Chance degeneracies can affect apparent K-hindrance
- Not all long-lived states are K-isomers!

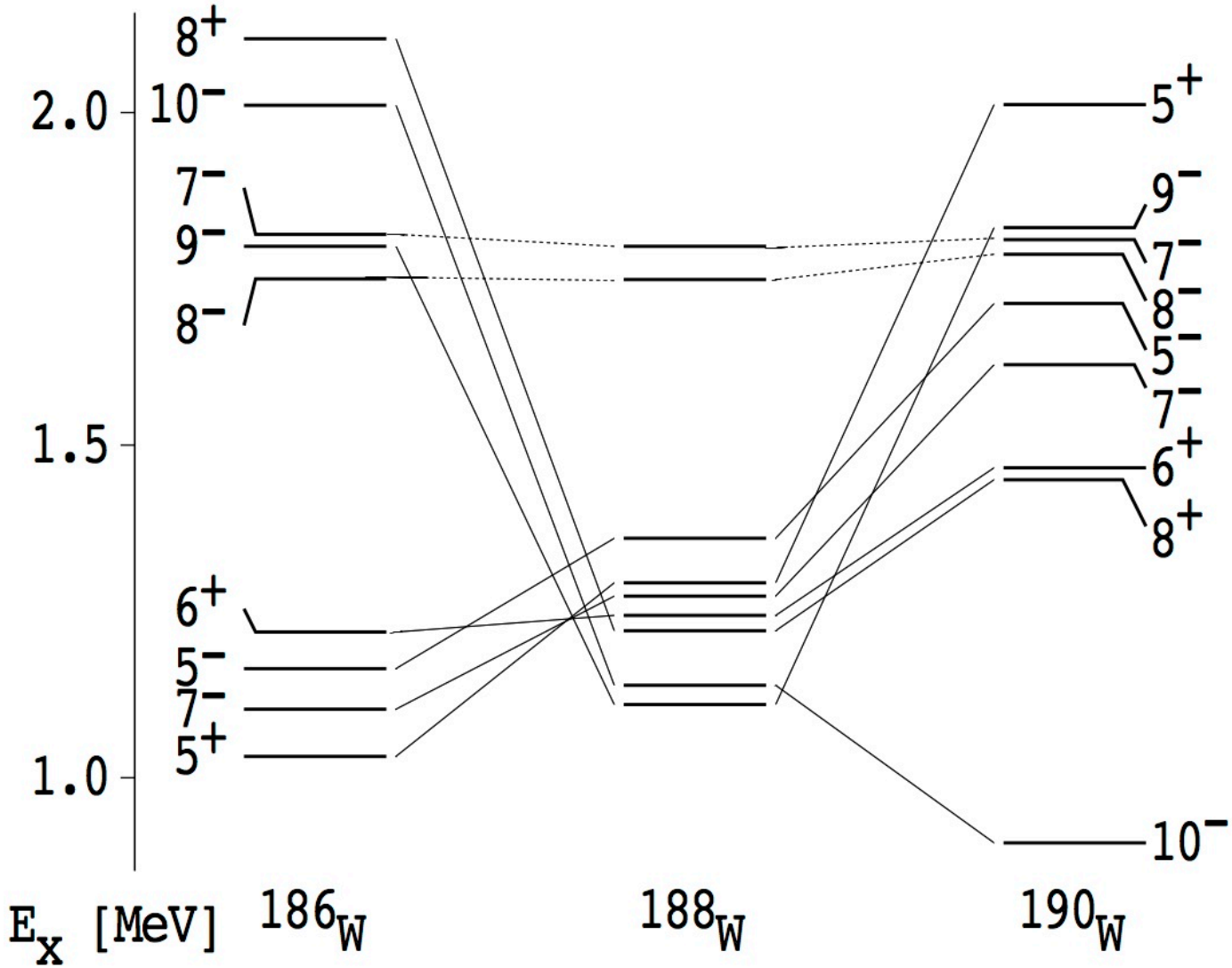
Care is needed to uncouple these phenomena…

Predicted two-quasiparticle intrinsic state systematics

Calculation for low-lying two-qp states

Large energy jumps due to changes in the deformation and neutron Fermi level

Changing configurations

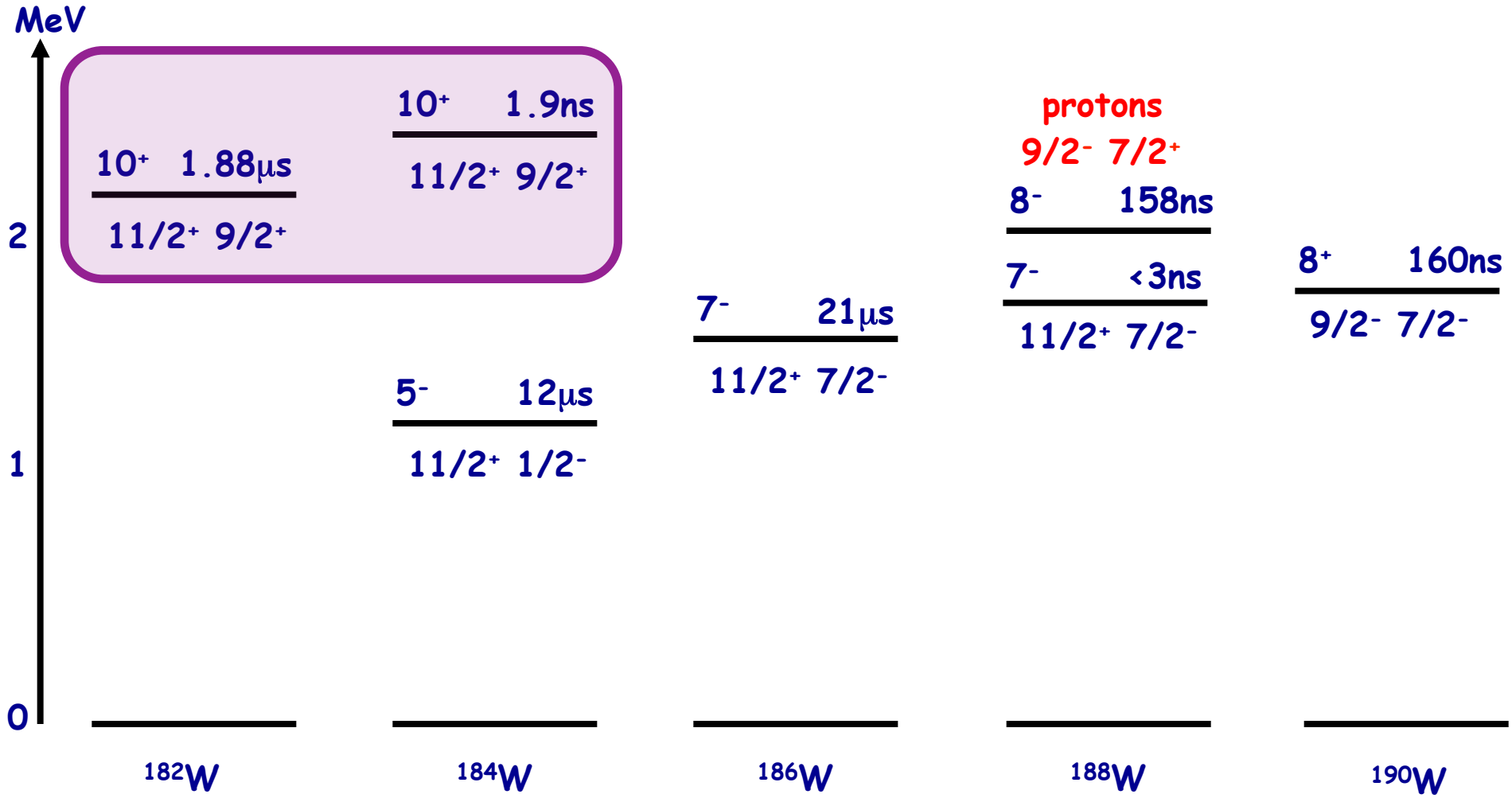


ε_2=0.208 ε_4=0.100

ε_2=0.192 ε_4=0.100

ε_2=0.158 ε_4=0.087

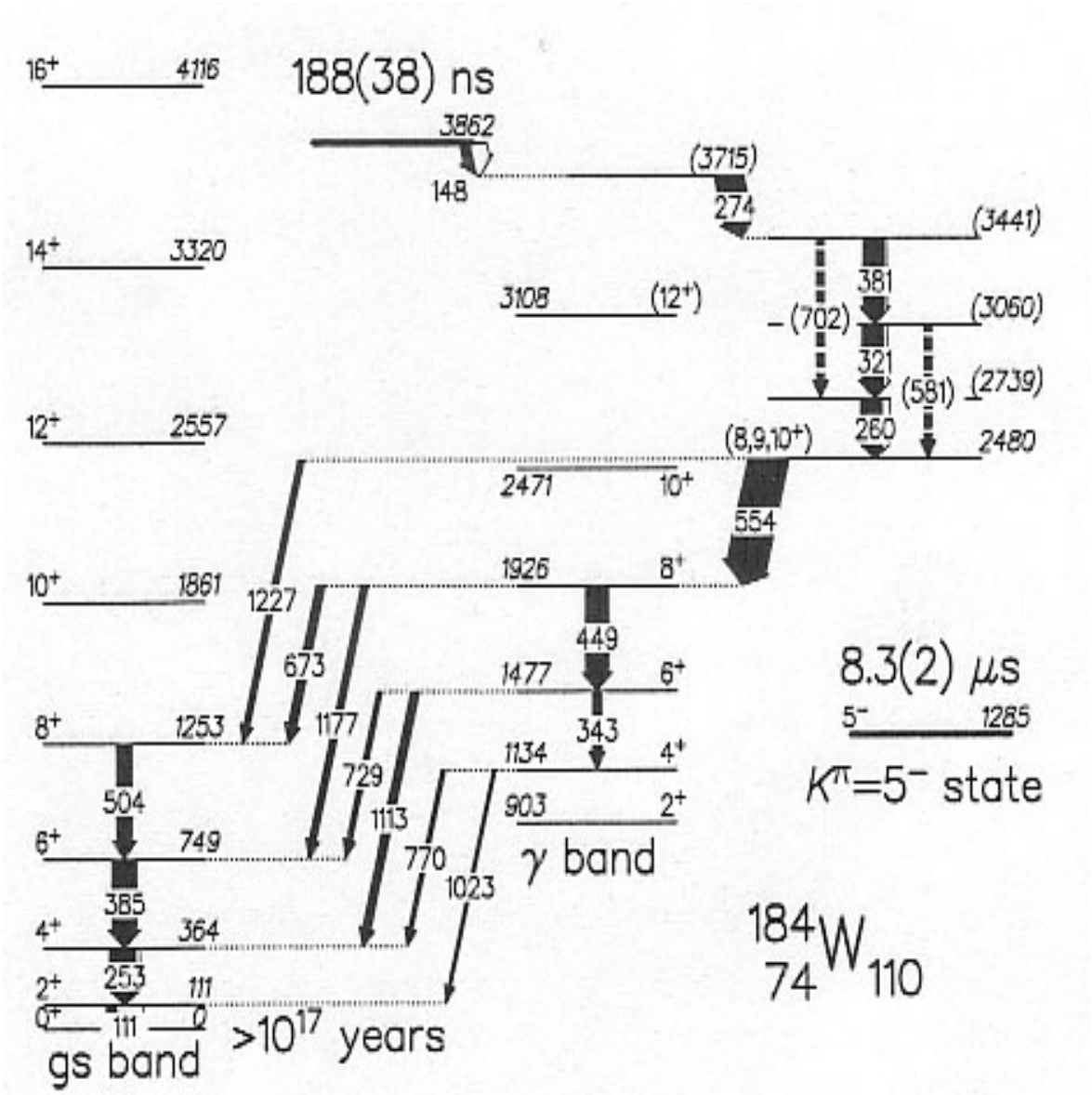
Low-lying two-quasiparticle isomers



Neutrons: 11/2+[615] 9/2+[624]
1/2-[510] 7/2-[503] 9/2-[505]

Protons: 7/2+[404] 9/2-[514]

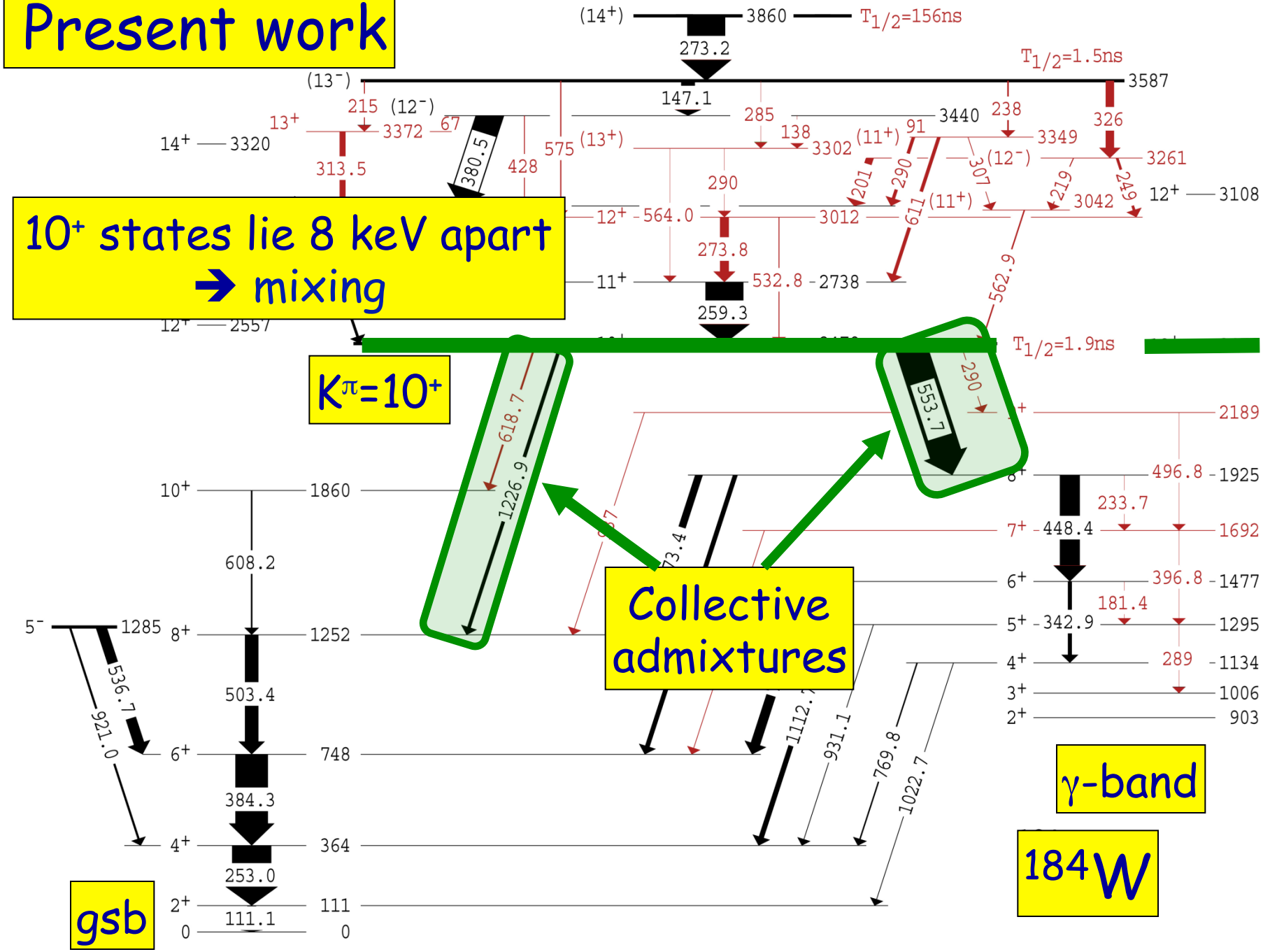
Previous level scheme for ^{184}W



Spins not known.
Isomer decay not fully characterised.

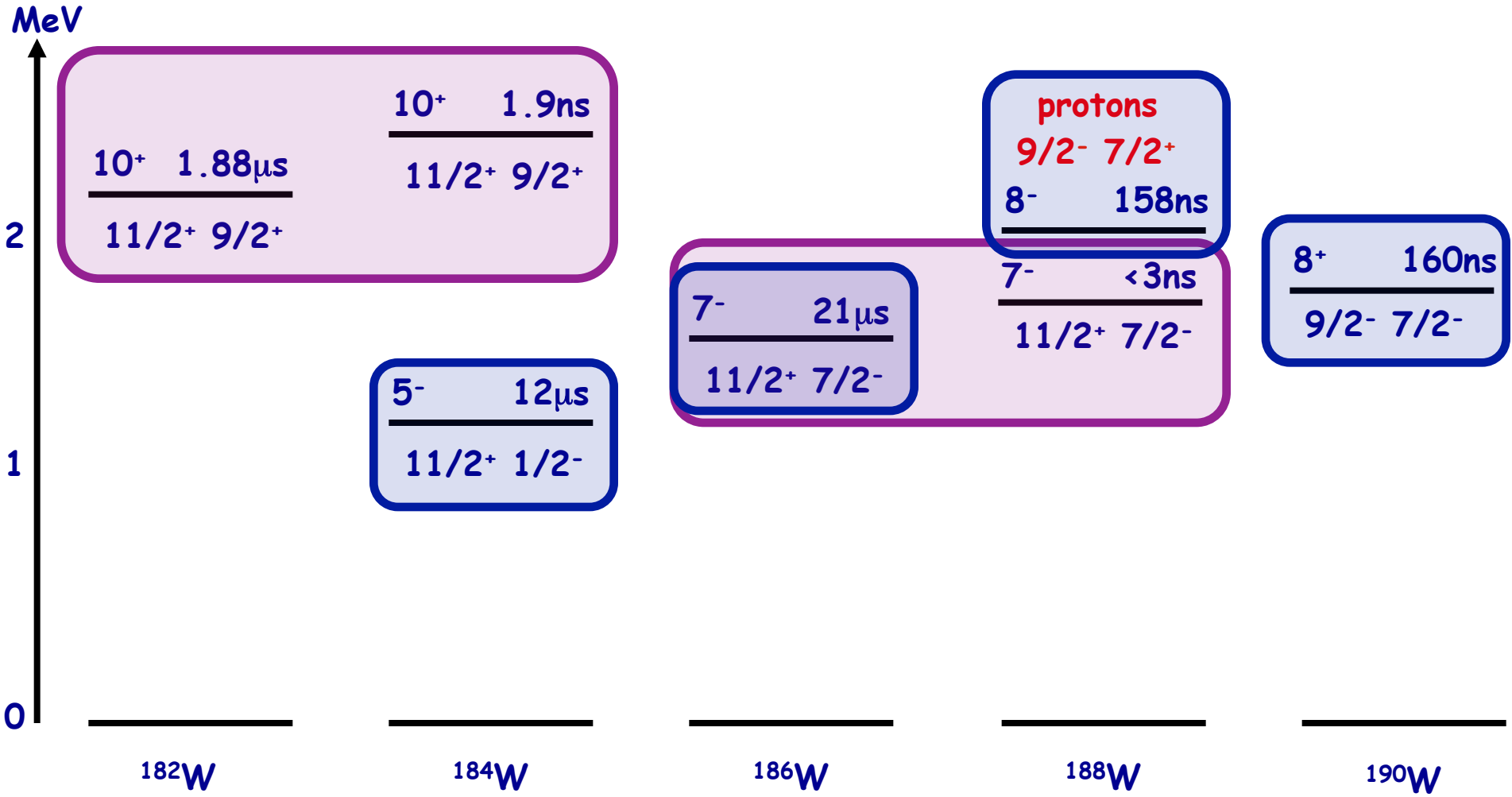
C. Wheldon et al, Eur. Phys. J. A 20 365-369 (2004)

Present work



10+ states lie 8 keV apart
➔ mixing

Low-lying two-quasiparticle isomers

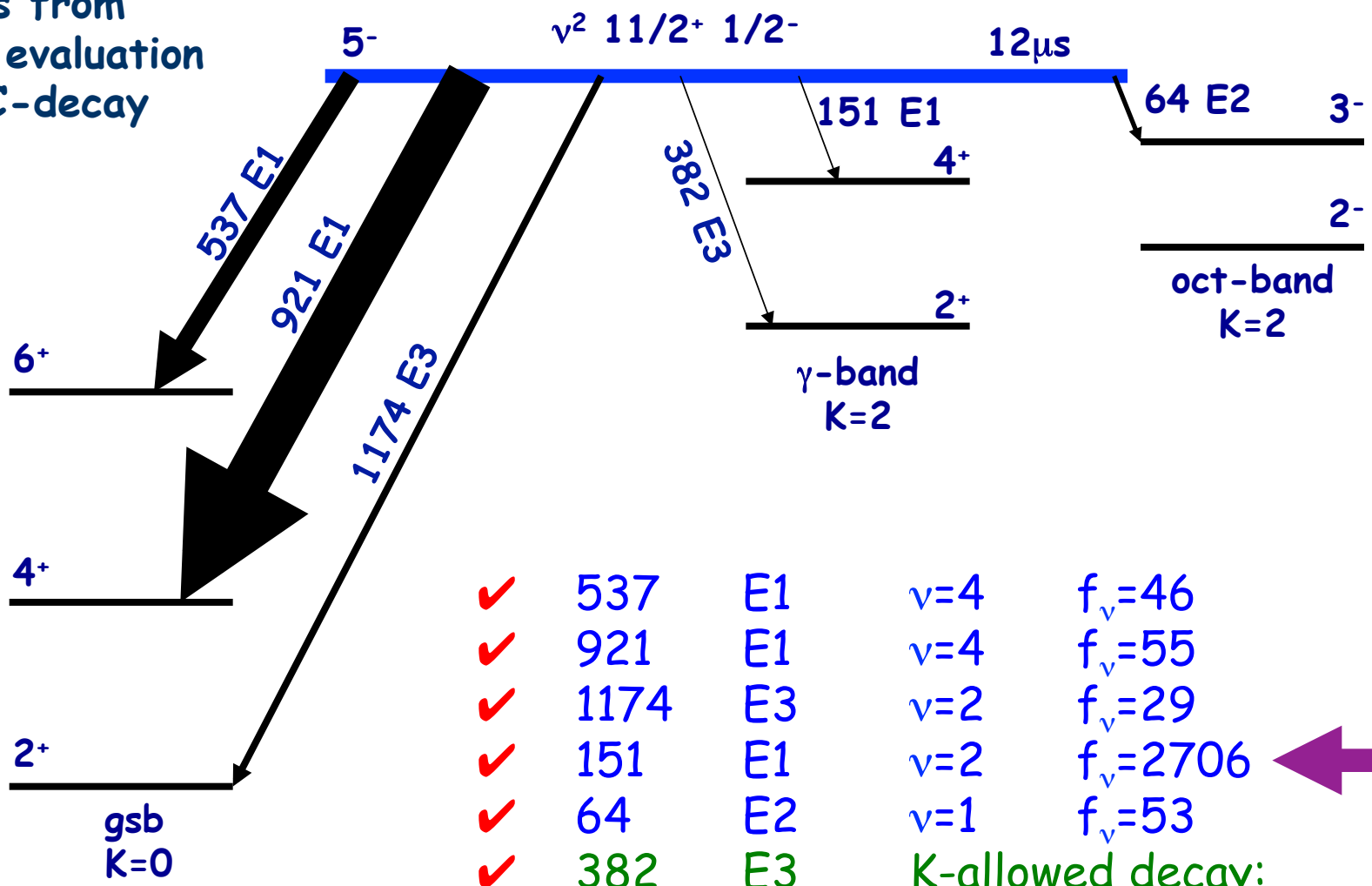


Neutrons: 11/2+[615] 9/2+[624]
1/2-[510] 7/2-[503] 9/2-[505]

Protons: 7/2+[404] 9/2-[514]

K-forbidden decays in ^{184}W

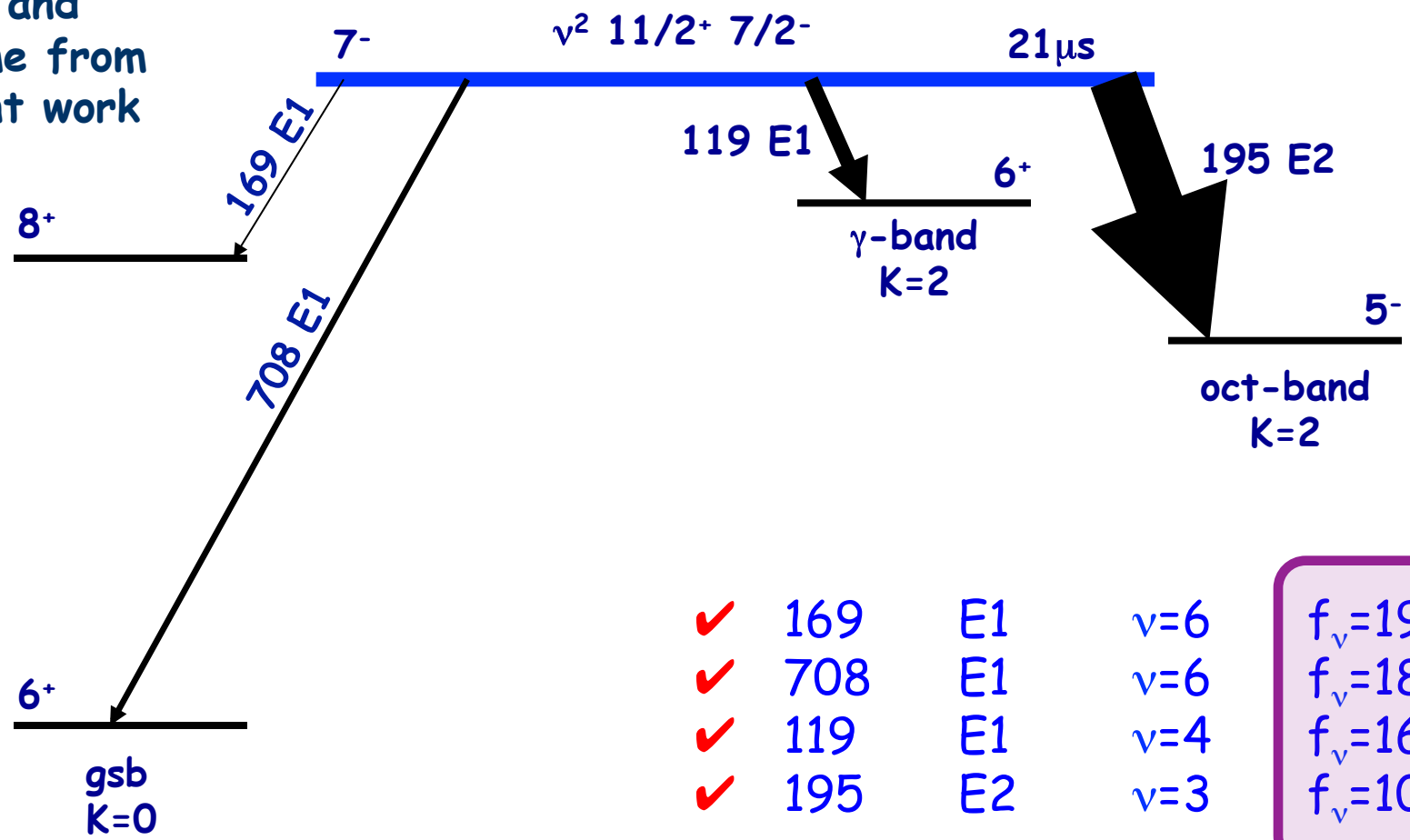
γ-ray branching ratios from NDS evaluation of EC-decay



✔	537	E1	$\nu=4$	$f_\nu=46$
✔	921	E1	$\nu=4$	$f_\nu=55$
✔	1174	E3	$\nu=2$	$f_\nu=29$
✔	151	E1	$\nu=2$	$f_\nu=2706$
✔	64	E2	$\nu=1$	$f_\nu=53$
✔	382	E3	K-allowed decay: B(E3) = 0.14 W.u.	

K-forbidden decays in ^{186}W

γ-ray branching ratios and lifetime from present work

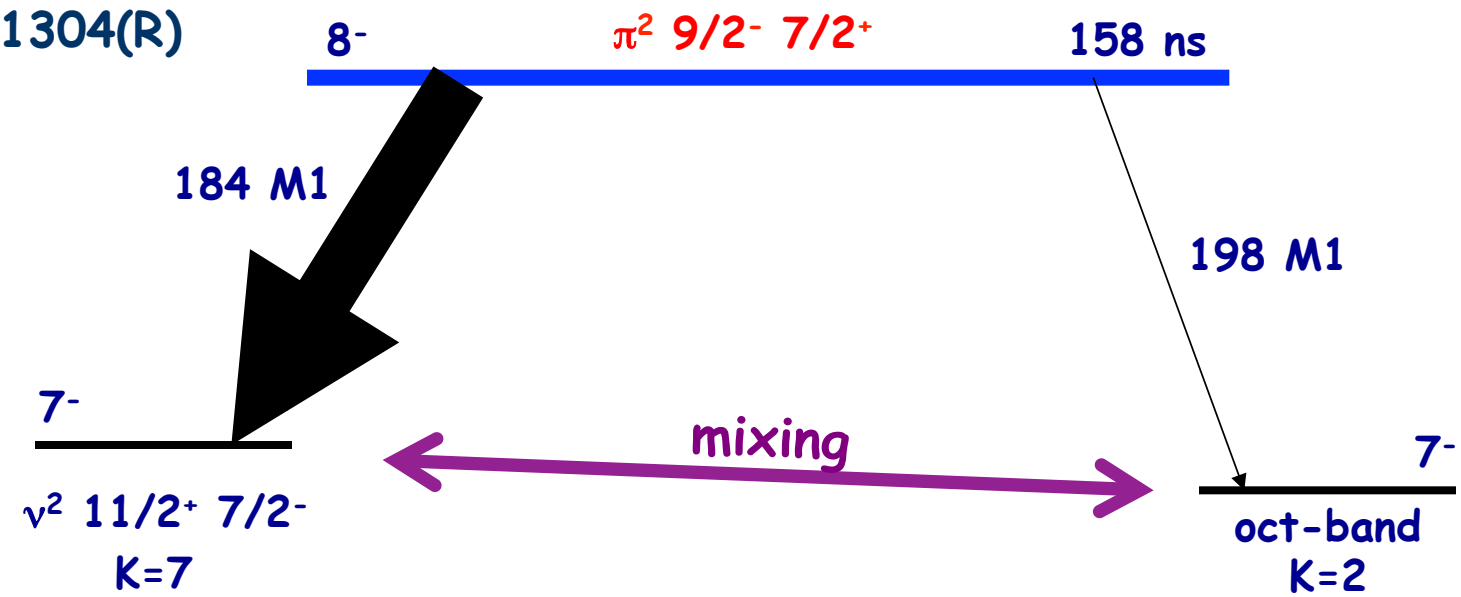


✔	169	E1	ν=6	f_ν=19
✔	708	E1	ν=6	f_ν=18
✔	119	E1	ν=4	f_ν=16
✔	195	E2	ν=3	f_ν=10

Lower values

K-forbidden decays in ^{188}W

Lane et al,
Phys Rev C 82
(2010) 051304(R)



198 M1 ν=5 f_ν=21 Looks OK?

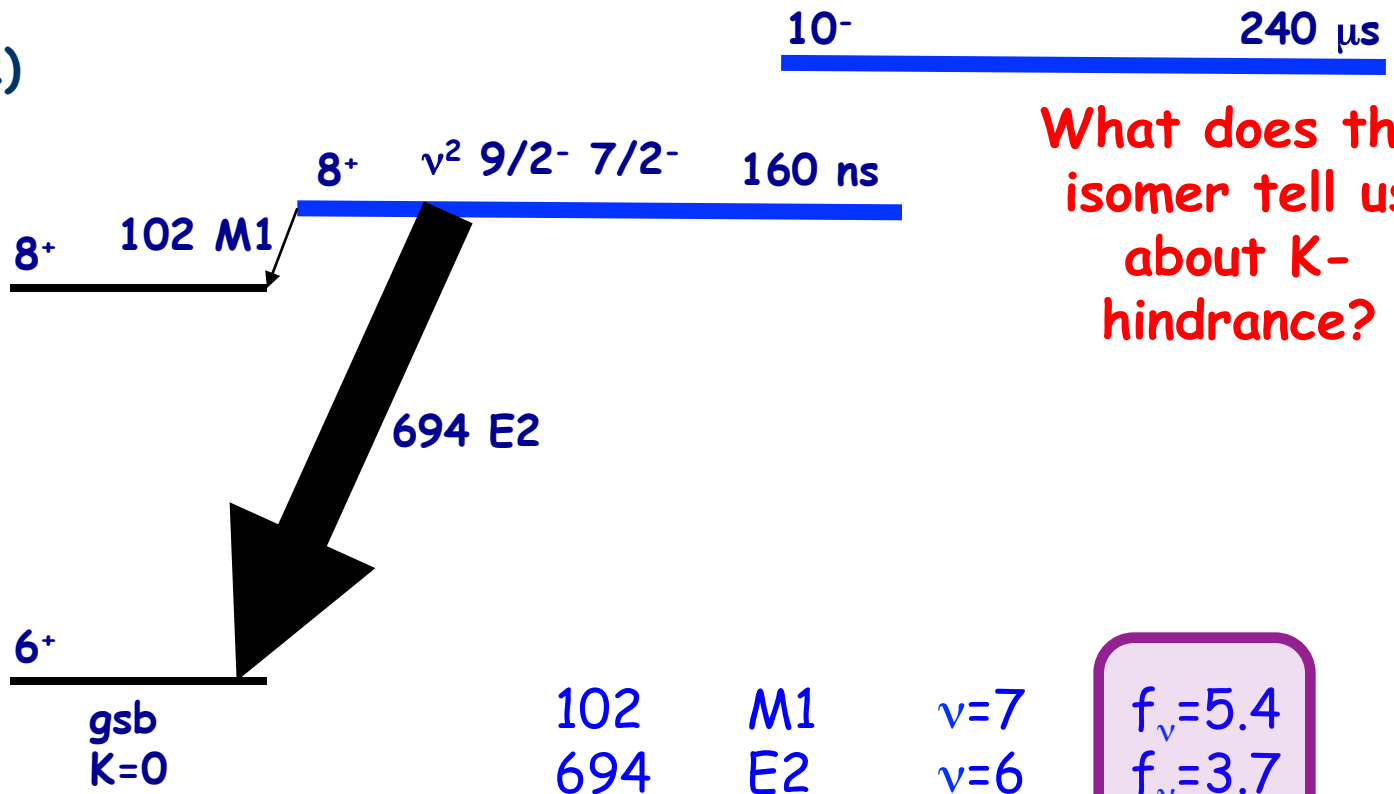
B(M1) for 198 could be due to a small wavefunction admixture that gives a K-allowed component. K-hindrance cannot be easily extracted…

184 M1 K-allowed decay
B(M1)=1.7x10^{-5} W.u.

Very weak! Due to $\pi^2 \rightarrow \nu^2$ configuration change?

K-forbidden decays in ^{190}W

Lane et al,
Phys Rev C 82
(2010) 051304(R)



What does this isomer tell us about K-hindrance?

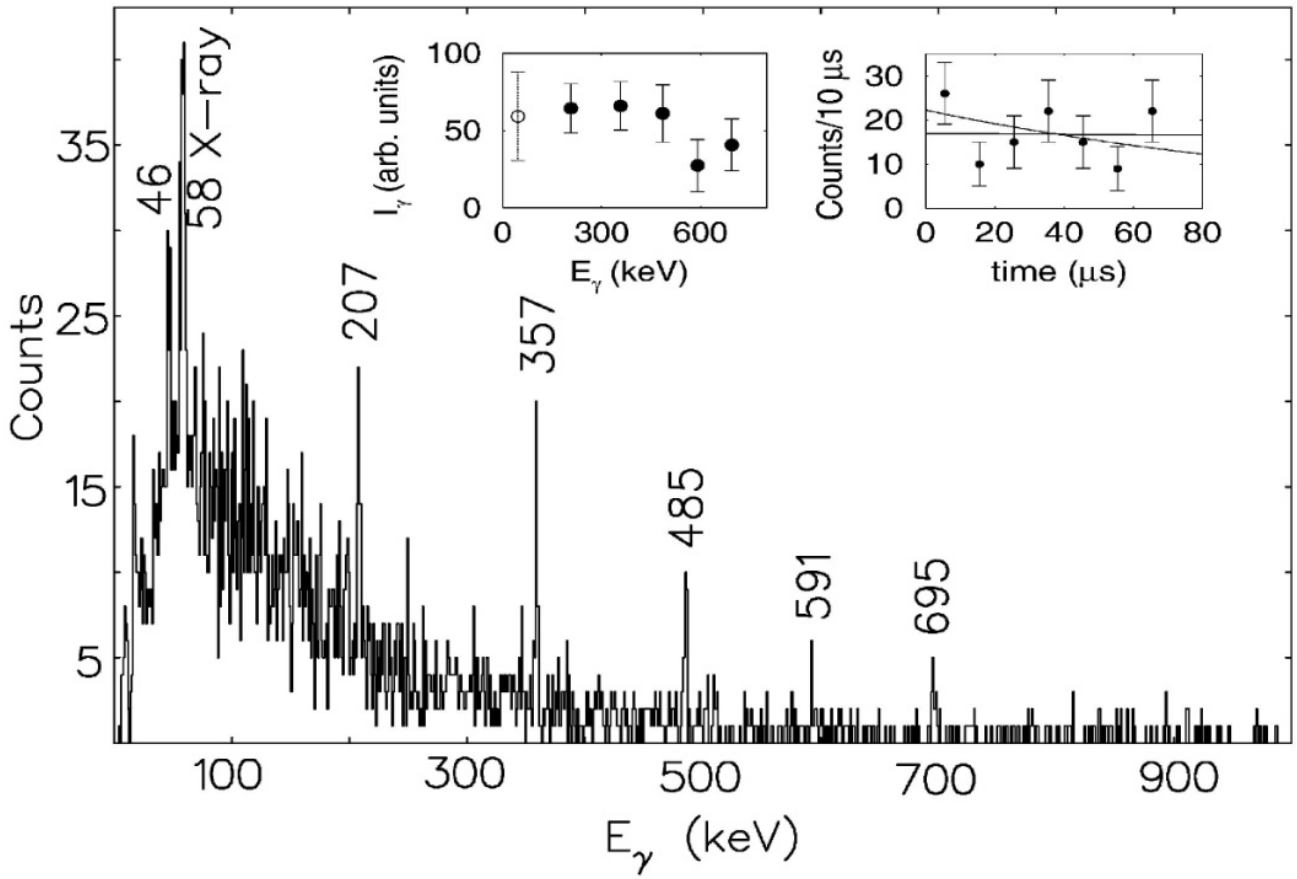
102	M1	ν=7	f_ν=5.4
694	E2	ν=6	f_ν=3.7

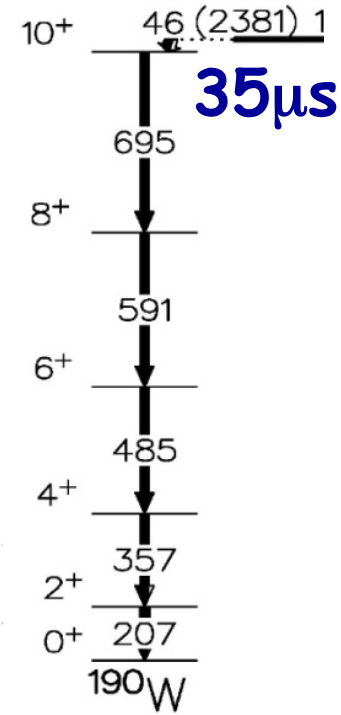
Even lower values

Overall decreasing trend in reduced hindrance from A=184 to A=190

10^- isomer in ^{190}W?

^{208}Pb fragmentation at GSI: Podolyak et al, PLB 491 (2000) 225.

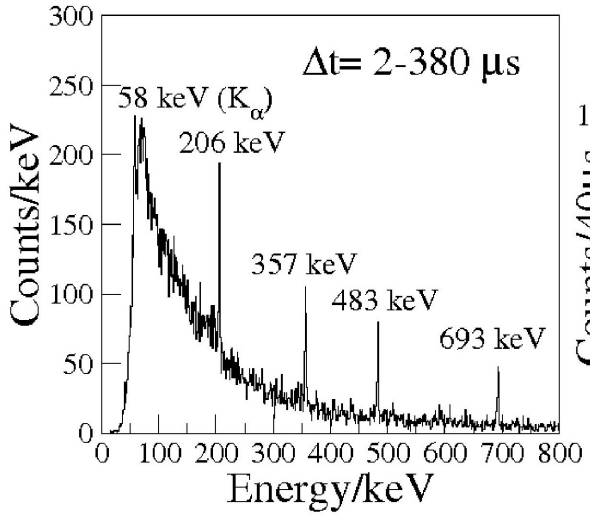


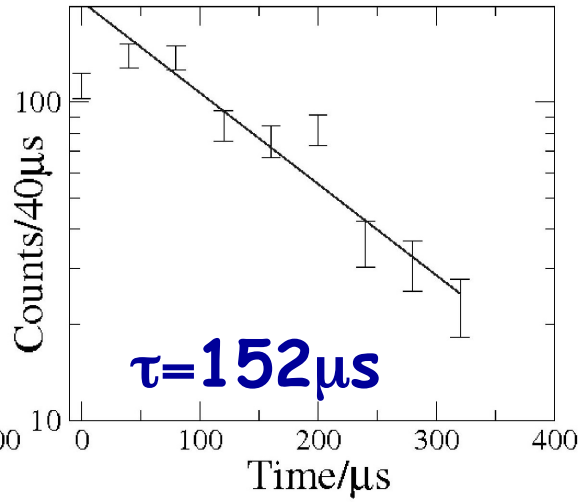


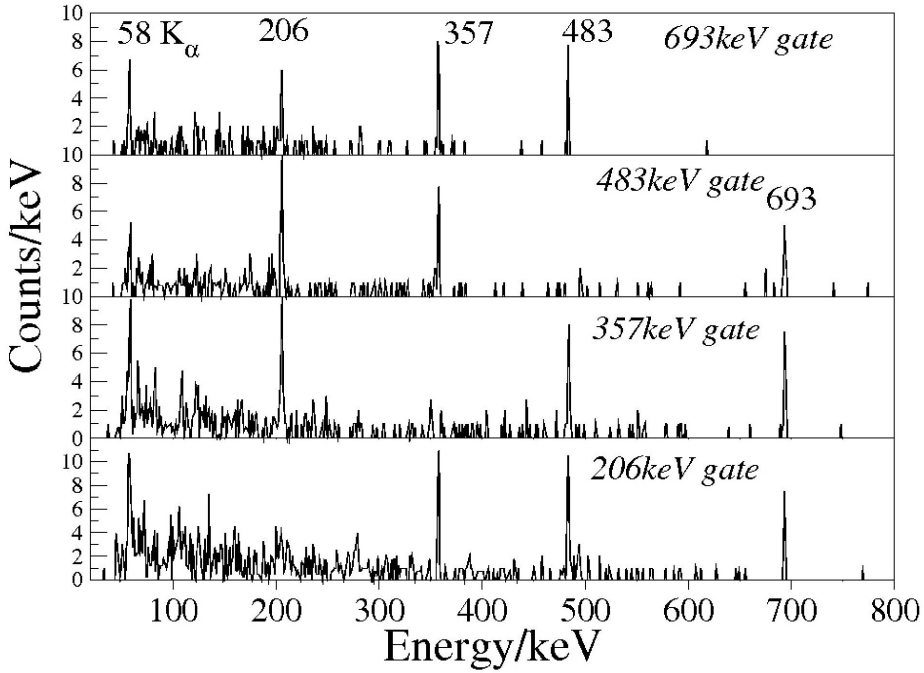
35μs<τ<3ms

Shape evolution: PLB 491 (2000) 225.
Shape coexistence: PRC 72 (2005) 047303
Oblate shape isomer: PLB 635 (2006) 286.
Rotation driven phase transition: PLB 659 (2008) 185.

^{190}W – Revised by the same authors





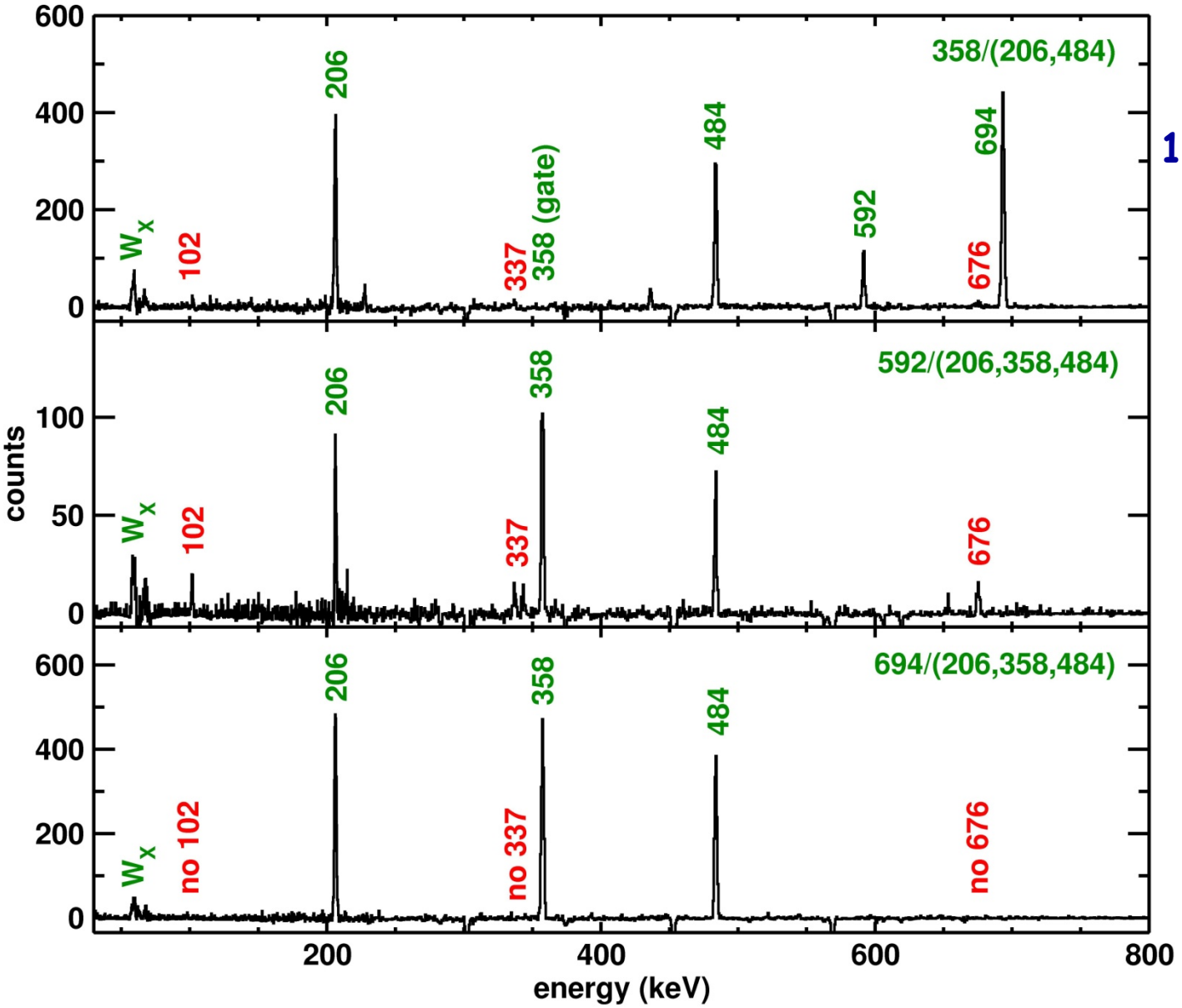


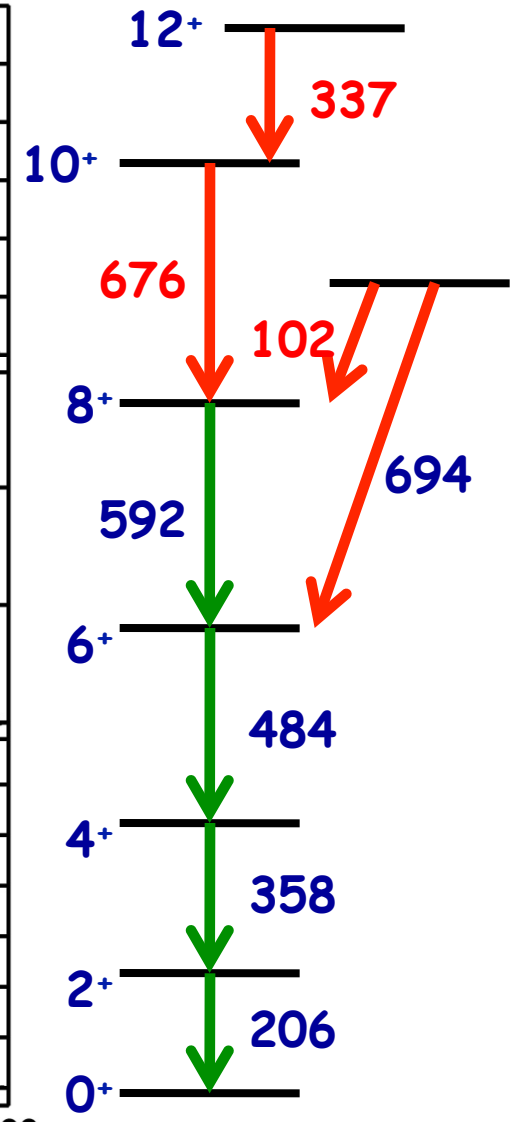
Repeat measurement with much better statistics – including (weak) gamma-ray coincidences.

Farrelly et al, Acta Phys. Pol. 40 (2009) 885.

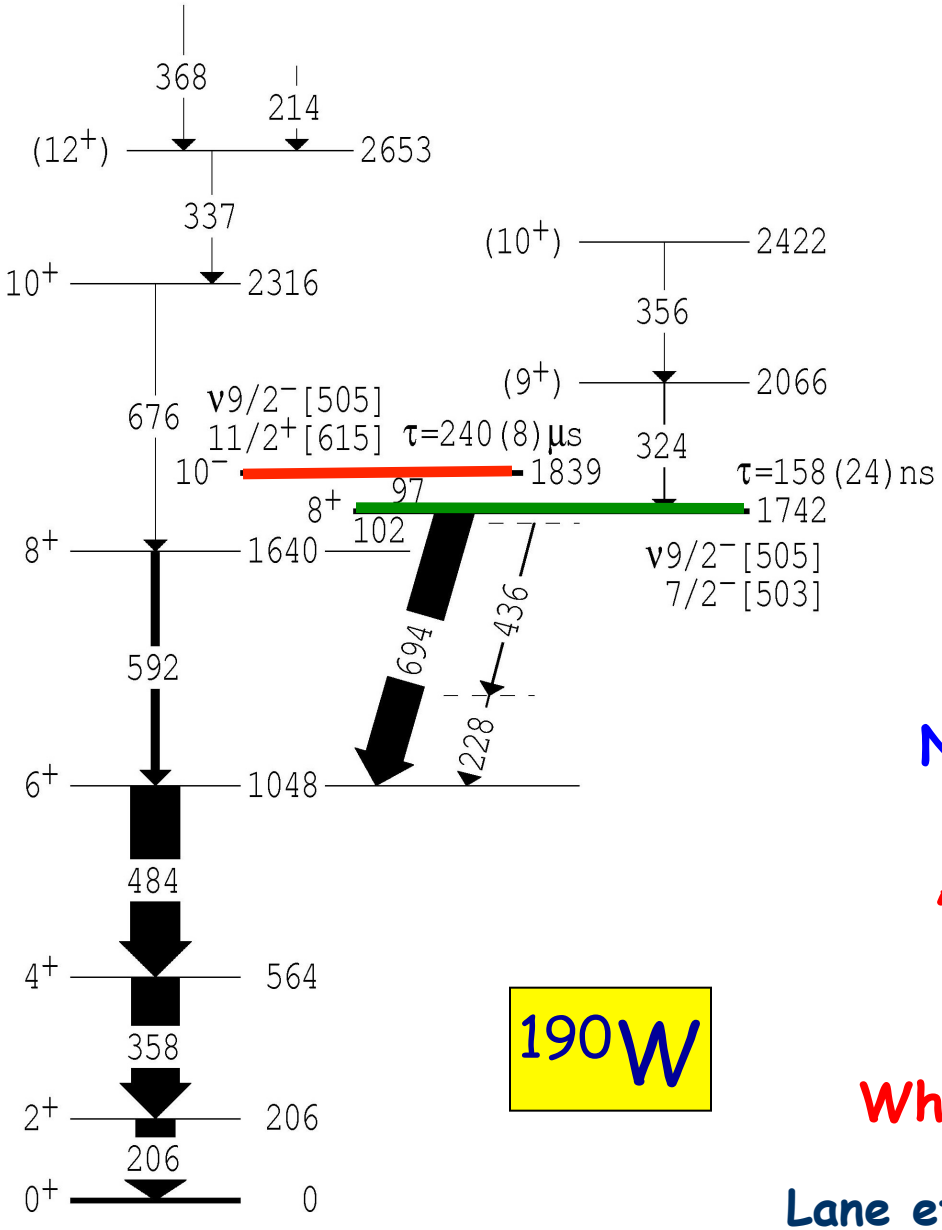
Reassigned as a K=8 isomer.

Our results for ^{190}W: definitive γ-ray coincidences





Our results: It is a 10^- isomer



10^-: ν9/2⁻[505] ν11/2⁺[615]

240μs

97 (M2)

8^+: ν9/2⁻[505] ν7/2⁻[503]

K-allowed transition with B(M2)=0.013 W.u.

Essentially unhindered.

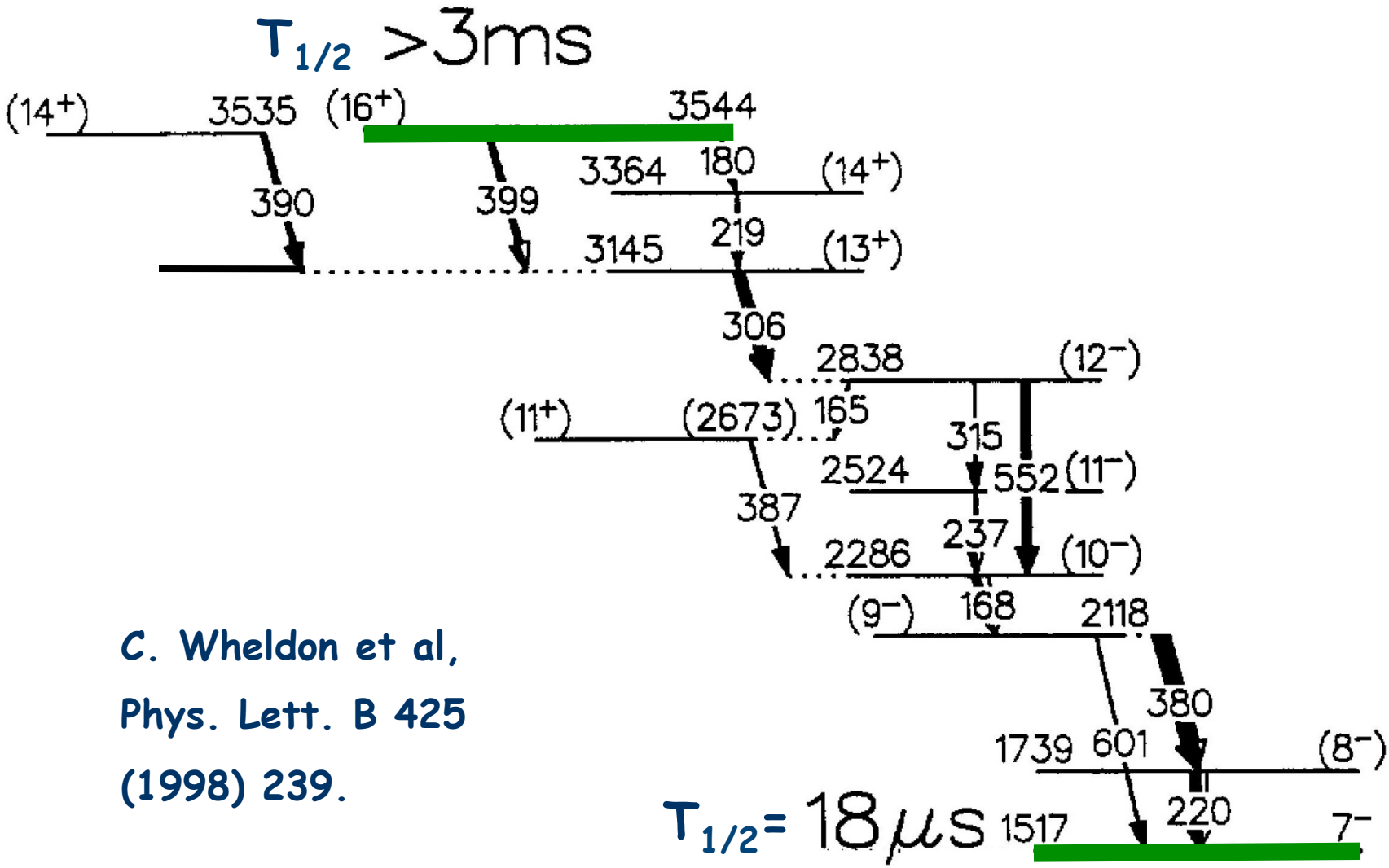
Not a K-isomer, but an yrast trap.

Another uncharacterised isomer known in tungsten nuclei: $T_{1/2}$>3ms state in ^{186}W

What does it say about K-hindrance?

Lane et al, Phys Rev C 82 (2010) 051304(R)

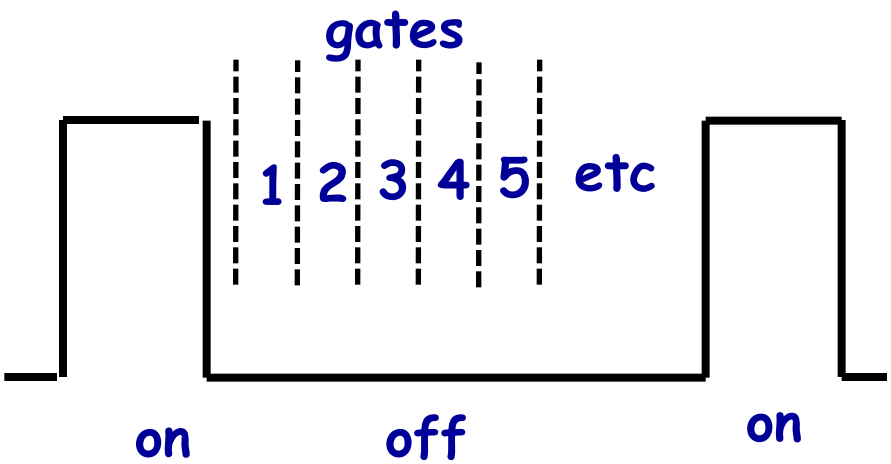
Previous level scheme for ^{186}W



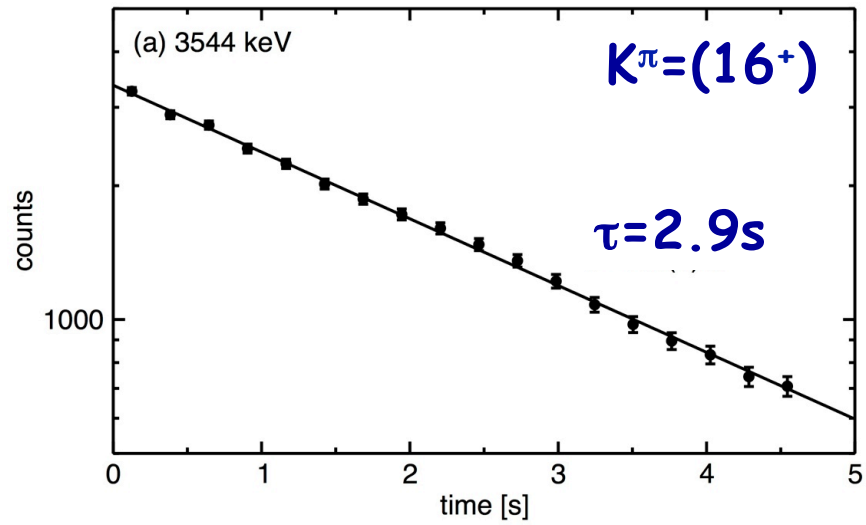
C. Wheldon et al, Phys. Lett. B 425 (1998) 239.

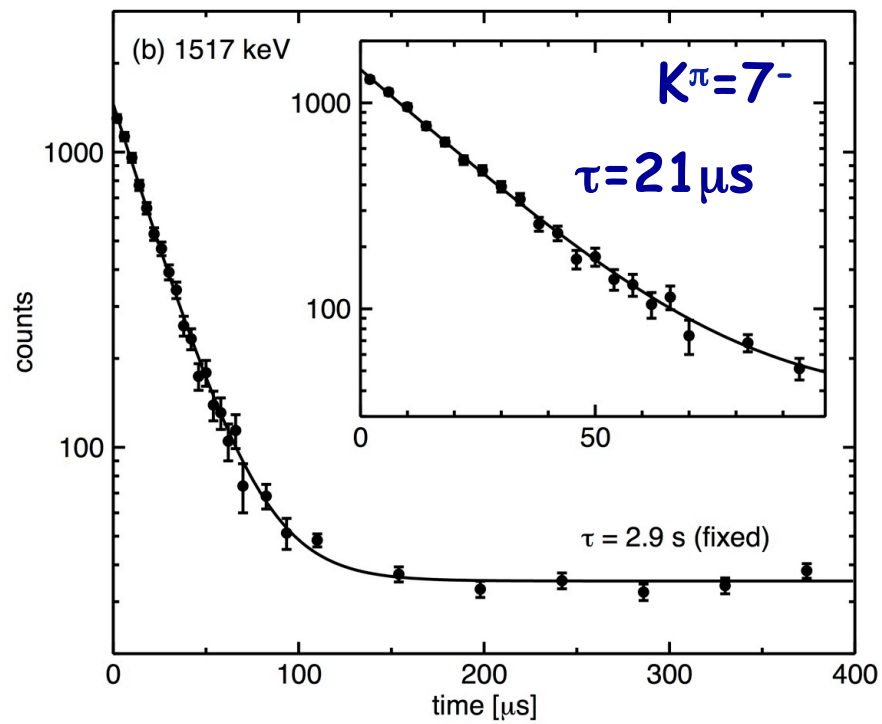
Long lifetimes in ^{186}W

Long beam chopping, various time ranges.

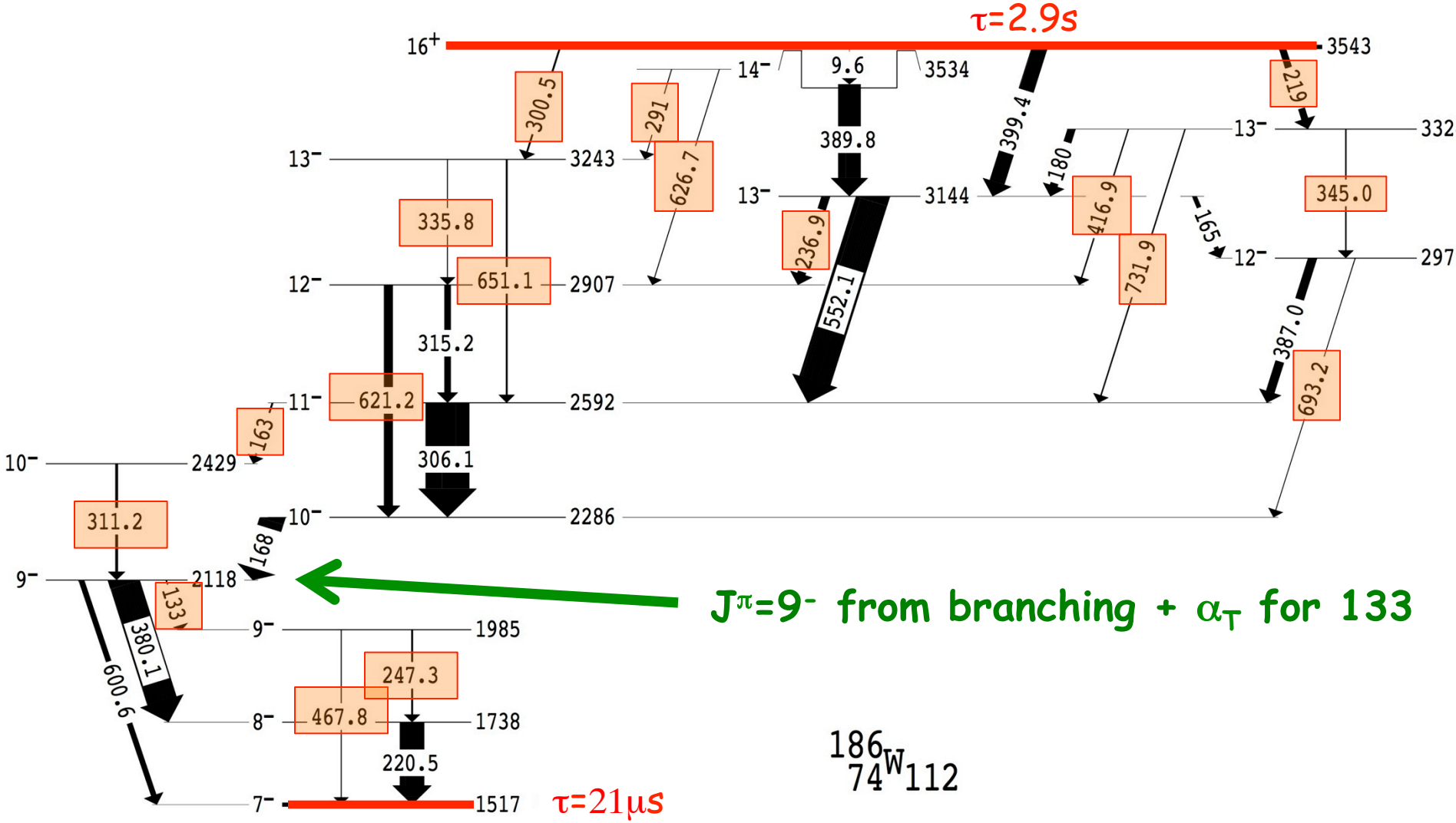


Measure γ-ray coincidence intensities out of beam





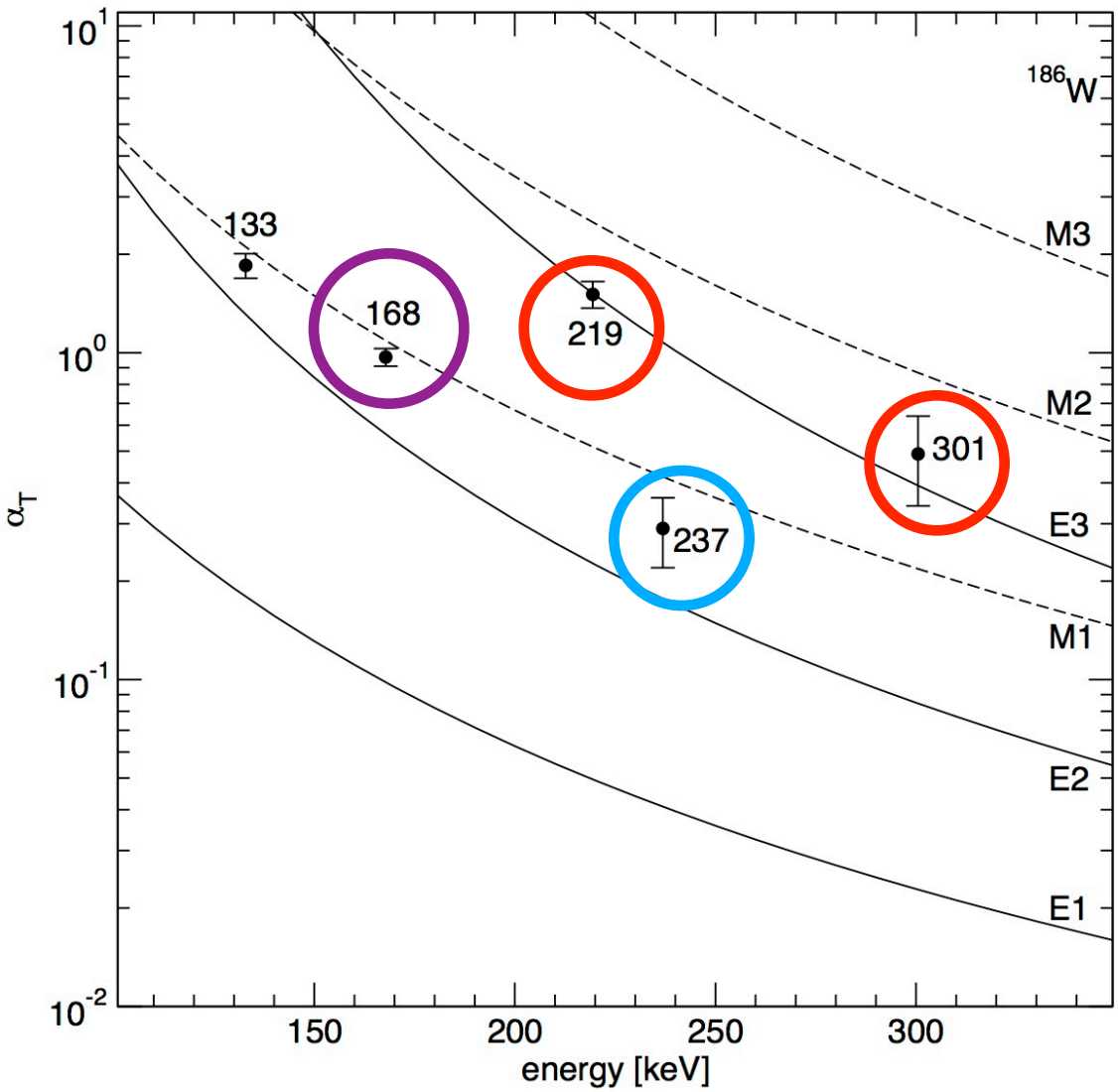
Extensive new level scheme for ^{186}W

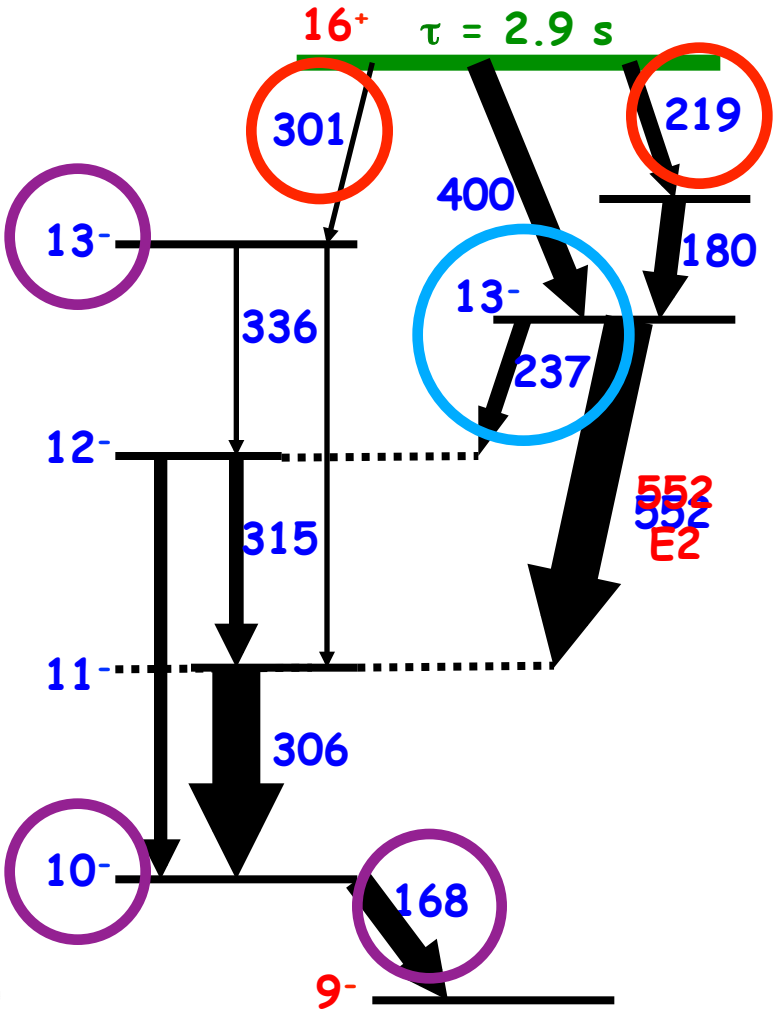


$J^{\pi}=9^{-}$ from branching + α_T for 133

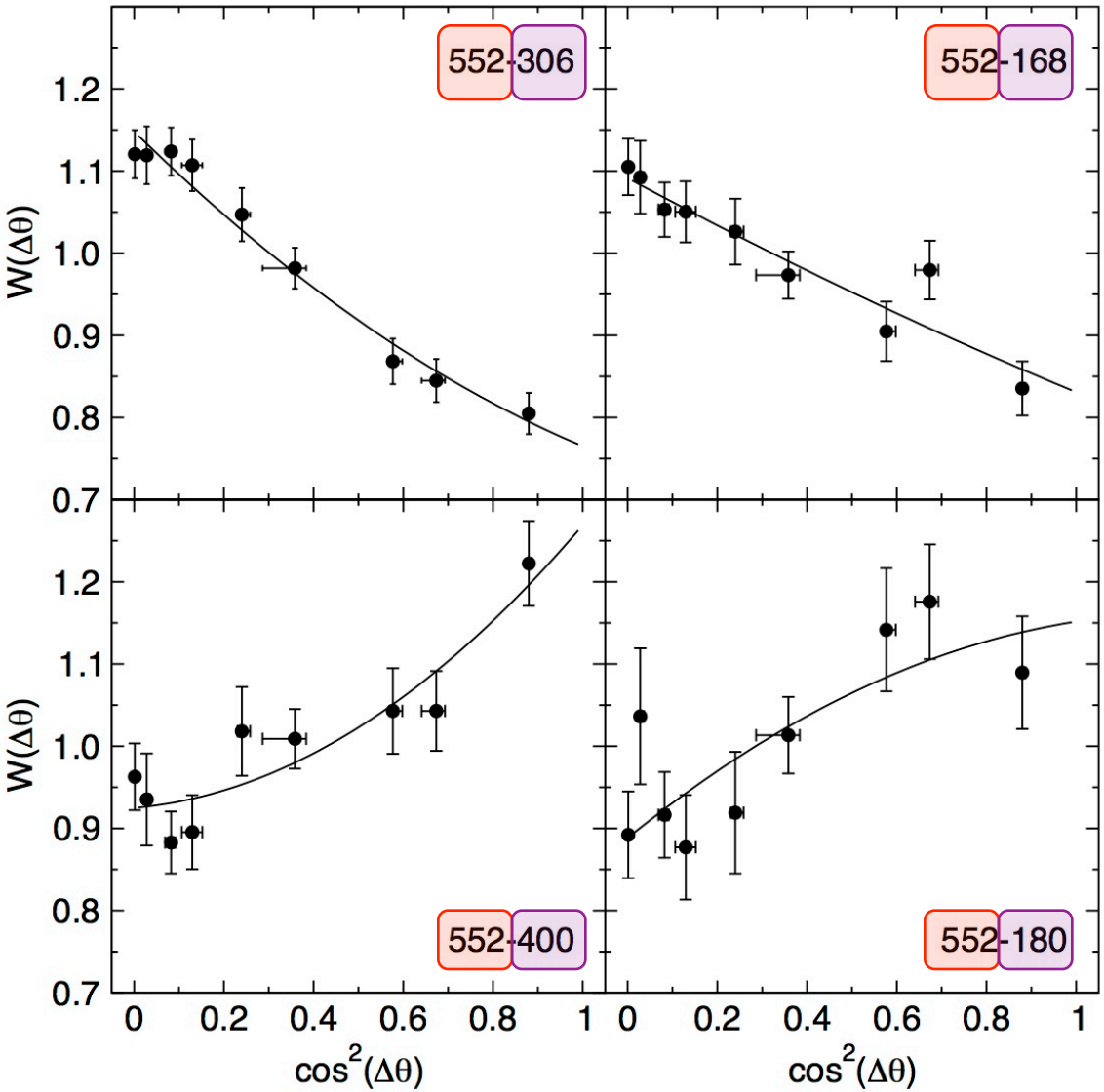
new transitions

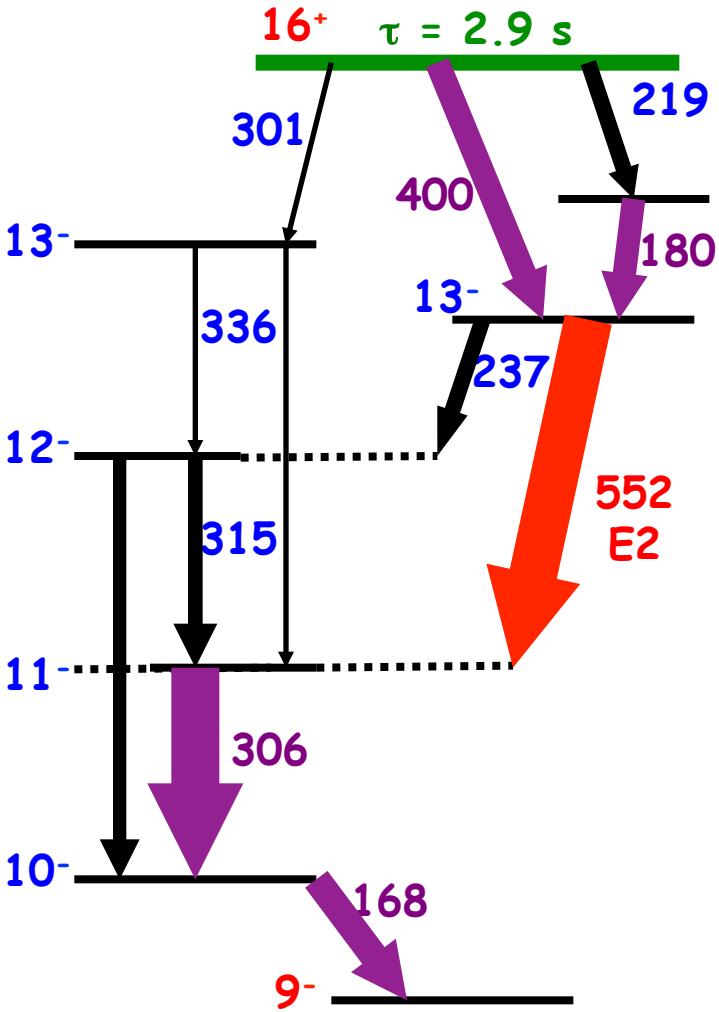
Spin assignments – ICC





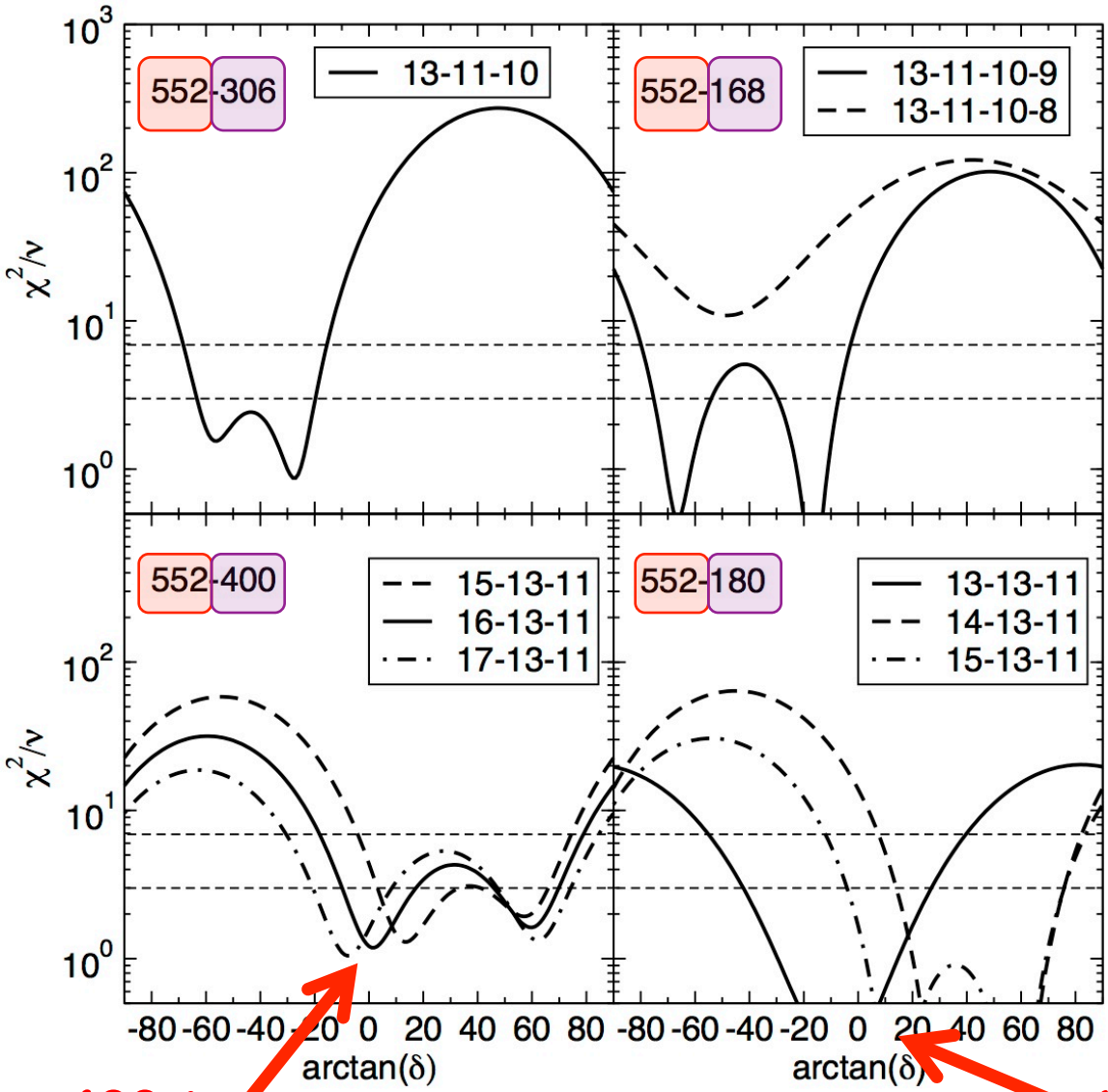
Spin assignments – Angular correlations

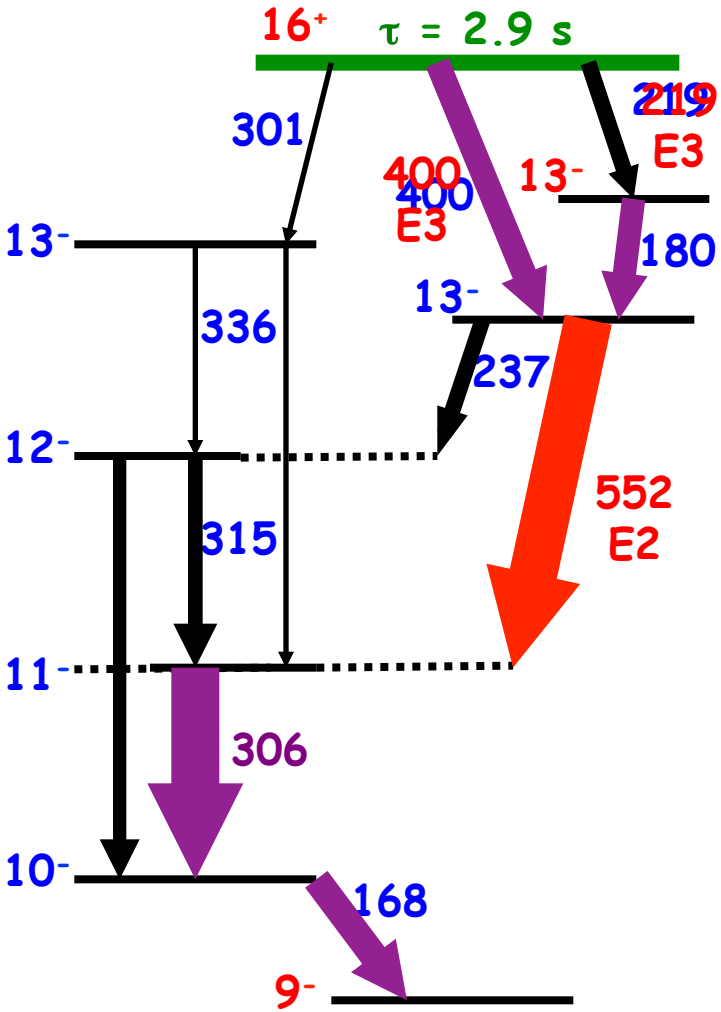




What spin sequences agree with these correlations?

Spin assignments – Angular correlations

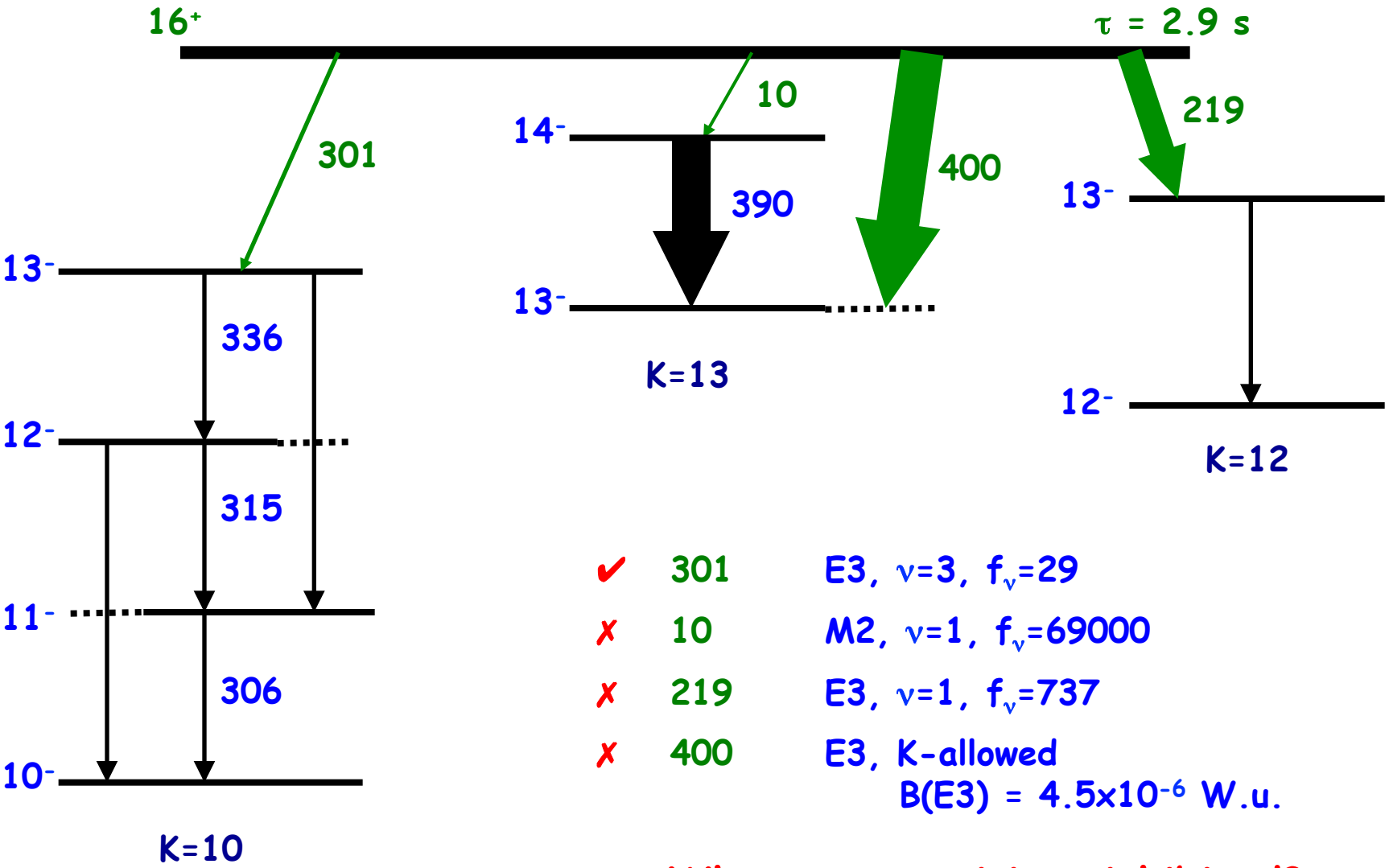




400 is pure L=3

180 is an unstretched dipole

Transition strengths for $K^{\pi}=16^{+}$ isomer decays



✔	301	E3, $\nu=3$, $f_\nu=29$
✗	10	M2, $\nu=1$, $f_\nu=69000$
✗	219	E3, $\nu=1$, $f_\nu=737$
✗	400	E3, K-allowed B(E3) = 4.5×10^{-6} W.u.

Why are transitions inhibited?

Investigate configurations…

MQP calcs and configuration assignments

see e.g. Kondev et al, NPA 617 (1997) 91

K^π	Configuration π	Configuration ν	E_{qp} (keV)	E_{res} (keV)	E_{calc} (keV)	E_{expt} (keV)
7^-		$11/2^+[615]$ $3/2^-[512]$	1572	−150	1422	1517
9^-		$11/2^+[615]$ $7/2^-[503]$	1591	+184	1775	2118
10^-		$11/2^+[615]$ $9/2^-[505]$	2022	−184	1838	2286
12^-		$11/2^+[615]$ $9/2^-[505]$ $1/2^-[510]$ $3/2^-[512]$	2998	−296	2702	2979
13^-		$11/2^+[615]$ $9/2^-[505]$ *$1/2^-[510]$* $7/2^-[503]$	3182	−187	2995	3144
15^+		$11/2^+[615]$ $9/2^+[624]$ $3/2^-[512]$ $7/2^-[503]$	3110	+80	3190	
16^+		$11/2^+[615]$ $9/2^+[624]$ $3/2^-[512]$ $9/2^-[505]$	3395	−280	3115	(3543)
16^+	$9/2^-[514]$ $5/2^+[402]$	$11/2^+[615]$ $7/2^-[503]$	3579	−87	3492	(3543)
18^+		$11/2^+[615]$ $9/2^+[624]$ $9/2^-[505]$ $7/2^-[503]$	3420	+163	3584	

firm assignments

Multiple candidates for 16^+ state
AND other states that should also be observed.

16^+ isomer configuration

There are two 16^+ candidates – which is correct?
Where are the related 15^+ and 18^+ states?

MQP calculation untuned

18^+	3584	$11/2^+$ $9/2^+$ $9/2^-$ $7/2^-$
16^+	3492	$9/2^-$ $5/2^+$ $11/2^+$ $7/2^-$
15^+	3190	$11/2^+$ $9/2^+$ $7/2^-$ $3/2^-$
16^+	3115	$11/2^+$ $9/2^+$ $9/2^-$ $3/2^-$

Experimental observations

10^-	2286	$11/2^+$ $9/2^-$
9^-	2118	$11/2^+$ $7/2^-$
7^-	1517	$11/2^+$ $3/2^-$

These can be related to the 15^+, 16^+, 18^+ four-neutron configurations

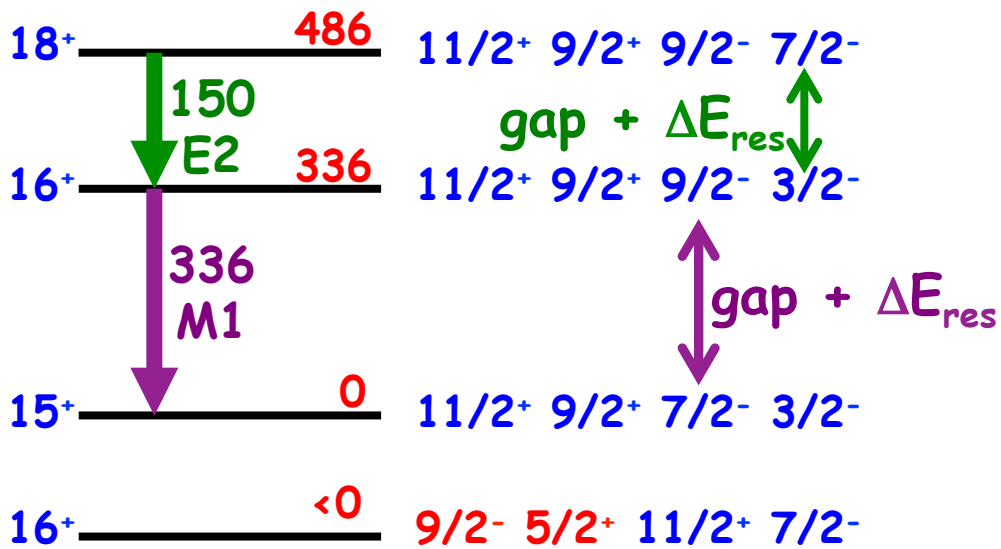
Neutrons: $11/2^+[615]$ $9/2^+[624]$ $3/2^-[512]$ $1/2^-[510]$ $7/2^-[503]$ $9/2^-[505]$

Protons: $5/2^+[402]$ $9/2^-[514]$

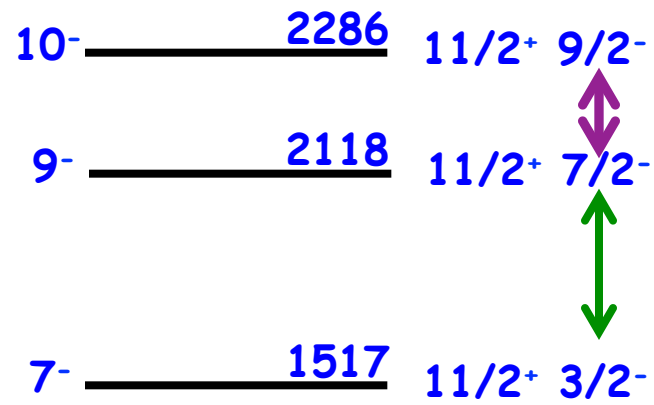
16^+ isomer configuration

There are two 16^+ candidates – which is correct?
Where are the related 15^+ and 18^+ states?

Internal (relative) calibration of the four-neutron states

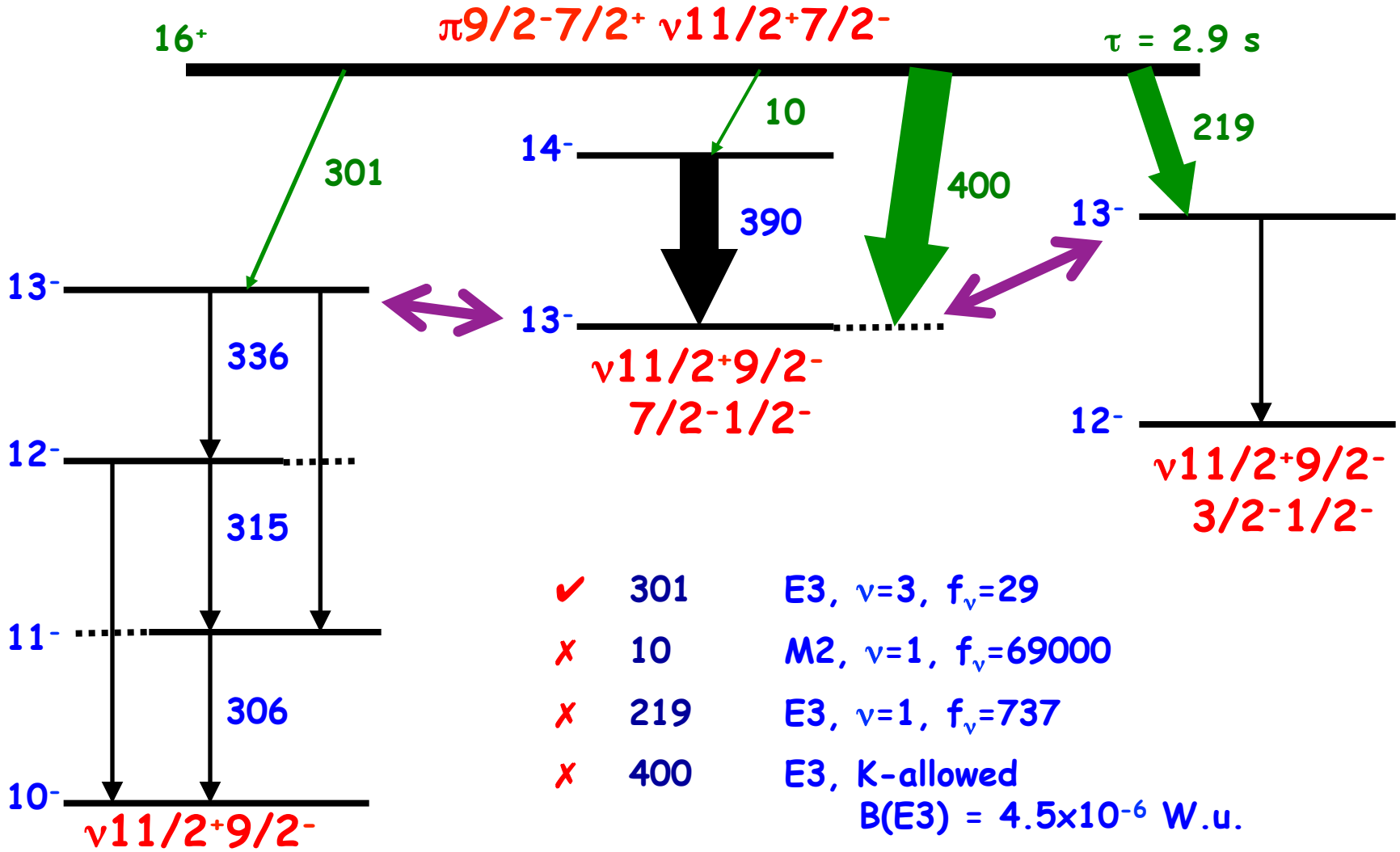


Experimental observations



The 16^+ $\pi^2\nu^2$ configuration must be the isomeric state and lie below the $15^+/16^+/18^+$ ν^4 states.

Transition strengths for $K^{\pi}=16^{+}$ isomer decays



✔	301	E3, $\nu=3$, $f_{\nu}=29$
✗	10	M2, $\nu=1$, $f_{\nu}=69000$
✗	219	E3, $\nu=1$, $f_{\nu}=737$
✗	400	E3, K-allowed B(E3) = 4.5×10^{-6} W.u.

Inhibited decays due to complex configuration changes?

Possible state mixing needs evaluation (but usually enhances!)

Conclusions

Isomers populated in neutron-rich nuclei with deep-inelastic reactions.

- Access to new regions.
- K-isomers discovered in a range of neutron-rich nuclei.
- Clarified the long-standing questions concerning long-lived states that were previously observed in ^{186}W and ^{190}W. Both are spin traps rather than K-isomers.
- General trend of decreasing hindrance in neutron-rich tungsten nuclei that is likely associated with an increase in triaxiality (shape and/or softness).
- However, detailed spectroscopy is necessary to properly understand the K-hindrance.
  - Accidental degeneracies
  - Configuration dependence