

ESR measurements of high-spin isomers in n-rich hafnium isotopes: **E109**

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K. Blaum, Y.A. Litvinov (MPI Heidelberg)
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- 1. Physics motivation**
- 2. Results so far**
- 3. Future plans**

Physics motivation

- Upper part of shell ($N=82-126$, $Z=50-82$)
- Reinforcing proton and neutron effects
- Prolate-to-oblate phase transition ($I=0$)
- Prolate deformation-aligned vs.
oblate rotation-aligned ($I=10-20$)

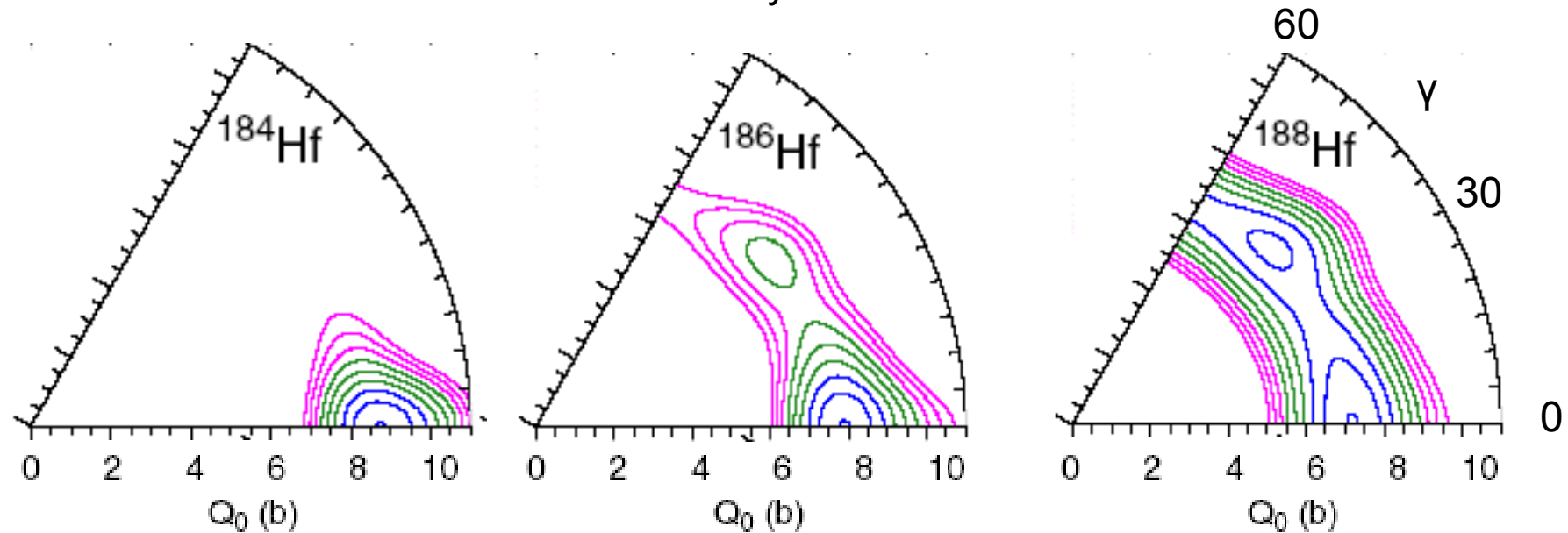
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prolate-oblate shape transition

n-rich hafnium ground states

HFB + SLy4

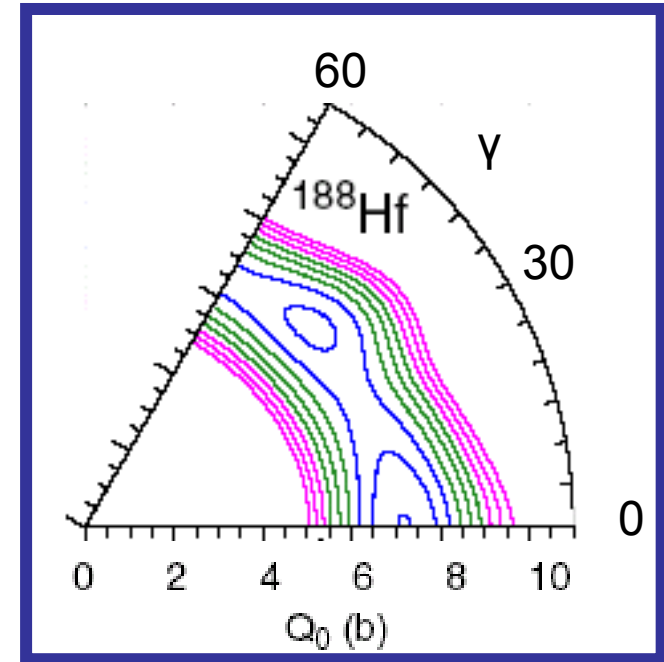
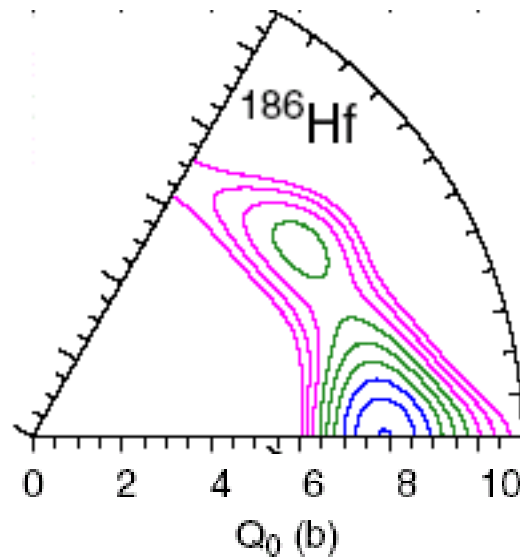
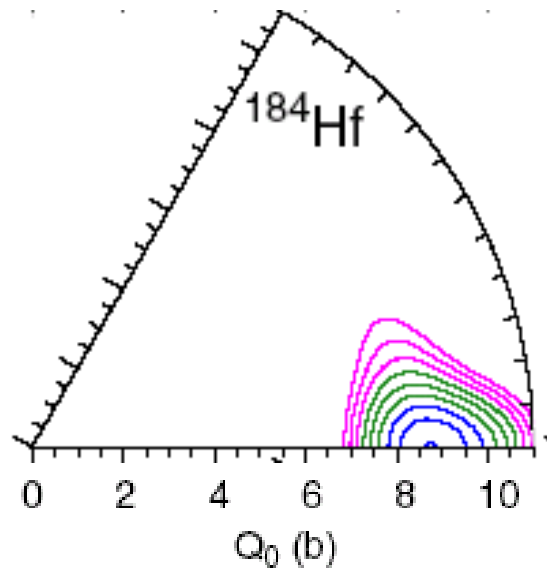


Robledo et al., *J. Phys. G: Nucl. Part. Phys.* **36**, 115104 (2009).

prolate-oblate shape transition

n-rich hafnium ground states

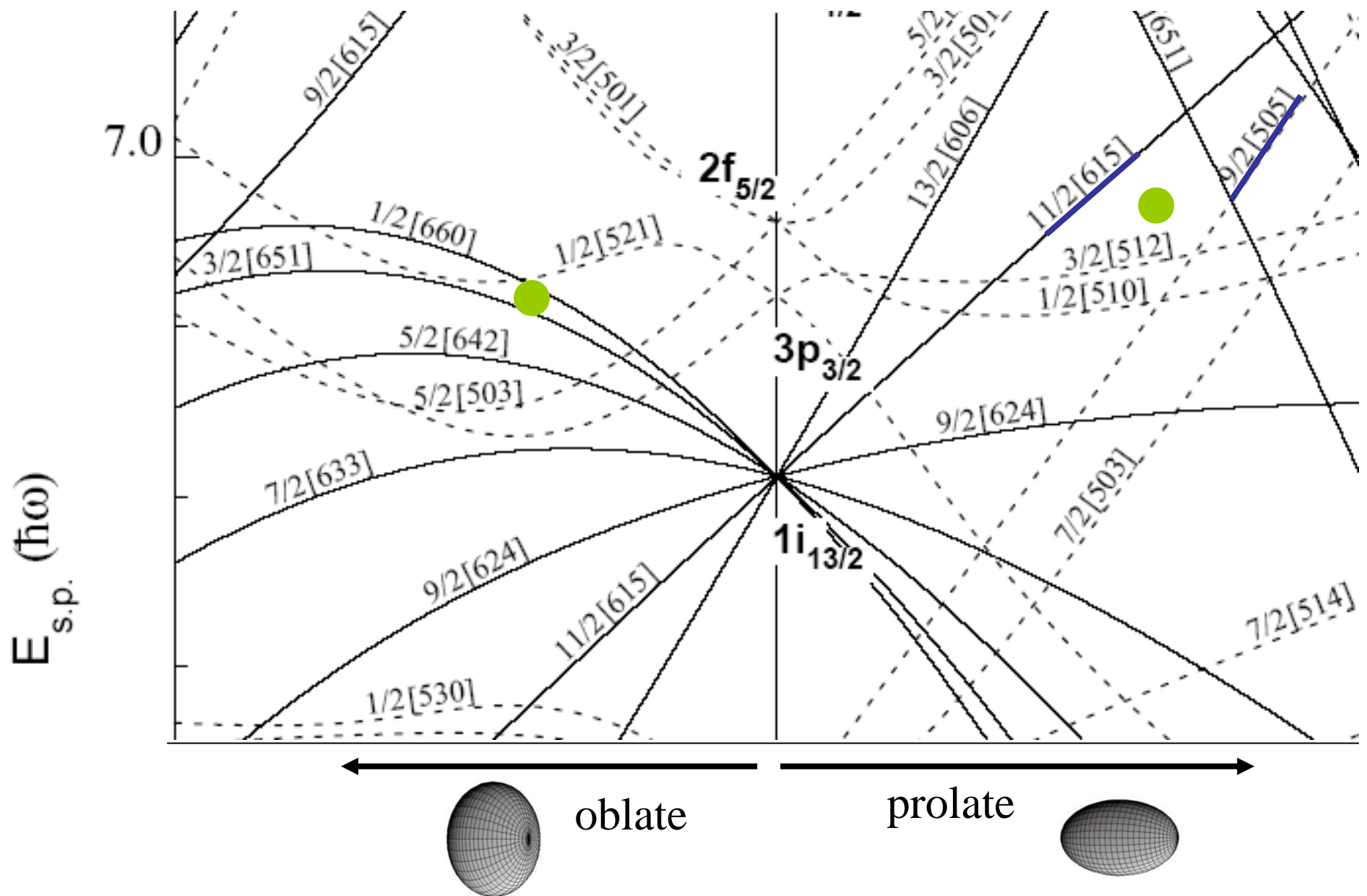
HFB + SLy4



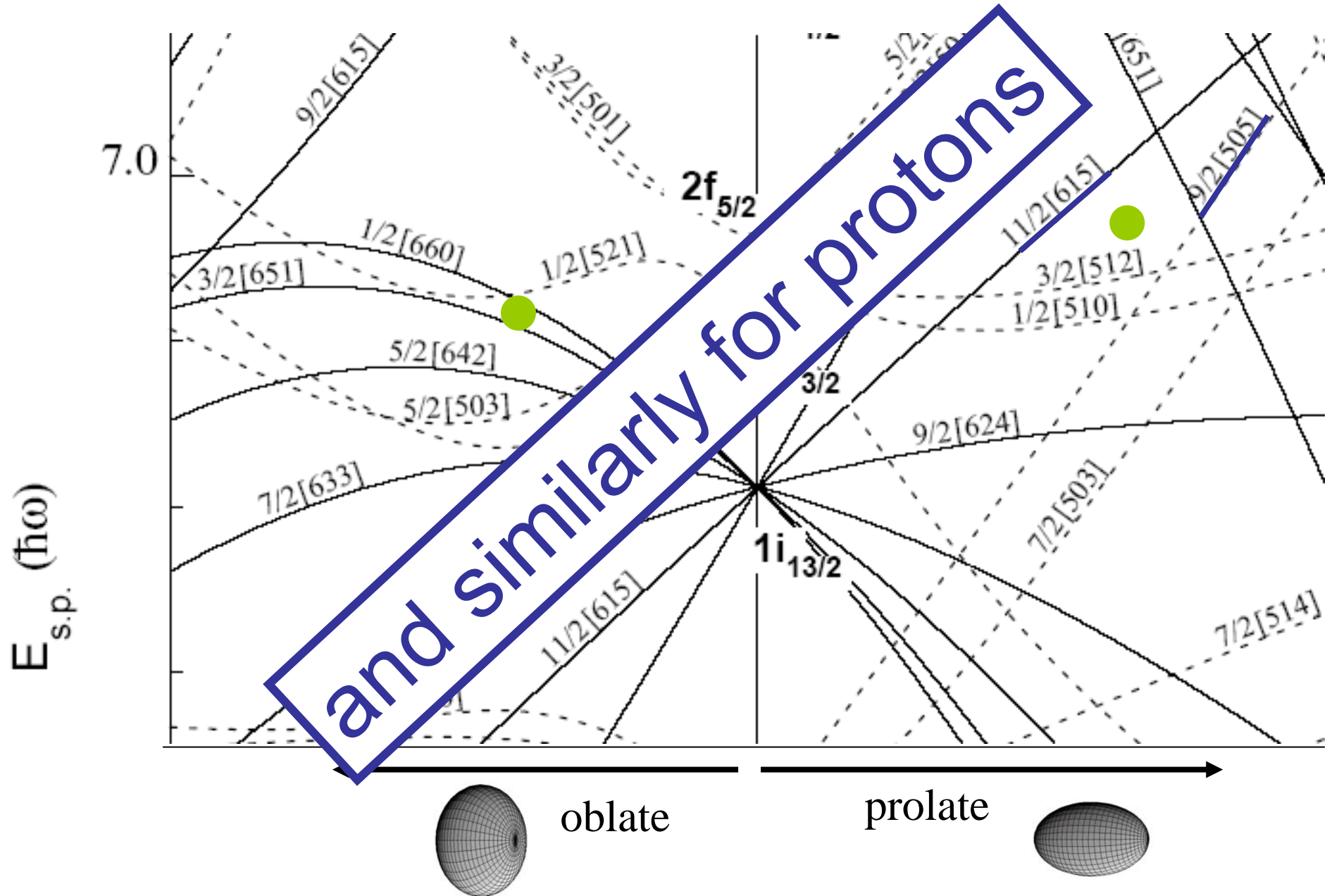
critical point

Robledo et al., *J. Phys. G: Nucl. Part. Phys.* **36**, 115104 (2009).

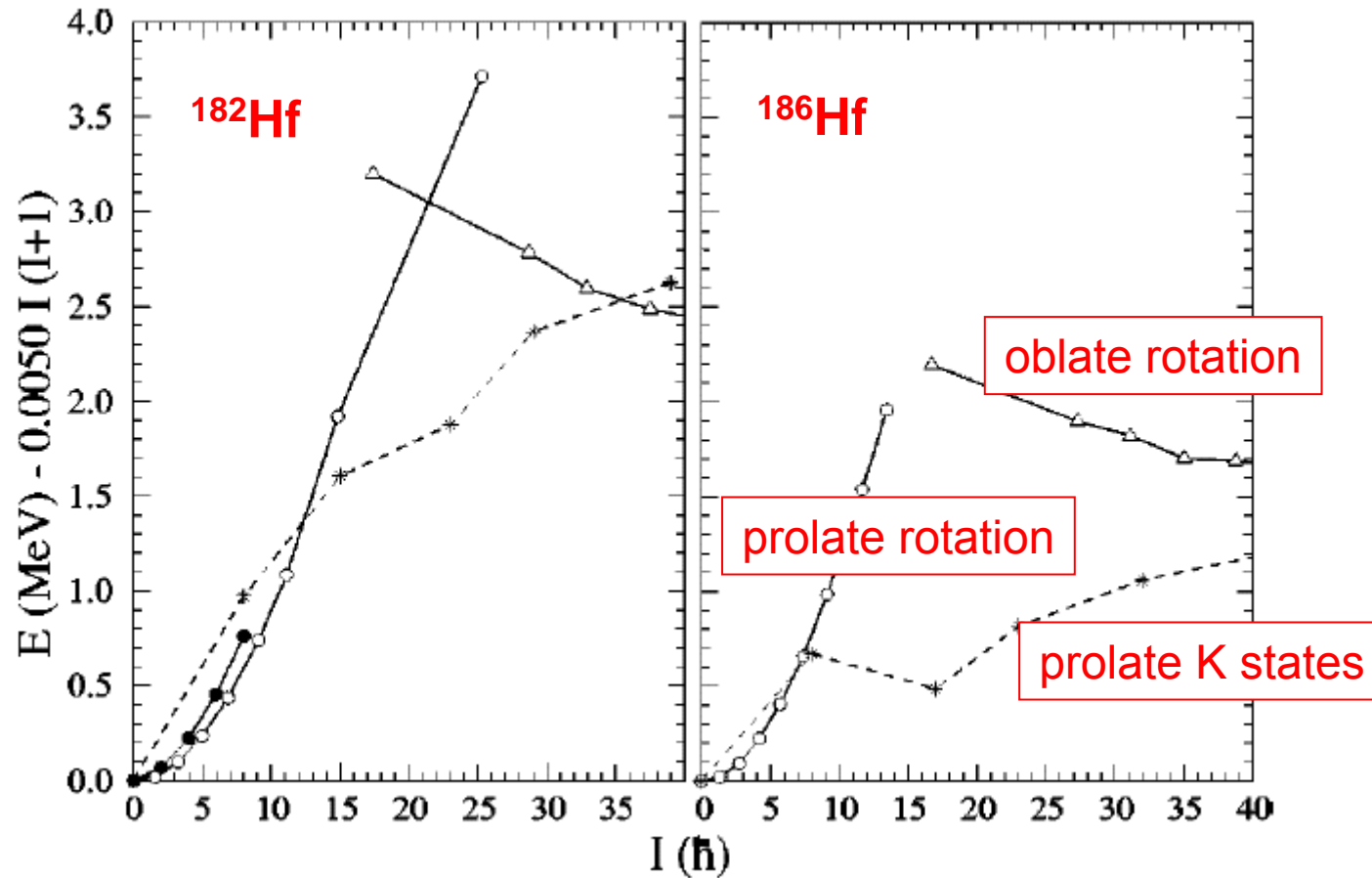
Nilsson single-particle diagram ● $N = 116$ Fermi level (^{188}Hf)



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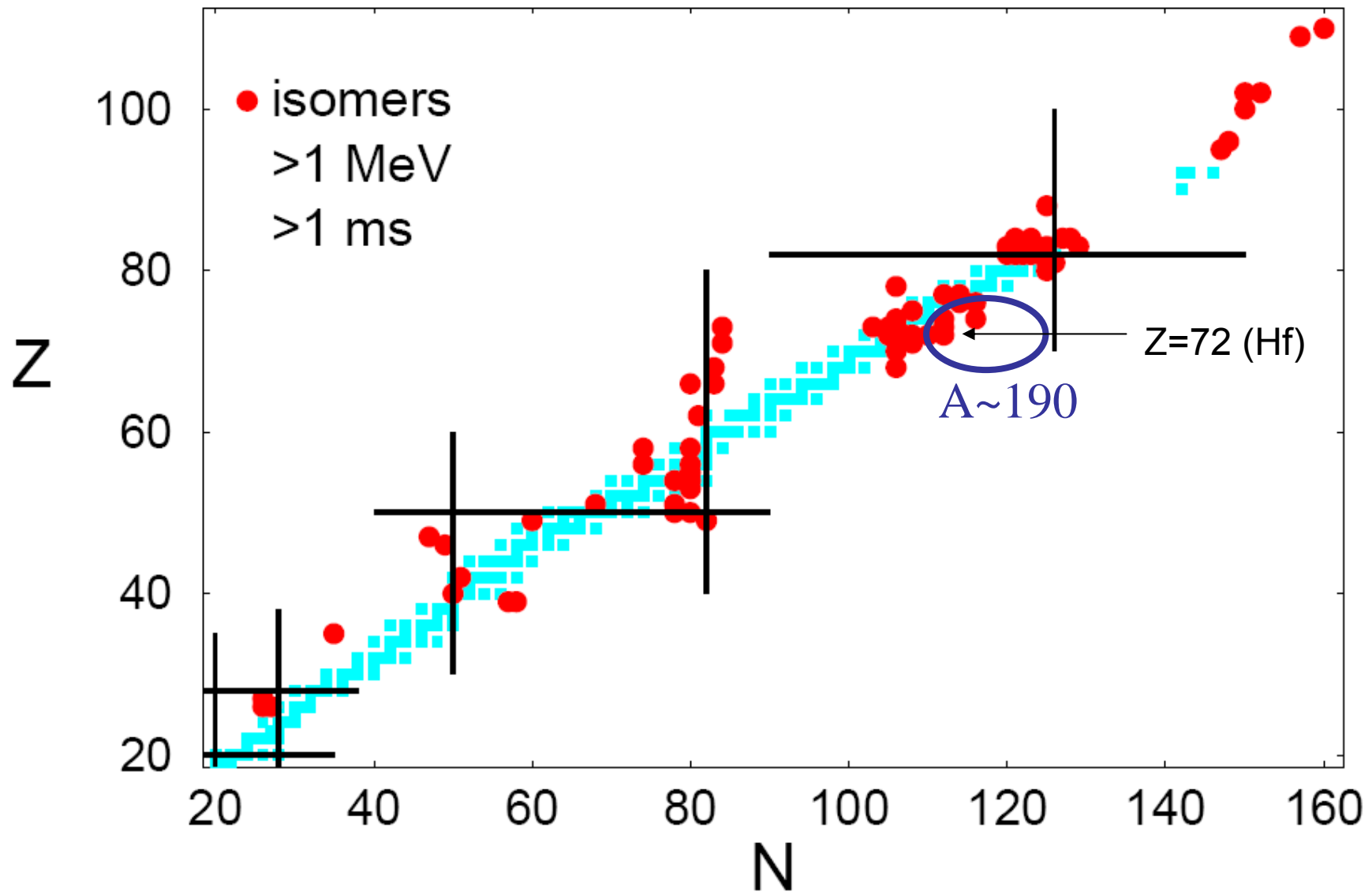
prolate-oblate shape transition



configuration constrained TRS calculations

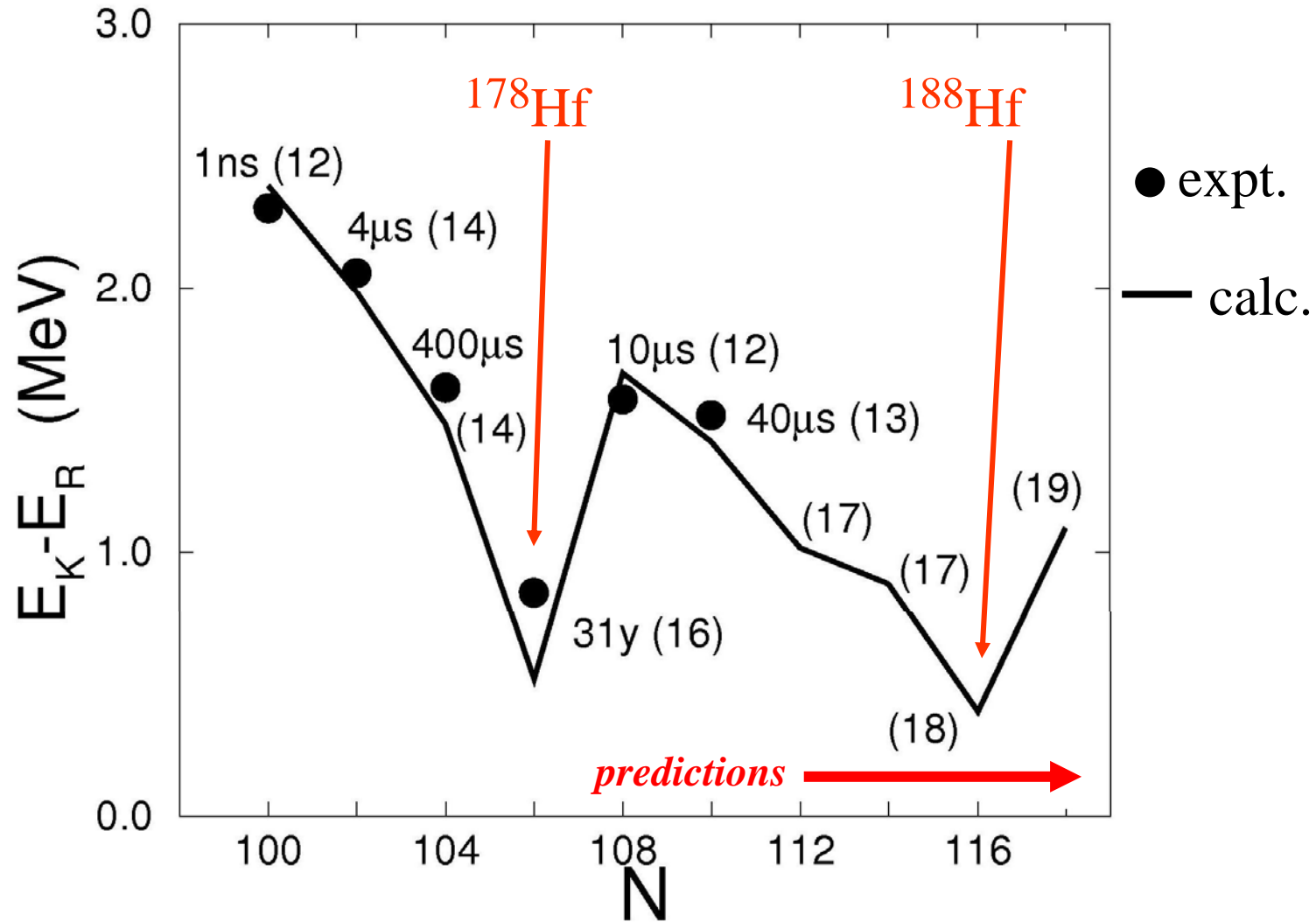
Xu, Walker and Wyss, Phys. Rev. C62 (2000) 014301

Nuclear chart with isomers



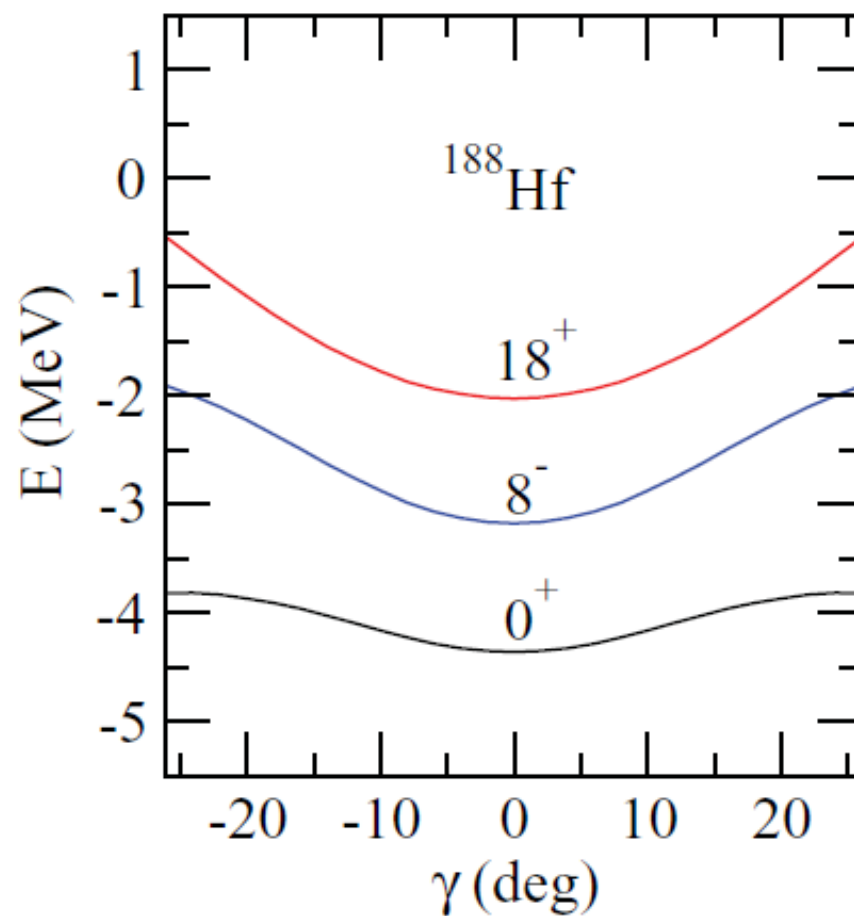
[Walker and Dracoulis, Nature 399 (1999) 35, updated]

hafnium (Z=72) 4-quasiparticle isomers



Walker and Dracoulis, Nature 399 (1999) 35; Hyp. Int. 135 (2001) 83

^{188}Hf high= K states from configuration-constrained TRS calculations

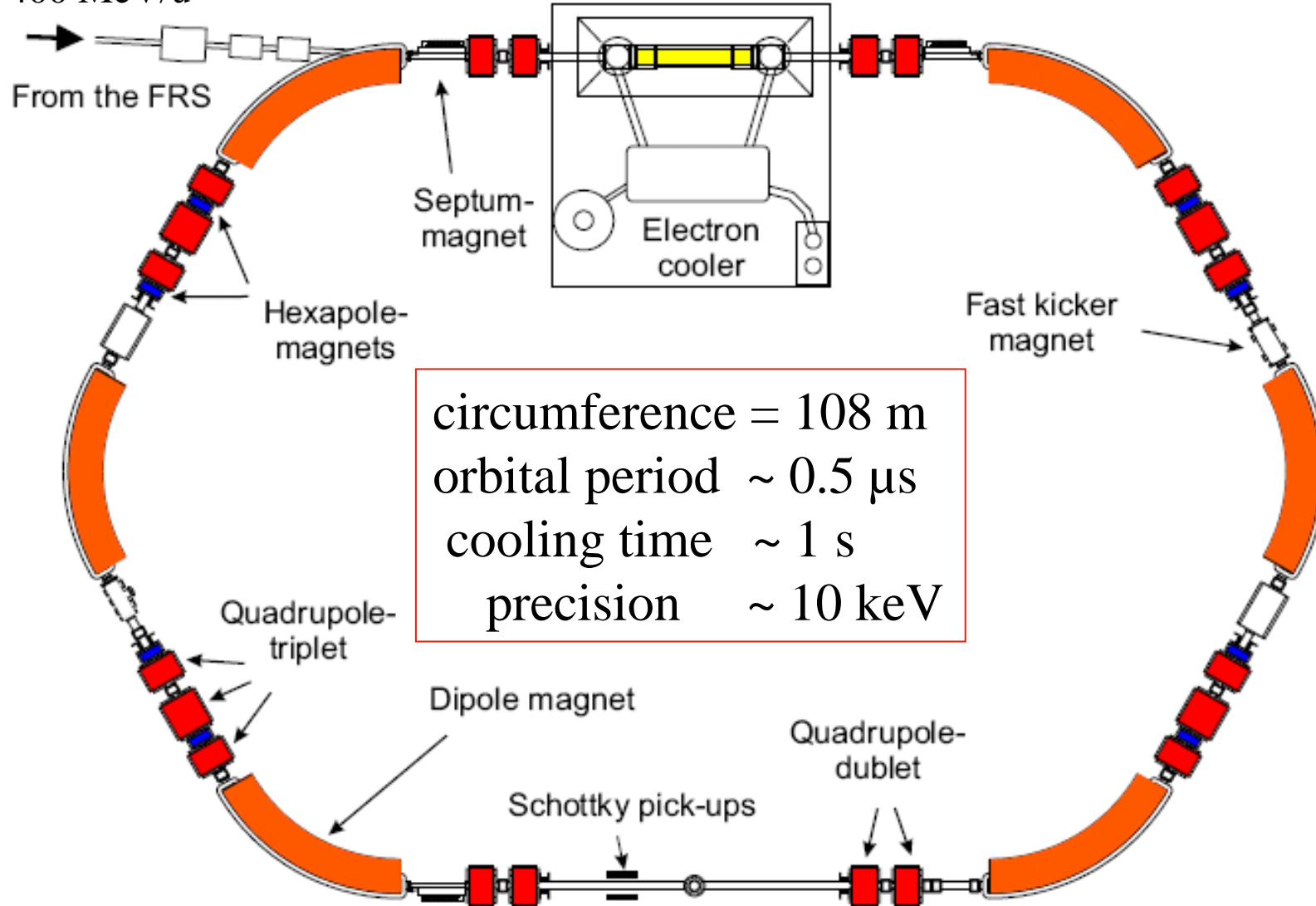


Isomer measurements

- RISING: $T_{1/2} \leq 1$ s, rate ≥ 1 ion per second
- ESR: $T_{1/2} \geq 1$ s, rate ≥ 1 ion per experiment

Experimental Storage Ring

ions ~ 400 MeV/u



¹⁹⁷Au fragmentation

2009
experiment

¹⁸⁷ Au 8.4 M	¹⁸⁸ Au 8.84 M	¹⁸⁹ Au 28.7 M	¹⁹⁰ Au 42.8 M	¹⁹¹ Au 3.18 H	¹⁹² Au 4.94 H	¹⁹³ Au 17.65 H	¹⁹⁴ Au 38.02 H	¹⁹⁵ Au 186.098 D	¹⁹⁶ Au 6.1669 D	¹⁹⁷ Au STABLE 100%
ε: 100.00% α: 3.0E-3%	ε: 100.00%	ε: 100.00% α: < 3.0E-5%	ε: 100.00% α: < 1.0E-6%	ε: 100.00%	ε: 100.00%	ε: 100.00%	ε: 100.00%	ε: 100.00%	ε: 93.00% β-: 7.00%	
¹⁸⁶ Pt 2.08 H	¹⁸⁷ Pt 2.35 H	¹⁸⁸ Pt 10.2 D	¹⁸⁹ Pt 10.87 H	¹⁹⁰ Pt 6.5E+11 Y 0.014%	¹⁹¹ Pt 2.83 D	¹⁹² Pt STABLE 0.782%	¹⁹³ Pt 50 Y	¹⁹⁴ Pt STABLE 32.967%	¹⁹⁵ Pt STABLE 33.832%	¹⁹⁶ Pt STABLE 25.242%
ε: 100.00% α: ≈ 1.4E-4%	ε: 100.00%	ε: 100.00% α: 2.6E-5%	ε: 100.00%	α: 100.00%	ε: 100.00%		ε: 100.00%			
¹⁸⁵ Ir 14.4 H	¹⁸⁶ Ir 16.64 H	¹⁸⁷ Ir 10.5 H	¹⁸⁸ Ir 41.5 H	¹⁸⁹ Ir 13.2 D	¹⁹⁰ Ir 11.78 D	¹⁹¹ Ir STABLE 37.3%	¹⁹² Ir 73.827 D	¹⁹³ Ir STABLE 62.7%	¹⁹⁴ Ir 19.28 H	¹⁹⁵ Ir 2.5 H
ε: 100.00%	ε: 100.00%	ε: 100.00%	ε: 100.00%	ε: 100.00%	ε: 100.00%		β-: 95.13% ε: 4.87%		β-: 100.00%	β-: 100.00%
¹⁸⁴ Os >5.6E+13 Y 0.02% α	¹⁸⁵ Os 93.6 D	¹⁸⁶ Os 2.0E+15 Y 1.59% α	¹⁸⁷ Os STABLE 1.6%	¹⁸⁸ Os STABLE 13.29%	¹⁸⁹ Os STABLE 16.21%	¹⁹⁰ Os STABLE 26.36%	¹⁹¹ Os 15.4 D	¹⁹² Os STABLE 40.93%	¹⁹³ Os 30.11 H	¹⁹⁴ Os 6.0 Y
	ε: 100.00%	α: 100.00%					β-: 100.00%		β-: 100.00%	β-: 100.00%
¹⁸³ Re 70.0 D	¹⁸⁴ Re 38.0 D	¹⁸⁵ Re STABLE 37.40%	¹⁸⁶ Re 3.7186 D	¹⁸⁷ Re 4.12E+10 Y 62.60% β-: 100.00% α: < 1.0E-4%	¹⁸⁸ Re 17.003 H	¹⁸⁹ Re 24.3 H	¹⁹⁰ Re 3.1 M	¹⁹¹ Re 9.8 M	¹⁹² Re 16 S	¹⁹³ Re
ε: 100.00%	ε: 100.00%		β-: 92.53% ε: 7.47%	β-: 100.00% α: < 1.0E-4%	β-: 100.00%	β-: 100.00%	β-: 100.00%	β-: 100.00%	β-: 100.00%	
¹⁸² W >8.3E+18 Y 26.50% α	¹⁸³ W >1.3E+19 Y 14.31% α	¹⁸⁴ W >2.9E+19 Y 30.64% α	¹⁸⁵ W 75.1 D	¹⁸⁶ W >2.7E+19 Y 28.43% α	¹⁸⁷ W 23.72 H	¹⁸⁸ W 69.78 D	¹⁸⁹ W 10.7 M	¹⁹⁰ W 30.0 M	¹⁹¹ W >300 NS	¹⁹² W >300 NS
			β-: 100.00%	α	β-: 100.00%	β-: 100.00%	β-: 100.00%	β-: 100.00%	β-	β-
¹⁸¹ Ta STABLE 99.988%	¹⁸² Ta 114.43 D	¹⁸³ Ta 5.1 D	¹⁸⁴ Ta 8.7 H	¹⁸⁵ Ta 49.4 M	¹⁸⁶ Ta 10.5 M	¹⁸⁷ Ta ≈ 2 M	¹⁸⁸ Ta ≈ 20 S	¹⁸⁹ Ta 3 S	¹⁹⁰ Ta 0.3 S	
	β-: 100.00%	β-: 100.00%	β-: 100.00%	β-: 100.00%	β-: 100.00%	β-	β-	β-	β-	
¹⁸⁰ Hf STABLE 35.08%	¹⁸¹ Hf 42.39 D	¹⁸² Hf 8.90E+6 Y	¹⁸³ Hf 1.067 H	¹⁸⁴ Hf 4.12 H	¹⁸⁵ Hf 3.5 M	¹⁸⁶ Hf 2.6 M	¹⁸⁷ Hf 30 S	¹⁸⁸ Hf 20 S		
	β-: 100.00%	β-: 100.00%	β-: 100.00%	β-: 100.00%	β-: 100.00%	β-: 100.00%	β-	β-		

beam

new
isomers
 $T_{1/2} > 10$ s

Reed et al., Phys. Rev. Lett. 105 (2010) 172501

¹⁹⁷Au fragmentation

2009
experiment

187Au 8.4 M	188Au 8.84 M	189Au 28.7 M	190Au 42.8 M	191Au 3.18 H	192Au 4.94 H	193Au 17.65 H	194Au 38.02 H	195Au 186.098 D	196Au 6.1669 D	197Au STABLE 100%
ε: 100.00% α: 3.0E-3%	ε: 100.00%	ε: 100.00% α: < 3.0E-5%	ε: 100.00% α: < 1.0E-6%	ε: 100.00%	ε: 100.00%	ε: 100.00%	ε: 100.00%	ε: 100.00%	ε: 93.00% β-: 7.00%	
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185Ir 14.4 H	186Ir 16.64 H	187Ir 10.5 H	188Ir 41.5 H	189Ir 13.2 D	190Ir 11.78 D	191Ir STABLE 37.3%	192Ir 73.827 D	193Ir STABLE 62.7%	194Ir 19.28 H	195Ir 2.5 H
ε: 100.00%	ε: 100.00%	ε: 100.00%	ε: 100.00%	ε: 100.00%	ε: 100.00%	ε: 100.00%	β-: 95.13% ε: 4.87%	β-: 100.00%	β-: 100.00%	β-: 100.00%
184Os >5.6E+13 Y 0.02% α	185Os 93.6 D	186Os 2.0E+15 Y 1.59% α	187Os STABLE 1.6%	188Os STABLE 13.29%	189Os STABLE 16.21%	190Os STABLE 26.36%	191Os 15.4 D	192Os STABLE 40.93%	193Os 30.11 H	194Os 6.0 Y
ε: 100.00%	ε: 100.00%	ε: 100.00%	ε: 100.00%	ε: 100.00%	ε: 100.00%	ε: 100.00%	β-: 100.00%	β-: 100.00%	β-: 100.00%	β-: 100.00%
183Re 70.0 D	184Re 38.0 D	185Re STABLE 37.40%	186Re 3.7186 D	187Re 4.12E+10 Y 62.60% α < 1.0E-4%	188Re 17.003 H	189Re 24.3 H	190Re 3.1 M	191Re 9.8 M	192Re 16 S	193Re
ε: 100.00%	ε: 100.00%	ε: 100.00%	β-: 92.53% ε: 7.47%	β-: 100.00% α < 1.0E-4%	β-: 100.00%	β-: 100.00%	β-: 100.00%	β-: 100.00%	β-: 100.00%	β-: 100.00%
182W >8.3E+18 Y 26.50% α	183W >1.3E+19 Y 14.31% α	184W >2.9E+19 Y 30.64% α	185W 75.1 D	186W >2.7E+19 Y 28.43% α	187W 23.72 H	188W 69.78 D	189W 10.7 M	190W 30.0 M	191W >300 NS	192W >300 NS
β-: 100.00%	β-: 100.00%	β-: 100.00%	β-: 100.00%	β-: 100.00%	β-: 100.00%	β-: 100.00%	β-: 100.00%	β-: 100.00%	β-	β-
181Ta STABLE 99.988%	182Ta 114.43 D	183Ta 5.1 D	184Ta 8.7 H	185Ta 49.4 M	186Ta 10.5 M	187Ta ≈ 2 M	188Ta ≈ 20 S	189Ta 3 S	190Ta 0.3 S	
β-: 100.00%	β-: 100.00%	β-: 100.00%	β-: 100.00%	β-: 100.00%	β-: 100.00%	β-	β-	β-	β-	
180Hf STABLE 35.08%	181Hf 42.39 D	182Hf 8.90E+6 Y	183Hf 1.067 H	184Hf 4.12 H	185Hf 3.5 M	186Hf 2.6 M	187Hf 30 S	188Hf 20 S		
β-: 100.00%	β-: 100.00%	β-: 100.00%	β-: 100.00%	β-: 100.00%	β-: 100.00%	β-: 100.00%	β-	β-		

beam

new
isomers
 $T_{1/2} > 10$ s

Reed et al., Phys. Rev. Lett. 105 (2010) 172501

isomers in the ESR

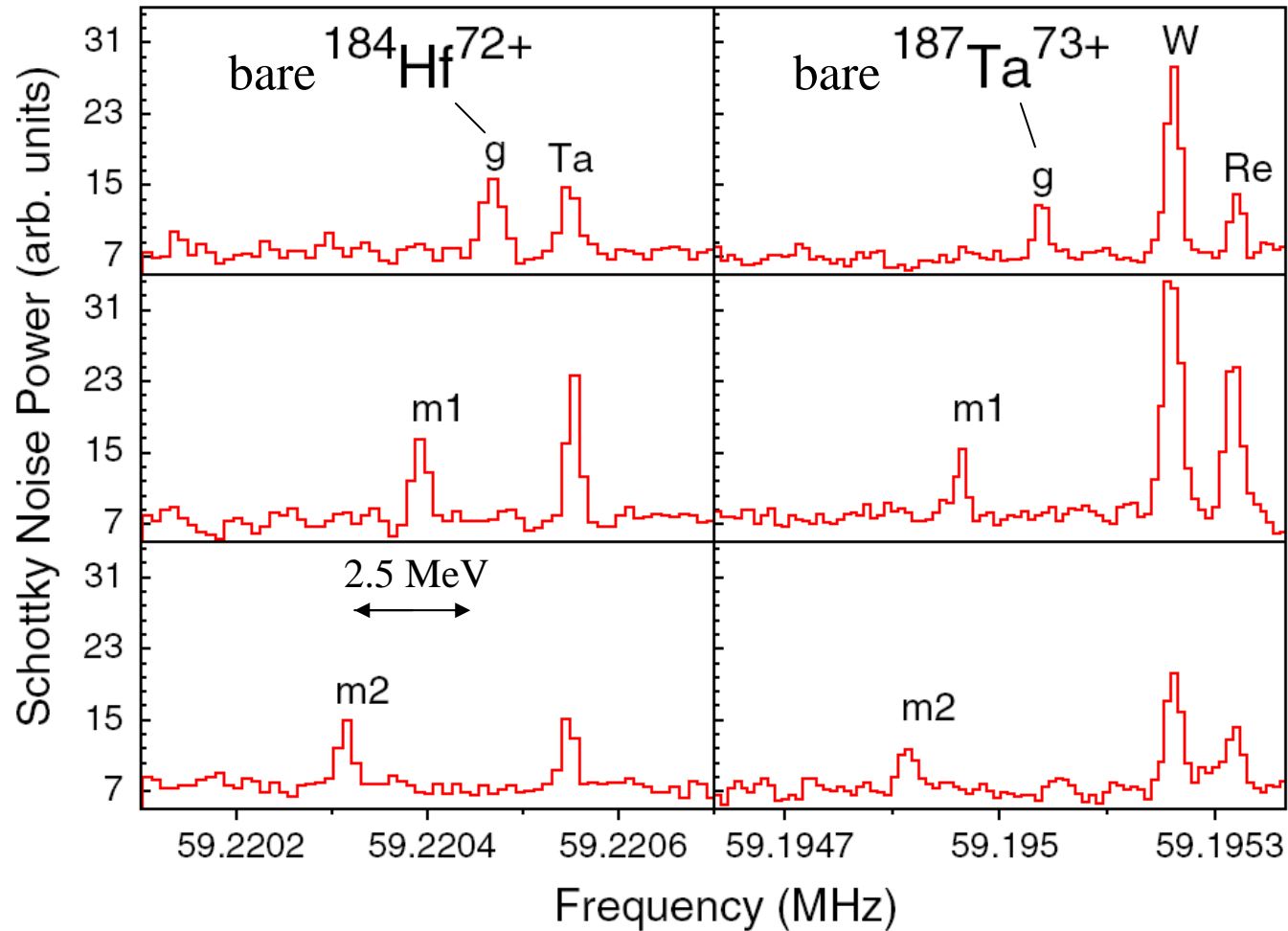
2009
experiment

10-second snapshots

$A = 184, q = 72+$

$A = 187, q = 73+$

^{197}Au fragmentation



isomers in the ESR

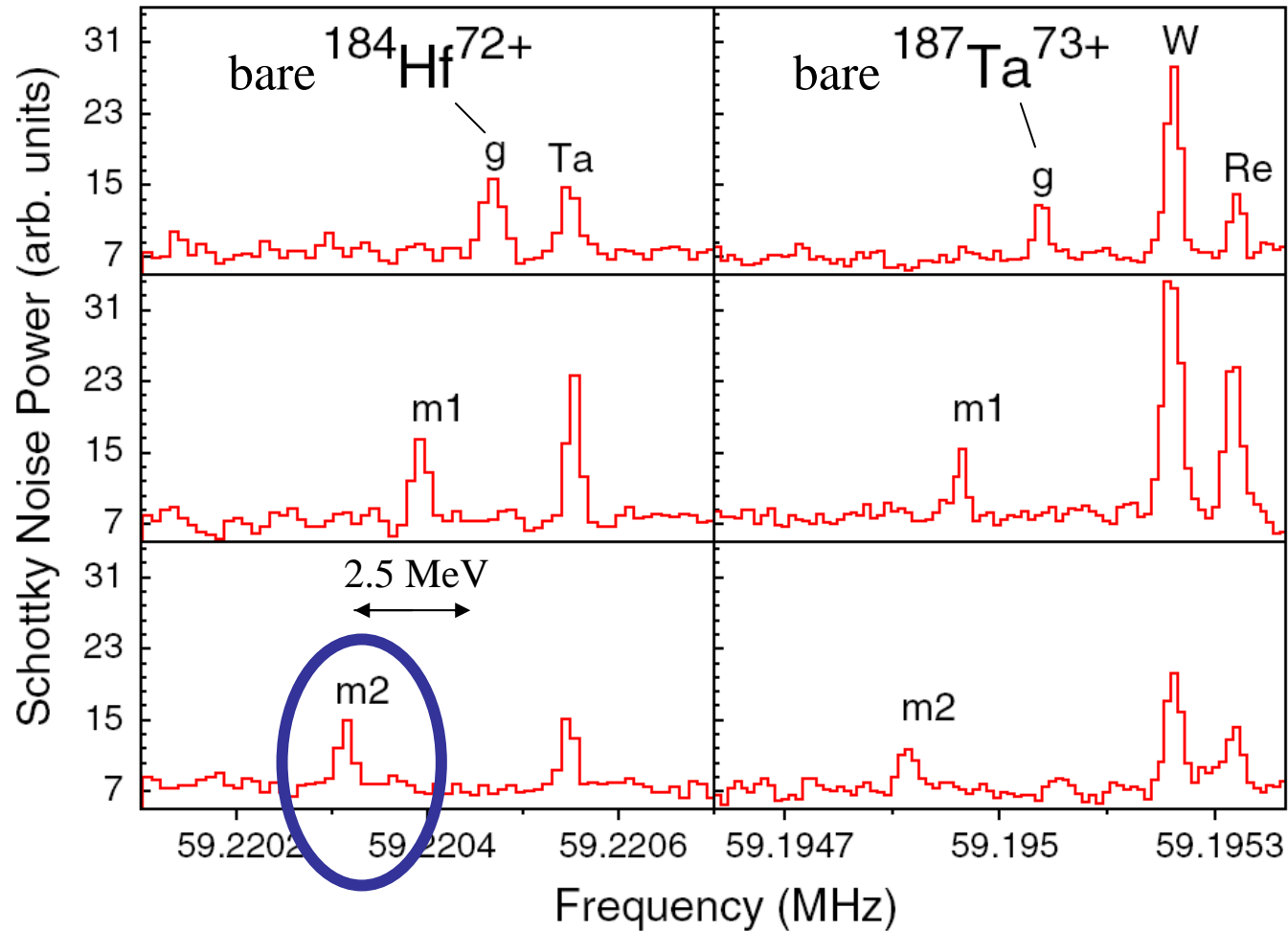
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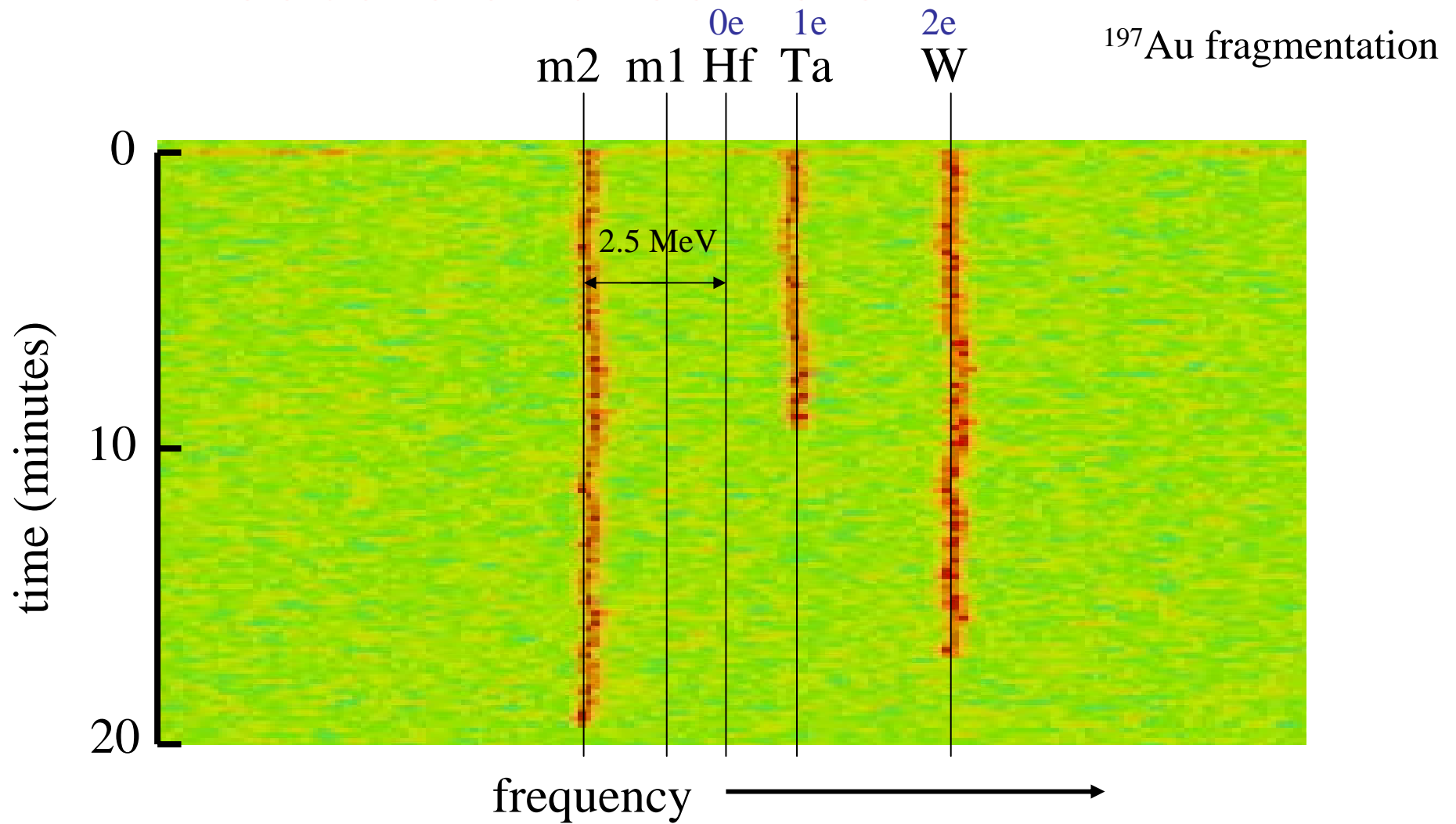
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^{197}Au fragmentation



A=184 (72⁺) isobars and isomers

2009
experiment



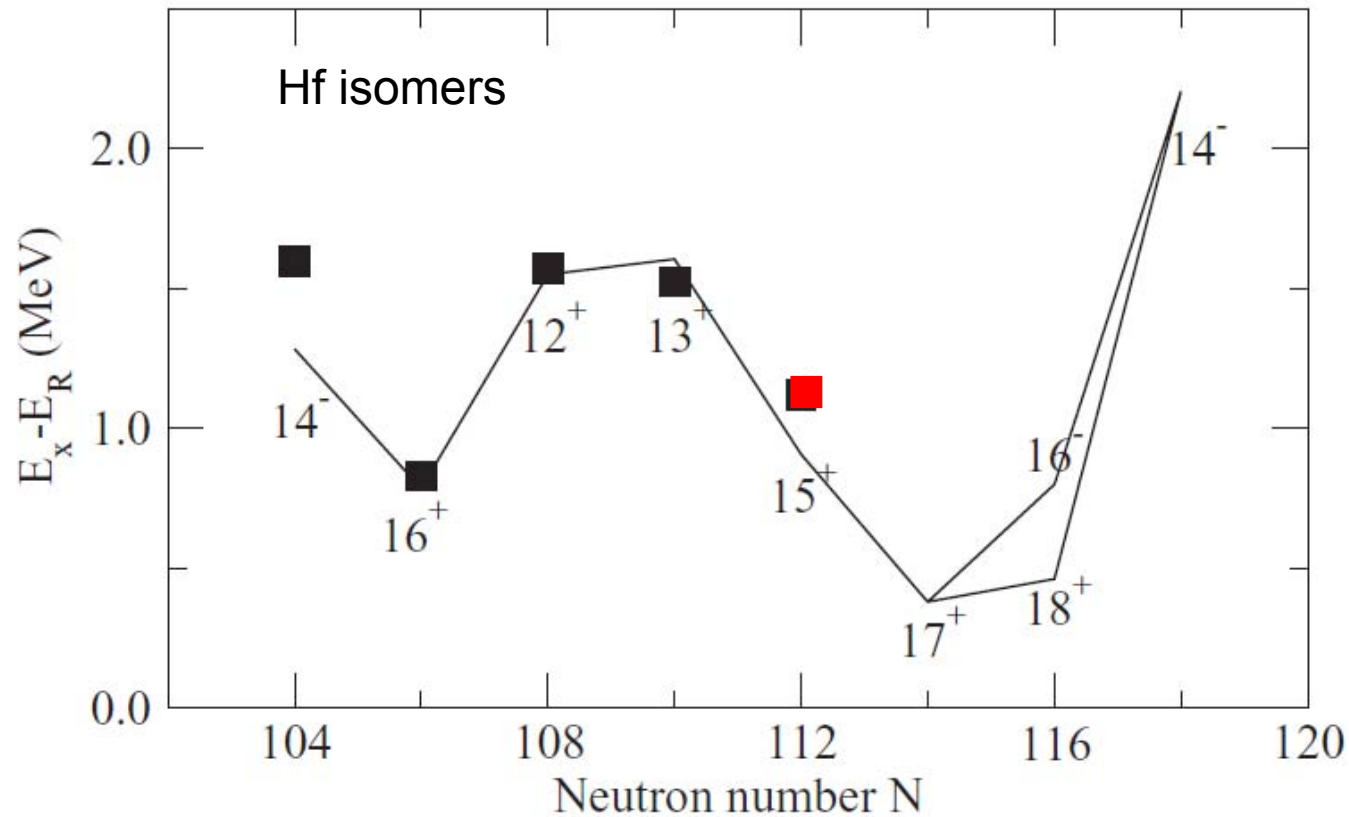
^{184}Hf isomers

	decay	$E_{\gamma\text{-spec}}^{\text{keV}}$	$E_{\text{ESR}}^{\text{keV}}$	$T_{1/2}(\text{exp})$
ground state (0^+)	β			4 h
isomer 1 (8^-)	$\gamma+\beta$	1272(1) ^a	1264(10)	48 s
isomer 2 (15^+)	β		2477(10)	12 min

^a Krumbholz et al., Z. Phys. A351 (1995) 11

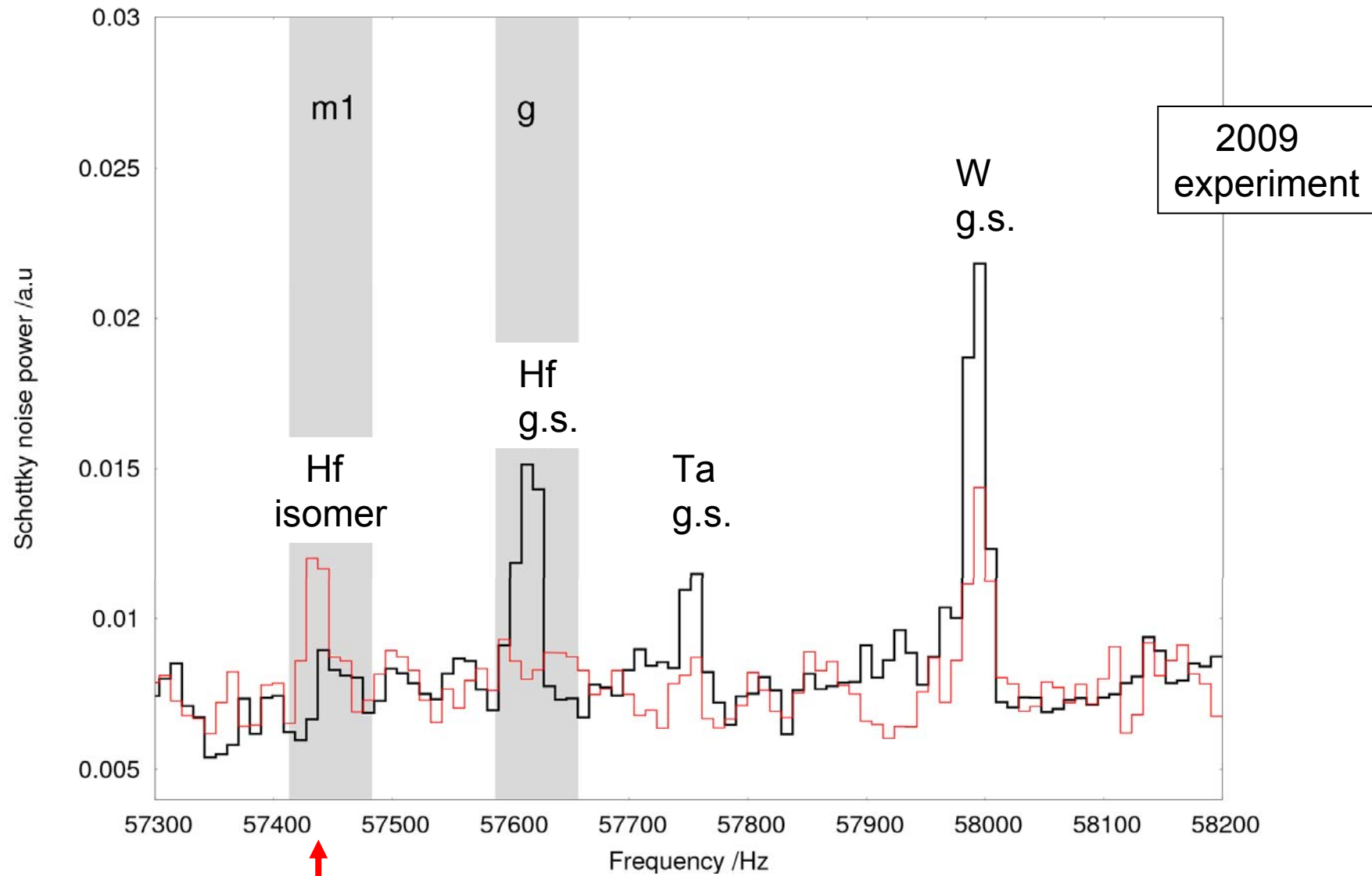
2009 ESR
experiment

Reed et al.
PRL105 (2010)
172501



Liu et al., Phys. Rev. C83 (2011) 067303

A=186 (72+) isobars and isomers



↑ only one ion of ^{186m}Hf seen

E109 experiment

^{208}Pb
beam

^{188}Hf	100 nb	15 shifts
^{186}Hf	560 nb	3 shifts
Setting up FRS and ESR (two settings)		3 shifts
Total beam time: 21 shifts		

^{197}Au
beam

Previous data: ^{184}Hf 550 nb 3 shifts
 ^{187}Ta 340 nb
 ^{186}Hf 34 nb (3 shifts)

2009
experiment