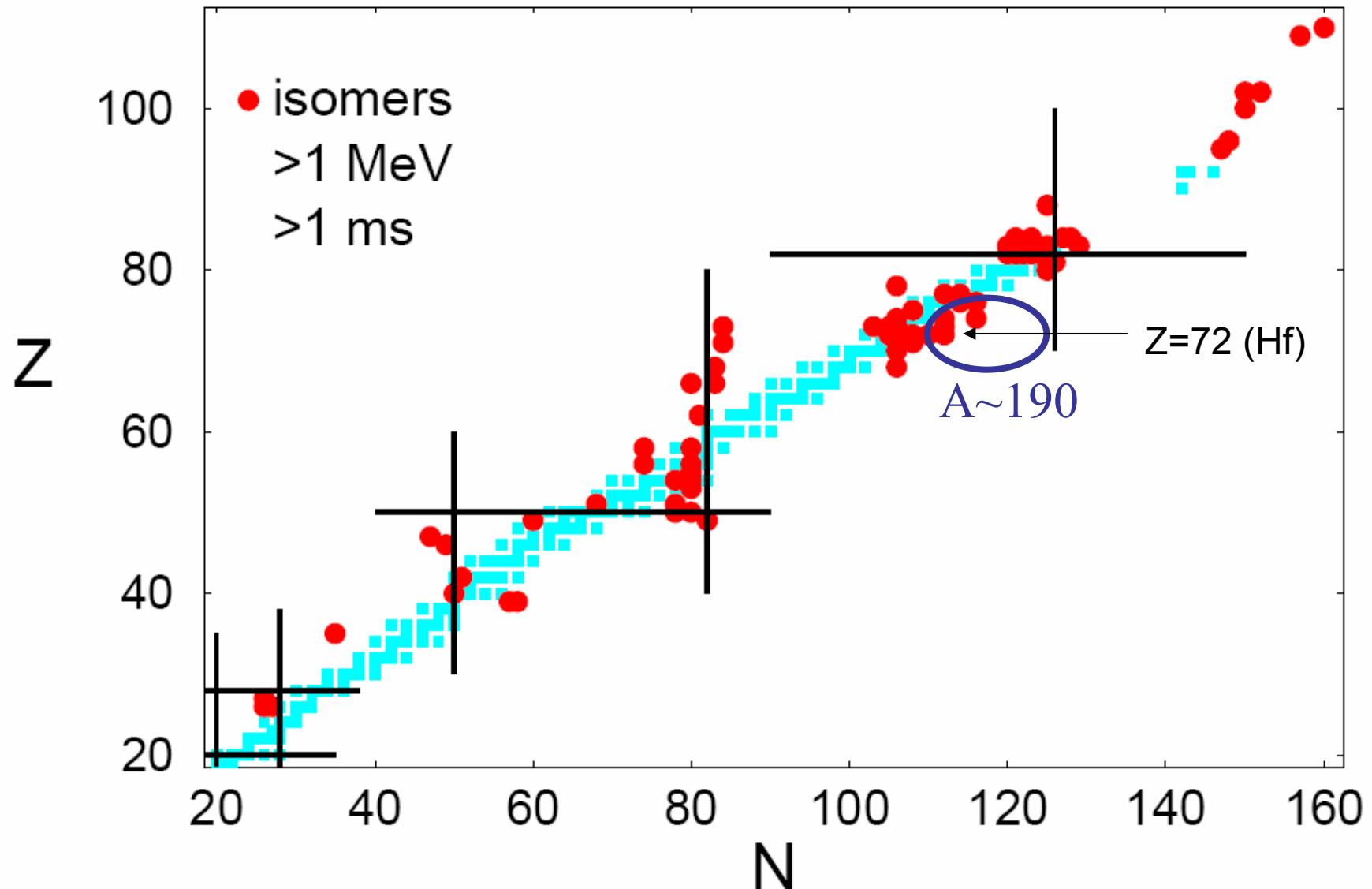


# **Long-lived isomers in neutron-rich hafnium isotopes: E109**

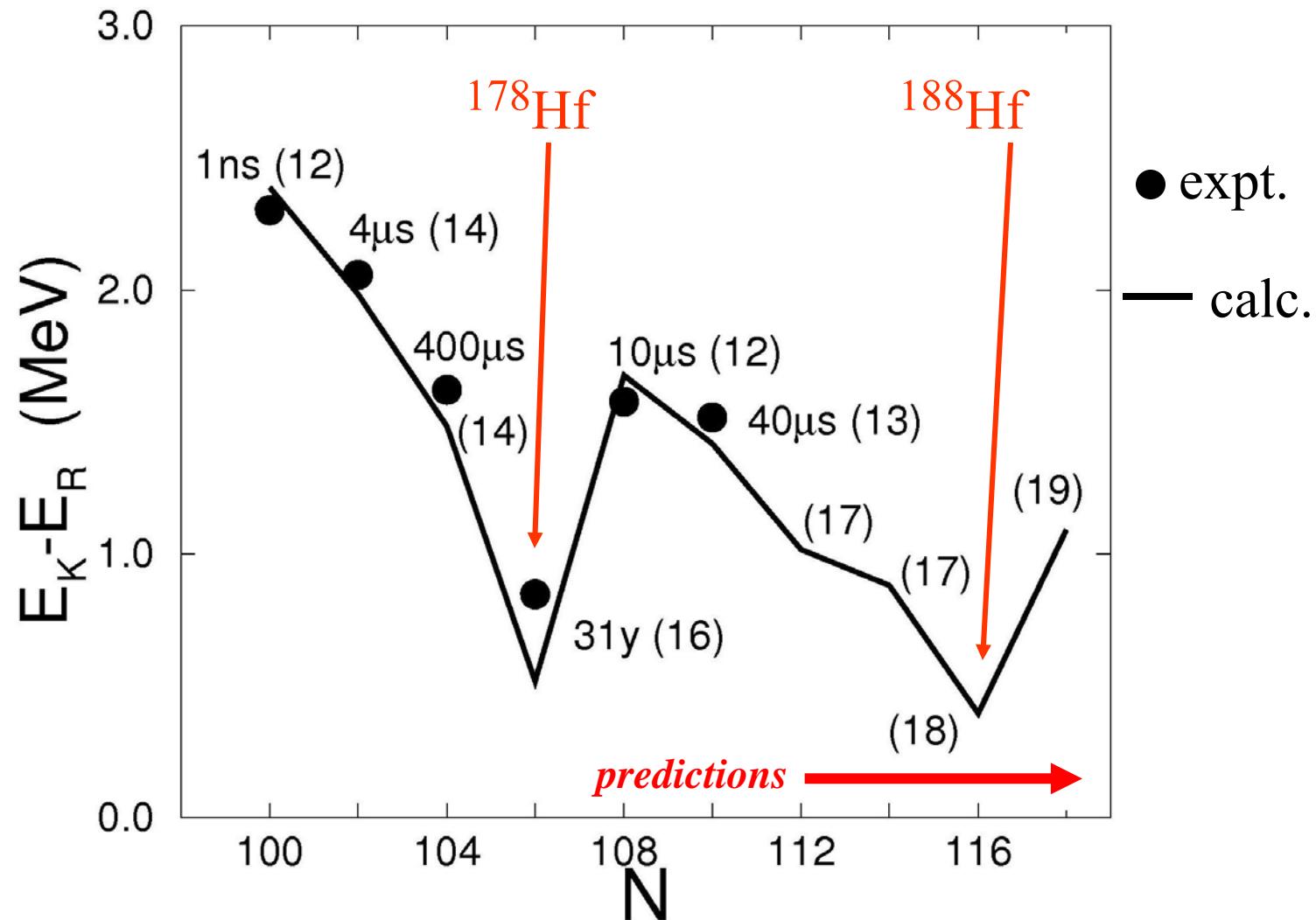
**P.M. Walker**, M.W. Reed, P.H. Regan, Z. Podolyak, R. Kempley (Surrey Univ.)  
F. Bosch, C. Brandau, H. Geissel, J. Gerl, M. Gorska, R. Knöbel, C. Kozhuharov,  
C. Scheidenberger, M. Steck, B. Sun, H. Weick, M. Winkler, N. Winckler,  
H-J. Wollersheim (GSI)  
K. Blaum, Y.A. Litvinov (MPI Heidelberg)  
W.R. Plass (Giessen Univ.)  
J.J. Carroll (Youngstown State Univ.)  
D.M. Cullen (Manchester Univ.)  
G.D. Dracoulis, G.J. Lane (Australian National Univ.)  
R. Mao, X. Ma, H. Xu (IMPCAS, Lanzhou)  
P.J. Woods, Z. Liu (Edinburgh Univ.)  
T. Yamaguchi (Saitama Univ.)  
T. Ohtsubo (Niigata Univ.)

# Nuclear chart with isomers



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

# hafnium ( $Z=72$ ) 4-quasiparticle isomers

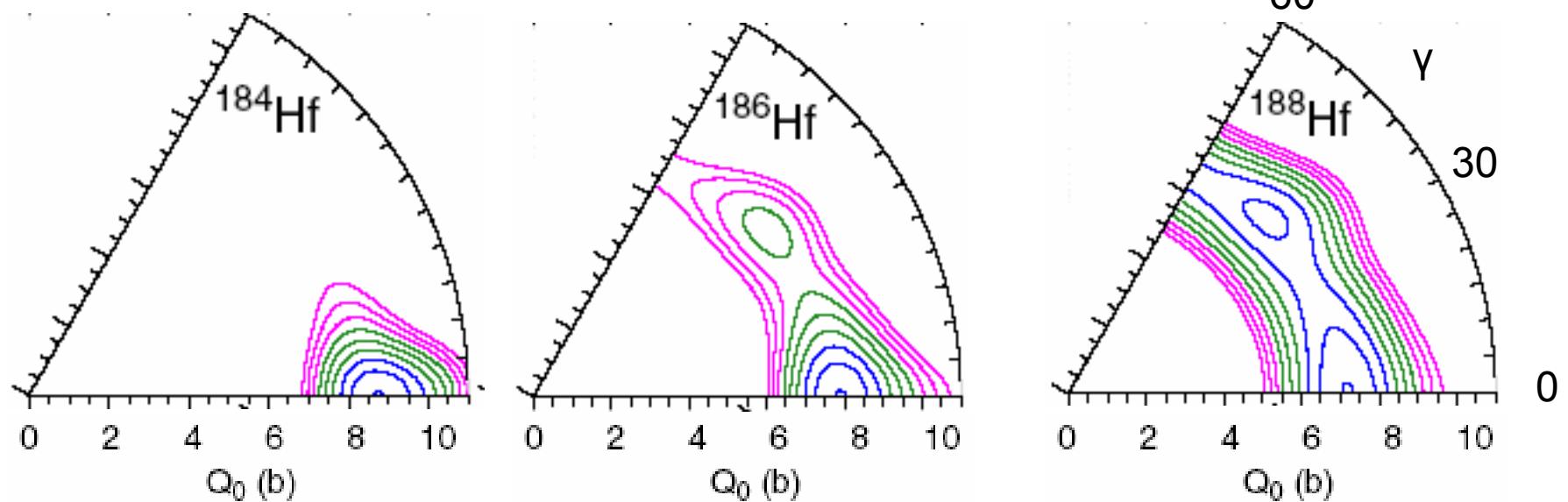


Walker and Dracoulis, Nature 399 (1999) 35; Hyp. Int. 135 (2001) 83

# prolate-oblate shape transition

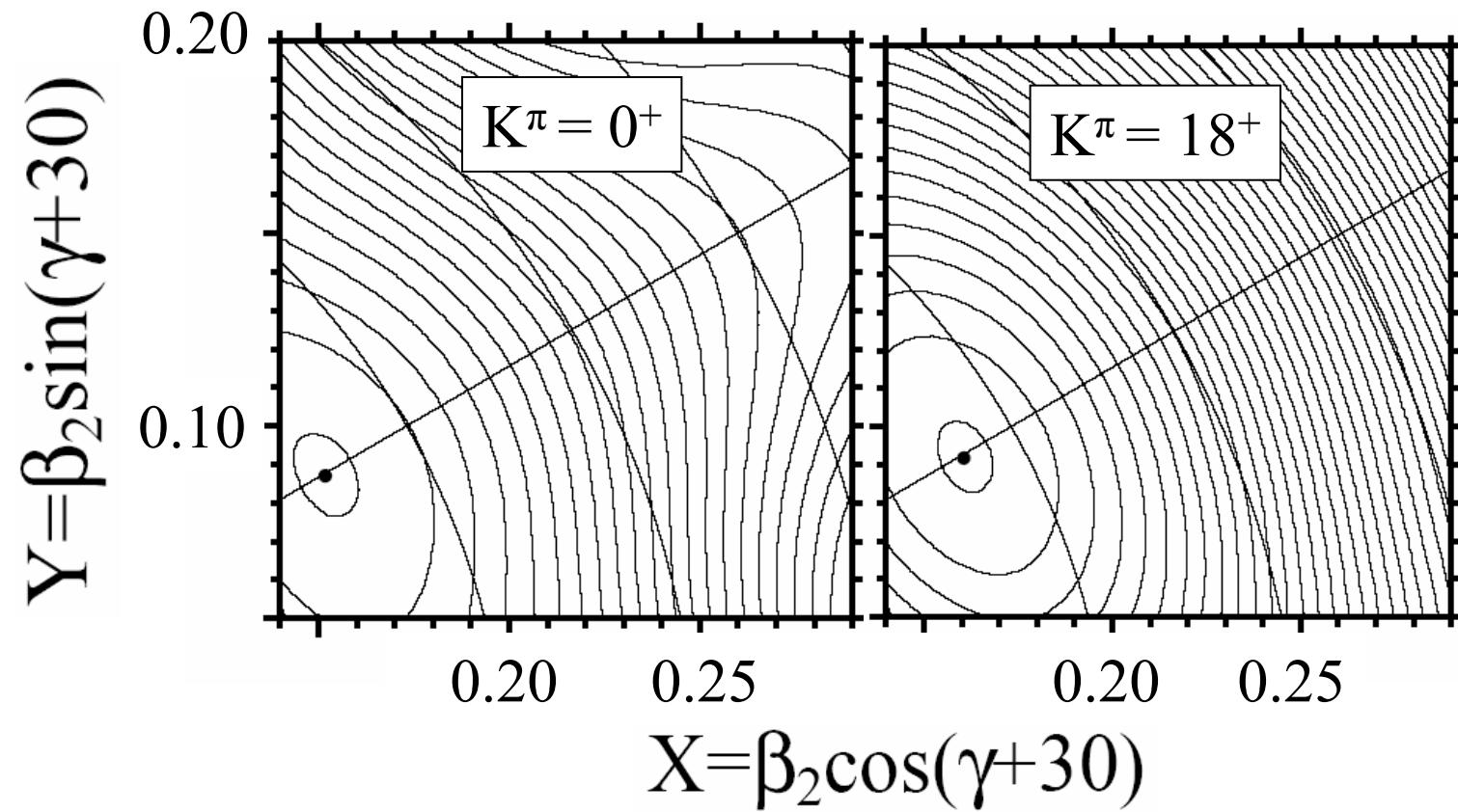
n-rich hafnium ground states

HFB + SLy4



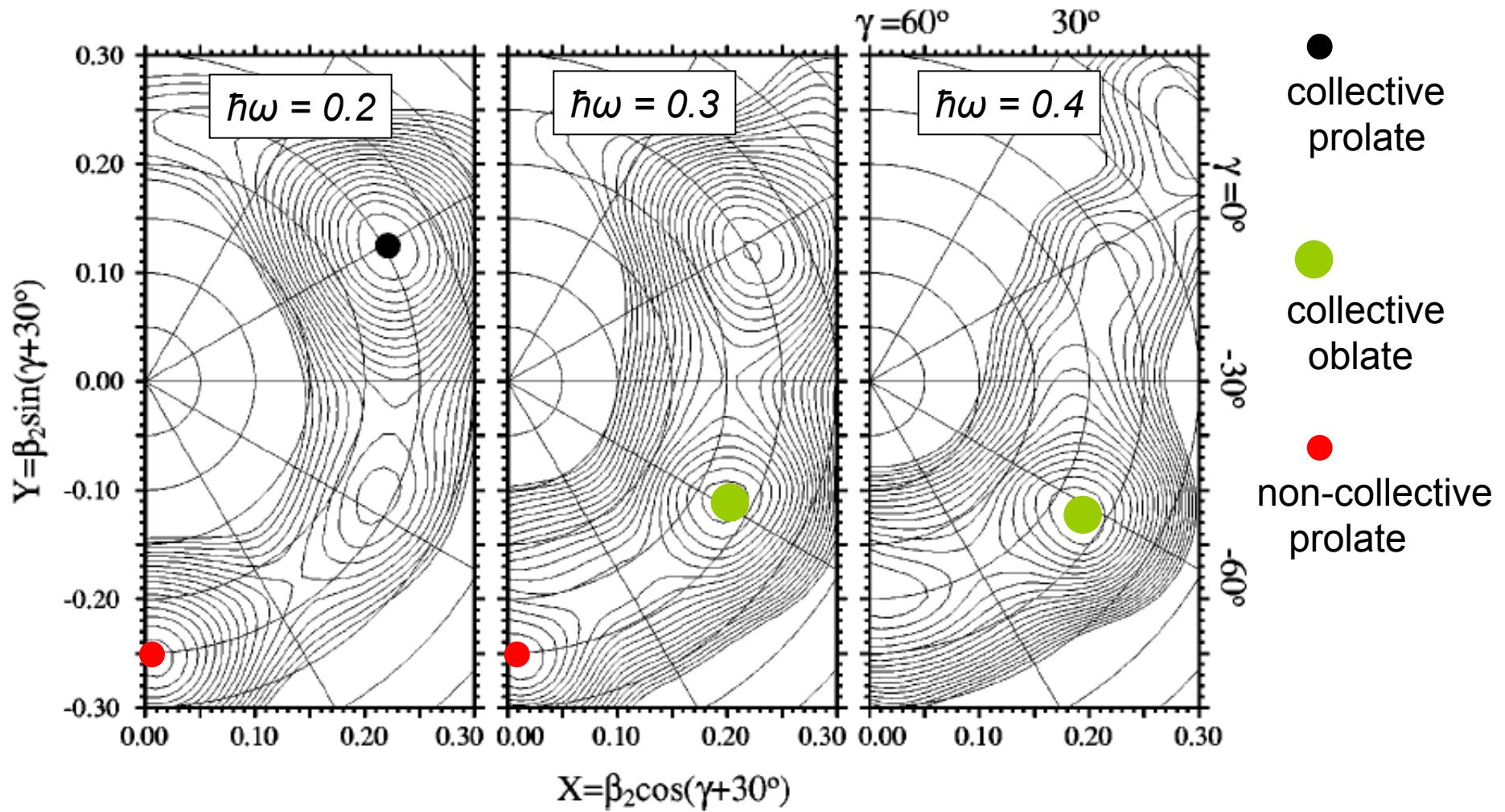
Robledo et al., *J. Phys. G: Nucl. Part. Phys.* **36**, 115104 (2009).

# $^{188}\text{Hf}$ shape from configuration-constrained TRS calculations



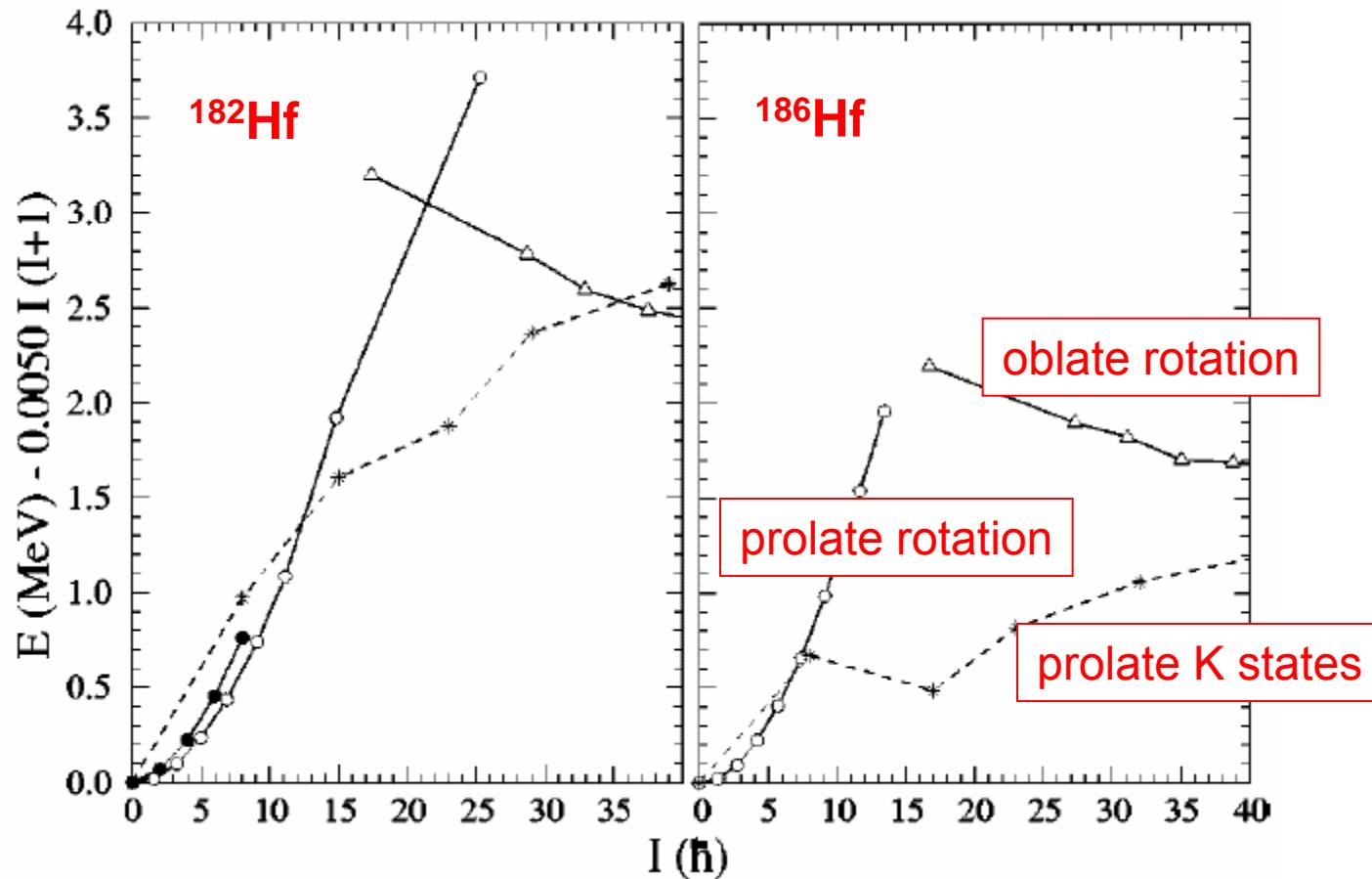
Xu, Walker and Wyss, Phys. Rev. C62 (2000) 014301

## cranked n-rich hafnium: 3 well-deformed minima



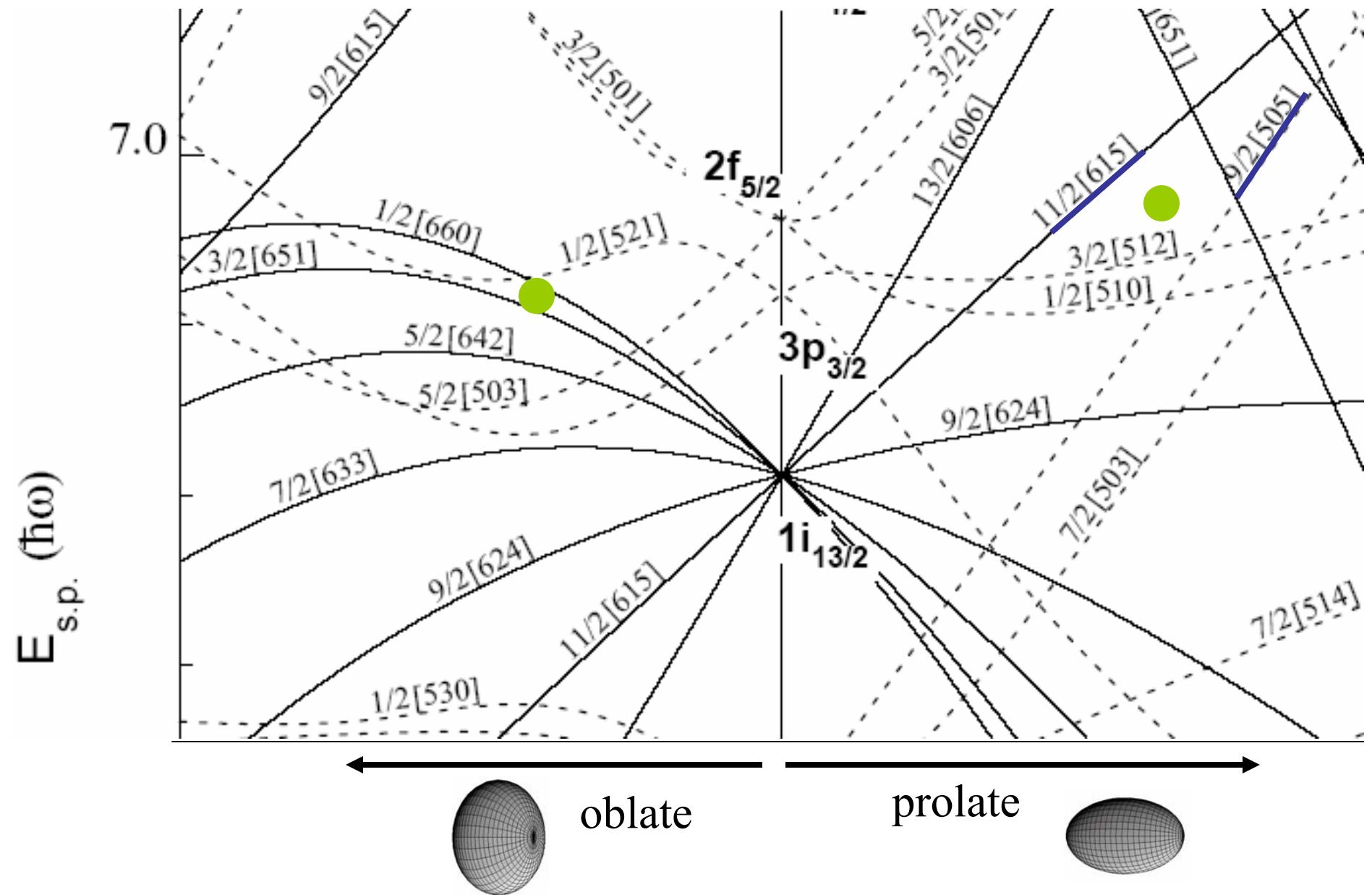
$^{182}\text{Hf}$  example: Xu, Walker and Wyss, Phys. Rev. C62 (2000) 014301

# prolate-oblate shape transition



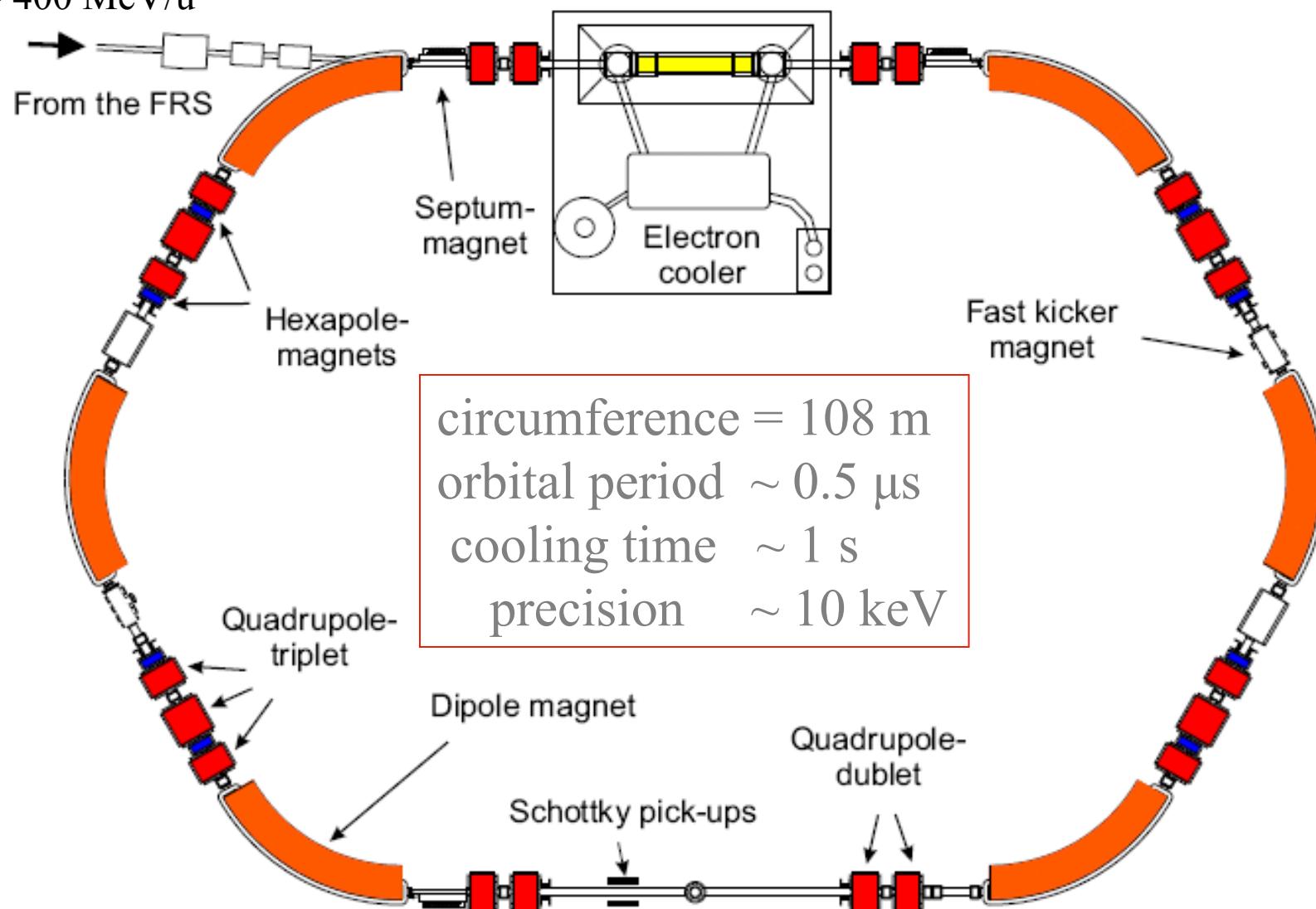
Xu, Walker and Wyss, Phys. Rev. C62 (2000) 014301

# Nilsson single-particle diagram



# Experimental Storage Ring

ions  $\sim 400$  MeV/u



# 197Au fragmentation

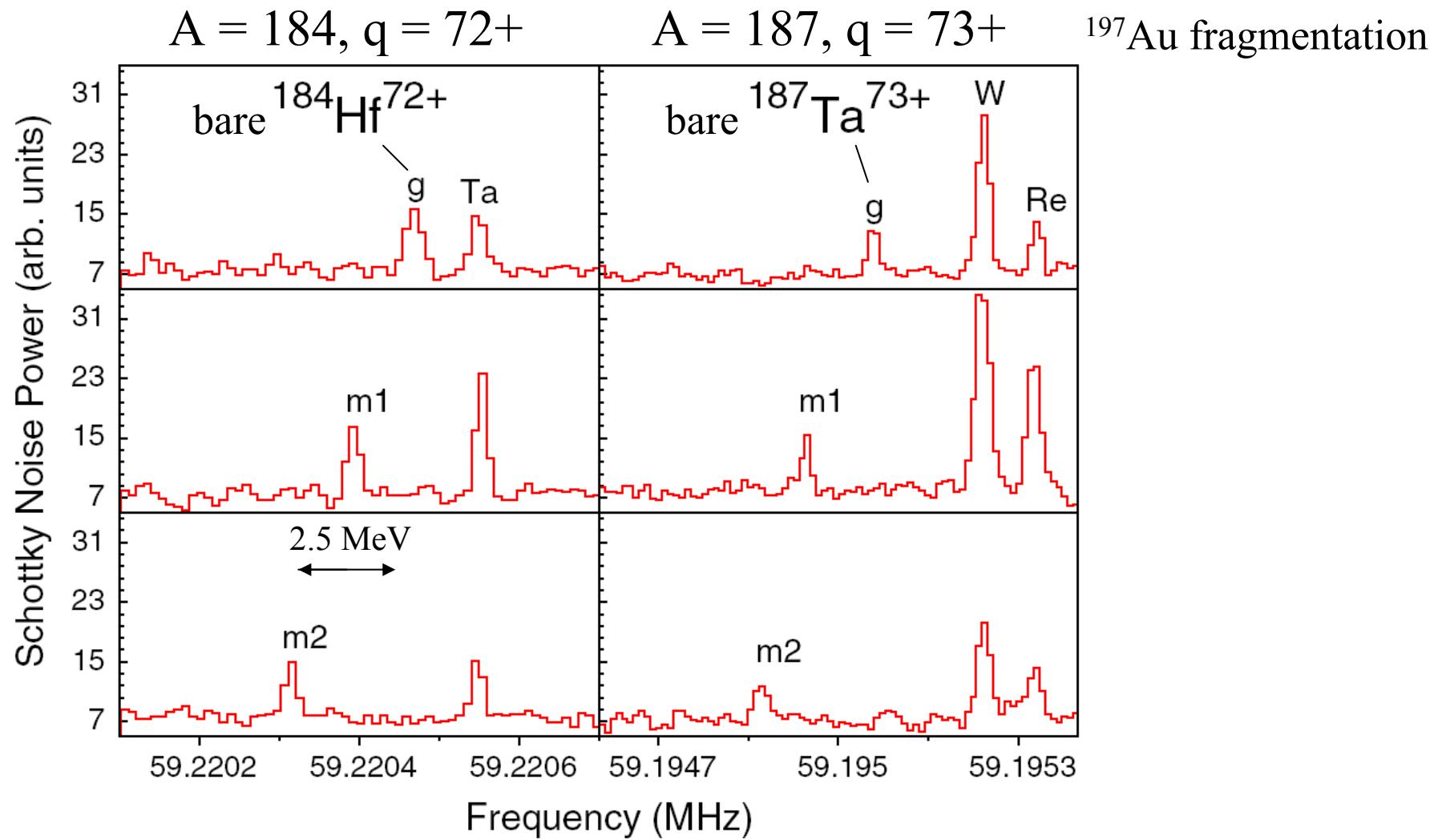
2009  
experiment

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

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

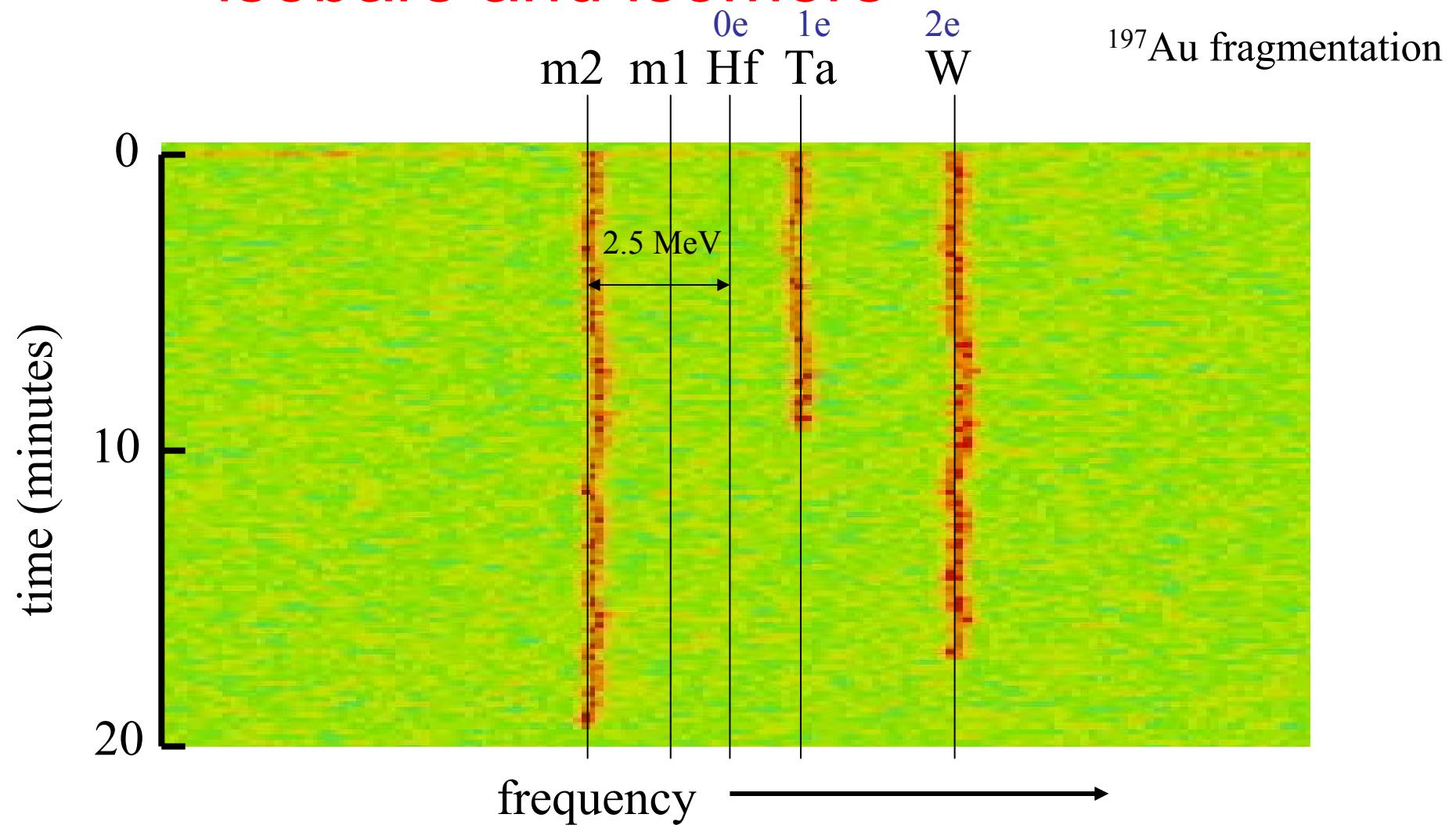
# new isomers in the ESR 10-second snapshots

2009  
experiment



# A=184 (72<sup>+</sup>) isobars and isomers

2009  
experiment

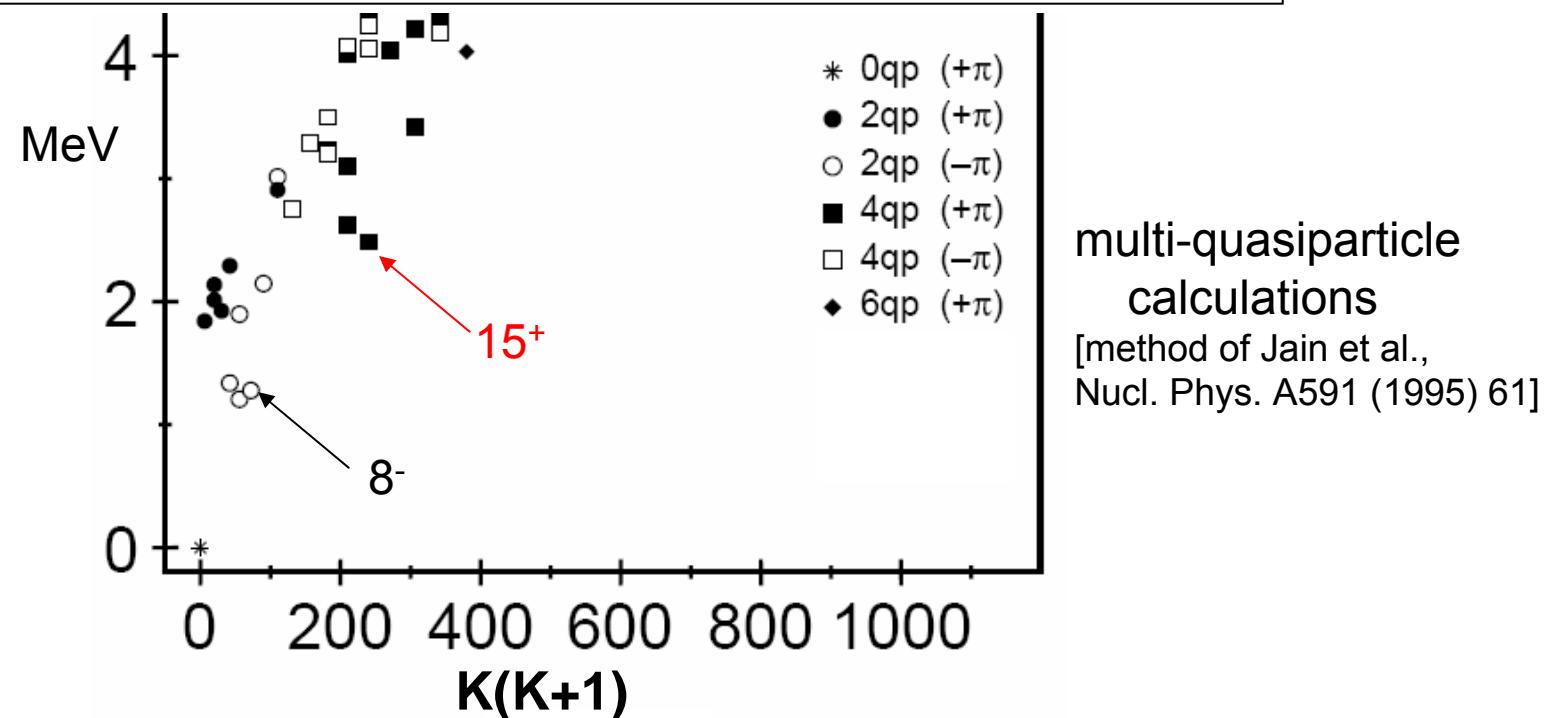


# $^{184}\text{Hf}$ isomers

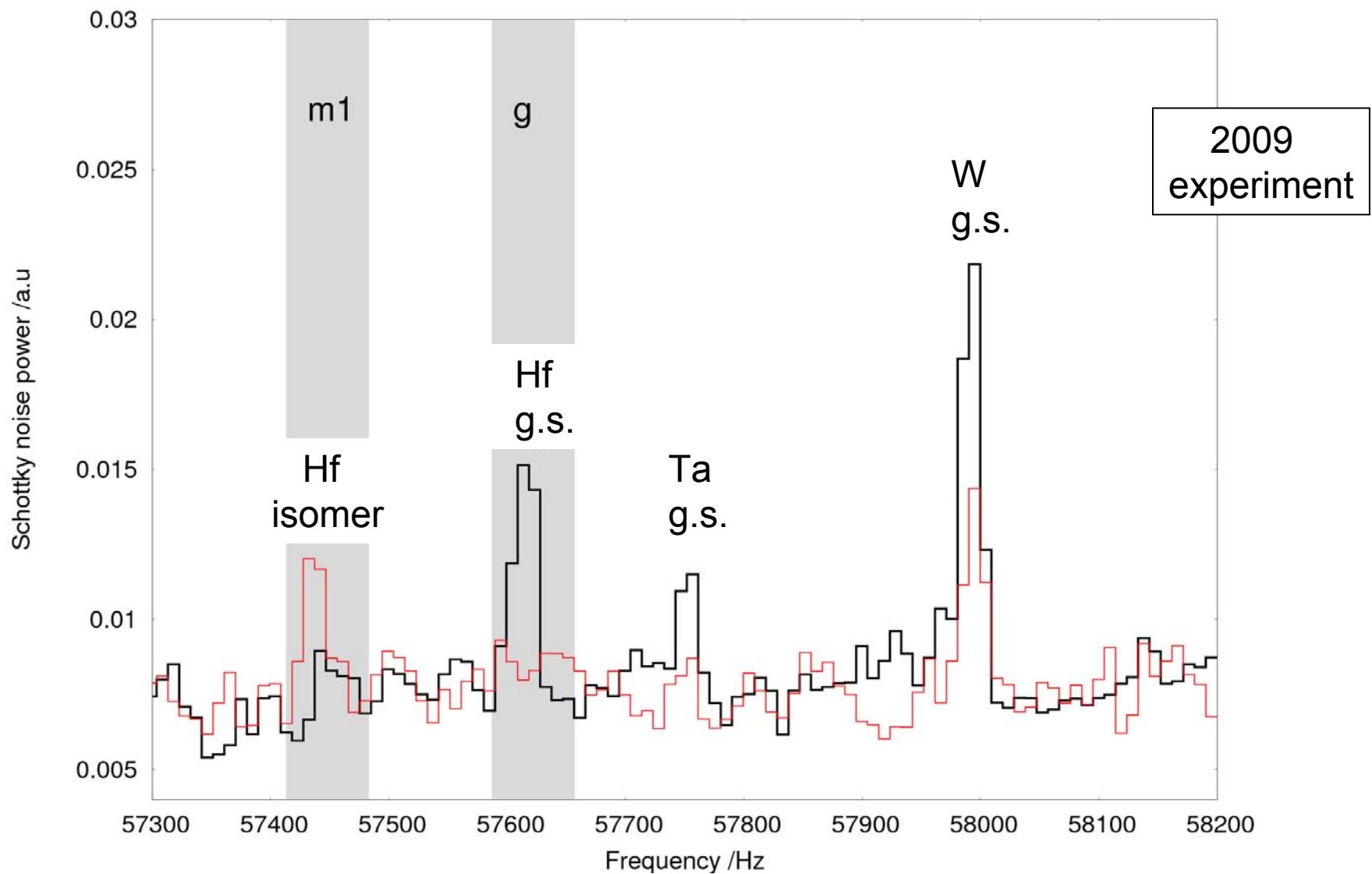
2009  
experiment

	decay	$E_{\gamma\text{-spec}}$ keV	$E_{\text{ESR}}$ keV	$E_{\text{calc}}$ keV	$T_{1/2}(\text{exp})$
ground state ( $0^+$ )	$\beta$				4 h
isomer 1 ( $8^-$ )	$\gamma$	1272(1) <sup>a</sup>	1264(10)	1241	48 s
isomer 2 ( $15^+$ )	$\beta$		2477(10)	2369	12 m

<sup>a</sup> Krumbholz et al., Z. Phys. A351 (1995) 11



# A=186 (72+) isobars and isomers



# E109 beam-time allocation

$^{208}\text{Pb}$   
beam

$^{188}\text{Hf}$

100 nb

15 shifts

$^{186}\text{Hf}$

560 nb

3 shifts

Setting up FRS and ESR (two settings)

3 shifts

**Total beam time: 21 shifts**

Surrey PhD student is waiting for the data

---

$^{197}\text{Au}$   
beam

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

2009  
experiment