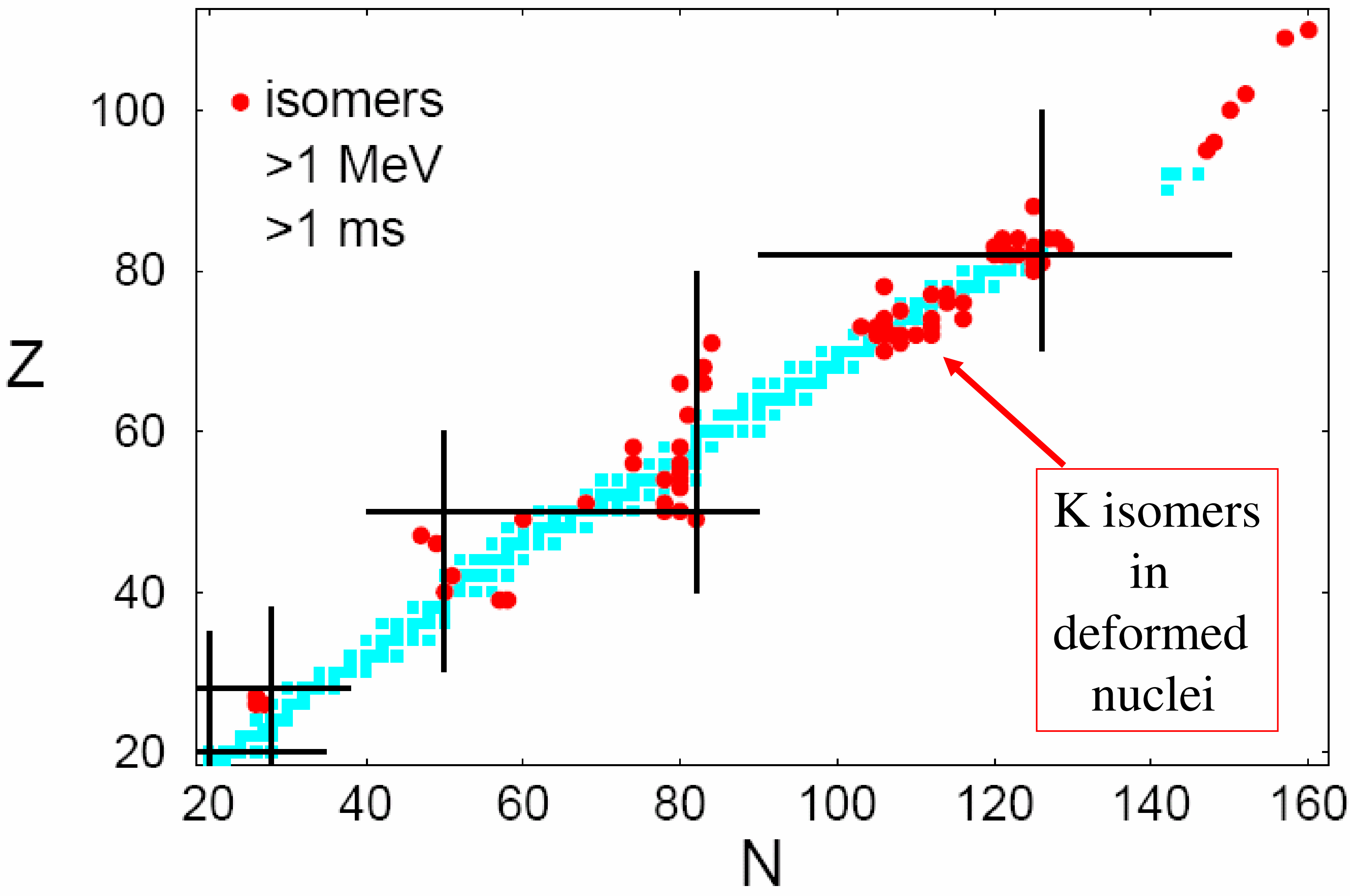
UNIVERSITY OF SURREY

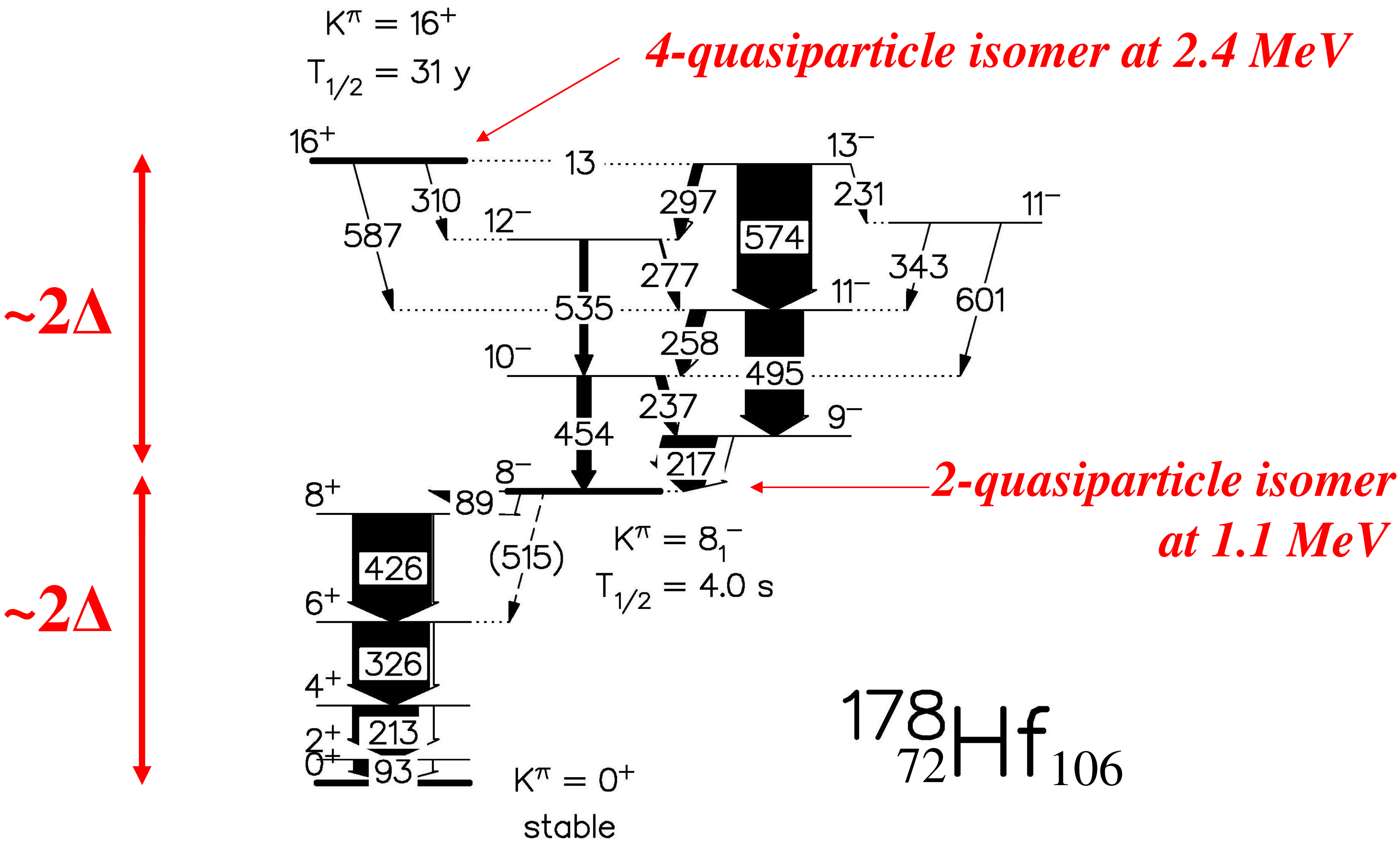
K-isomer decay rates

Phil Walker

- introduction
- exploring the different degrees of freedom
- exotic nuclei

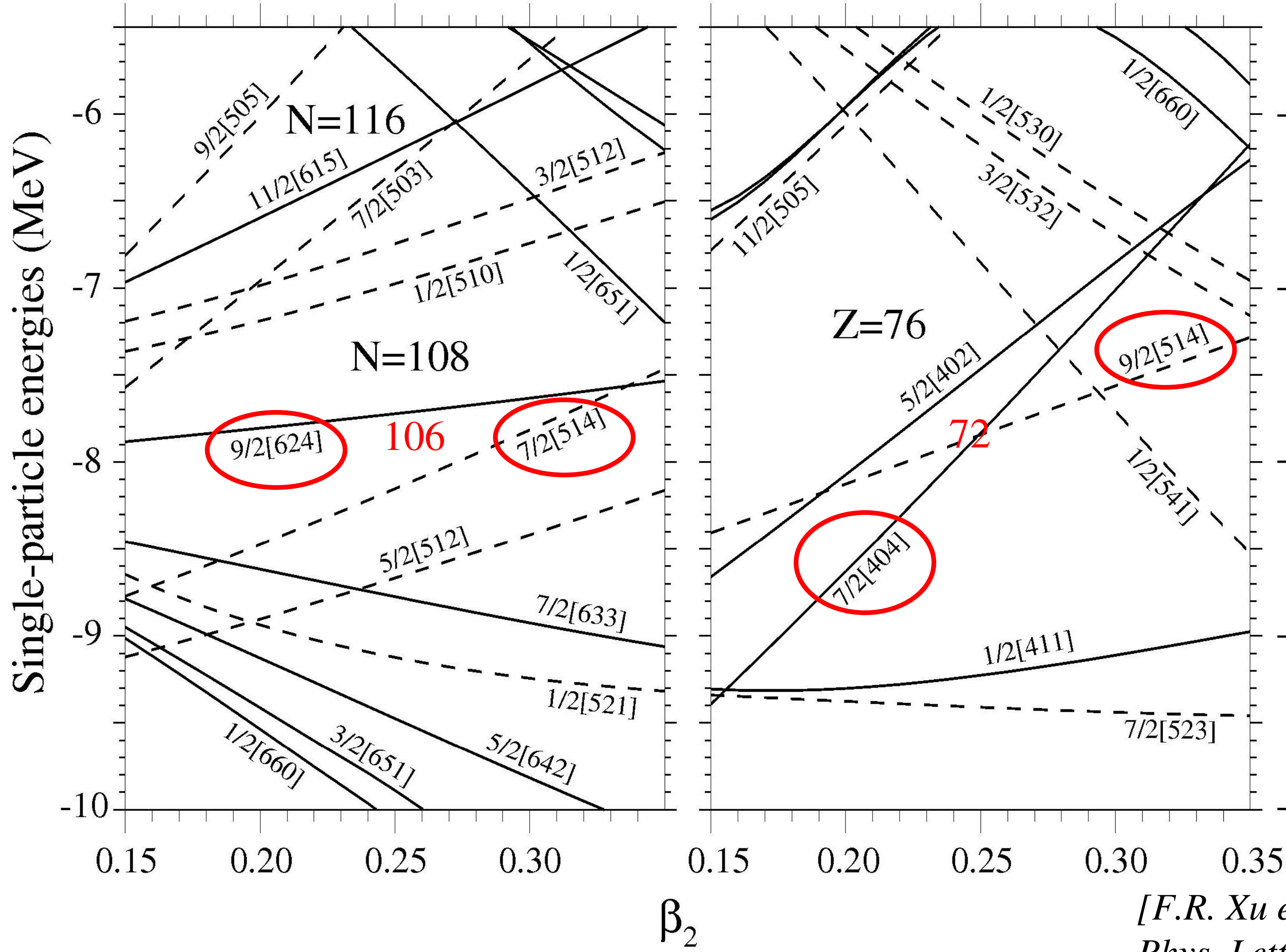


adapted from Walker and Dracoulis, Nature 399 (1999) 35



[Smith et al., Phys. Rev. C68 (2003) 031302(R)]

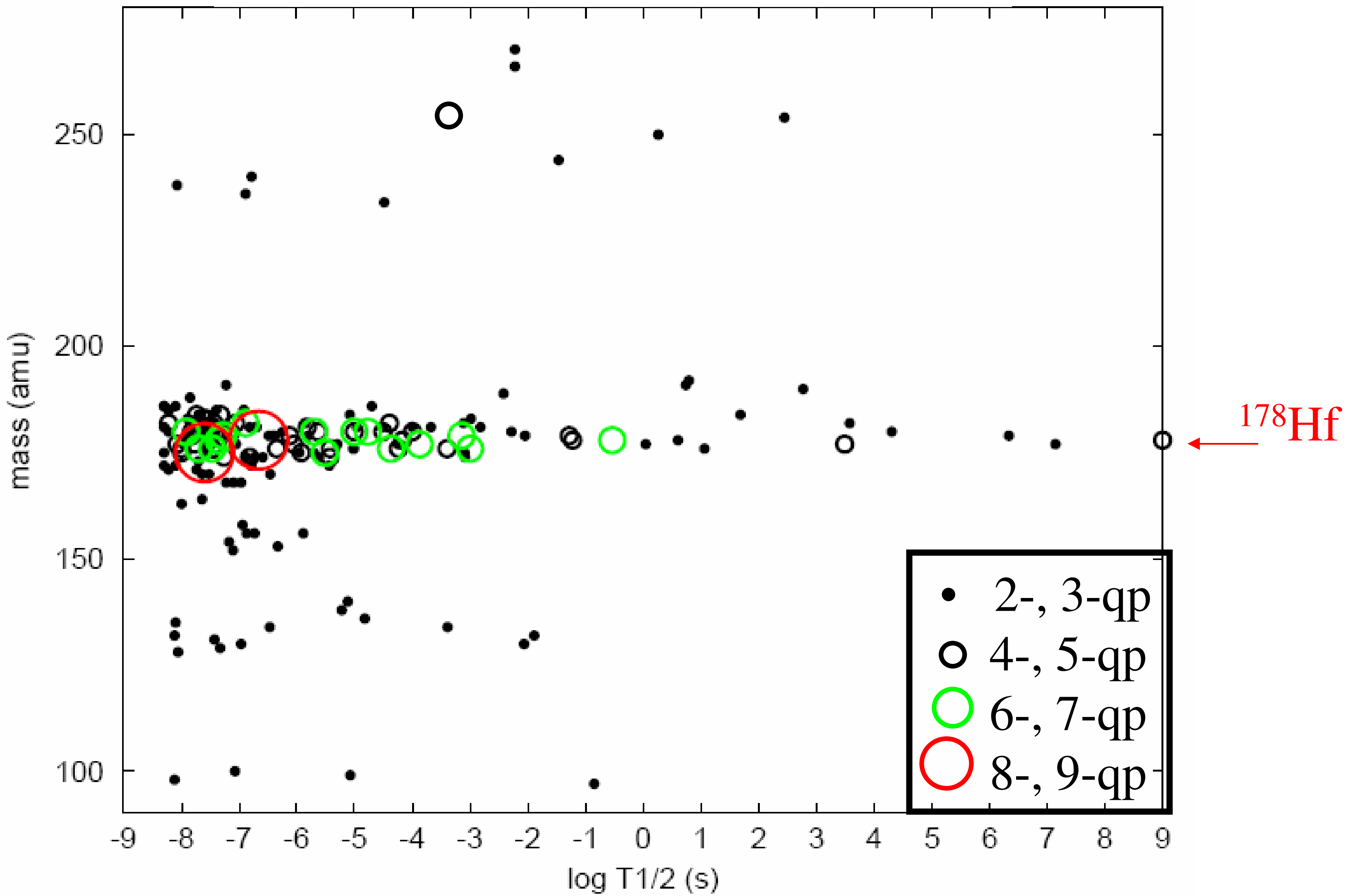
^{178}Hf has N=106, Z=72, β_2~0.25



Woods-Saxon potential

[F.R. Xu et al., Phys. Lett. B435 (1998) 257]

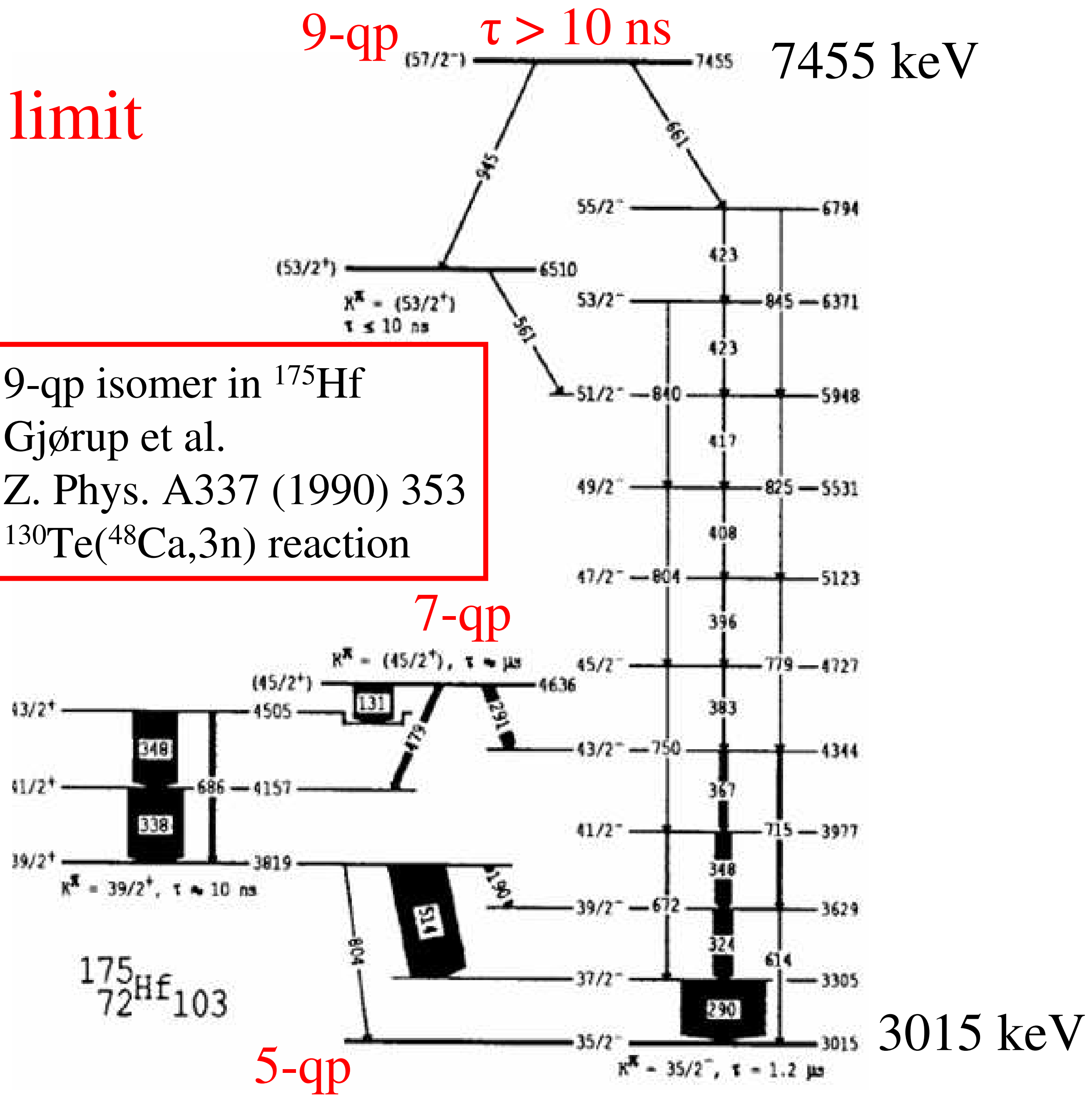
multi-quasiparticle K isomers > 5ns



excludes 2-qp isomers in odd-odd nuclei

Walker, AIP-CP819 (2006) 16

K-isomer energy/spin limit



9-qp isomer in ^{175}Hf
Gjørup et al.
Z. Phys. A337 (1990) 353
^{130}Te(^{48}Ca,3n) reaction

K isomers

- structure
- energies
- transition rates?

deformed shell model

transition-rate hindrance factors

$$F_W = T^{\gamma}_{1/2}/T^{W}_{1/2}$$ *Weisskopf hindrance*

$$\nu = \Delta K - \lambda$$ *degree of K forbiddenness*

$$f_\nu = (F_W)^{1/\nu}$$ *reduced hindrance*

(hindrance per degree of K forbiddenness)

contains the physics

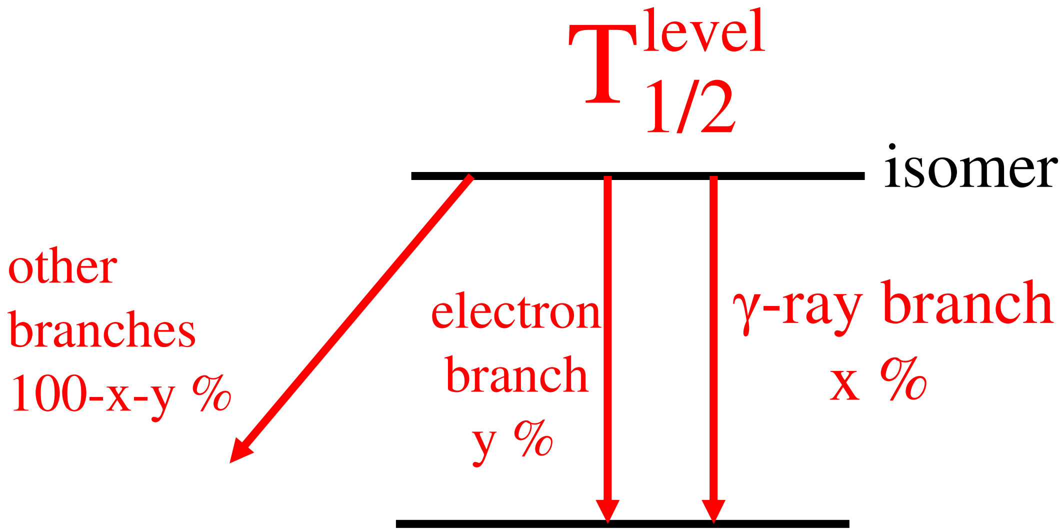
Weisskopf transition rates

Weisskopf single-particle half-lives[a]

Electric dipole (E1)	$T_{1/2}^{W} = 6.76 \times 10^{-6} E^{-3} A^{-2/3}$
Magnetic dipole (M1)	$T_{1/2}^{W} = 2.20 \times 10^{-5} E^{-3}$
Electric quadrupole (E2)	$T_{1/2}^{W} = 9.52 \times 10^{6} E^{-5} A^{-4/3}$
Magnetic quadrupole (M2)	$T_{1/2}^{W} = 3.10 \times 10^{7} E^{-5} A^{-2/3}$

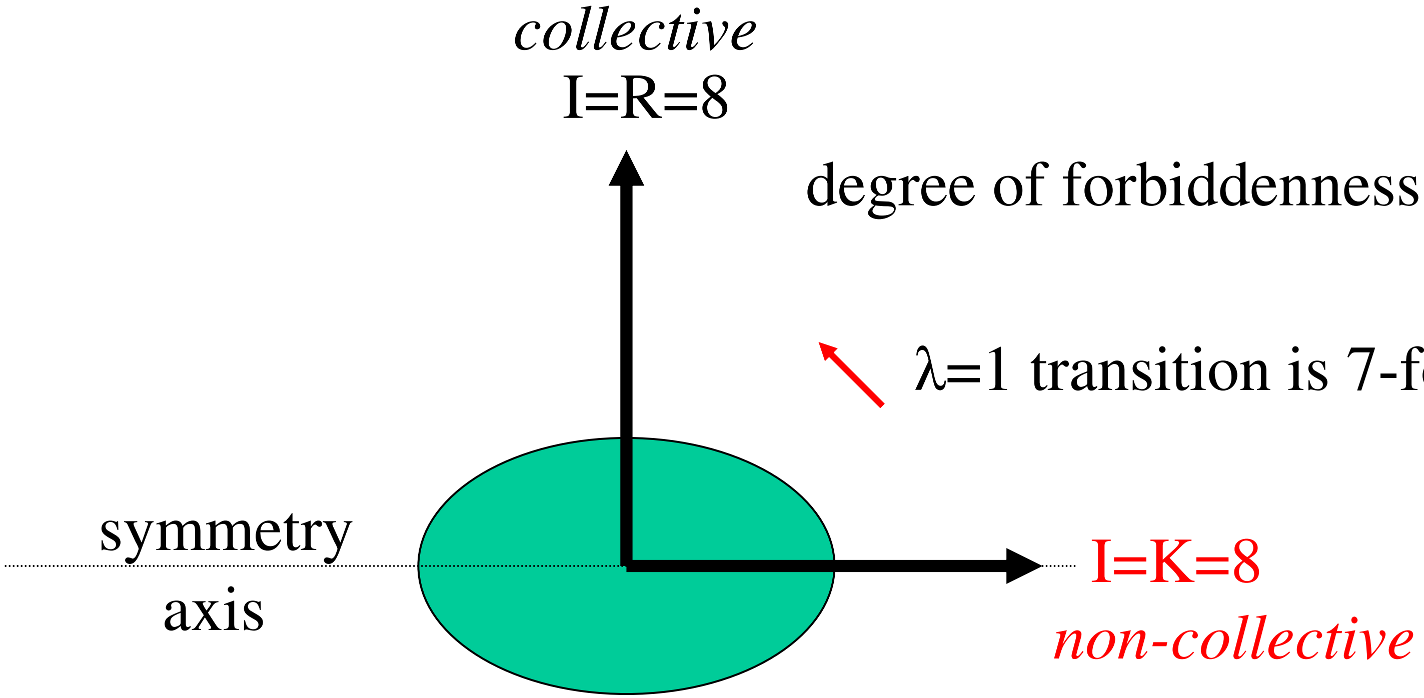
[a] For transition energies (E) in keV, the half-lives are in seconds

partial γ-ray half-life: $T_{1/2}^{\gamma}$



$$T_{1/2}^{\gamma} = T_{1/2}^{level} \cdot 100/x$$

K-forbidden γ-ray transitions

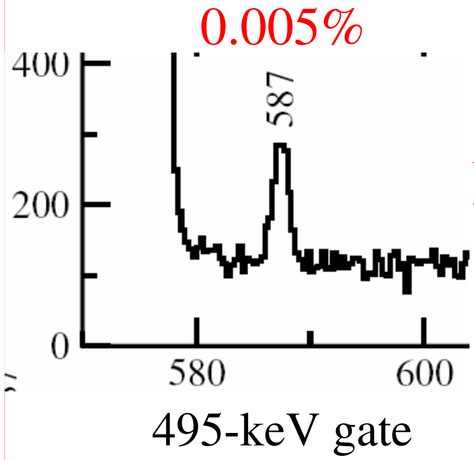


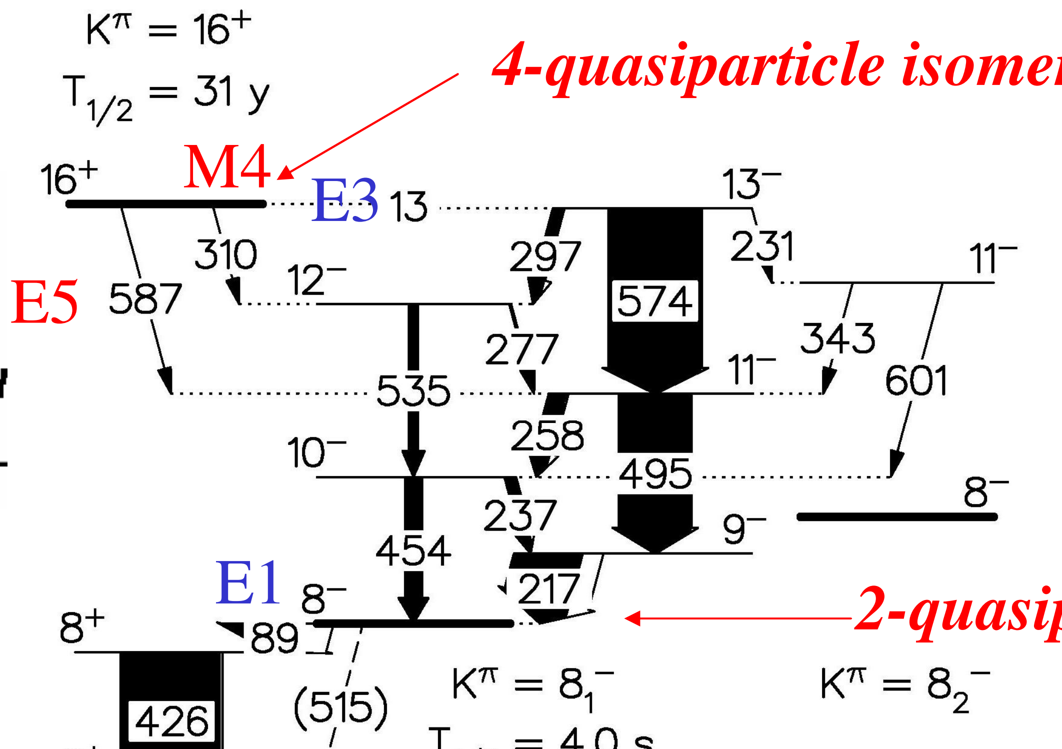
degree of forbiddenness, $\nu = \Delta K - \lambda$

λ=1 transition is 7-fold forbidden

($\nu = 7$)

angular momentum has both magnitude and direction!

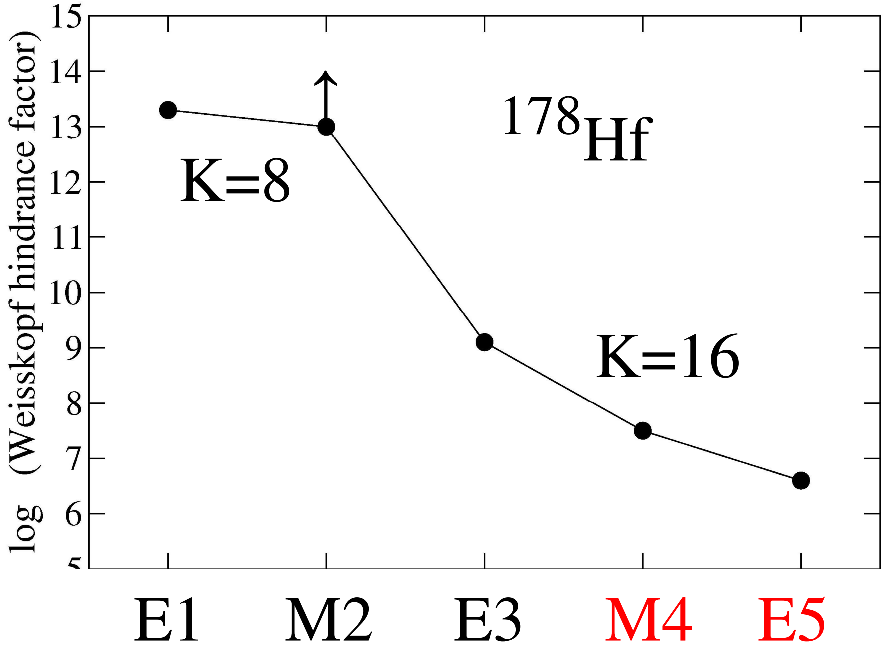




$^{178}_{72}$Hf

data from the 8π spectrometer at TRIUMF

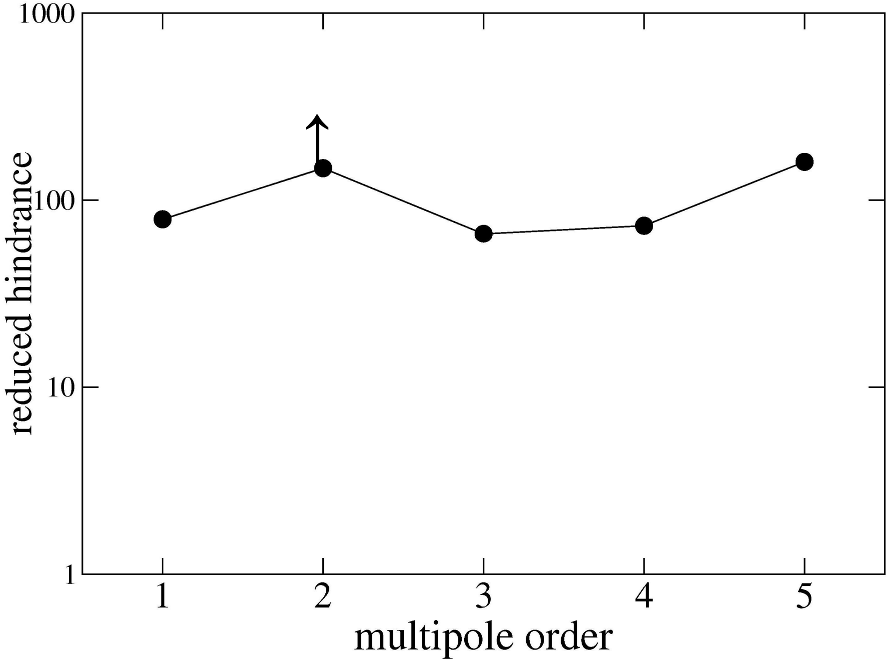
[Smith et al., Phys. Rev. C68 (2003) 031302(R)]



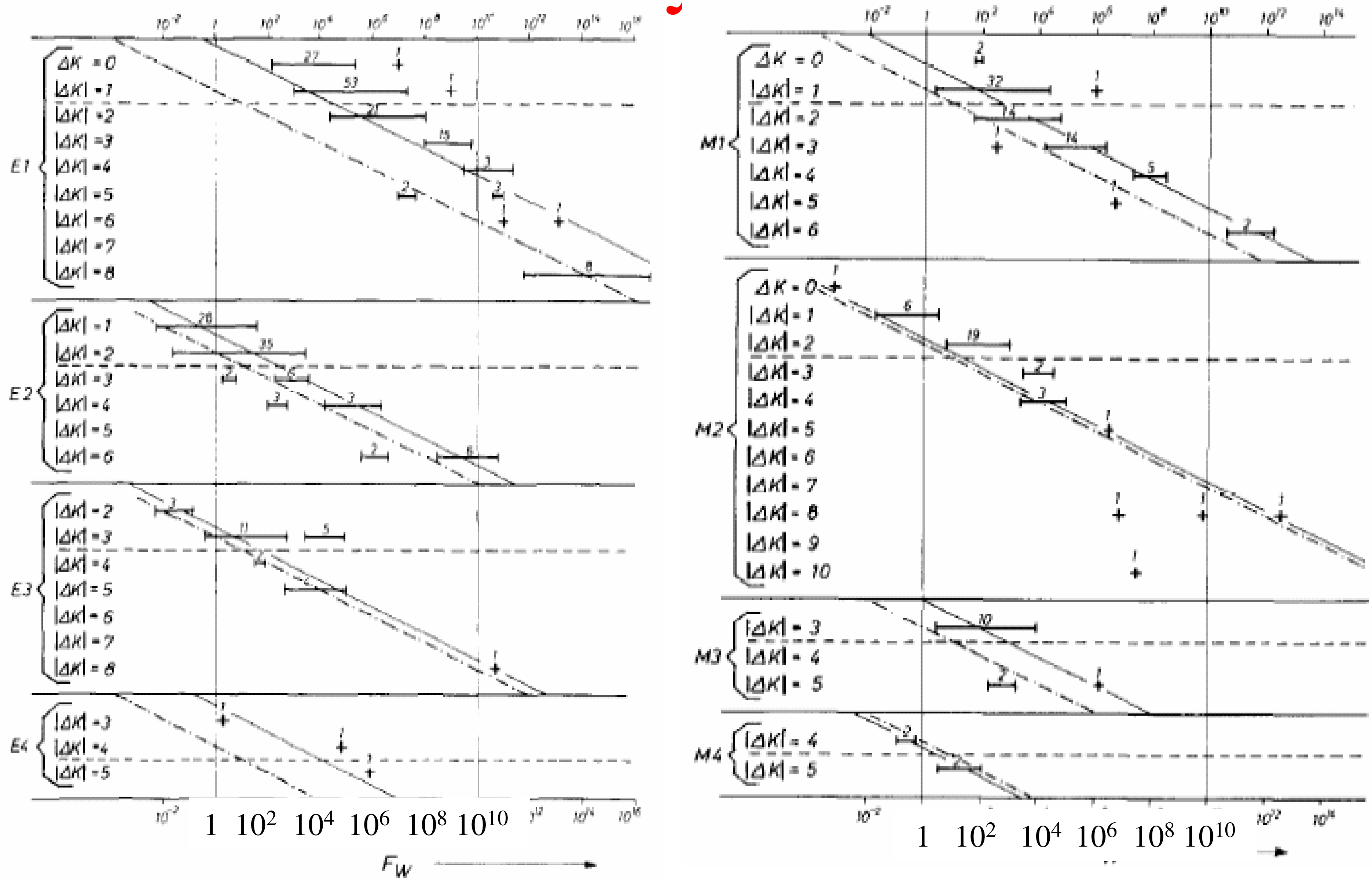
$$F_W = T^{\gamma}_{1/2} / T^{W}_{1/2}$$

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

$$f_{\nu} = (F_W)^{1/\nu}$$

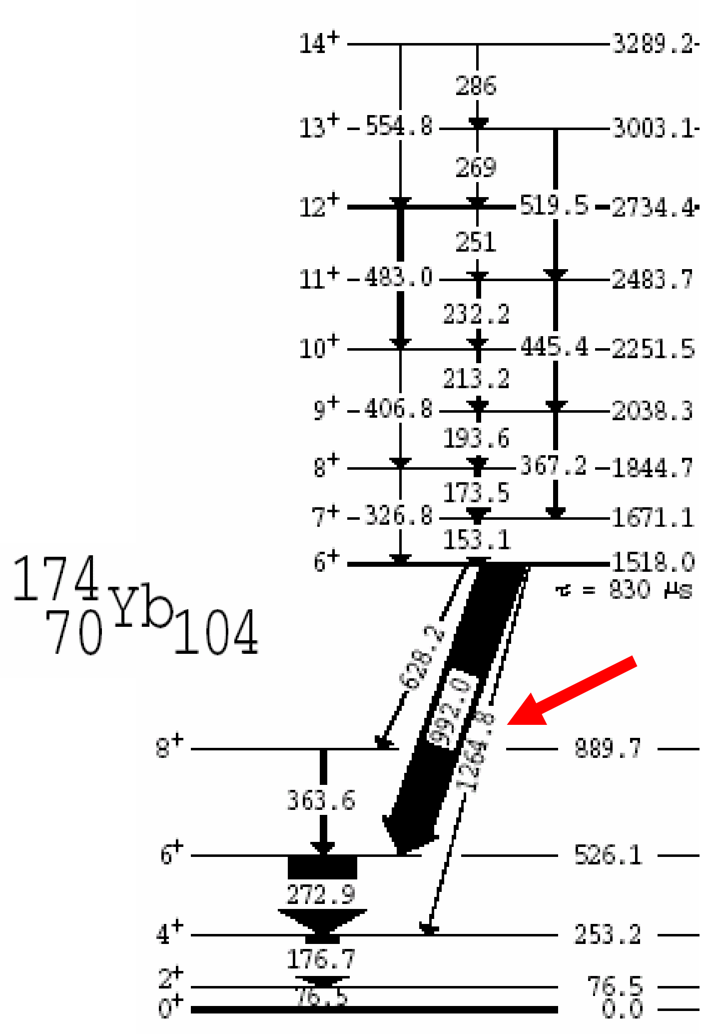


Löbner systematics

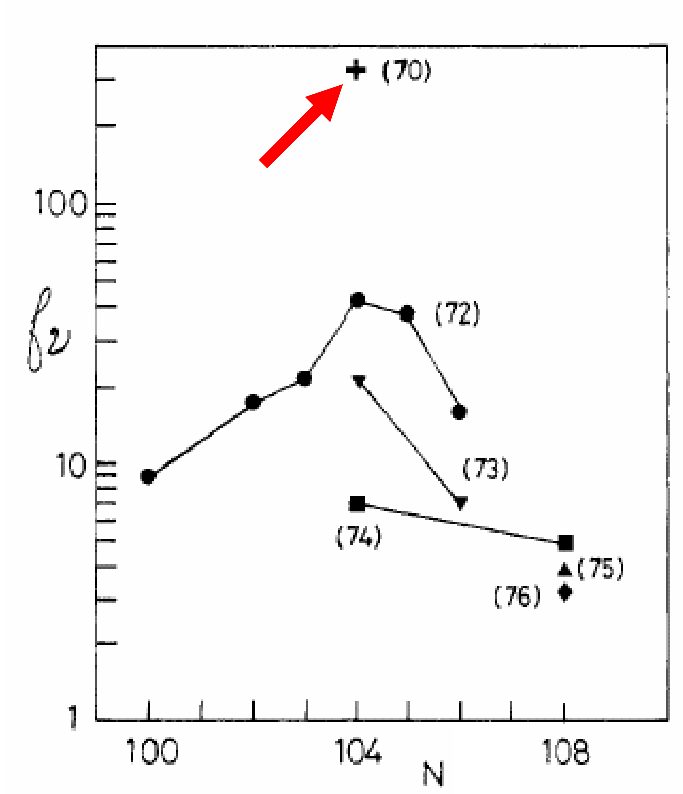


Löbner, Phys. Lett. B26 (1968) 369

2- and 3-qp E2 reduced hindrances

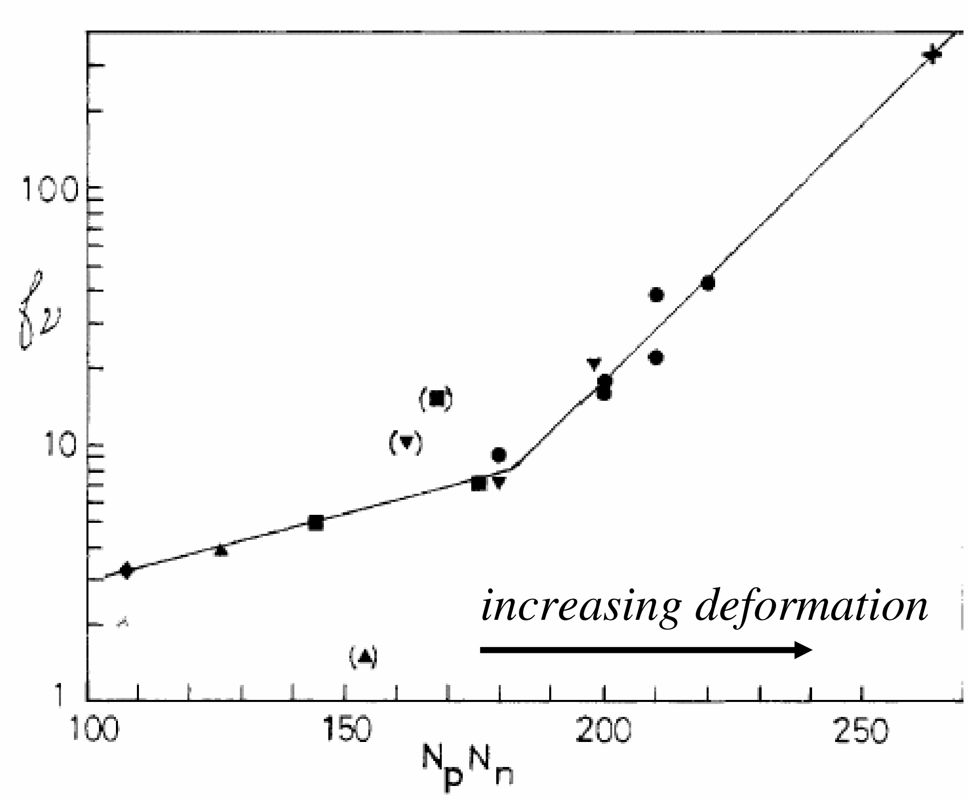


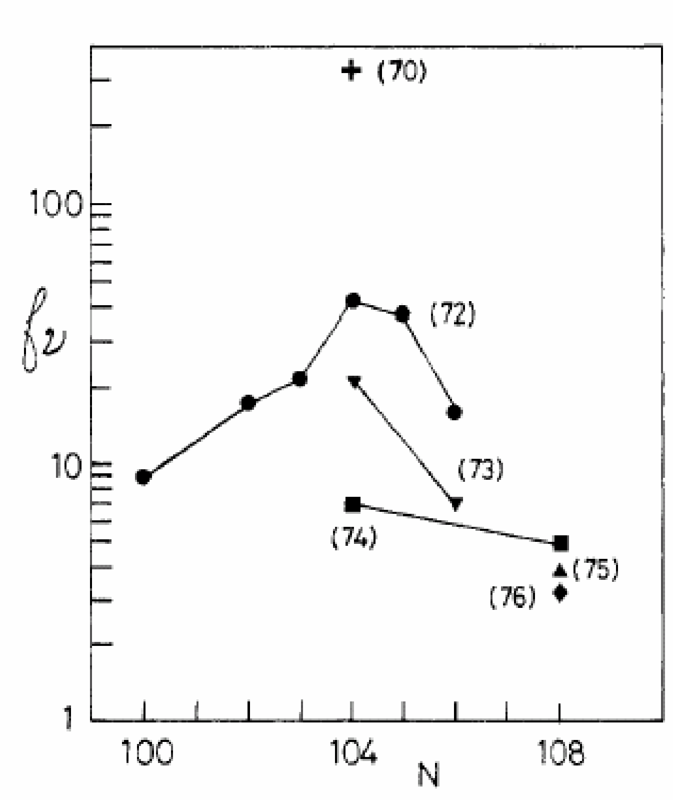
Dracoulis et al., Phys. Rev. C71 (2005) 044326



Walker, J. Phys. G16 (1990) L233

2- and 3-qp E2 reduced hindrances

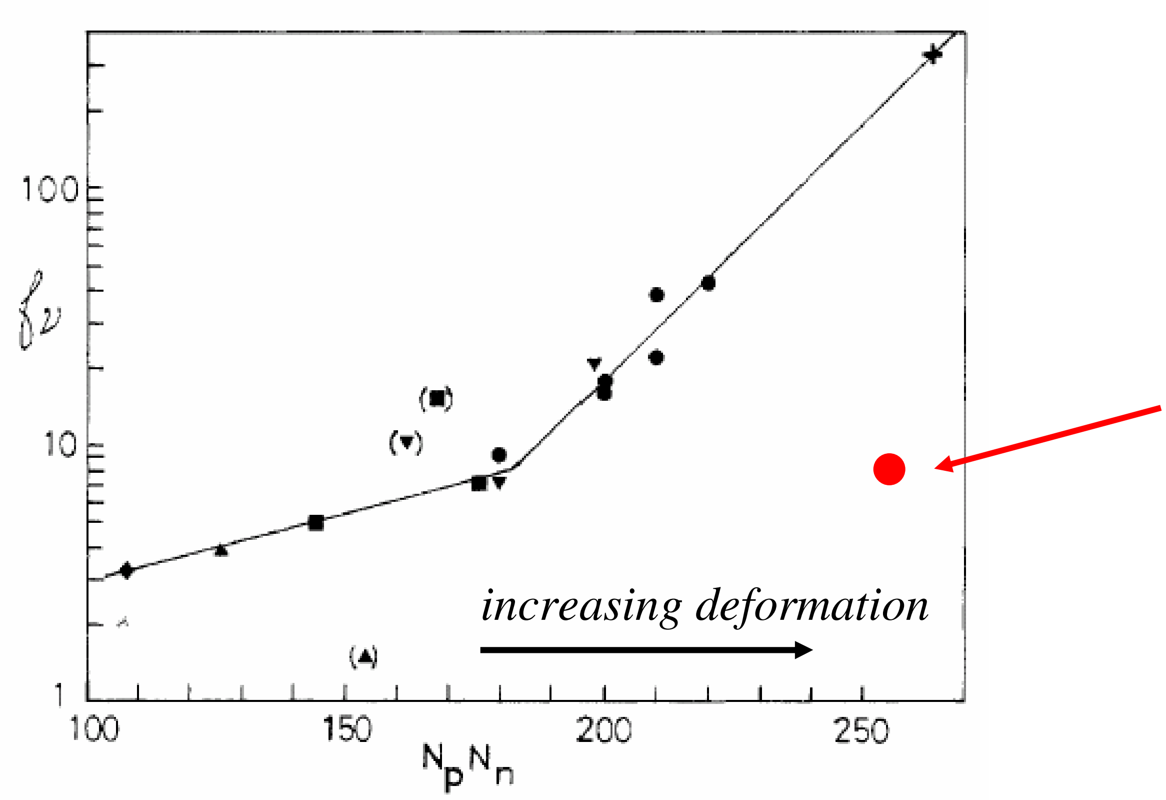




N_pN_n: product of valence nucleon numbers, e.g. ^{174}Yb (+) has Z=70, N_p=12; N=104, N_n=22 => N_pN_n=264

Walker, J. Phys. G16 (1990) L233

2- and 3-qp E2 reduced hindrances



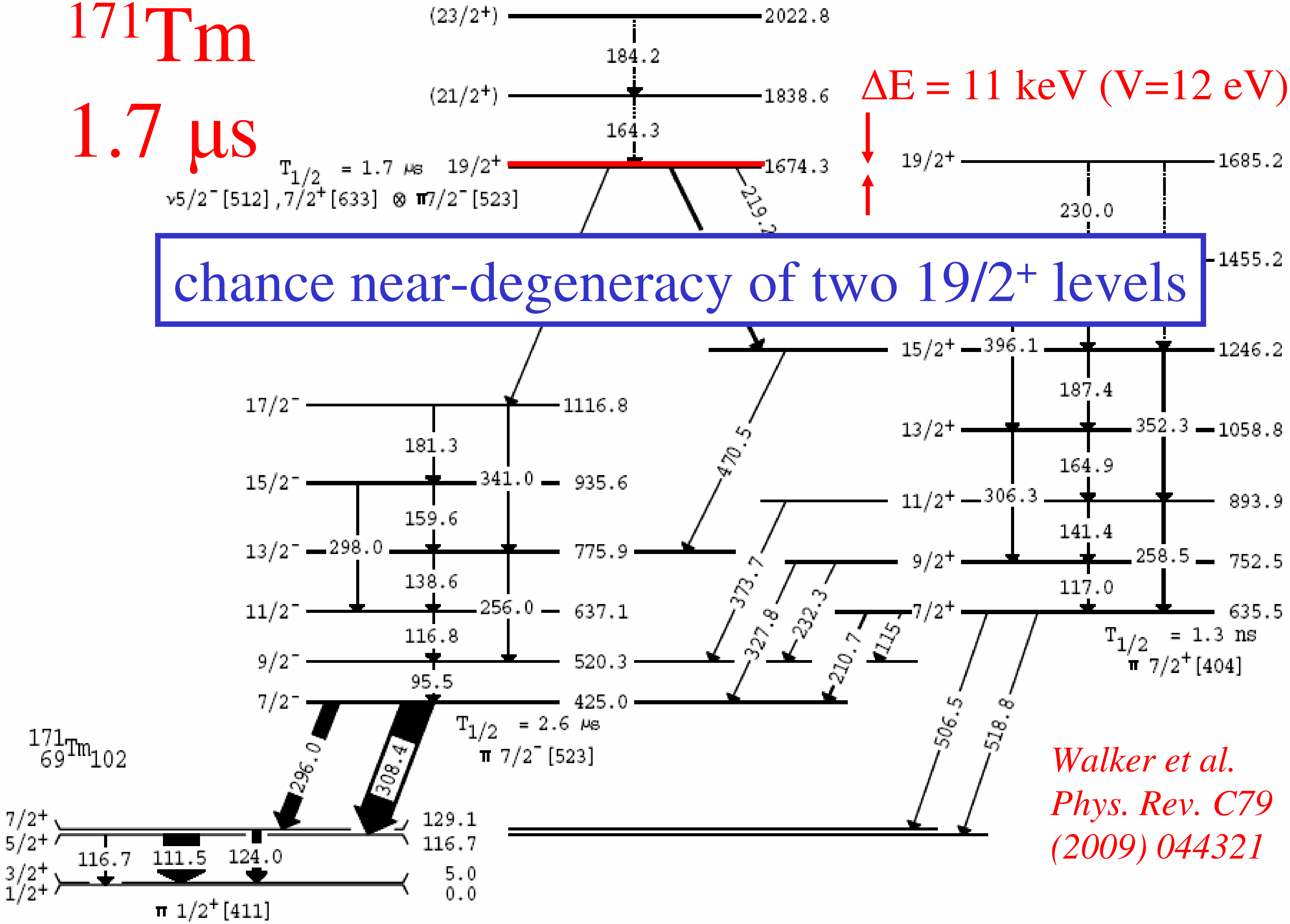
^{171}Tm

Walker et al.
Phys. Rev. C79
(2009) 044321

N_pN_n: product of valence nucleon numbers, e.g. ^{174}Yb (+) has Z=70, N_p=12; N=104, N_n=22
=> N_pN_n=264

^{171}Tm 1.7 µs

ΔE = 11 keV (V=12 eV)



chance near-degeneracy of two 19/2+ levels

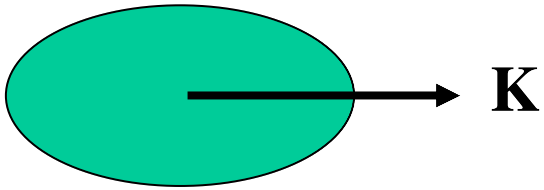
Walker et al.
Phys. Rev. C79
(2009) 044321

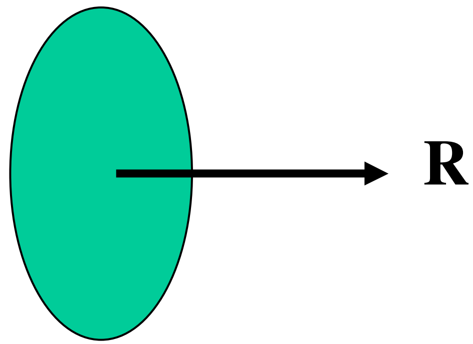
K-mixing mechanisms

- chance near-degeneragies – hard to predict!
- Coriolis mixing (rotational – orientation change)

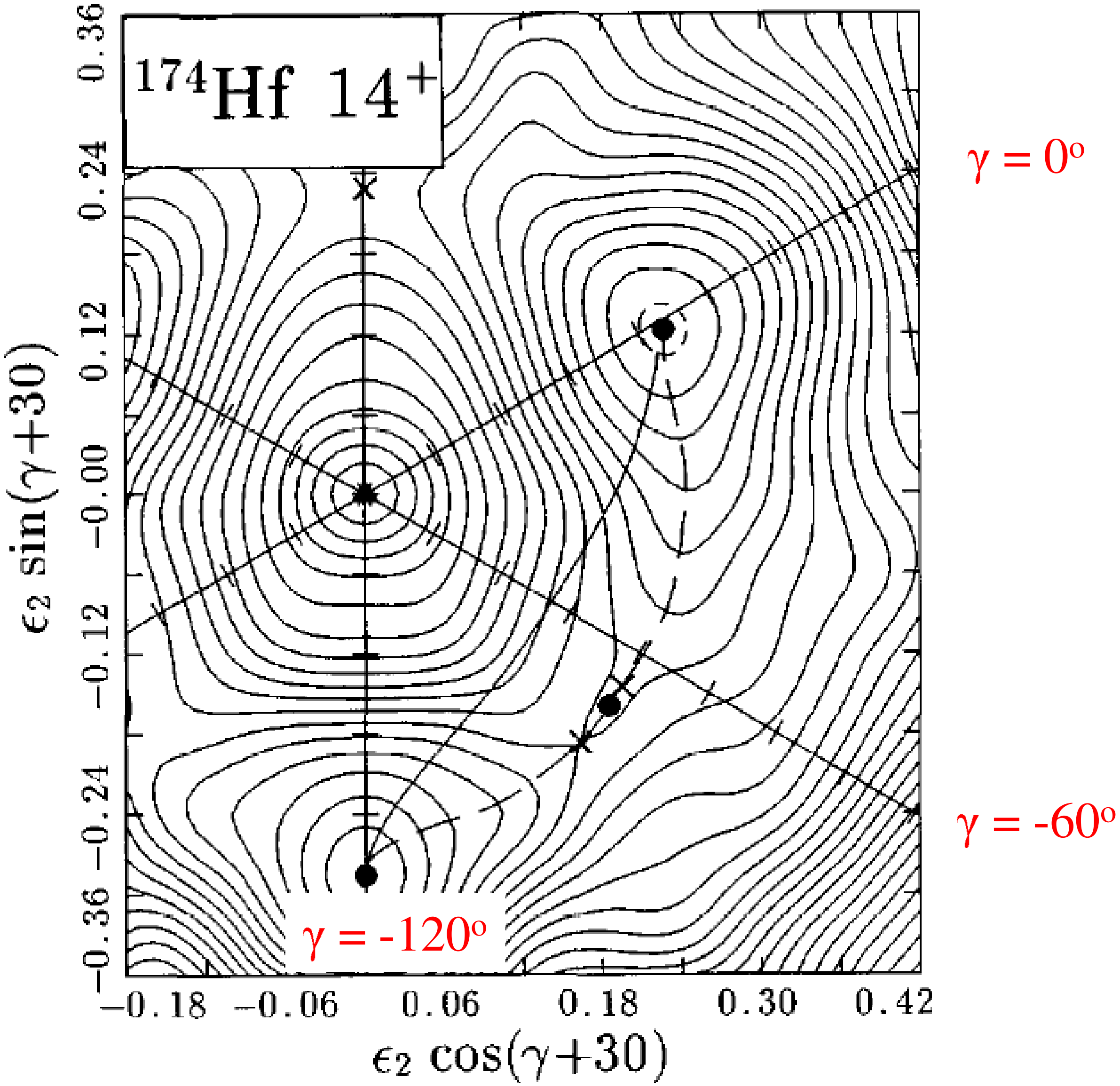
larger deformation (N_pN_n) => less Coriolis mixing

- γ tunnelling (vibrational – shape change)
- level density (thermal – statistical)





γ tunnelling

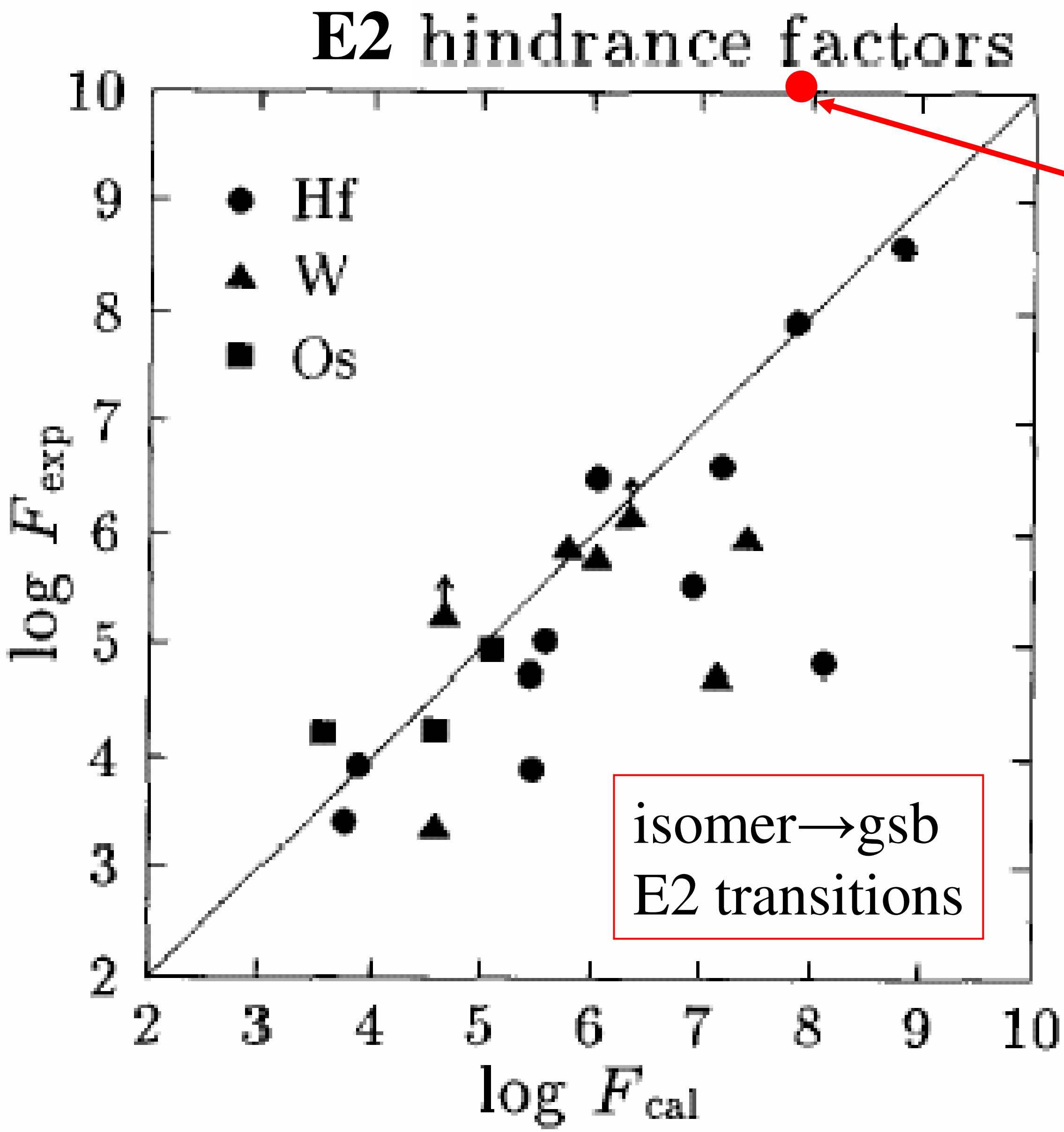


Narimatsu et al.,
Nucl. Phys. A601
(1996) 69

K. Narimatsu et al. / Nuclear Physics A 601 (1996) 69–88

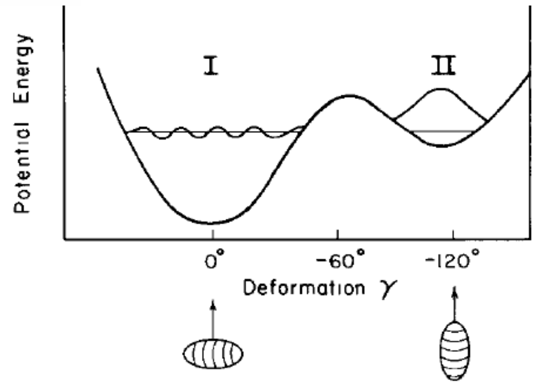
γ-tunnelling description of K-isomer decay

A~180 region

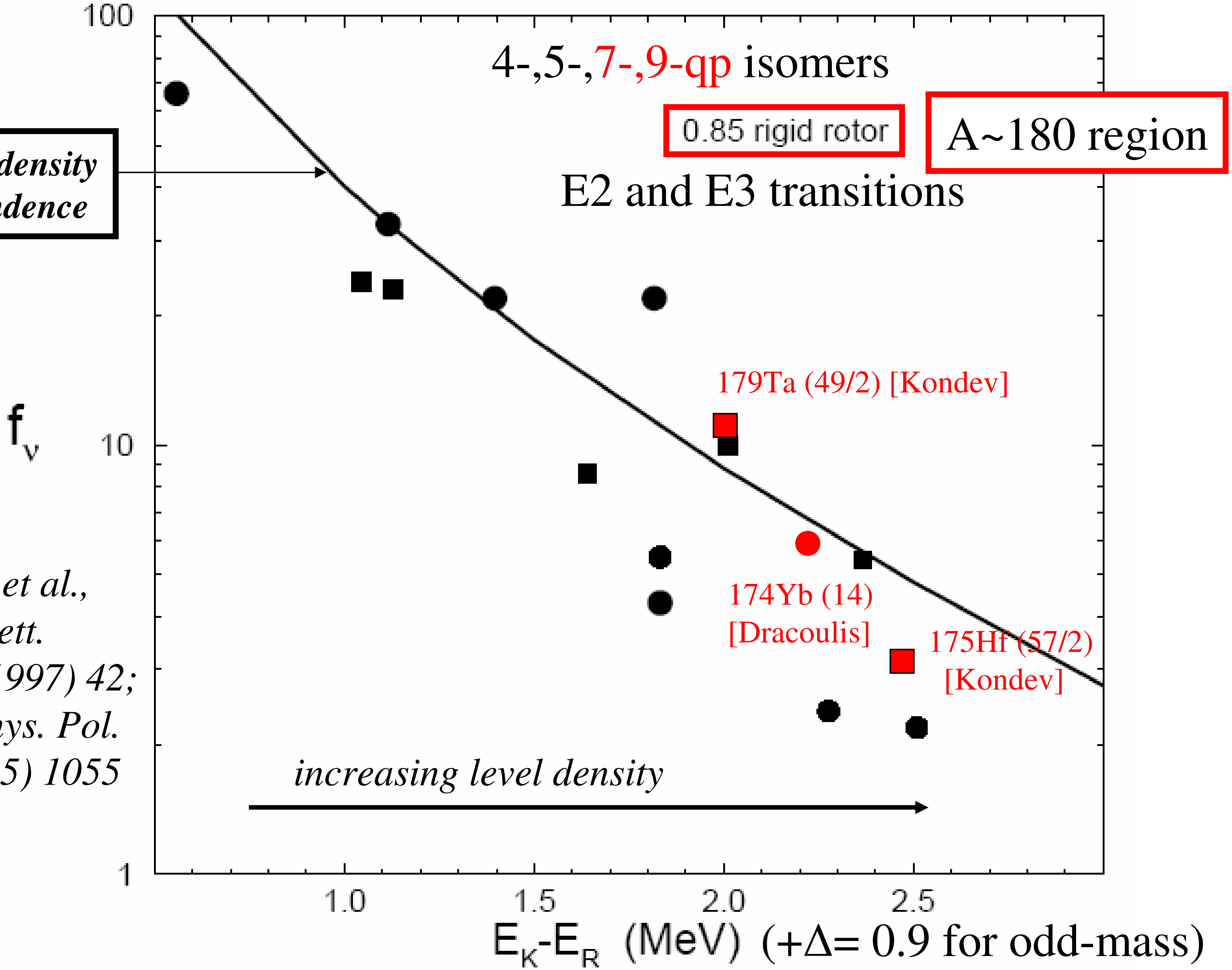


^{174}Yb (K=6)

see Dracoulis et al. Phys. Rev. C71 (2005) 044326

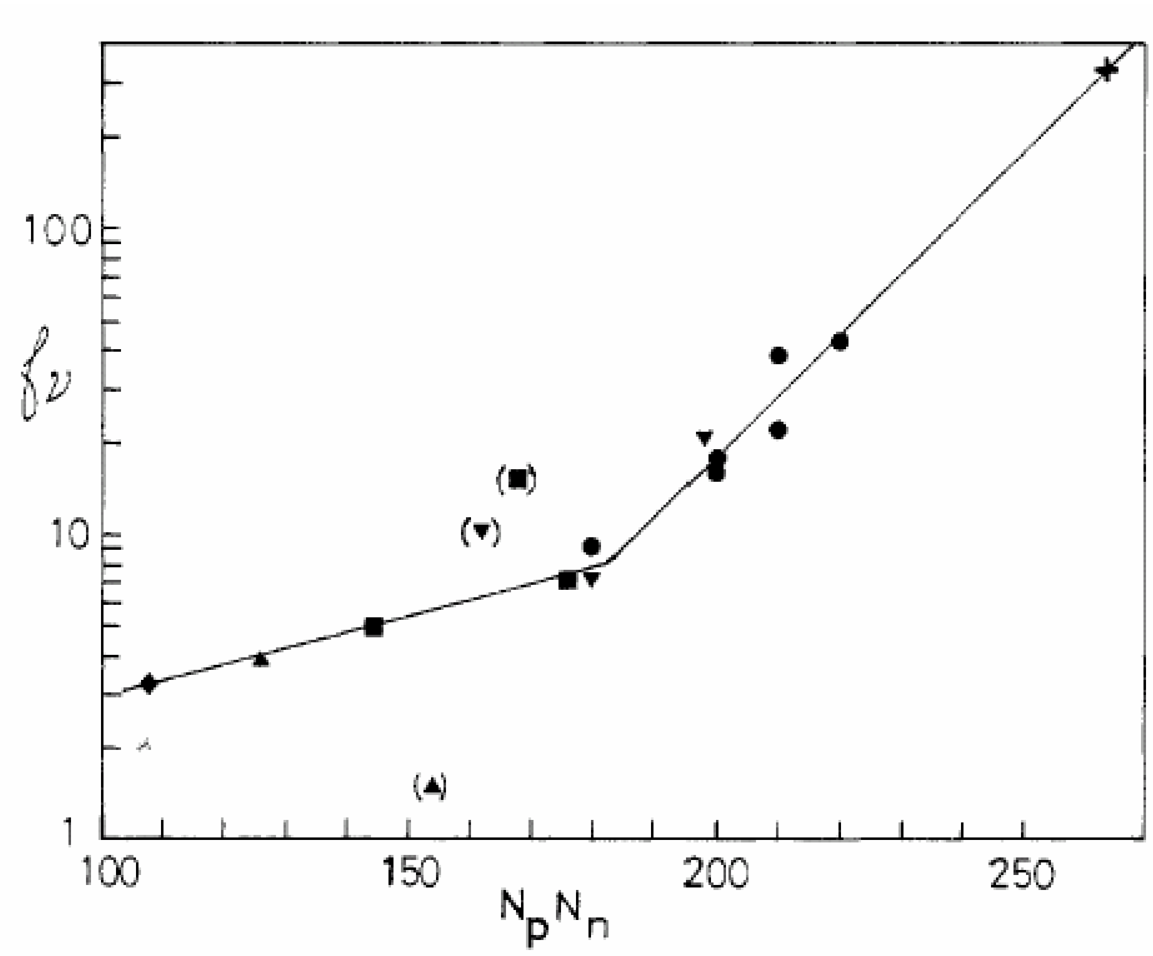


Chowdhury et al., Nucl. Phys. A485 (1988) 136



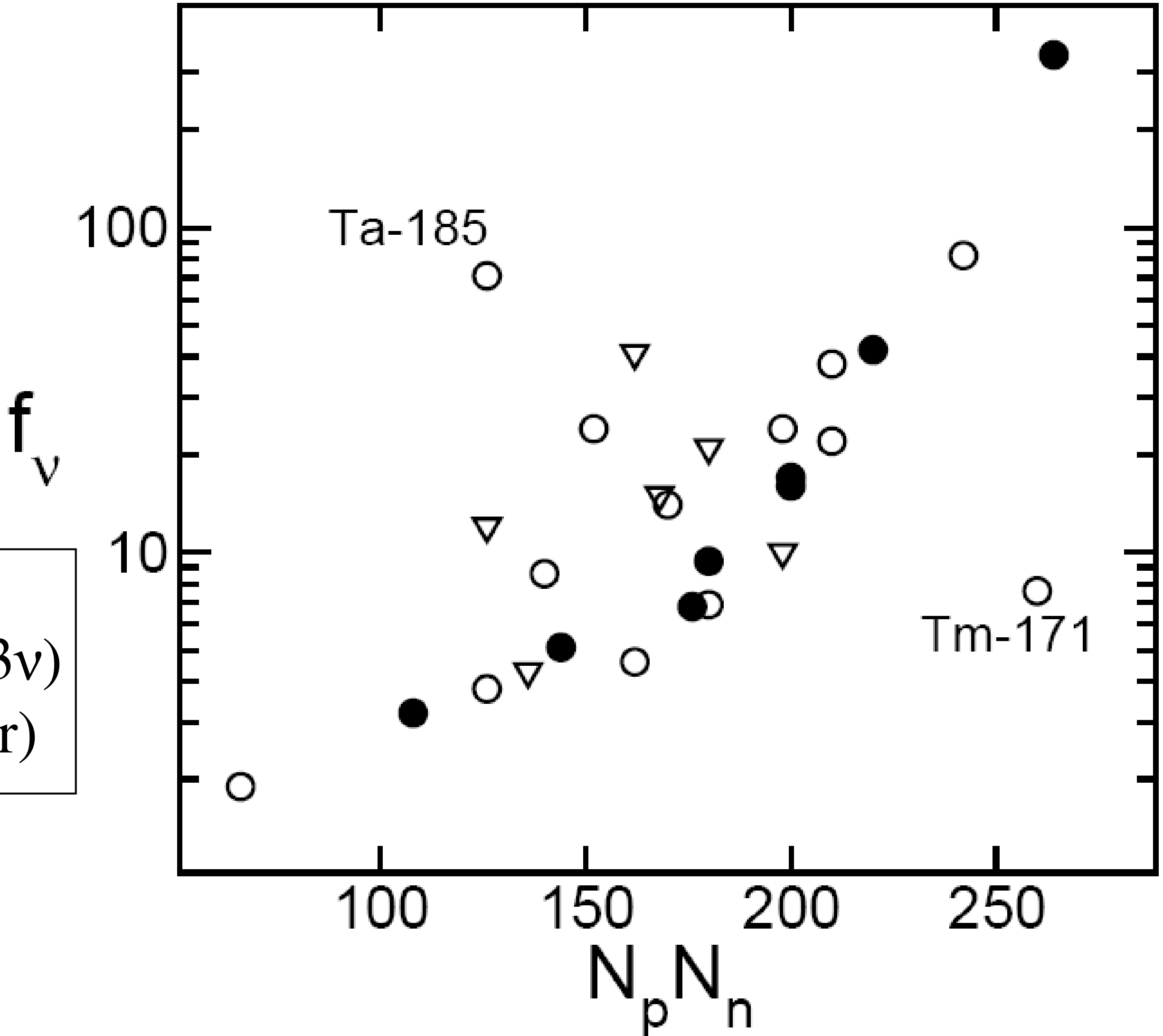
Walker et al., Phys. Lett. B408 (1997) 42; Acta Phys. Pol. 36 (2005) 1055

back to 2- and 3-qp isomers



back to 2- and 3-qp isomers

^{185}Ta:
Lane et al.,
Phys. Rev. C80
(2009) 024321

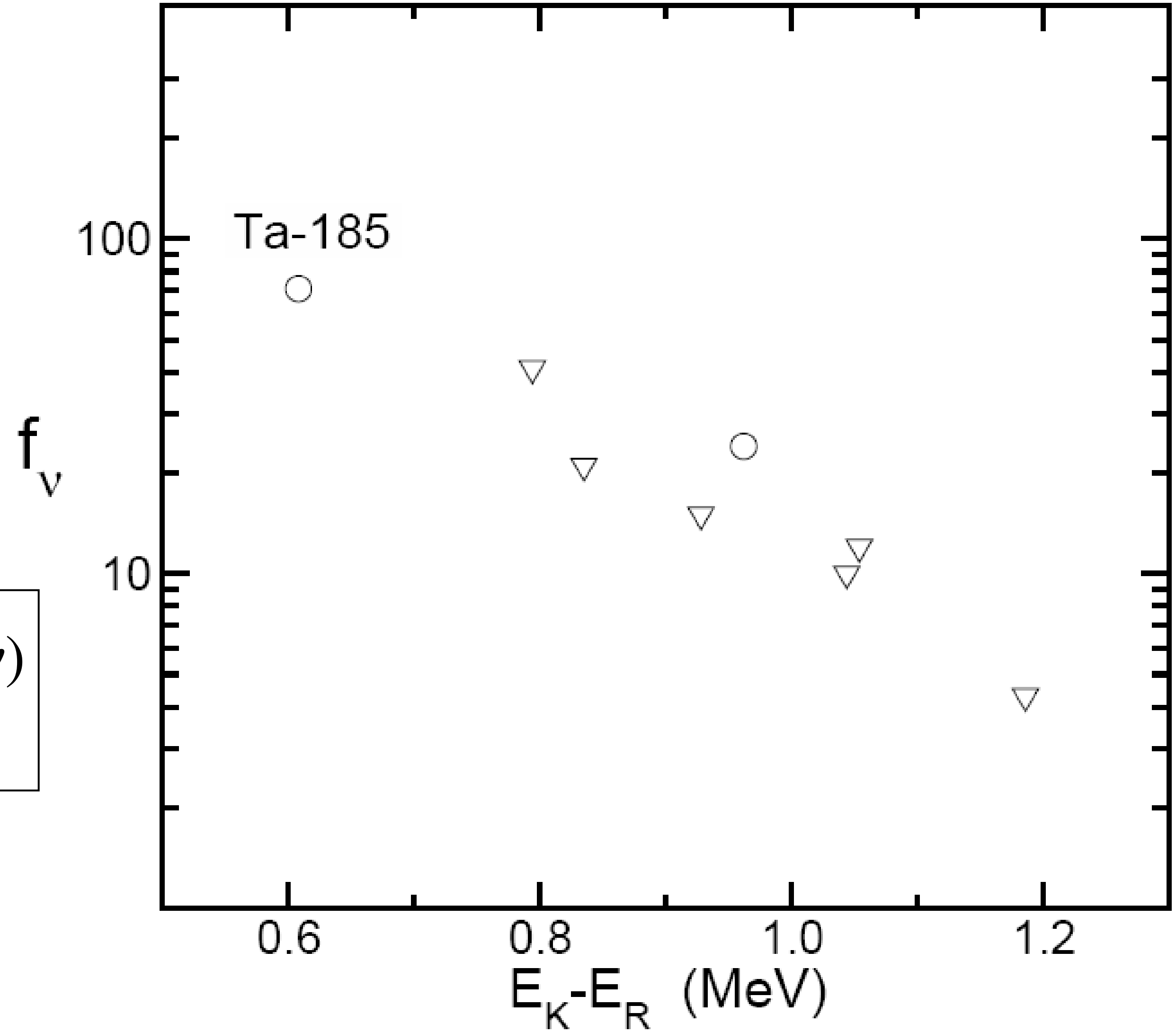


● 2-qp
▽ 3-qp (3π, 3ν)
○ 3-qp (other)

Walker et al., Phys. Rev. C81 (2010) 041304(R)

back to 2- and 3-qp isomers

^{185}Ta:
Lane et al.,
Phys. Rev. C80
(2009) 024321



▽ 3-qp (3π, 3ν)
○ 3-qp (other)

Walker et al., Phys. Rev. C81 (2010) 041304(R)

Where next?

Where next?

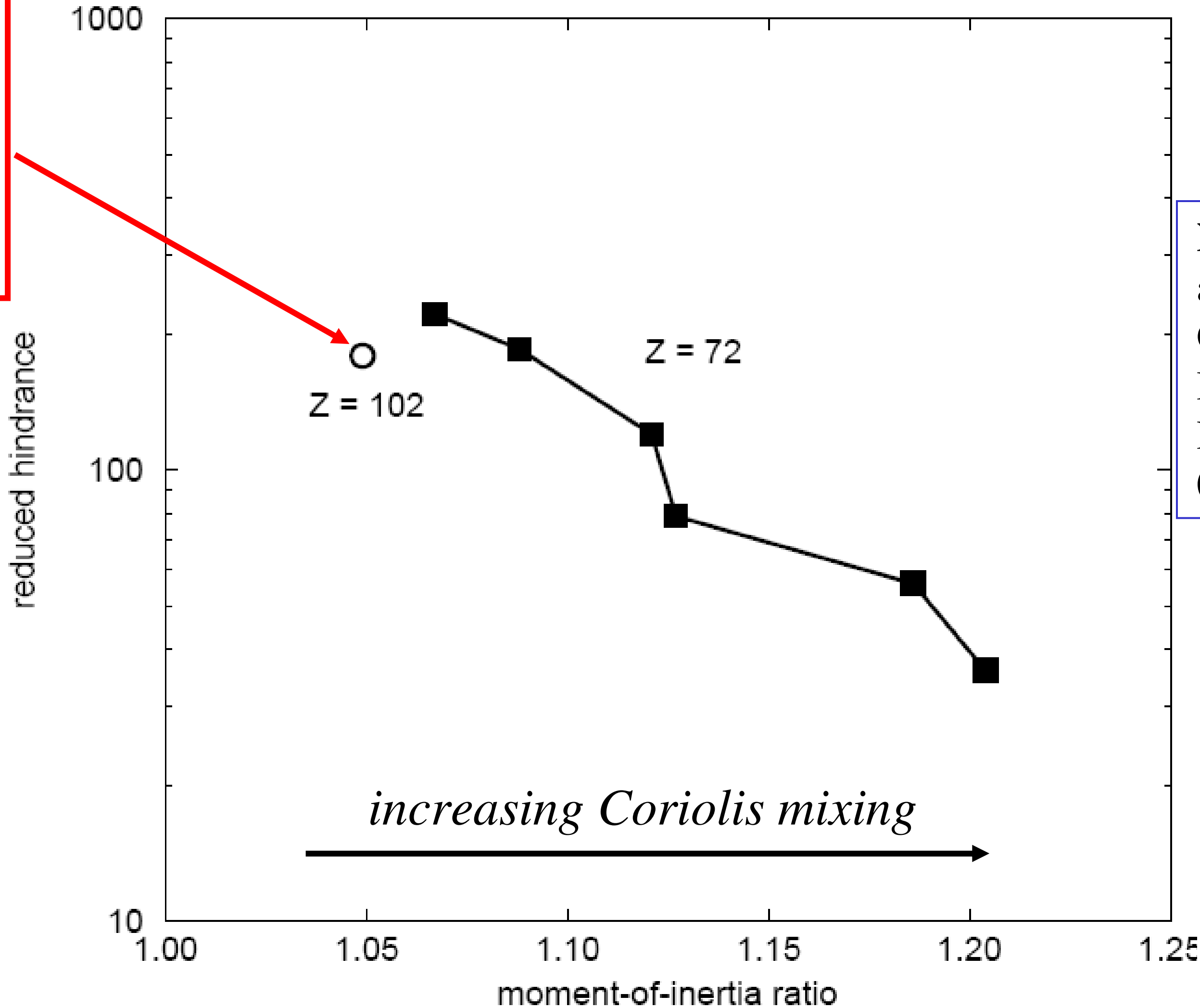
- need for quantitative theory

- compare with other mass regions

- make and test predictions for exotic nuclei

$K^{\pi} = 8^{-}$ isomers, E1 decays ($\nu = 7$)

^{252}No
Sulignano
et al.
EPJA33
(2007) 327



(dynamic/kinematic)

N=106 and allowance for Coriolis mixing: Dracoulis et al., PRC79 (2009) 061303(R)

extends analysis of Walker et al., Phys. Rev. C49 (1994) 1718

2-qp E2 reduced hindrances

even-even nuclides, $K^{\pi} = 6^{+}, 10^{+}$ isomers

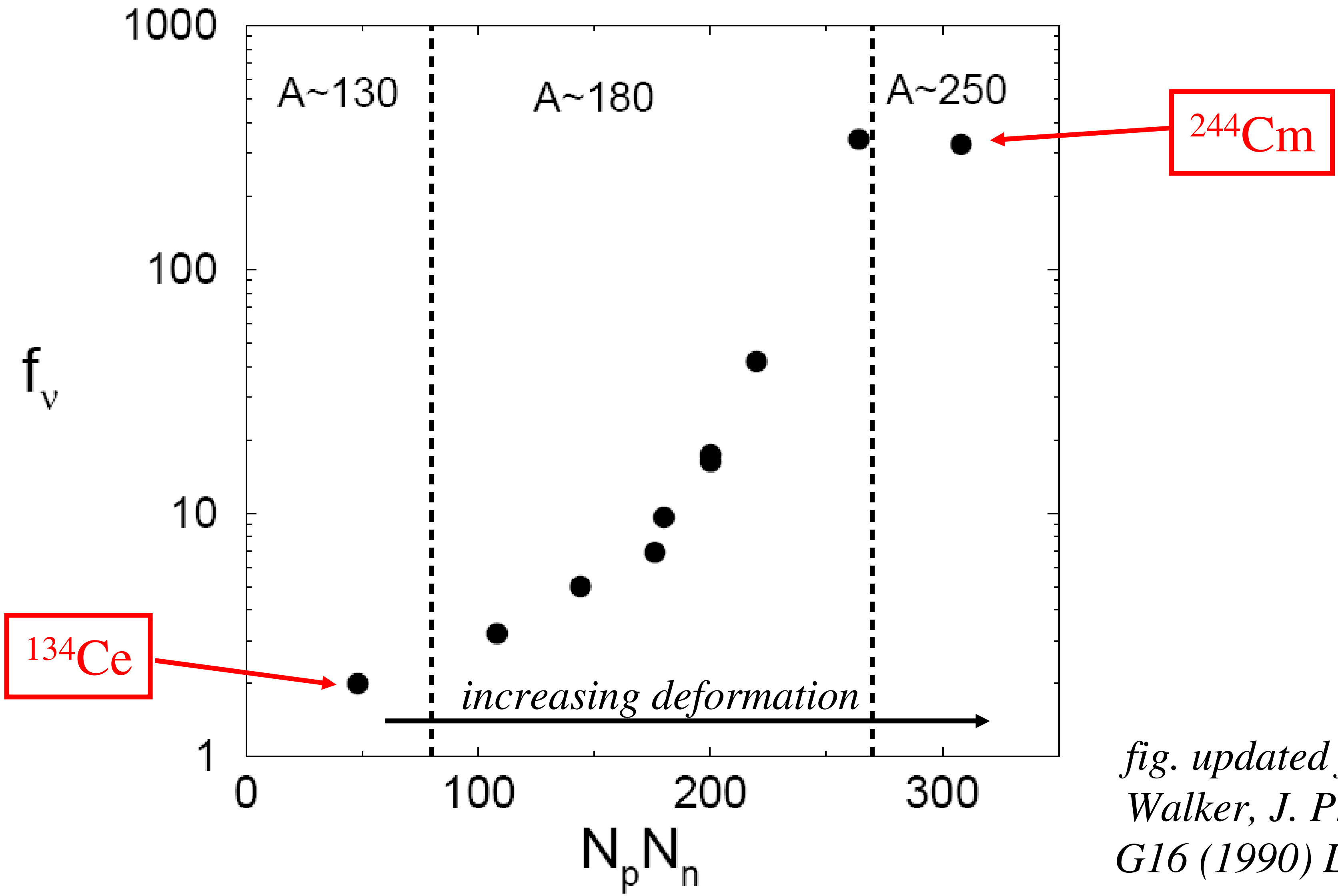
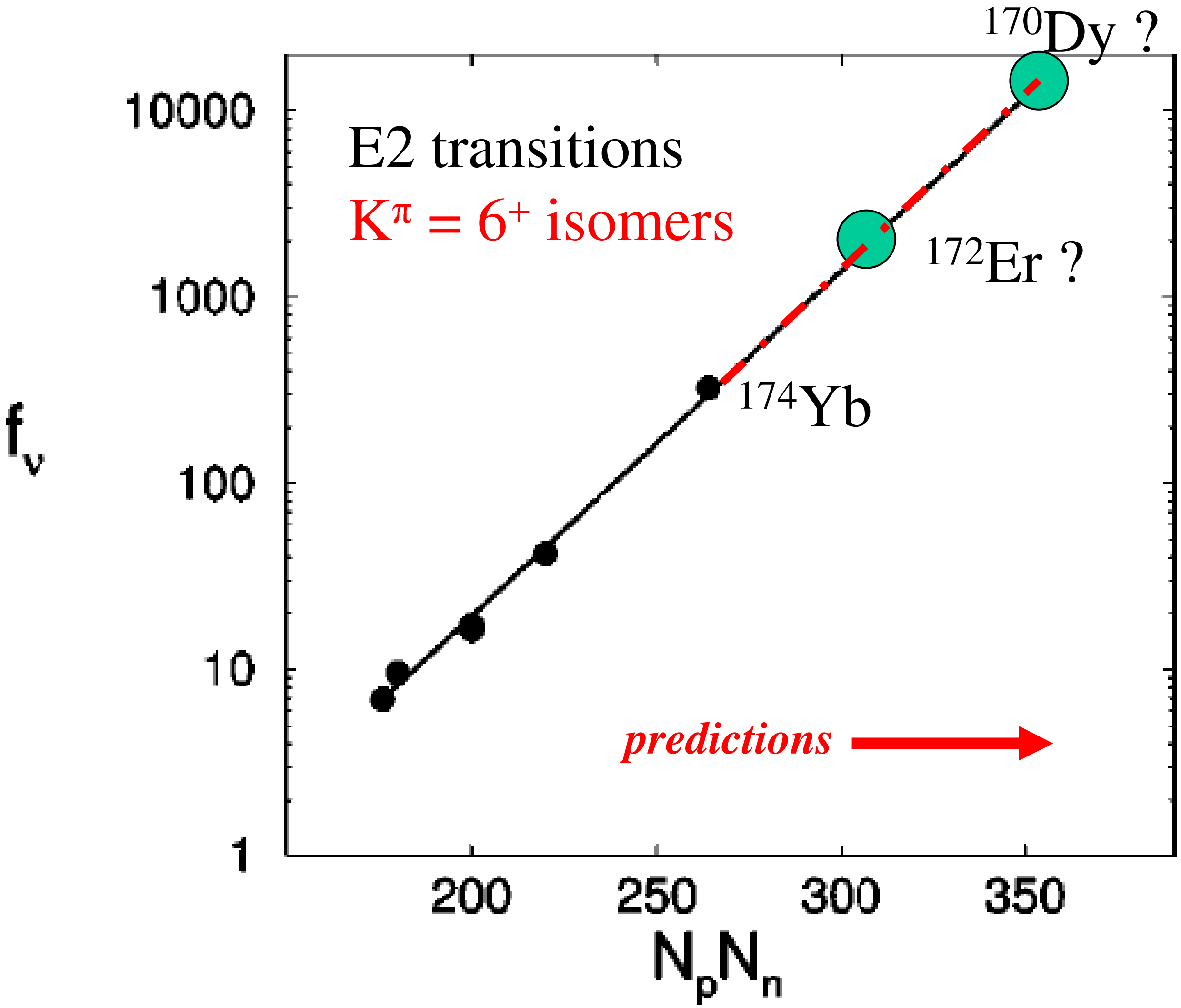


fig. updated from Walker, J. Phys. G16 (1990) L233

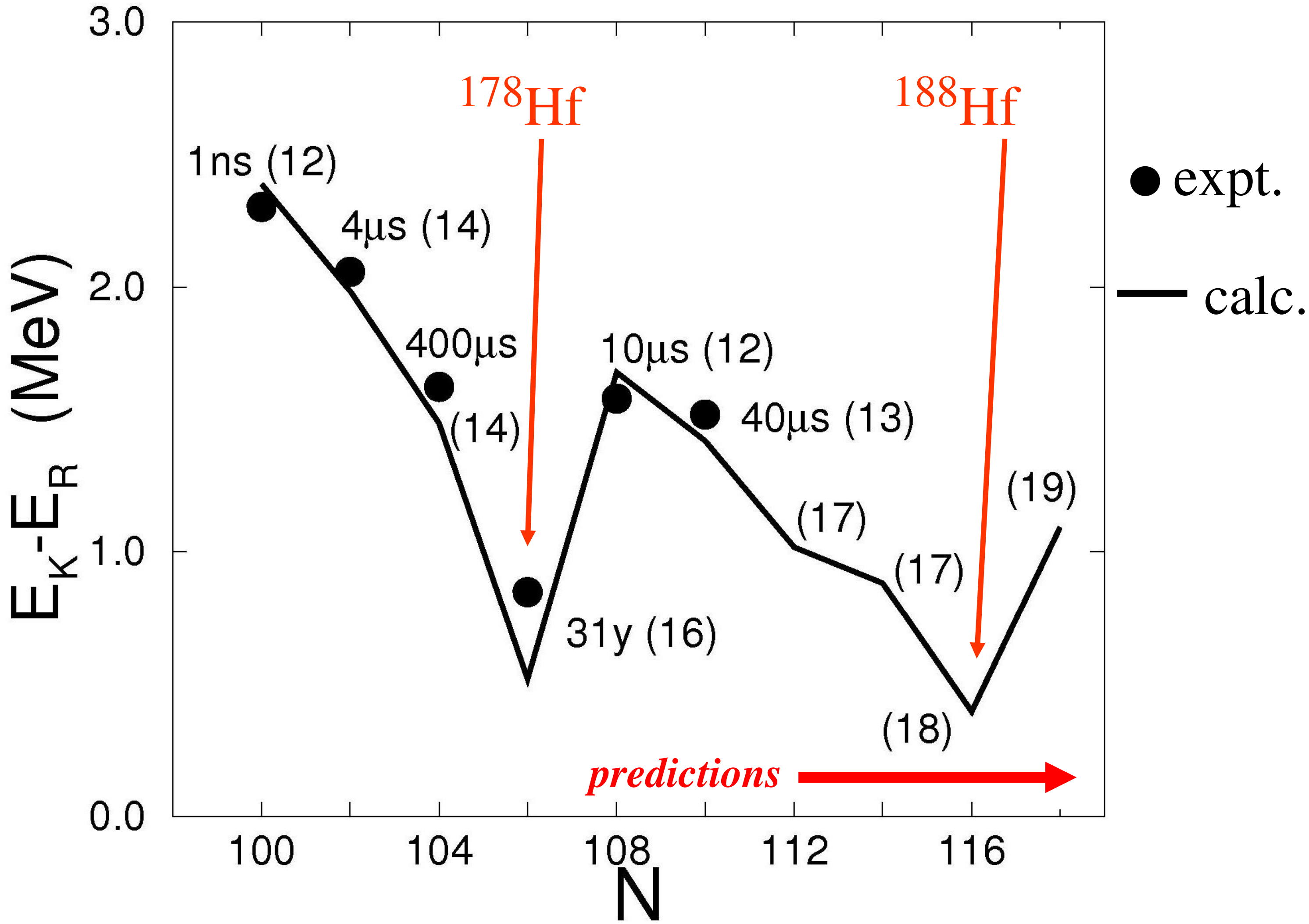
^{170}Dy: doubly mid-shell



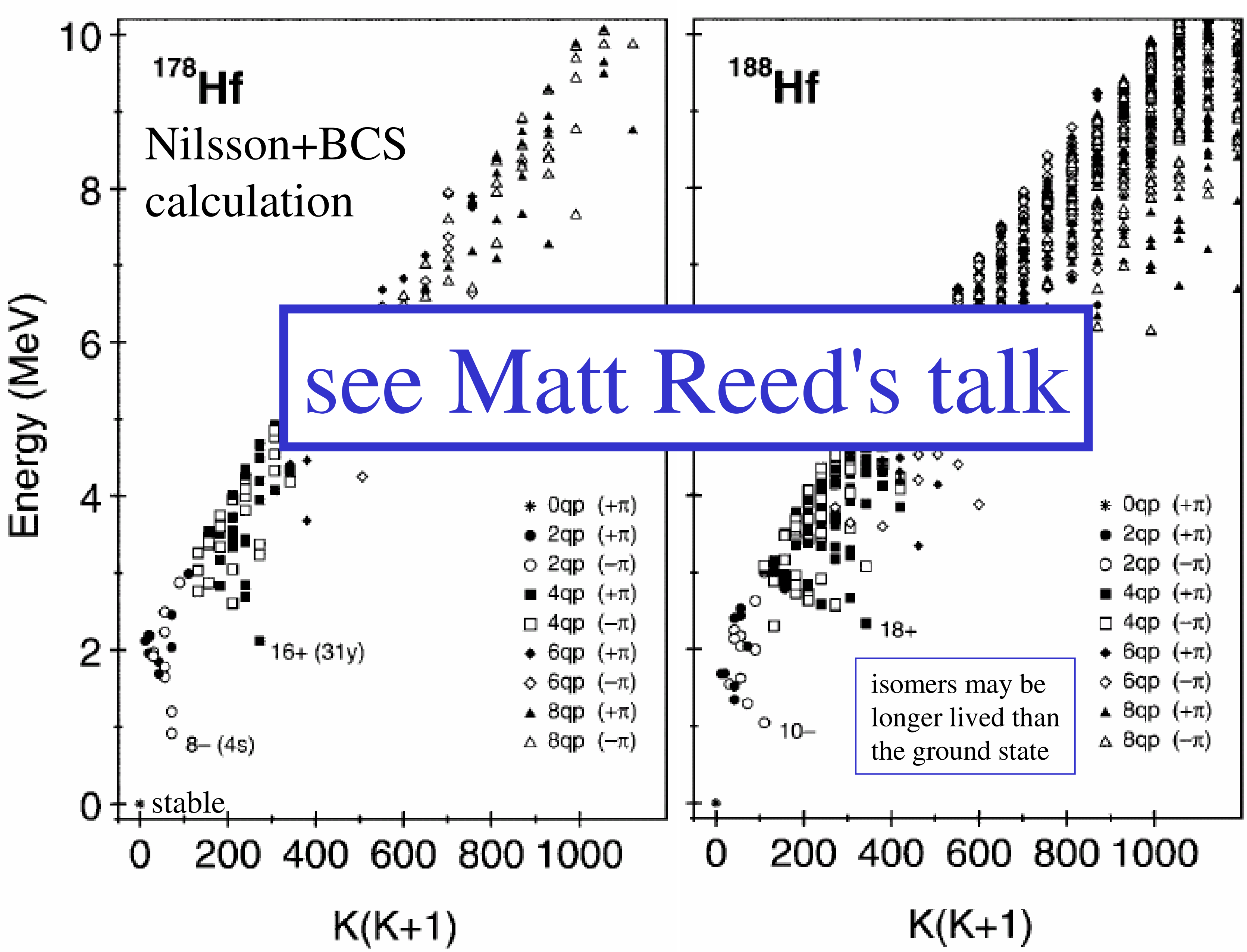
P.H. Regan et al., Phys. Rev. C65 (2002) 037302

A.K. Rath et al., Phys. Rev. C68 (2003) 044315

hafnium (Z=72) 4-qp isomers



Walker and Dracoulis, Hyp. Int. 135 (2001) 83



[Walker and Dracoulis, Hyp. Int. 135 (2001) 83]

Summary
K isomers & K mixing

f_ν dependence: N_pN_n (E2 transitions, 2-qp)
Coriolis effects
γ tunnelling
level-density (mqp)
chance near-degeneracy

theory needed, but predictions possible

n-rich predictions – long-lived isomers