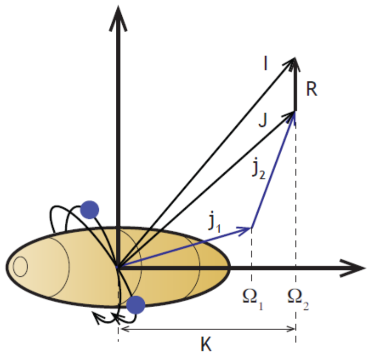
n-rich high-K isomers in the hafnium region

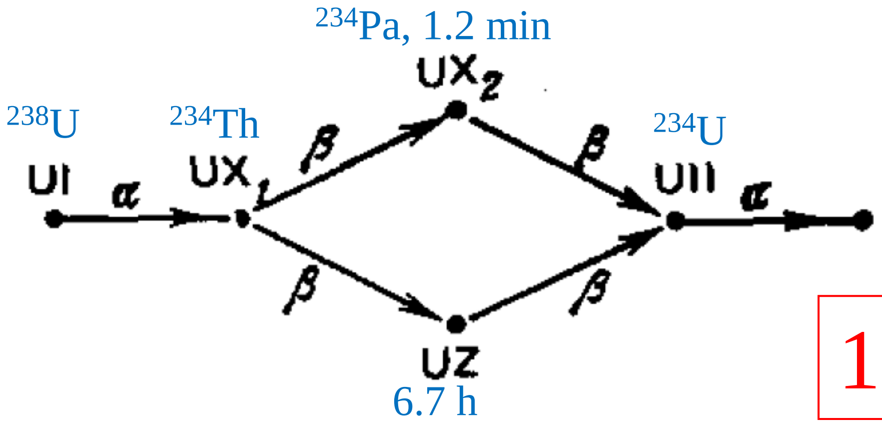
time-correlated events across long-lived isomers (10 – 100 μs)

Phil Walker

University of Surrey



^{234}Pa: first example of isomeric pair => first example of nuclear structure



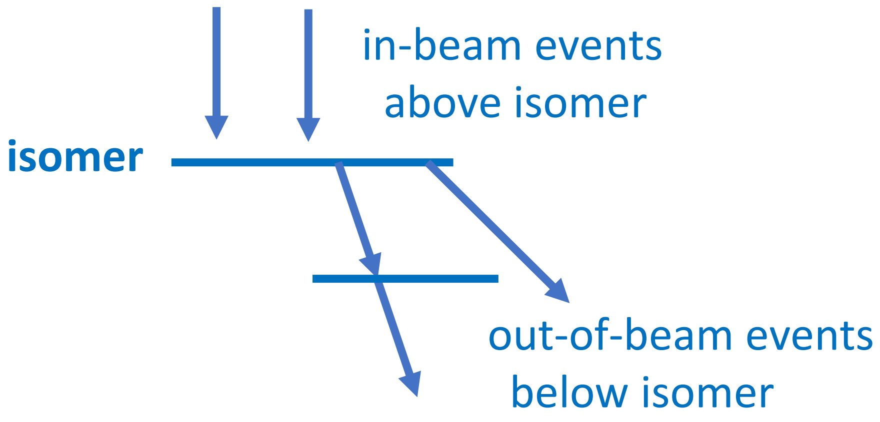
100 years ago

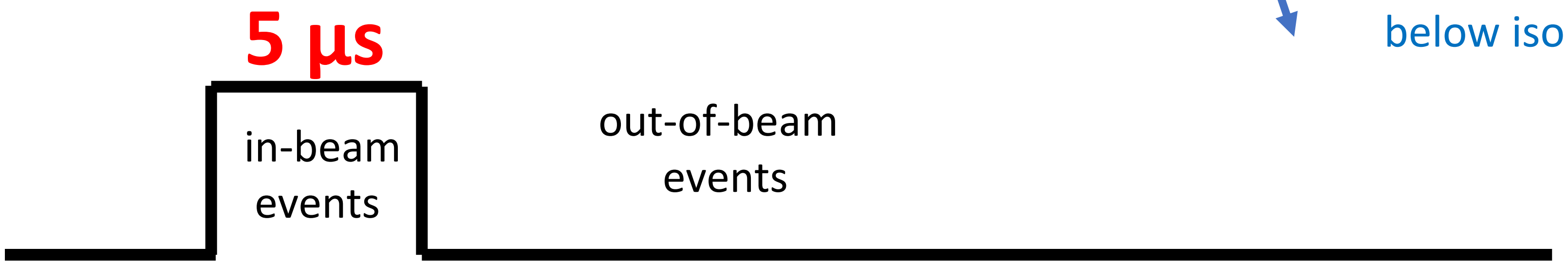
***Isomer observation*:**
O. Hahn, Ber. Deutsch. Chem. Ges. B54 (1921) 1131
"It would therefore be a dual decay, in which both branches are created by a β-ray transition. Such a case has not been observed before in radioactive transformations."

Otto Hahn
1921
discovers
first isomer

Walker & Podolyák, Phys. Scr. 95 (2020) 044004; Physics World 34 (April 2021) 29

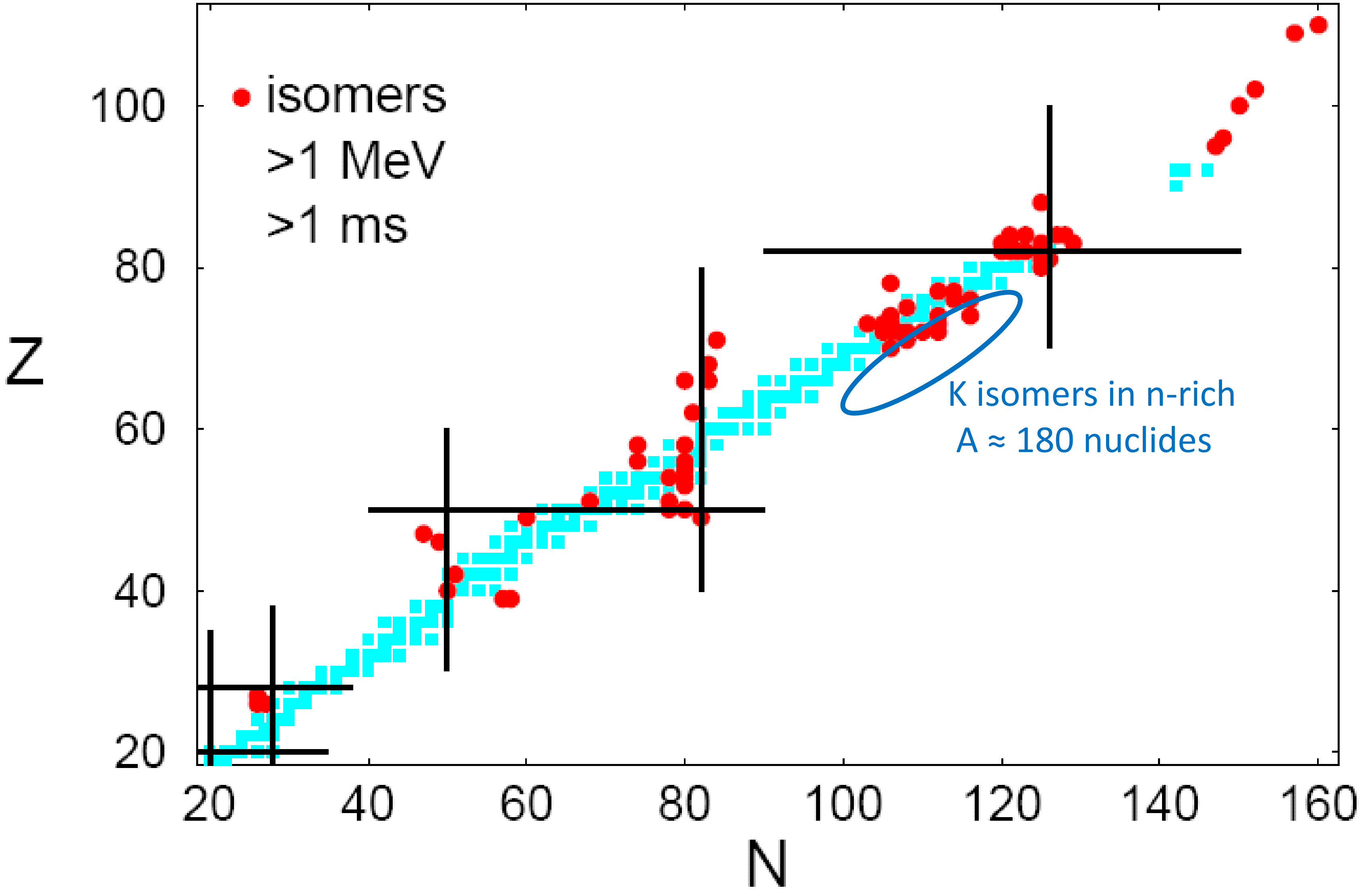
5 µs beam pulsing
& multi-nucleon transfer
=> n-rich isomers with high spin



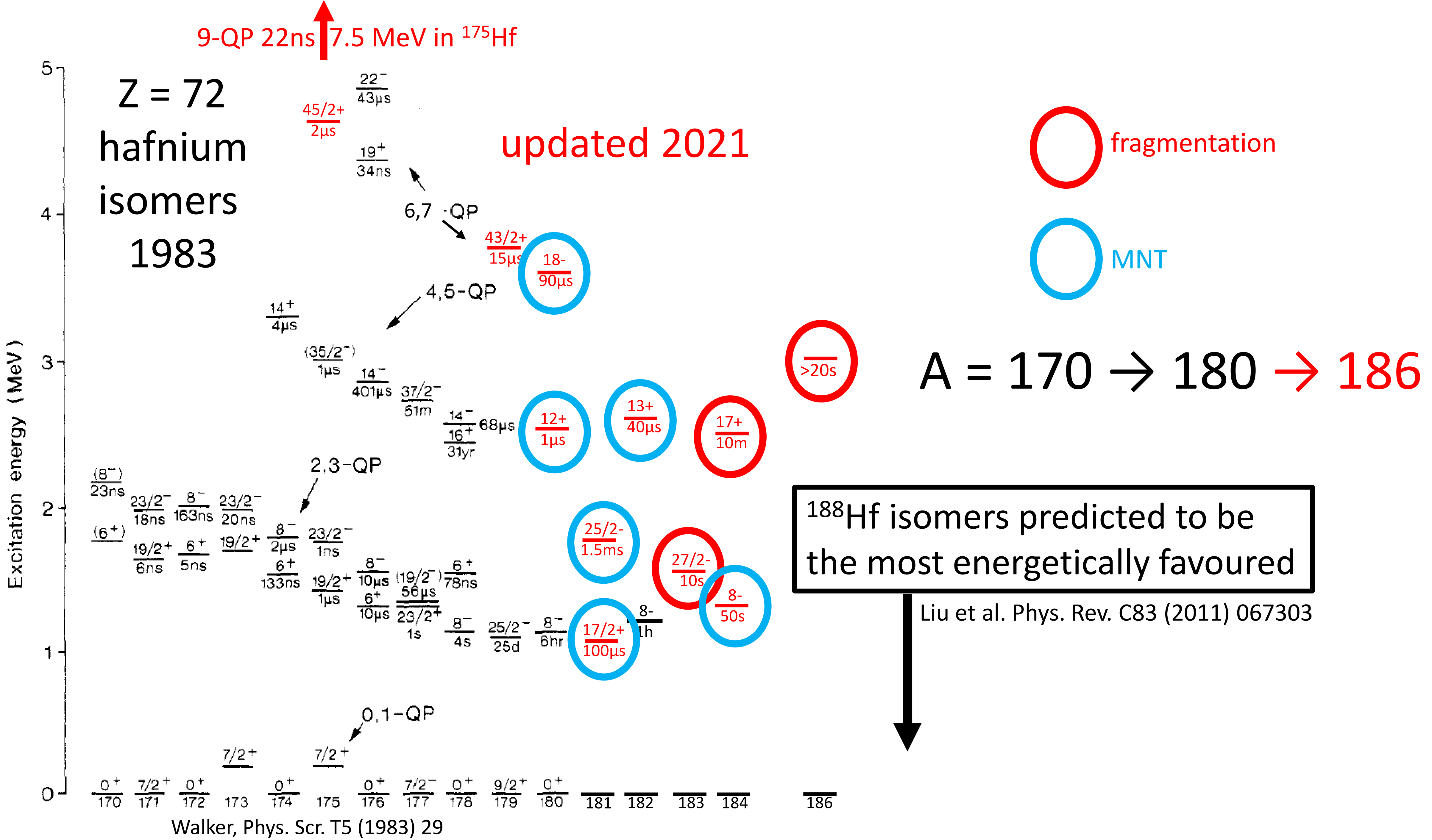


- specification of deadtime
- reduction of randoms (γ-γ out-of-beam)
- 25% duty factor is good for isomer decays!

nuclear chart with >1 MeV isomers

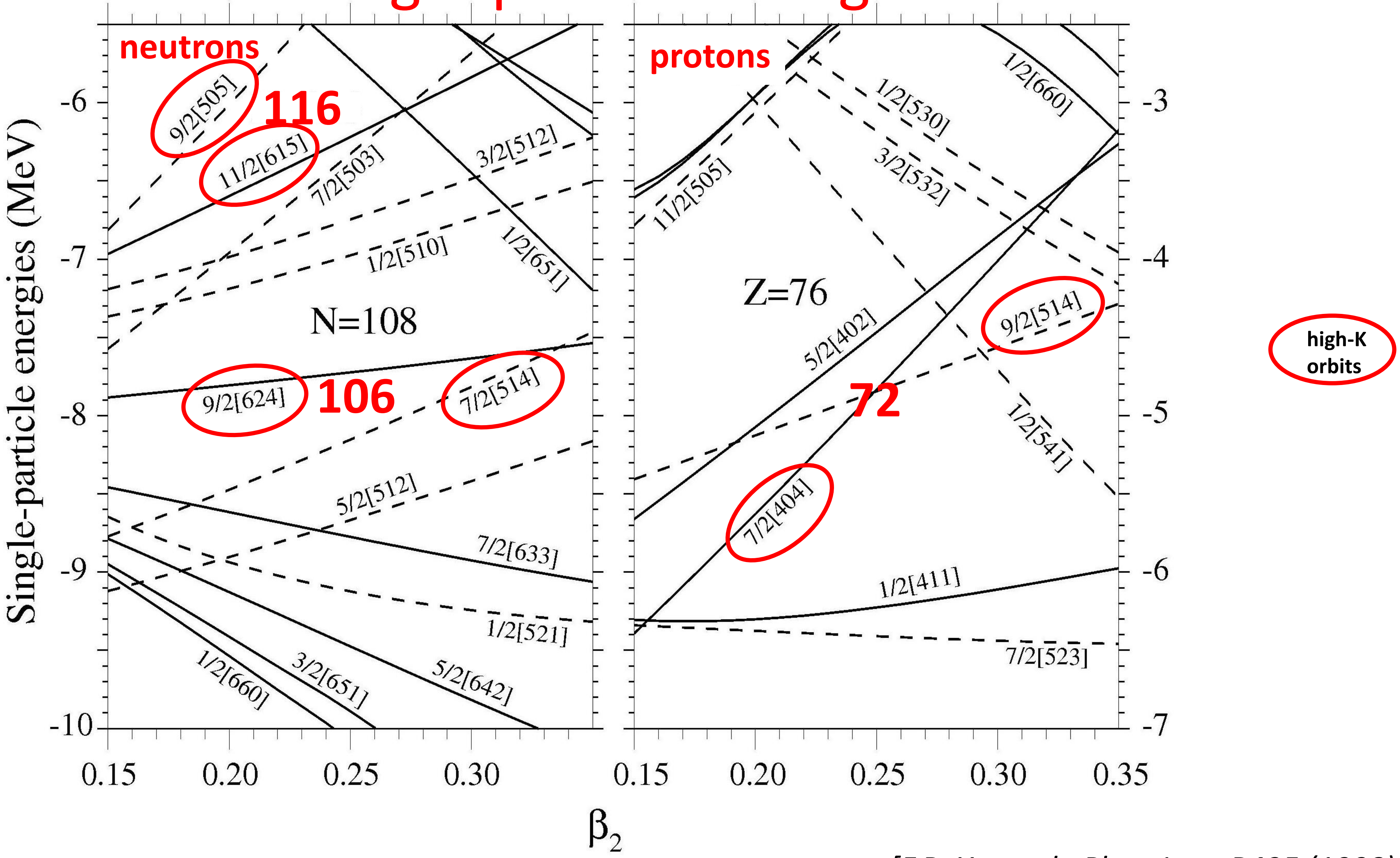


adapted from Walker and Dracoulis, Nature 399 (1999) 35



9-QP 22ns
7.5 MeV in 175Hf
Z = 72
hafnium
isomers
1983
updated 2021
fragmentation
MNT
A = 170 → 180 → 186
188Hf isomers predicted to be the most energetically favoured
Liu et al. Phys. Rev. C83 (2011) 067303
Excitation energy (MeV)
6,7 -QP
4,5-QP
2,3-QP
0,1-QP
45/2+ 2μs
22− 43μs
19+ 34ns
43/2+ 15μs
18- 90μs
14+ 4μs
(35/2−) 1μs
14− 401μs
37/2− 51m
14− 16+ 68μs 31yr
12+ 1μs
13+ 40μs
17+ 10m
>20s
25/2- 1.5ms
27/2- 10s
8- 50s
8- 1h
17/2+ 100μs
170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 186
Walker, Phys. Scr. T5 (1983) 29

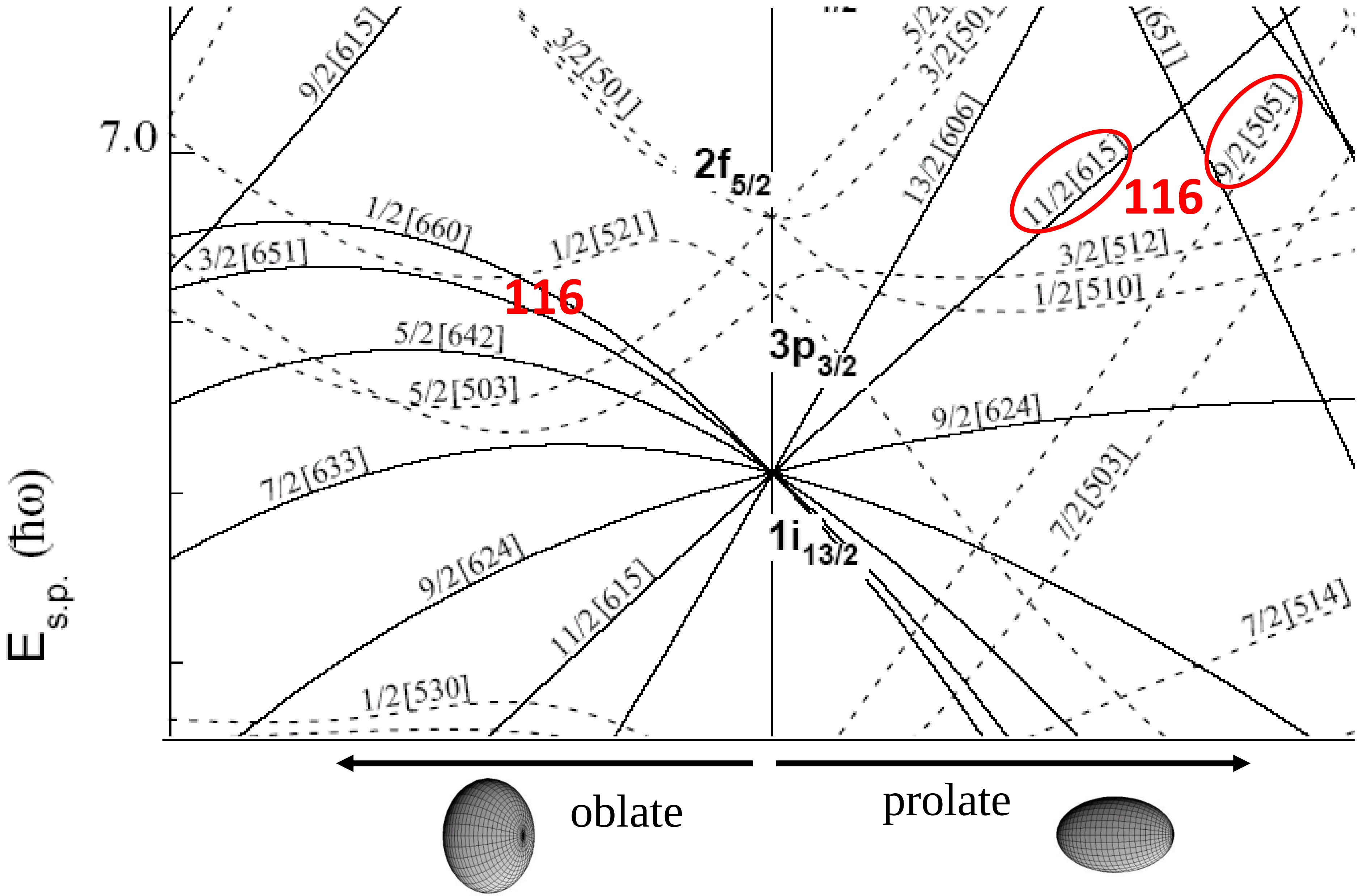
single-particle energies



Woods-Saxon potential

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

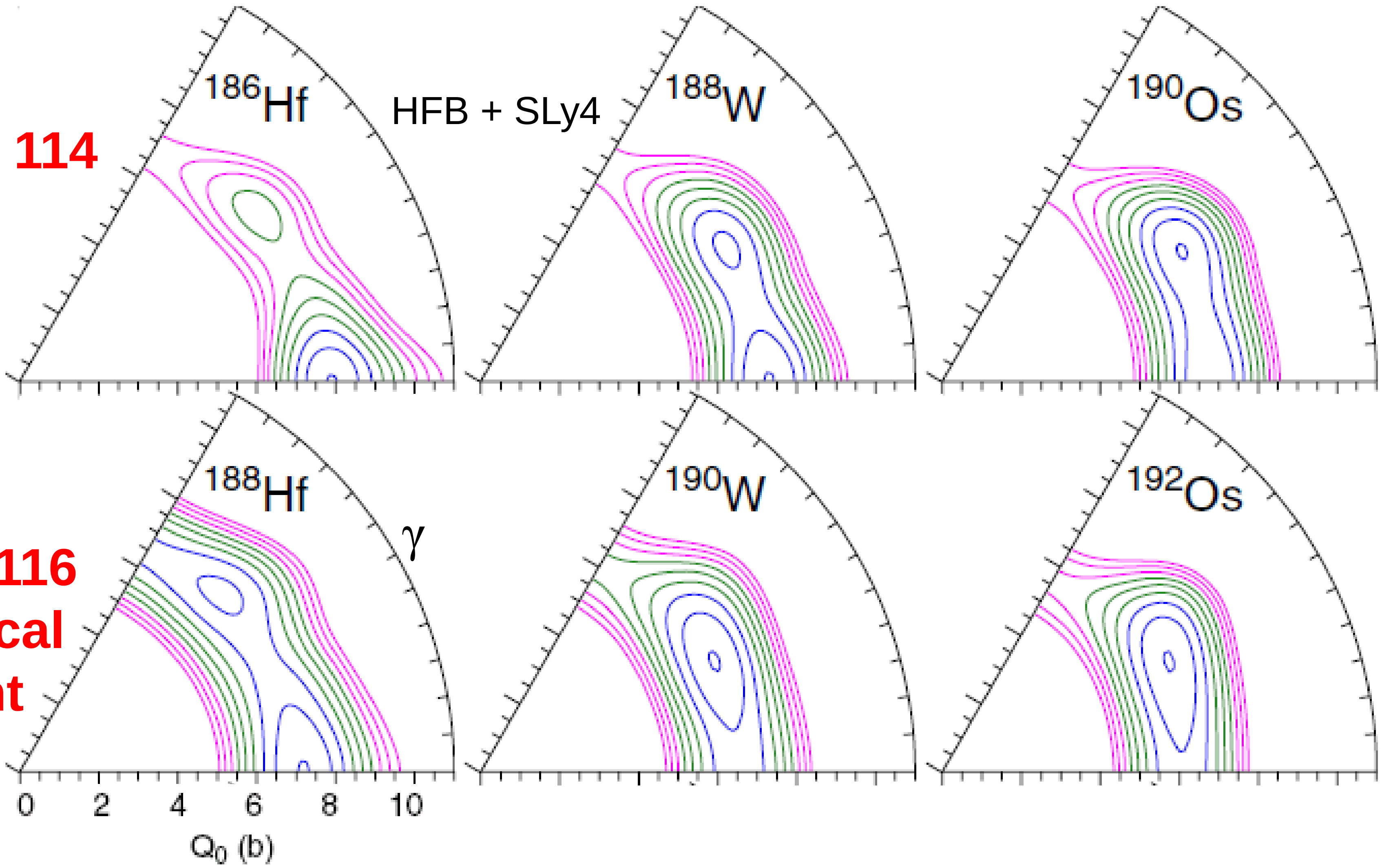
neutron single-particle energies



prolate-oblate shape transition (ground states)

N = 114

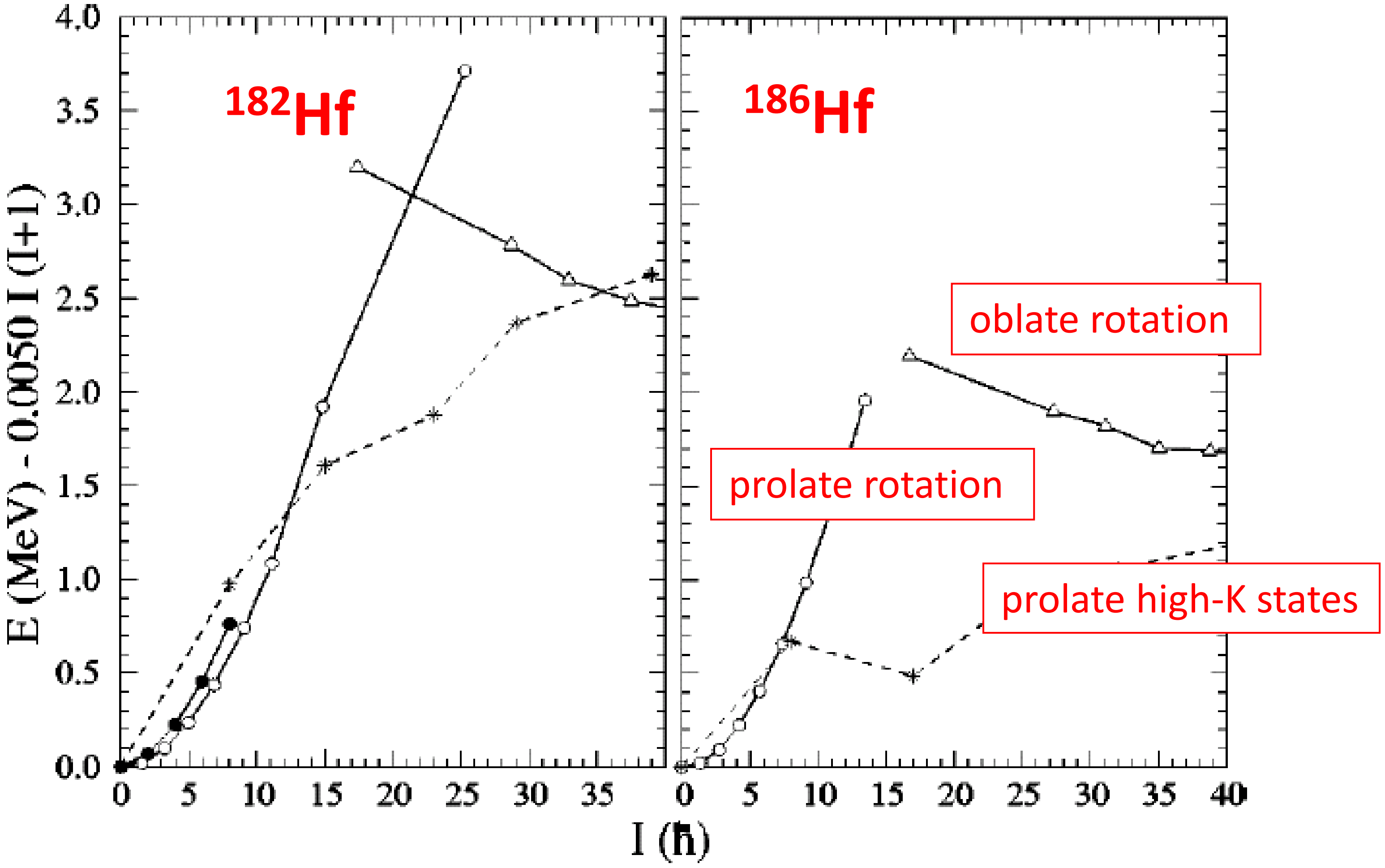
N = 116 critical point



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

prolate/oblate/high-K co-existence at high spin

neutron-rich hafnium (Z = 72) predicted excited states



Xu, Walker and Wyss, Phys. Rev. C62 (2000) 014301 n-rich portion of the nuclear chart

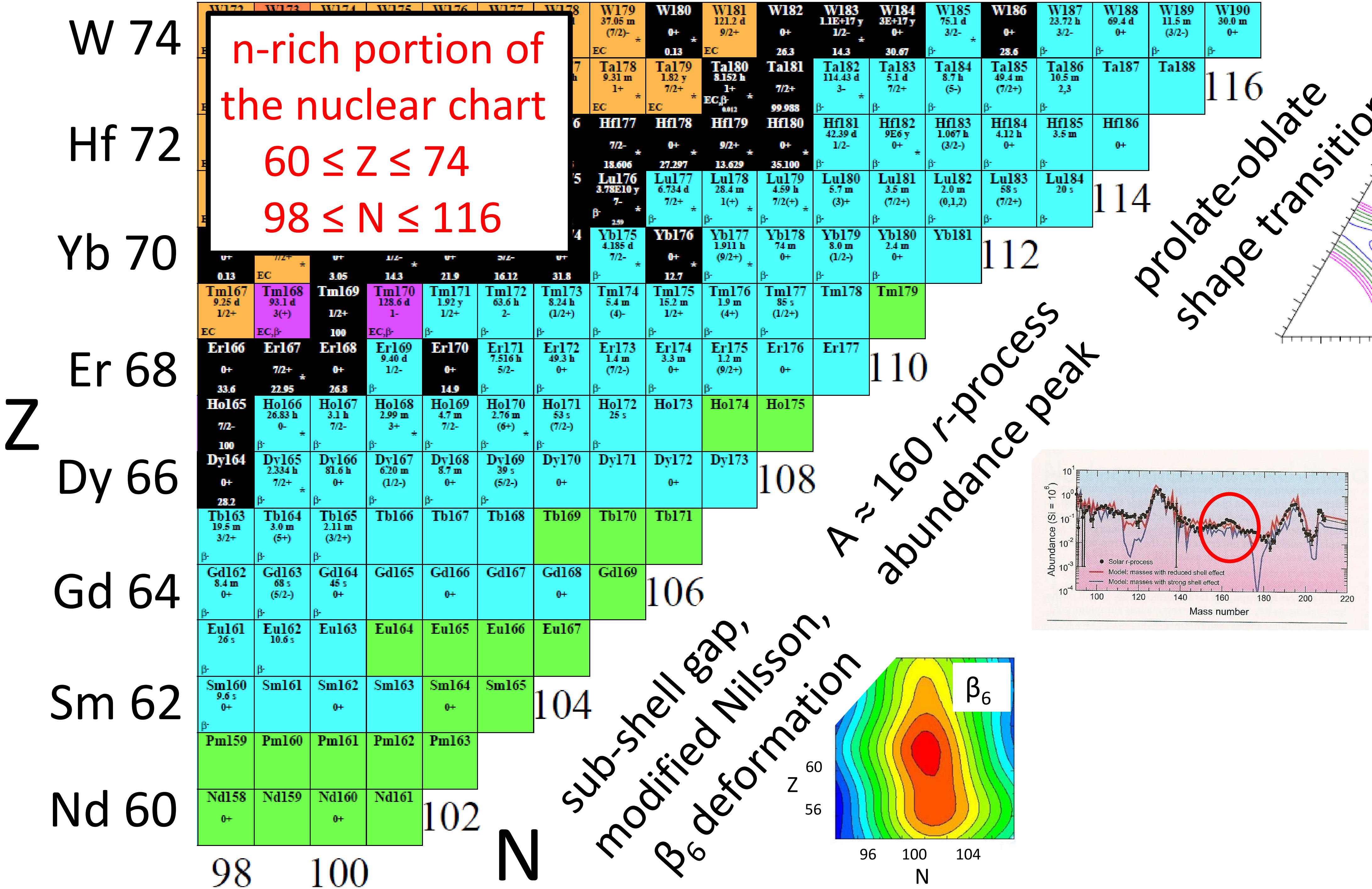
60 ≤ Z ≤ 74

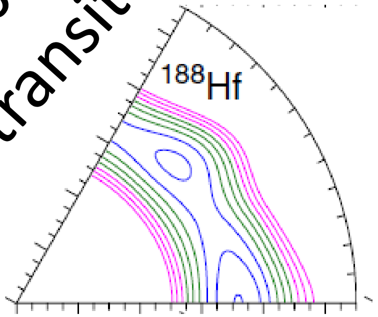
98 ≤ N ≤ 116

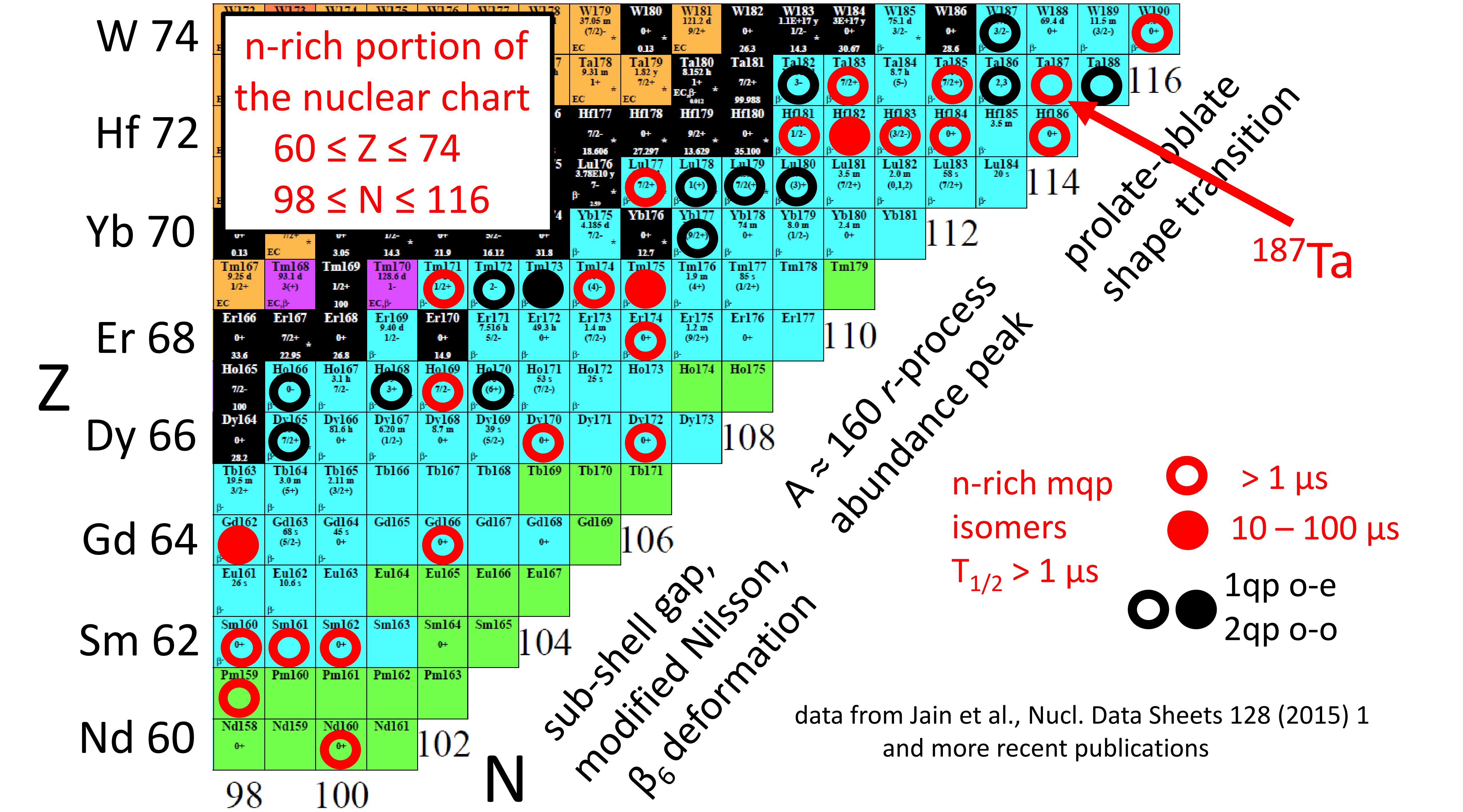
prolate-oblate shape transition

A ≈ 160 r-process abundance peak

sub-shell gap, modified Nilsson, β_6 deformation



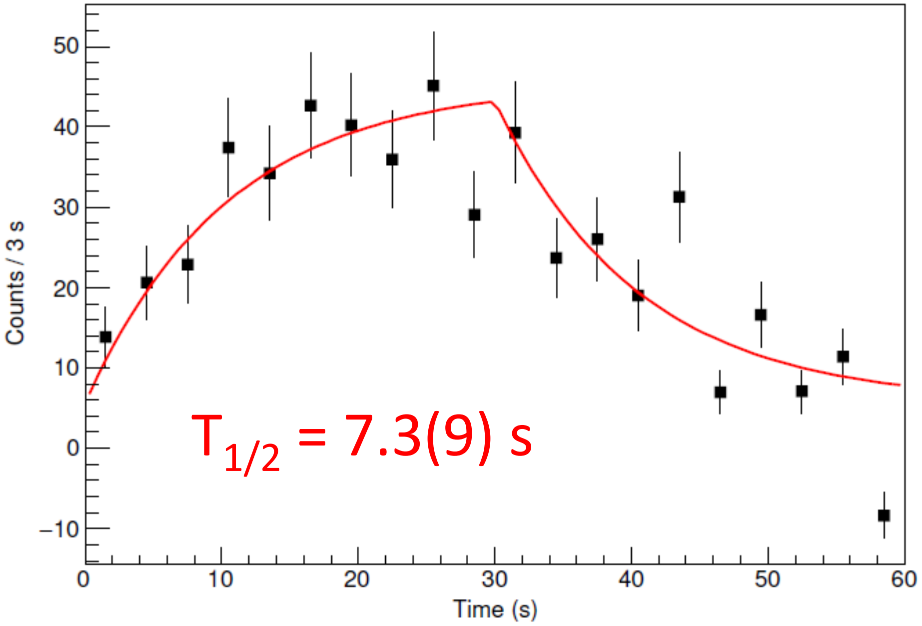




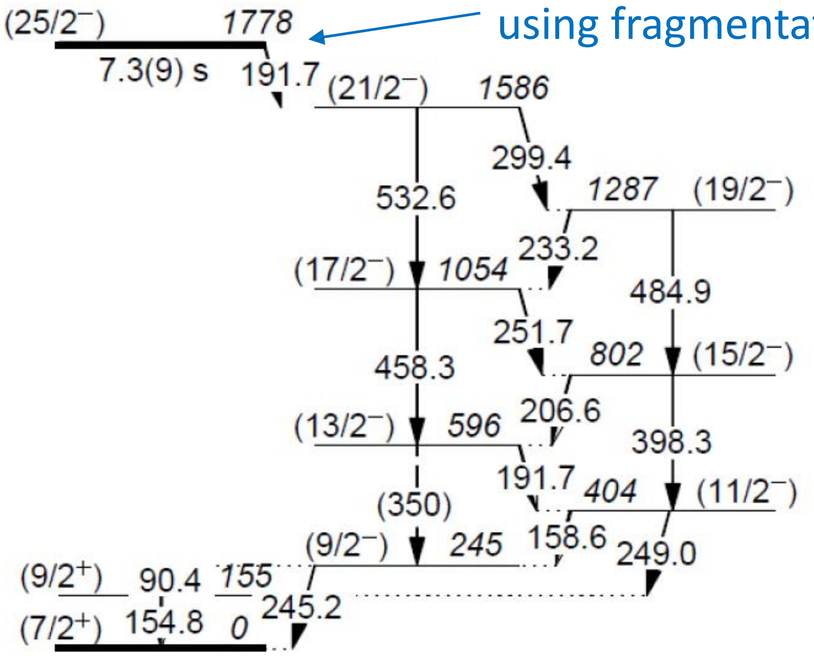
n-rich portion of the nuclear chart
60 ≤ Z ≤ 74
98 ≤ N ≤ 116
W 74
Hf 72
Yb 70
Er 68
Z
Dy 66
Gd 64
Sm 62
Nd 60
98
100
102
104
106
108
110
112
114
116
N
prolate-oblate shape transition
187Ta
A ≈ 160 r-process abundance peak
sub-shell gap, modified Nilsson, β6 deformation
n-rich mqp isomers
T1/2 > 1 μs
> 1 μs
10 – 100 μs
1qp o-e
2qp o-o
data from Jain et al., Nucl. Data Sheets 128 (2015) 1
and more recent publications

^{187m1}Ta KISS data (RIKEN) – KEK isotope separation system

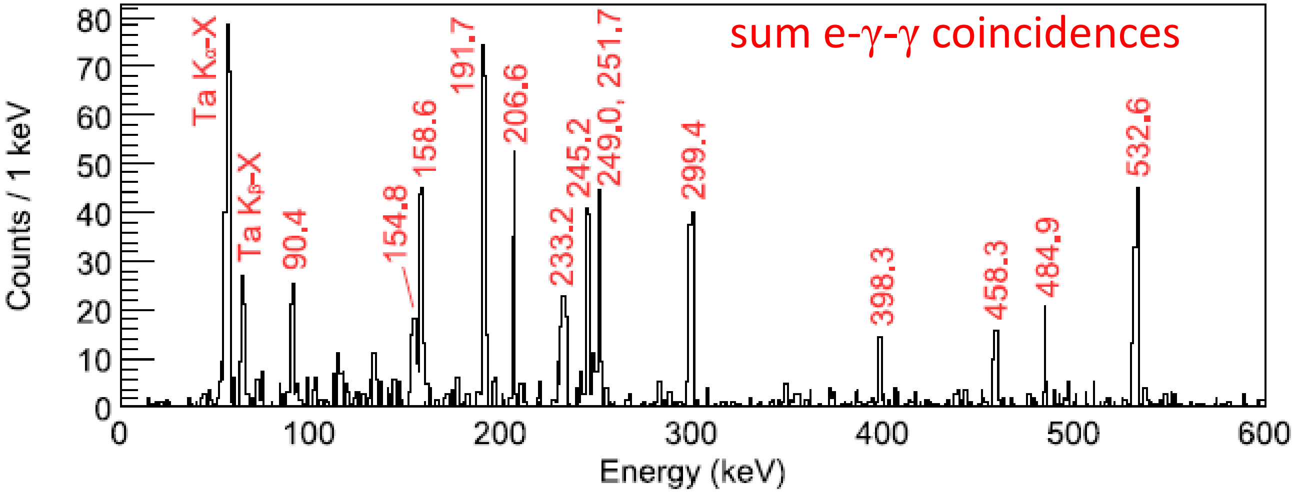
Walker, Hirayama et al. Phys. Rev. Lett. 125 (2020) 192505



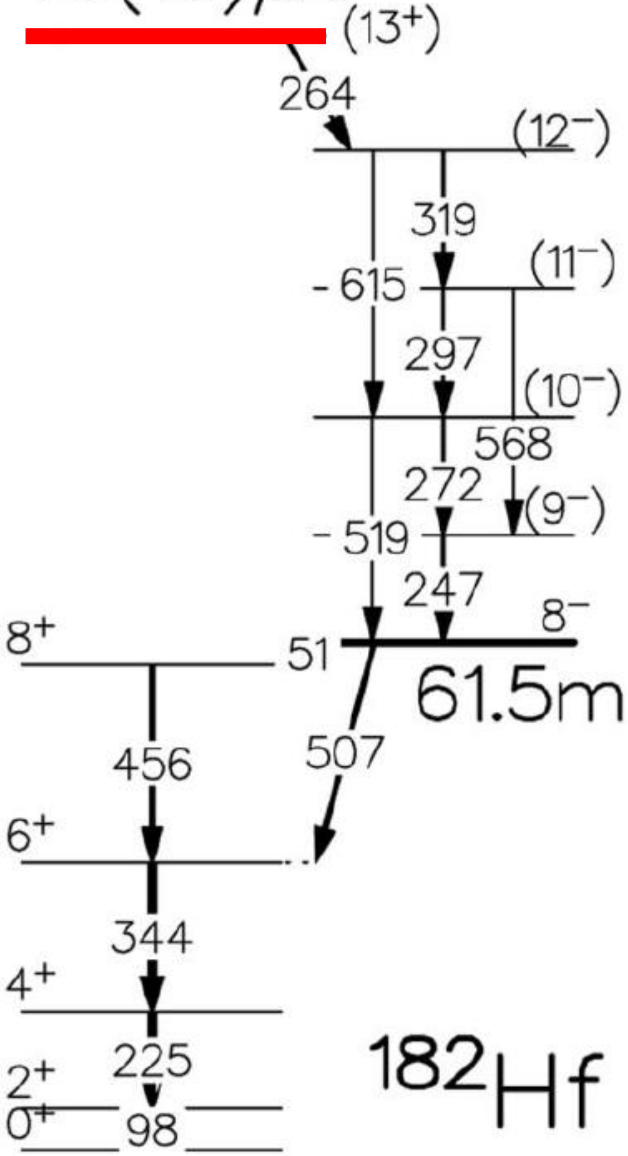
isomer first identified in ESR (GSI) using fragmentation



level scheme from MNT reactions



$T_{1/2} = 40(10)\mu s$



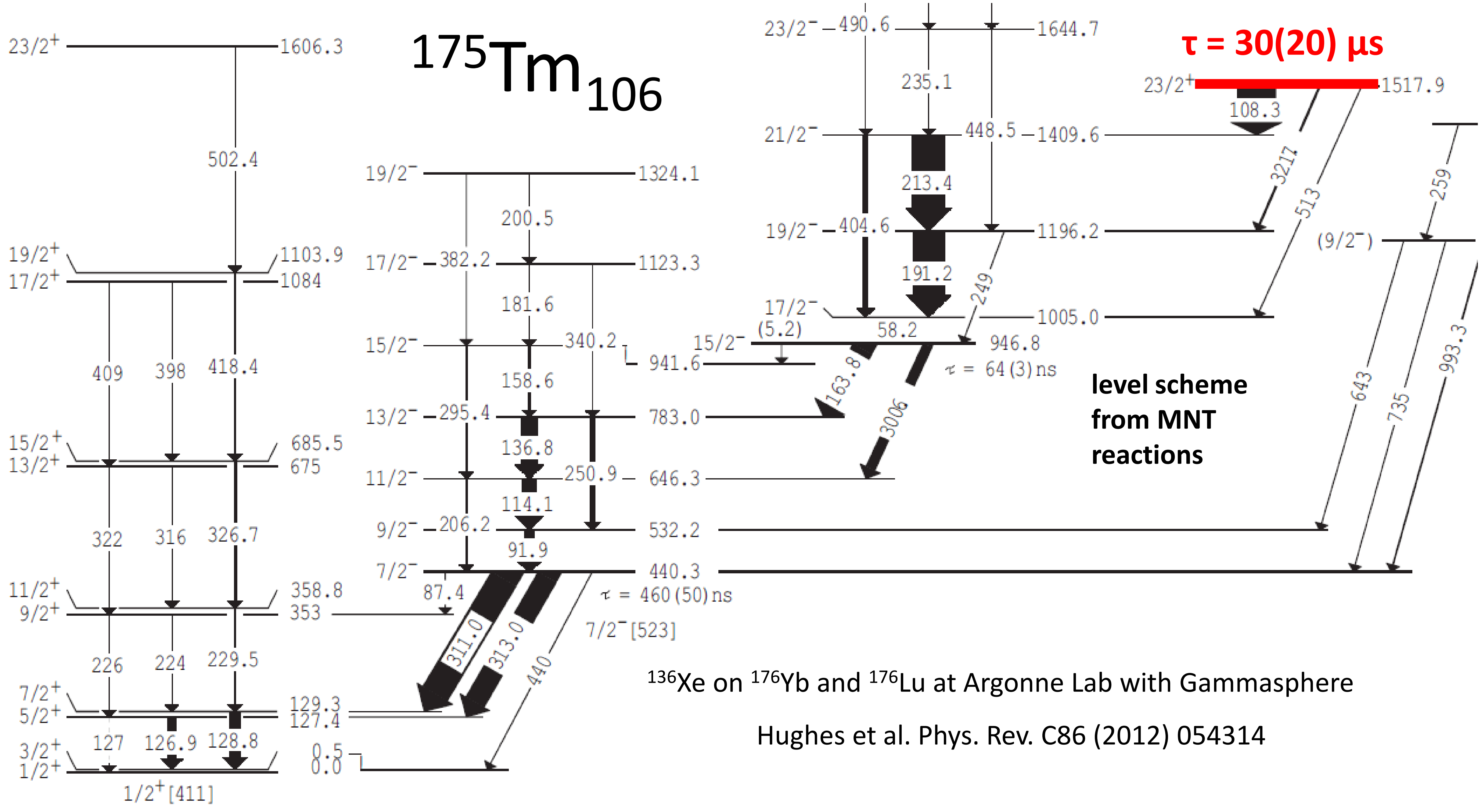
level scheme from MNT reactions

^{208}Pb on ^{180}Hf at Argonne Lab with Argonne-Notre Dame array (12 x Ge)

D'Alarcao et al. Phys. Rev. C59 (1999) R1227

$^{175}Tm_{106}$

τ = 30(20) µs

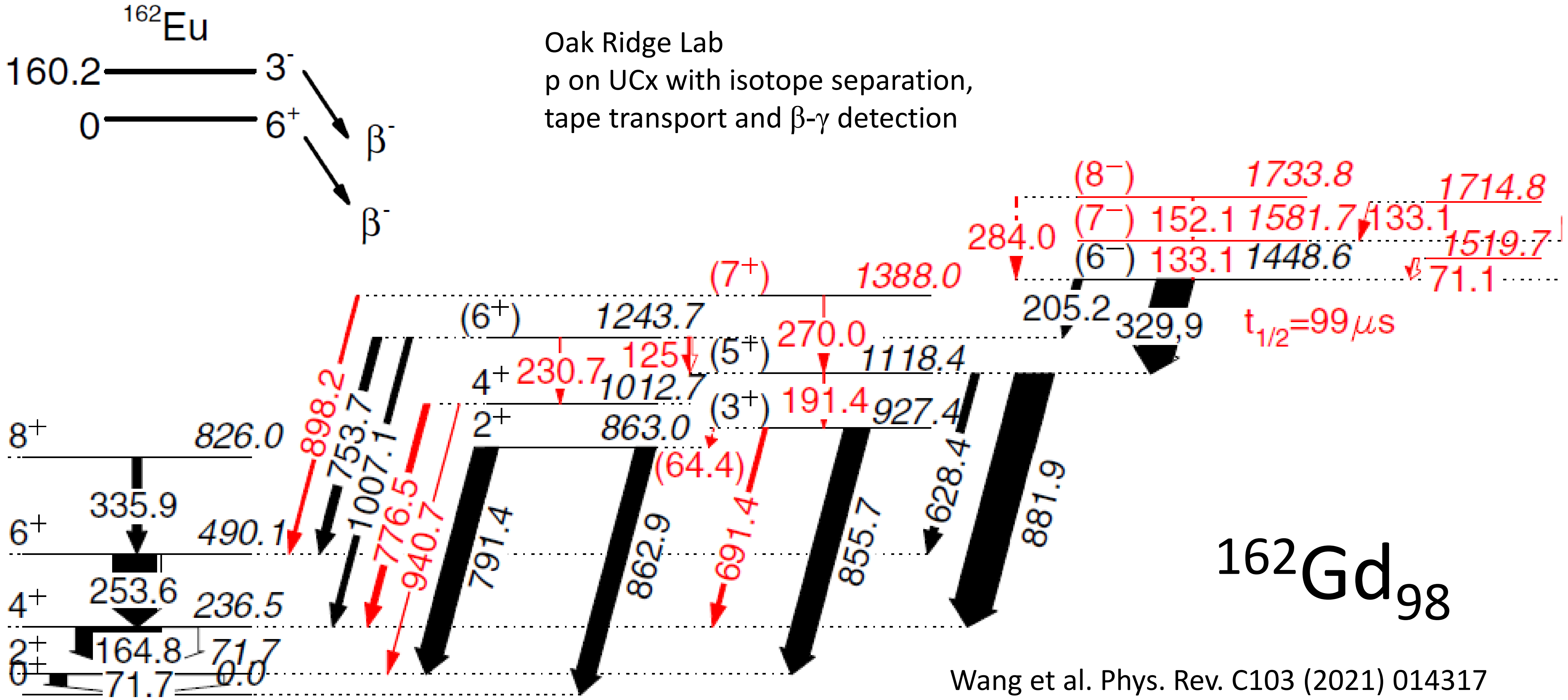


level scheme from MNT reactions

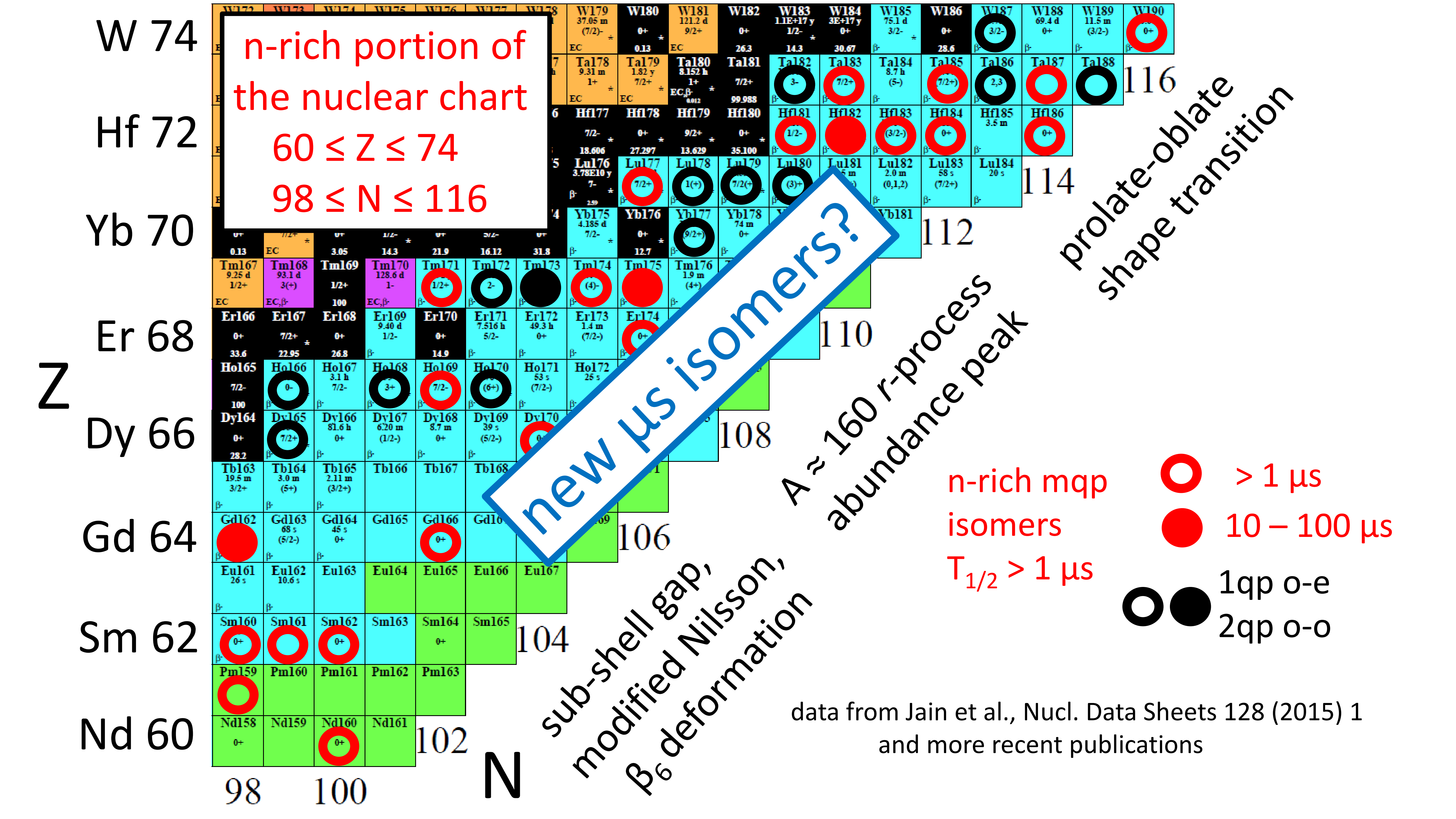
^{136}Xe on ^{176}Yb and ^{176}Lu at Argonne Lab with Gammasphere

Hughes et al. Phys. Rev. C86 (2012) 054314

Oak Ridge Lab
p on UCx with isotope separation,
tape transport and β-γ detection



Wang et al. Phys. Rev. C103 (2021) 014317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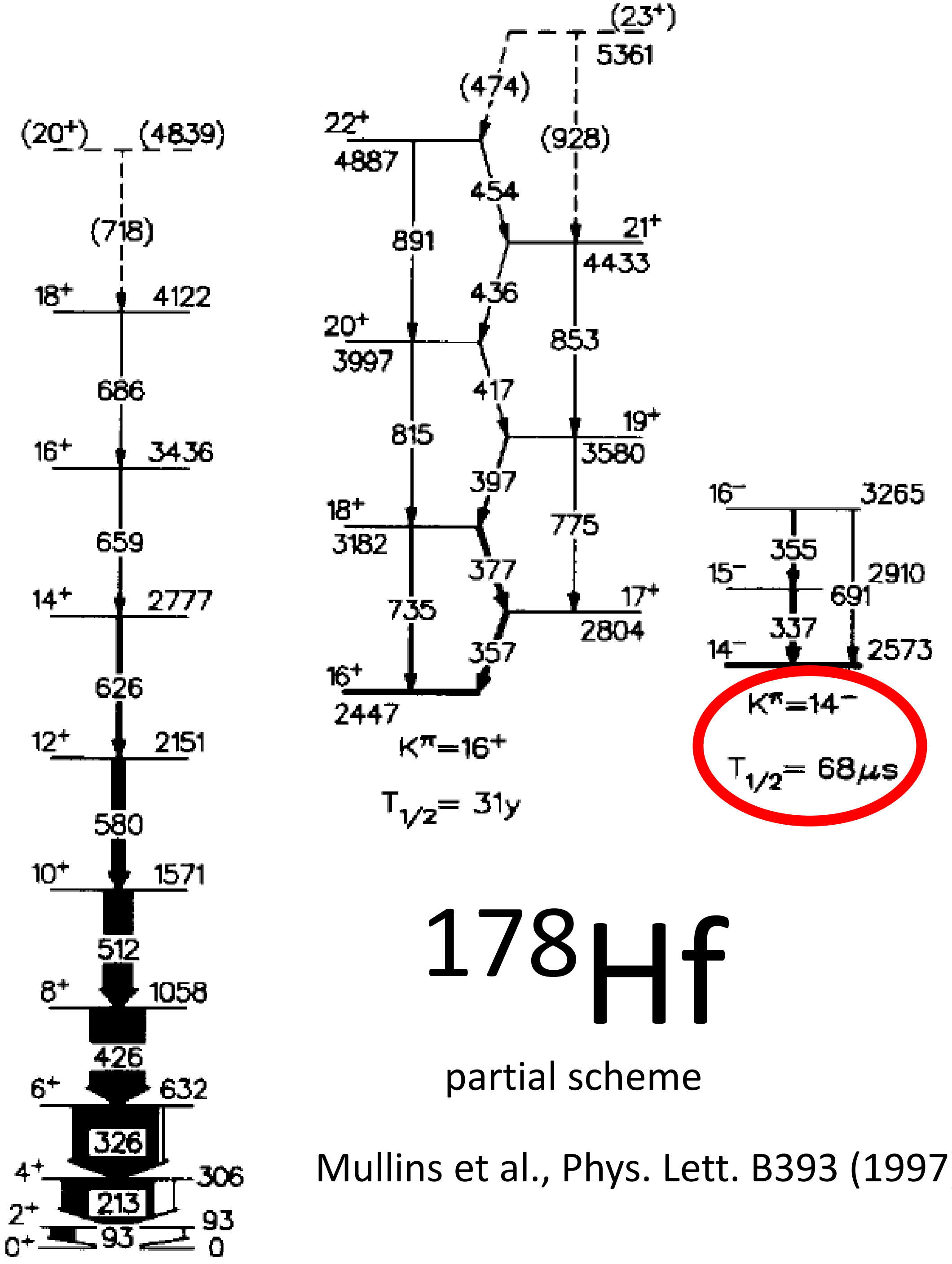
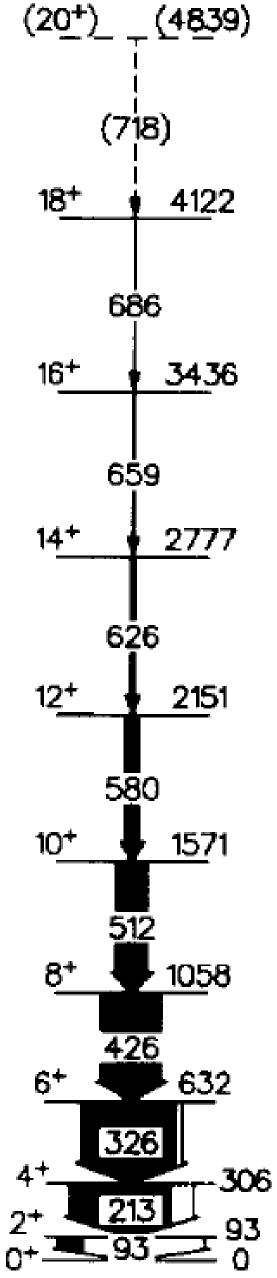
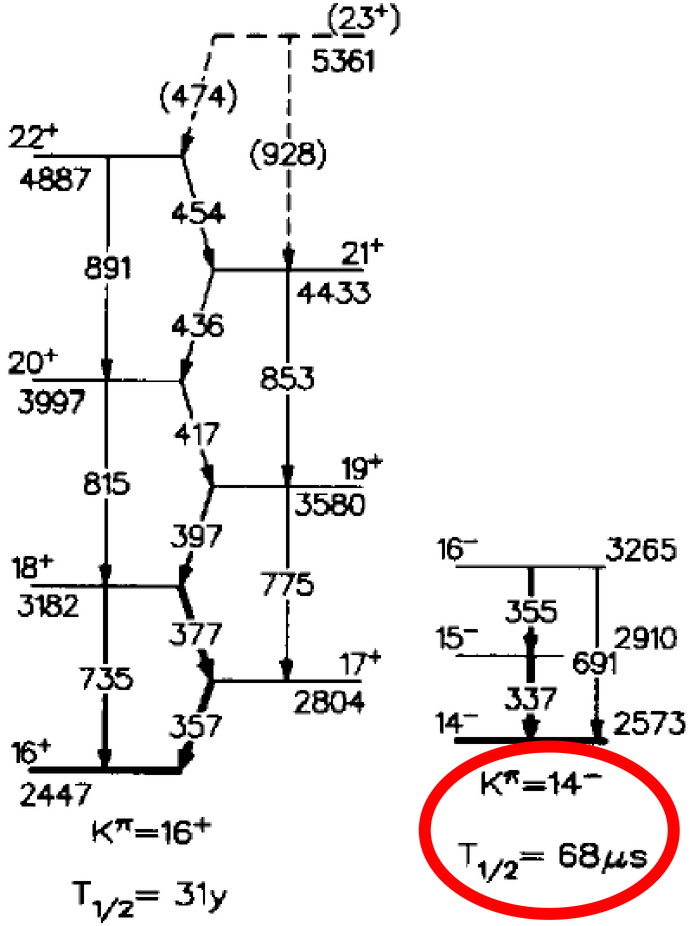


^{178}Hf

partial scheme

Mullins et al., Phys. Lett. B393 (1997) 279

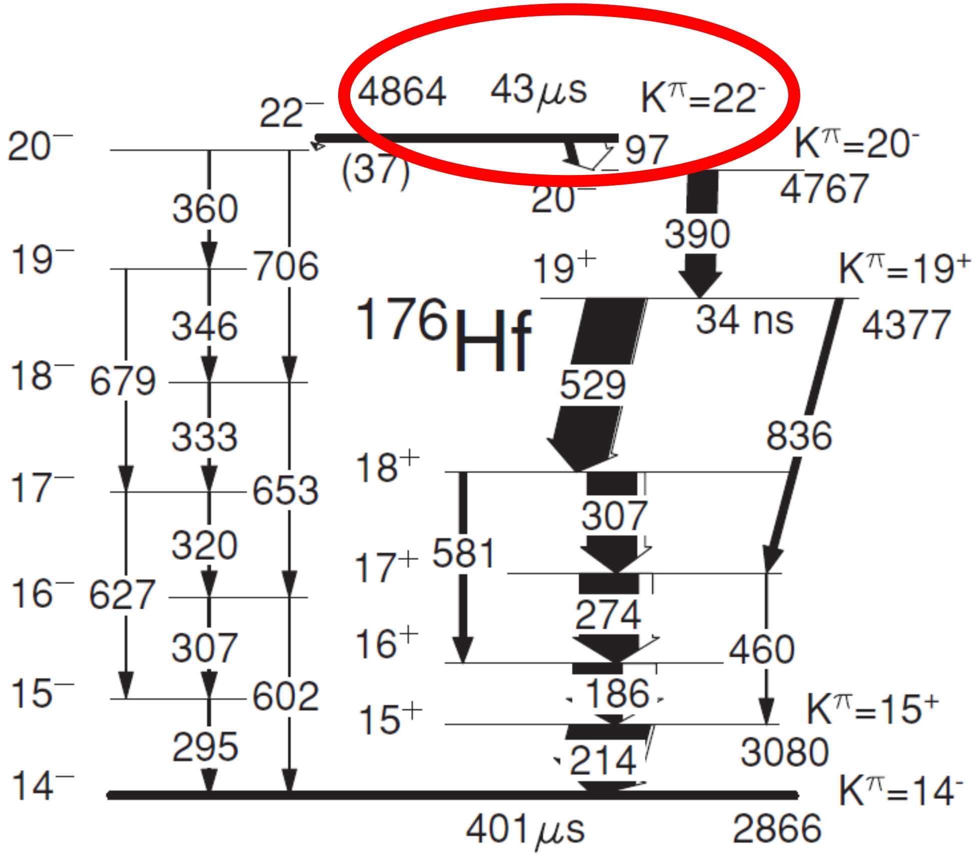




^{178}Hf

partial scheme

Mullins et al., Phys. Lett. B393 (1997) 279

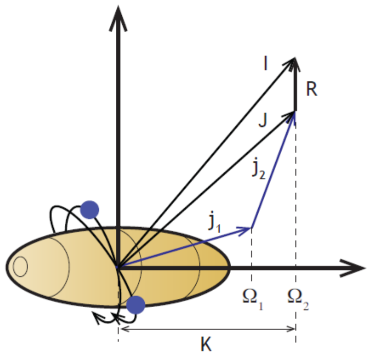


partial scheme

Mukherjee et al., Phys. Rev. C82 (2010) 054316

summary: n-rich region of high-K isomers

- seeing across 10 – 100 μs isomers requires dedicated effort
- a variety of physics opportunities present themselves
- several isomers are good candidates: e.g. ^{162}Gd, ^{175}Tm, ^{182}Hf …
- possibility of new μs isomers



thank you!