Exotic isomeric states

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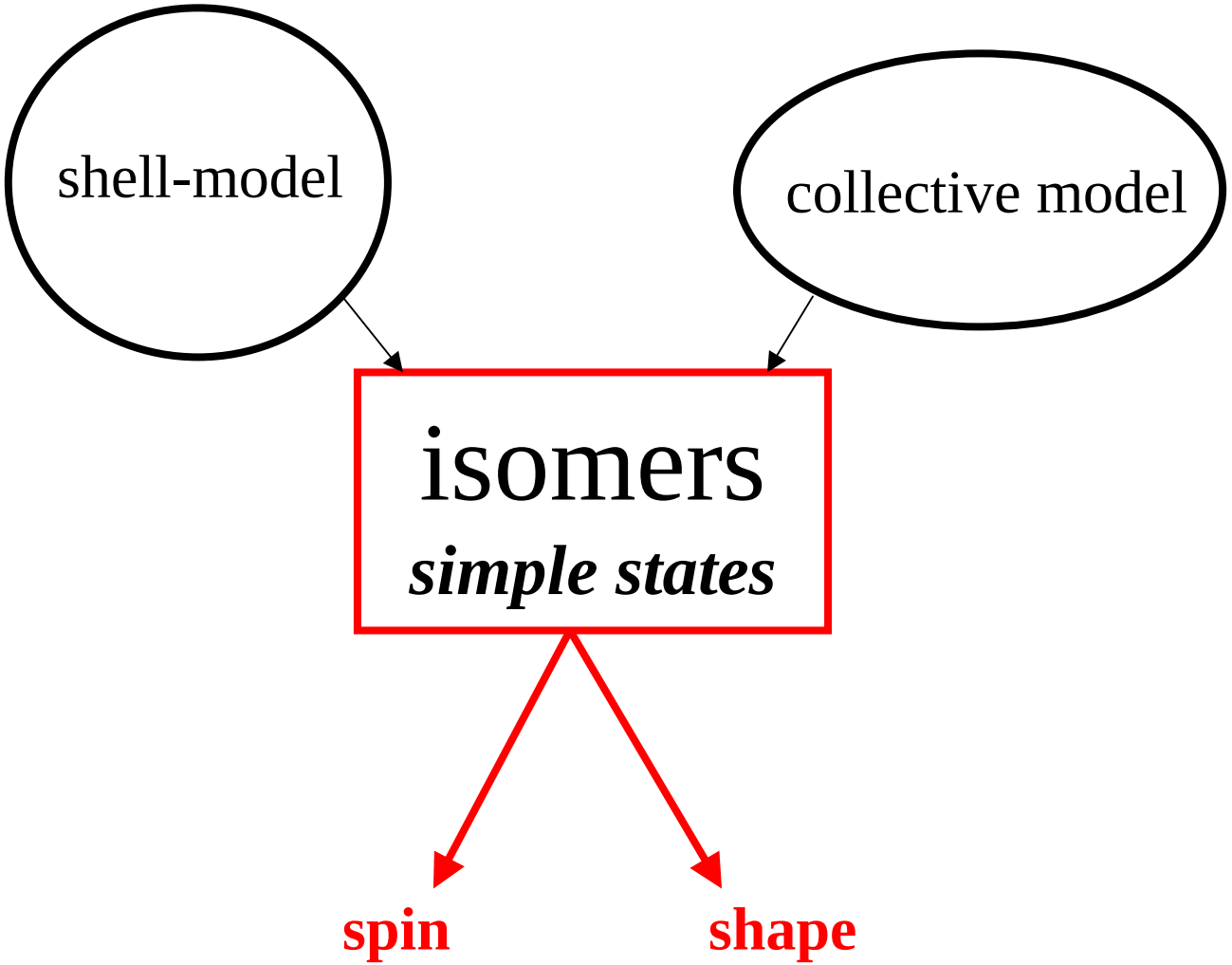
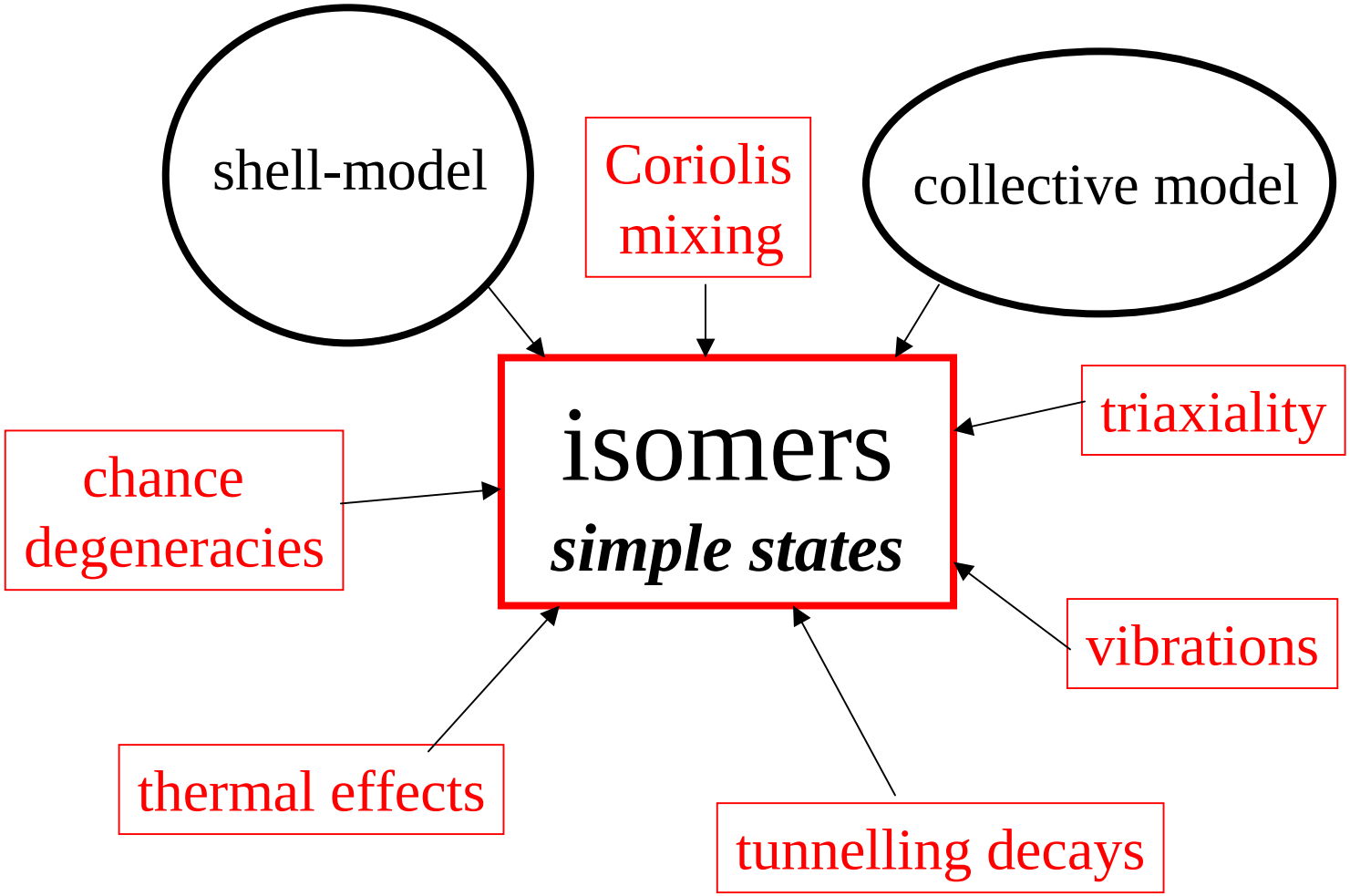
- extreme isomers
- isomer beams
- atomic-nuclear interface
- induced isomer decay

Picasso 1955

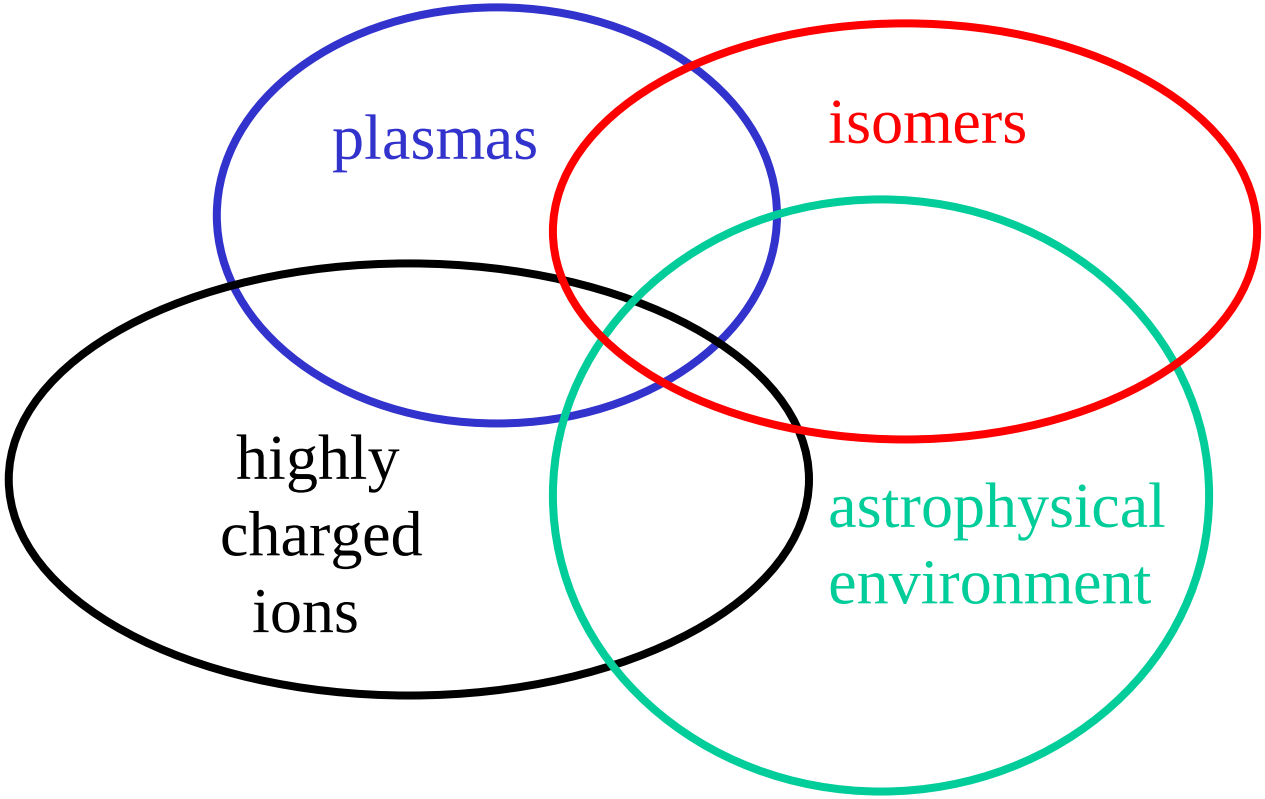
Don Quixote: Cervantes 1605


shell-model
collective model
isomers
simple states
spin
shape


shell-model
Coriolis mixing
collective model
isomers
simple states
chance degeneracies
triaxiality
vibrations
thermal effects
tunnelling decays

atomic-nuclear interface

vital role of orbiting electrons



atomic-nuclear interface

Well known

Atomic hyperfine structure and isotope shifts

Electron capture (EC)

Internal electron conversion (IC)

Bound-state β decay

Barely known

Nuclear excitation by electronic transition (NEET)[1]

Bound-state internal conversion (BIC)[2]

Unconfirmed

Nuclear excitation by electron capture (NEEC)[3]

α decay rate modification via electron screening[4]

References: [1]Kishimoto et al., Phys. Rev. C74 (2006) 031301(R)
[2]Carreyre et al., Phys. Rev. C62 (2000) 024311
[3]Palffy et al., Phys. Rev A73 (2006) 012715
[4]Kettner et al., J. Phys. G32 (2006) 489

Extreme isomers ($T_{1/2} > 5$ ns)

long half-life:	^{180}Ta, 9^-, 75 keV, $>10^{15}$ y	PRC 1985
high spin**:	^{212}Fr, 34^+, 8.5 MeV, 24 μs	PRC 1990
high energy*:	^{152}Er, ~36, 13 MeV, 11 ns	PRC 1992
low energy*:	^{229}Th, $3/2^+$, ~5.5 eV, ~10 h?	PRC 2005
p rich:	^{94}Ag, 21^+, 5.8 MeV, 300 ms	Nature 2006
n rich:	^{130}Cd	preliminary
high mass:	^{270}Ds, (10^-), ~1 MeV, ~6 ms	EPJA 2001
	^{254}No, ~16, ~2.5 MeV, 184 μs	Nature 2006

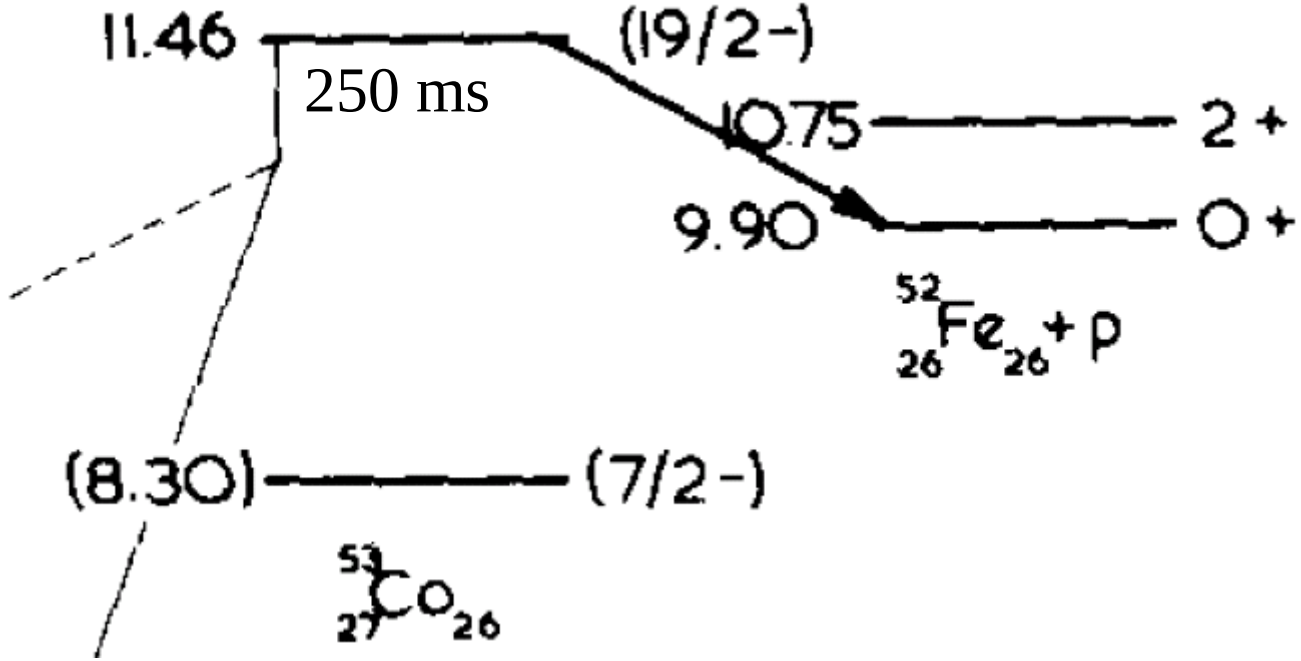
* *unbound to both p and n emission*

* *no fission: Walker et al., ZPA 1997*

* *Flambaum, PRL97 (2006) 092502*

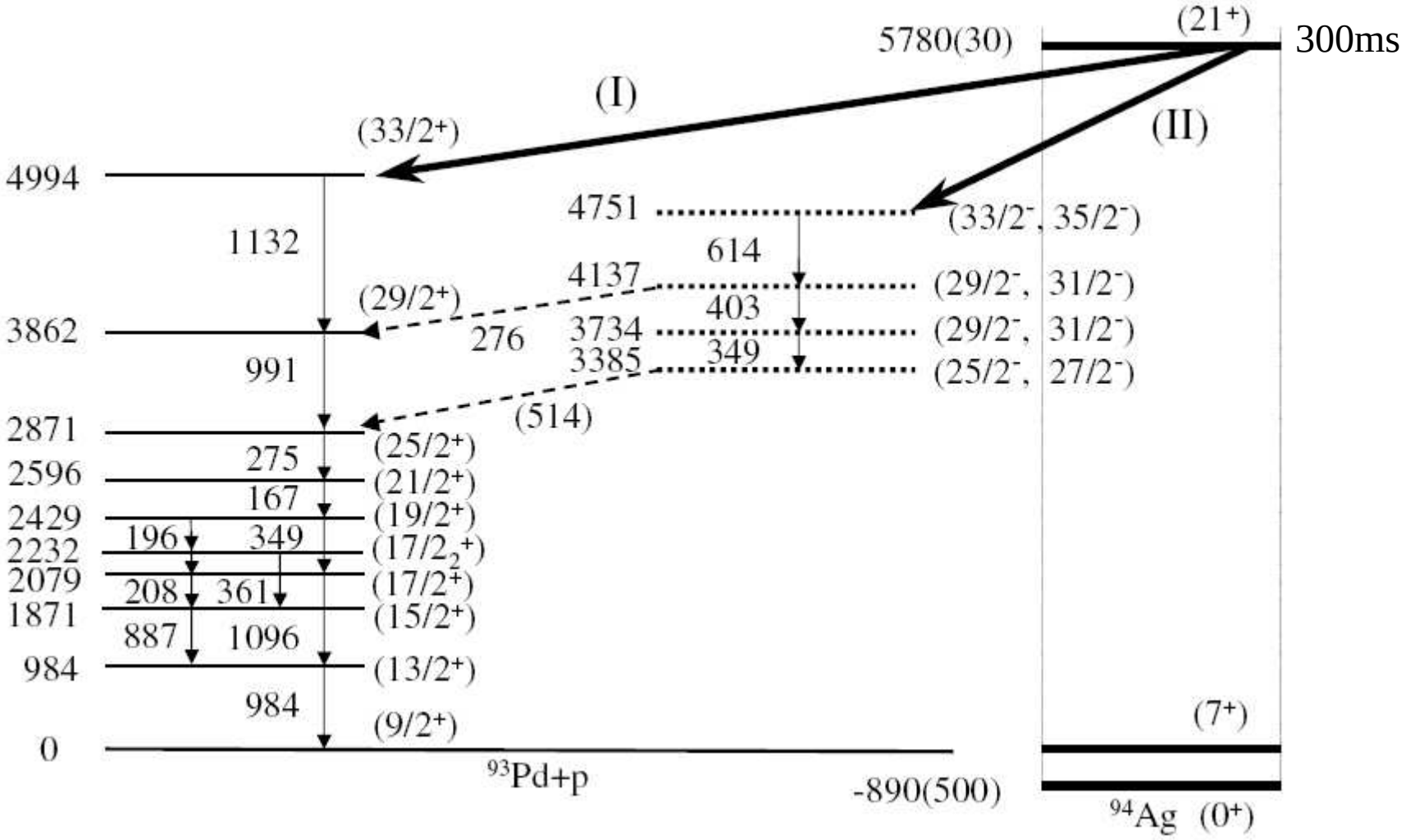
^{53}Co proton decay (1.56 MeV)

first example of proton radioactivity



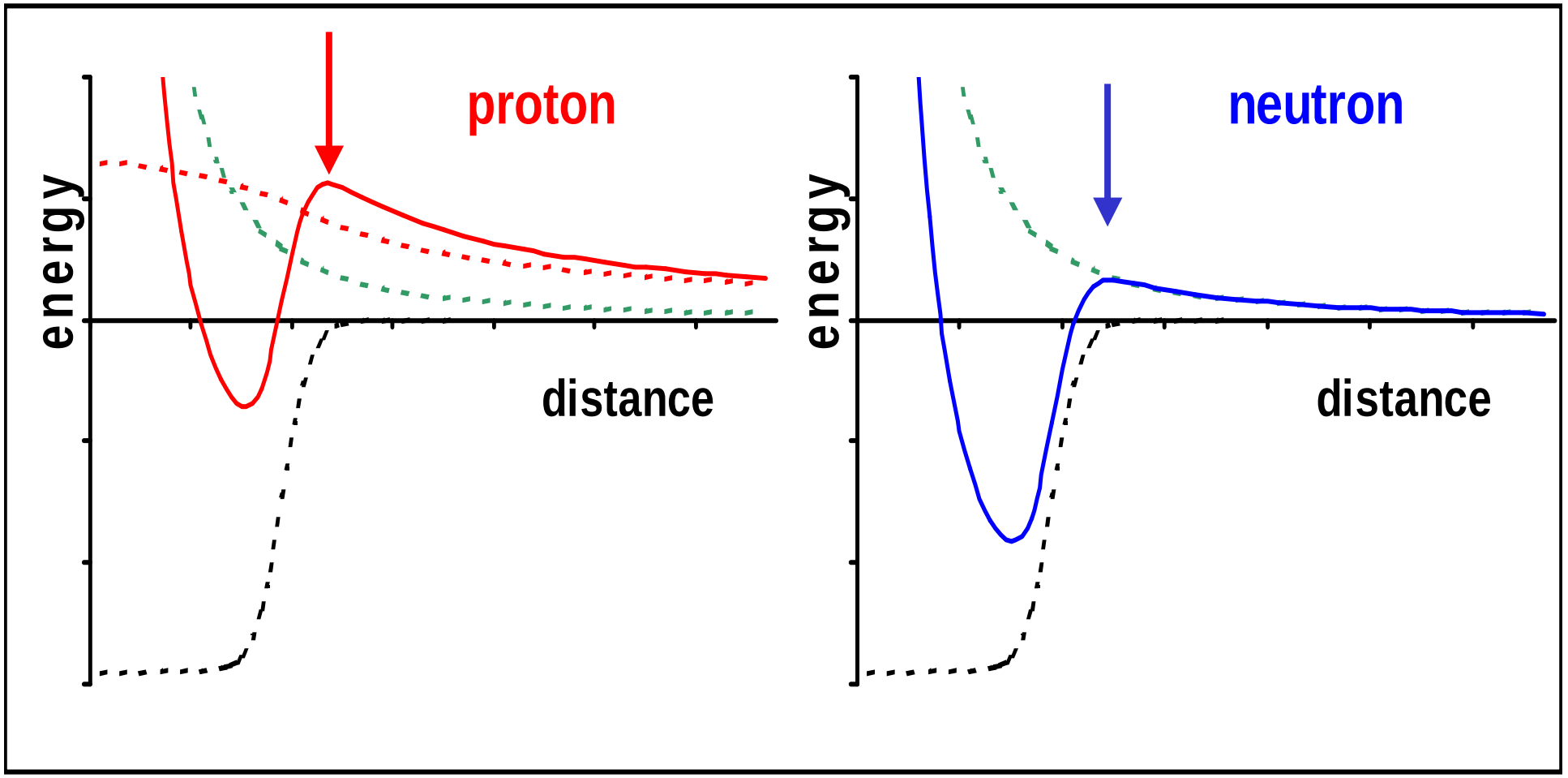
[Jackson et al., Phys. Lett. B33 (1970) 281]

^{94}Ag (21^+) proton decay



[Mukha et al., Phys. Rev. Lett. 95 (2005) 022501]

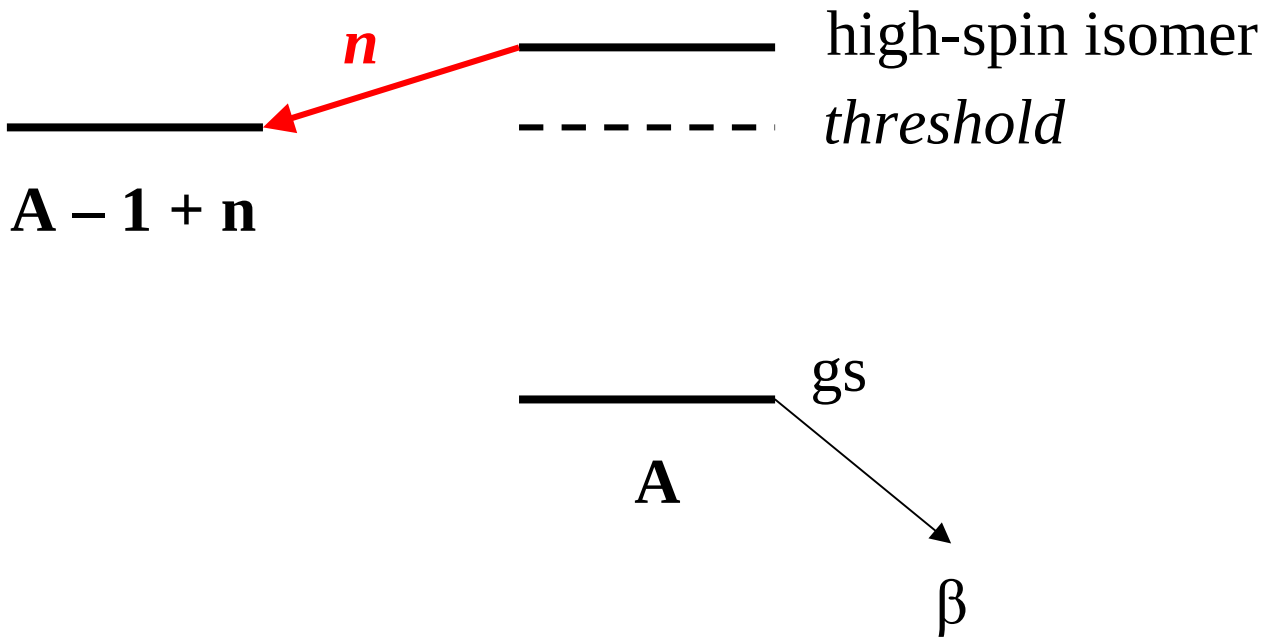
Coulomb and centrifugal barriers



$A \sim 100$, $\boldsymbol{I} \sim 5\hbar$

neutron radioactivity

unique to isomers?



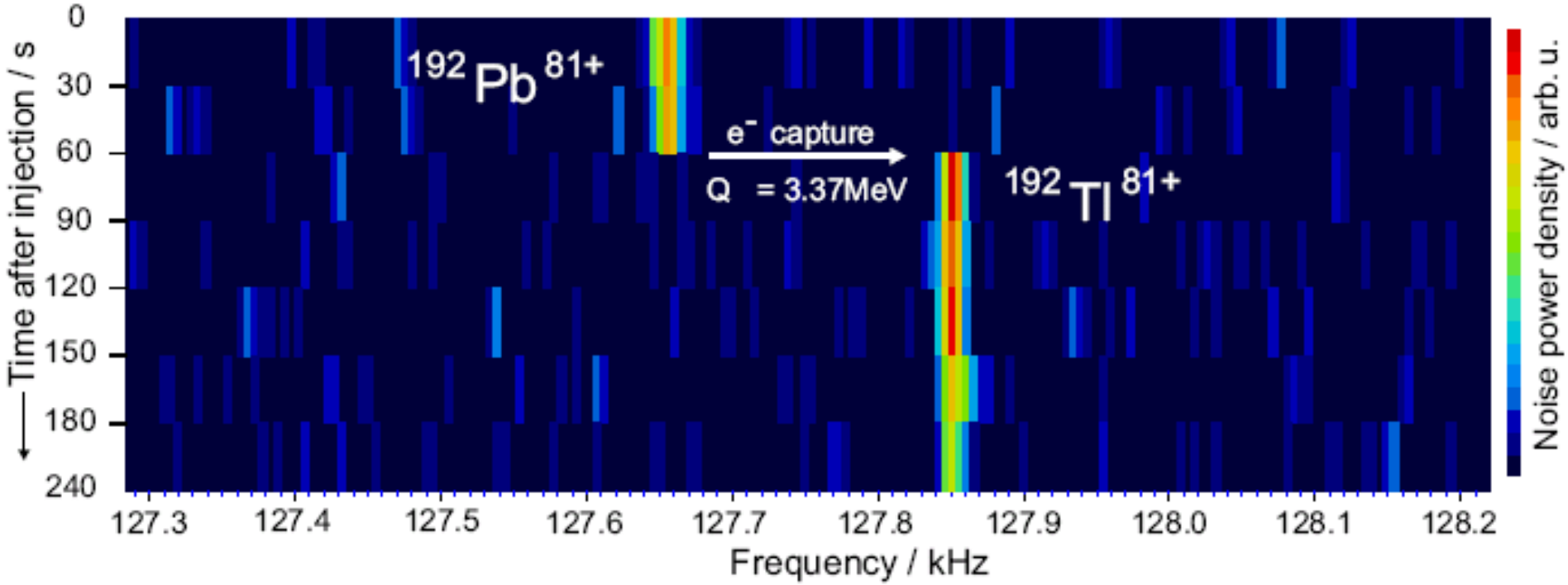
NB: ***mono-energetic neutrons ~1MeV***

neutron-decay isomer candidates

involving a high level of speculation

^{63}Ti, ^{67}Fe, ^{121}Zr: Peker et al., Phys. Lett. B36 (1971) 547
Bugrov et al., Sov. J. Nucl. Phys. 42 (1985) 34
SPIRAL-2 Physics Case (2006) p19-20
^{187}Hf: Walker, AIP Conf. Proc. 819 (2006) 16

ESR: single-ion in-ring decay

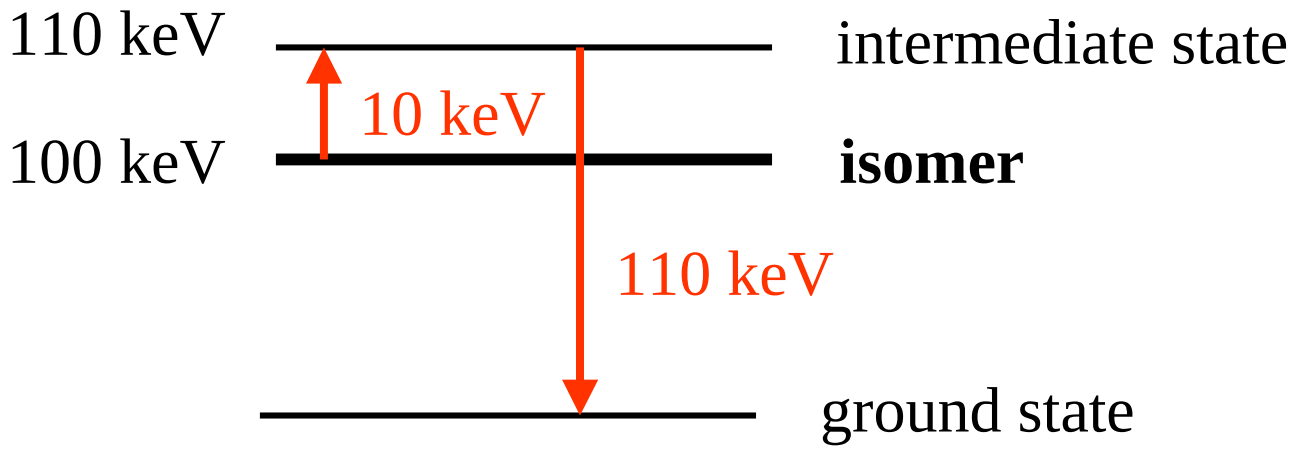


[Litvinov et al., Nucl. Phys. A756 (2005) 3]

photon-induced isomer de-excitation

a unique aspect of isomers

conceptual picture:



photon-induced isomer de-excitation

a unique aspect of isomers

nuclear batteries?

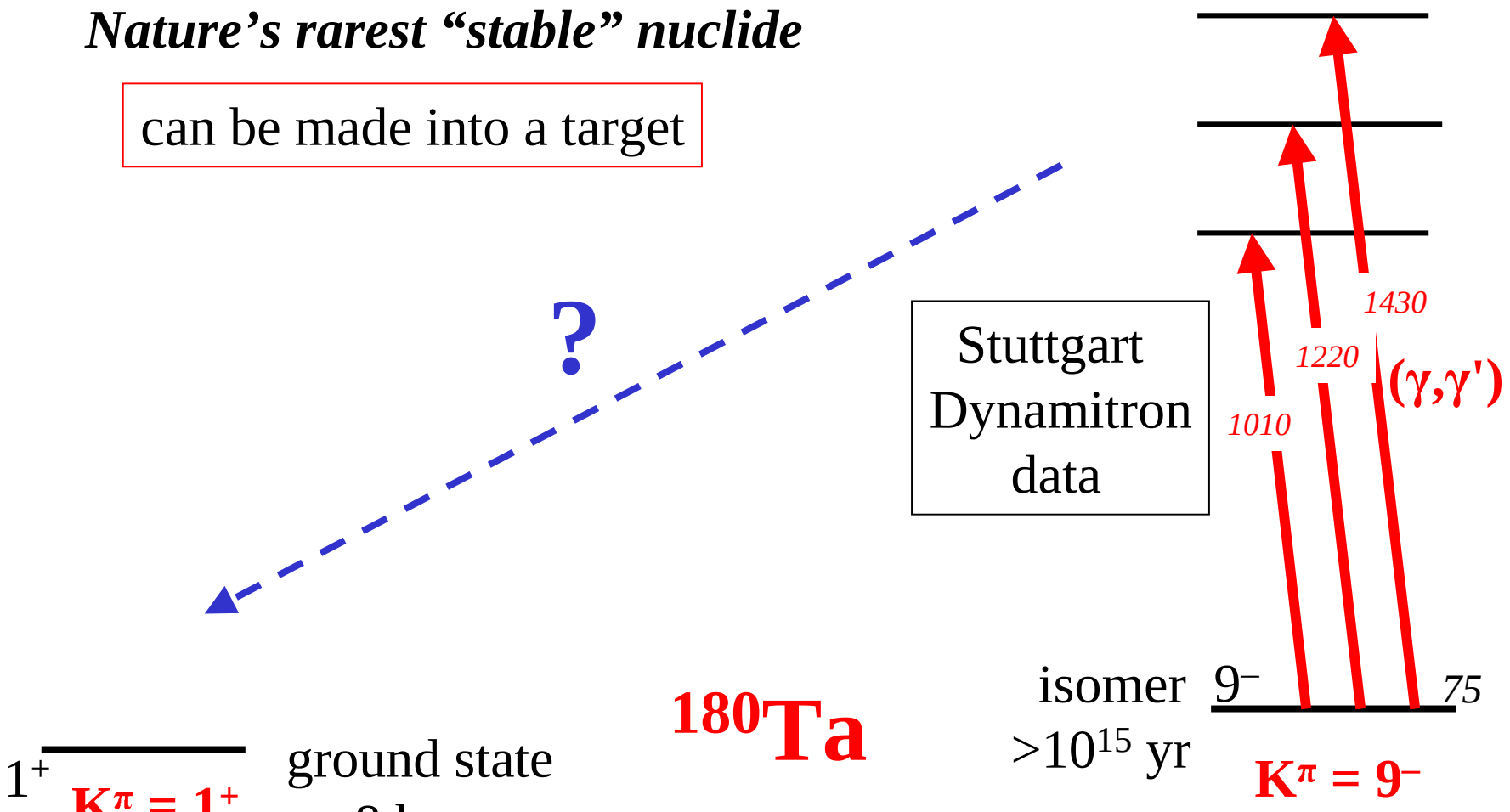
γ-ray lasers?

astrophysics implications?

^{180}Ta photoexcitation and decay

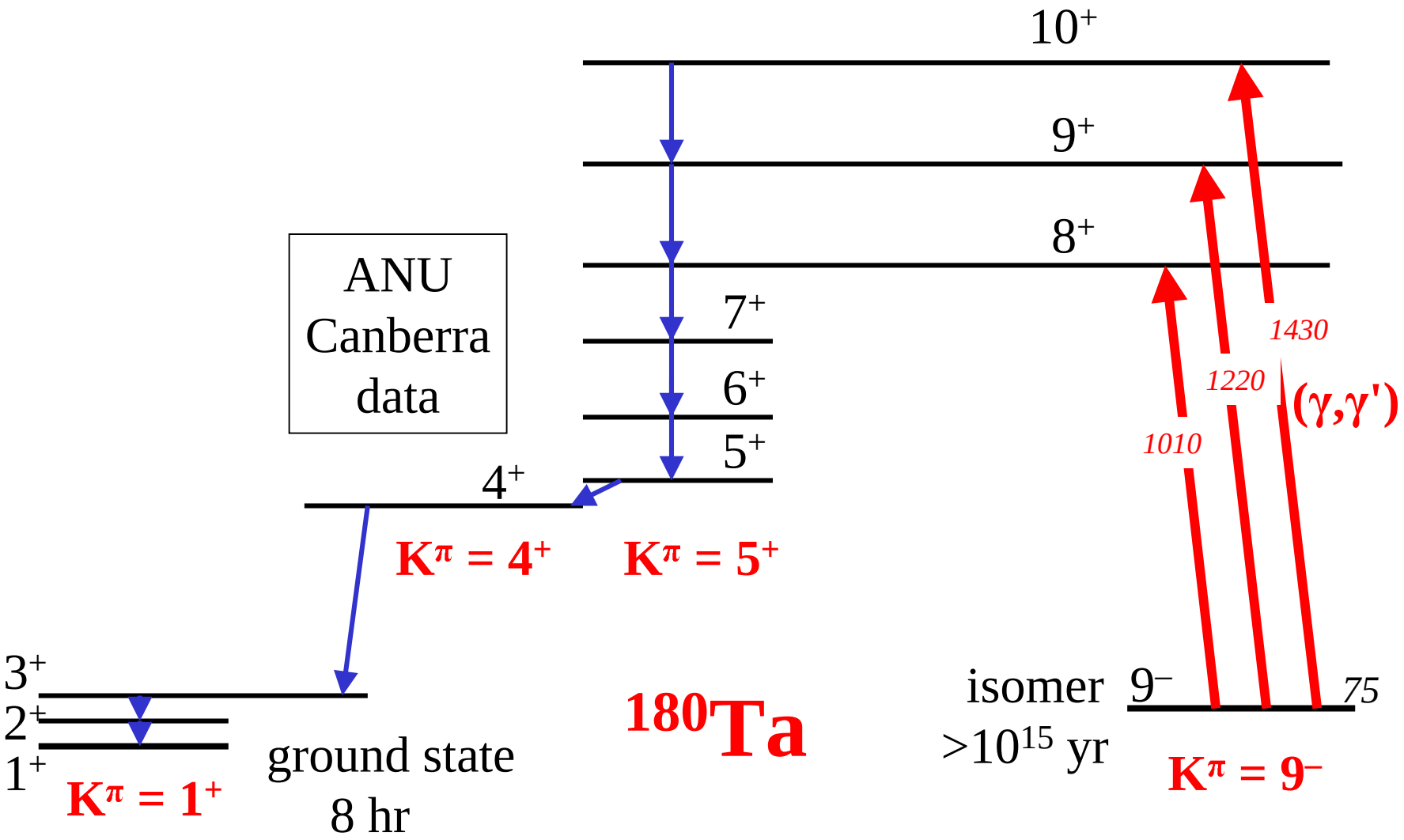
Nature's only "stable" isomer
Nature's rarest "stable" nuclide

can be made into a target



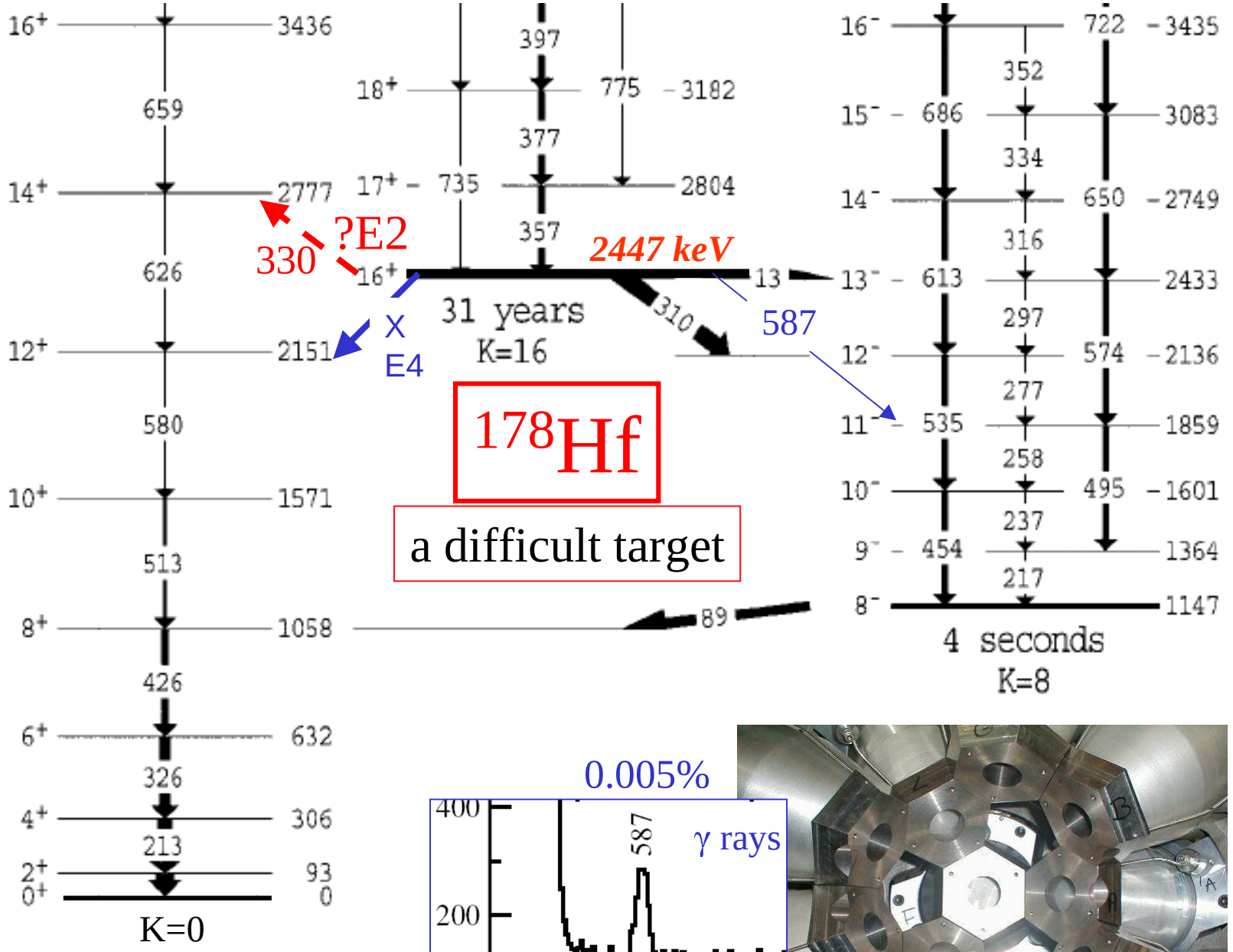
[Belic et al., Phys. Rev. Lett. 83 (1999) 5242]

^{180}Ta photoexcitation and decay



[Walker et al., Phys. Rev. C64 (2001) 061302(R)]

Hayes et al.: K mixing sets in for gsb I > 12



^{178}Hf

a difficult target

0.005%

8π spectrometer
TRIUMF, Canada

Walker and Dracoulis, Hyp. Int. 135 (2001) 83
Smith et al., Phys. Rev. C68 (2003) 031302
Hayes et al., Phys. Rev. Lett. 96 (2006) 042505

isomer target *vs.* isomer beam

stable beam

e.g. ^{208}Pb

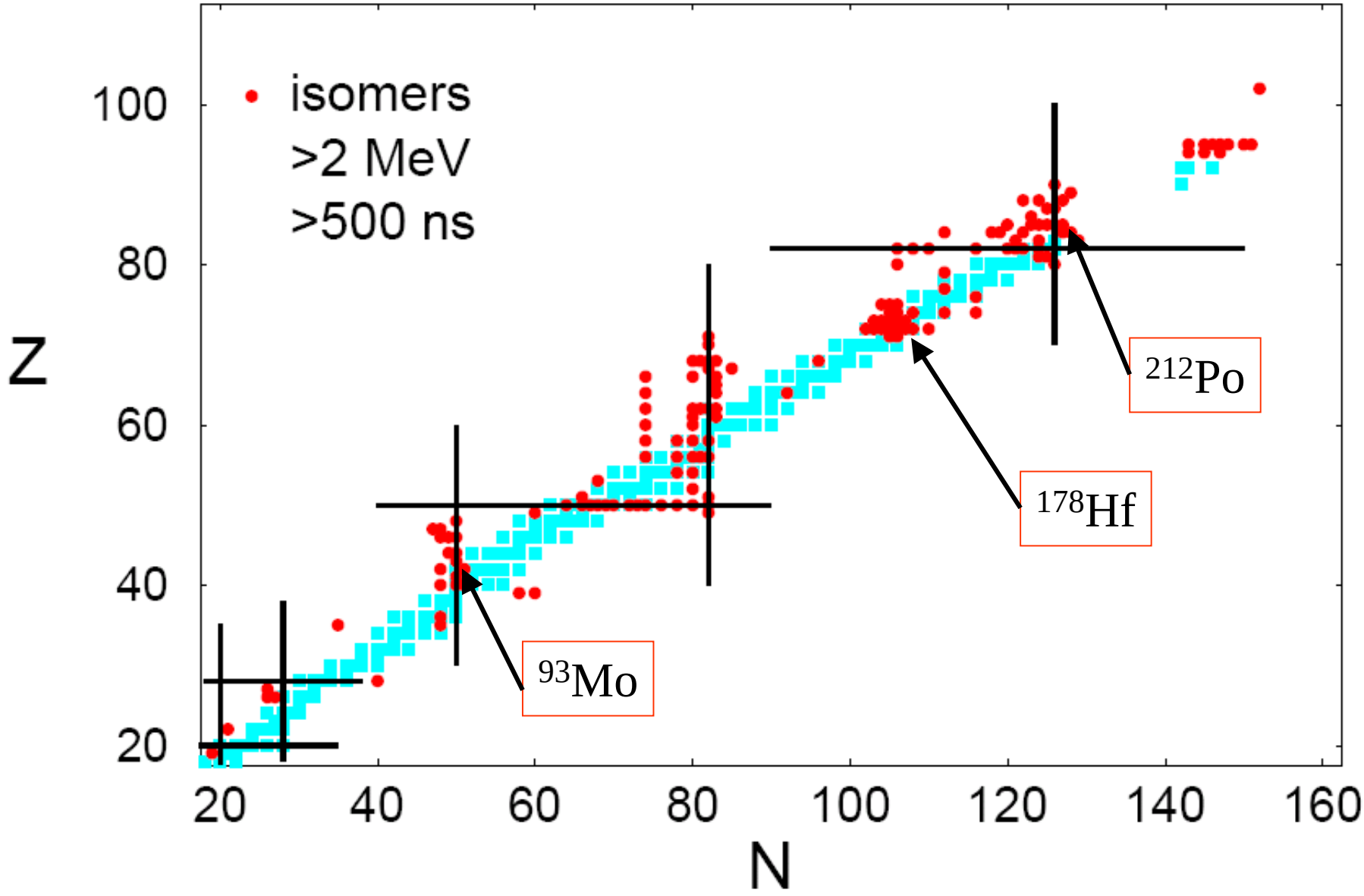
isomer target
e.g. ^{178m2}Hf
~10^{15} nuclei
~10^{6} decays/sec background

isomer beam

e.g. ^{178m2}Hf
~10^{6} nuclei/sec
~10^{5} sec measurement

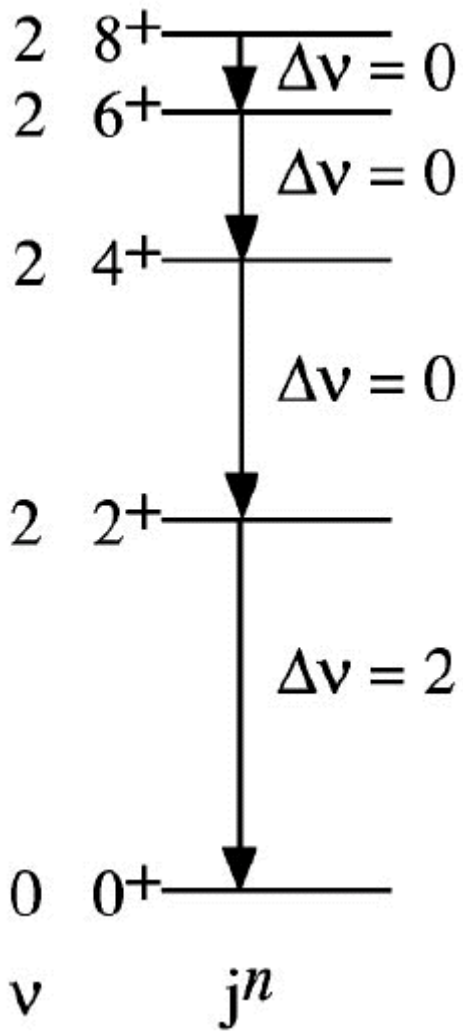
stable target
e.g. ^{208}Pb
<100 decays/sec background

some potential isomer beams



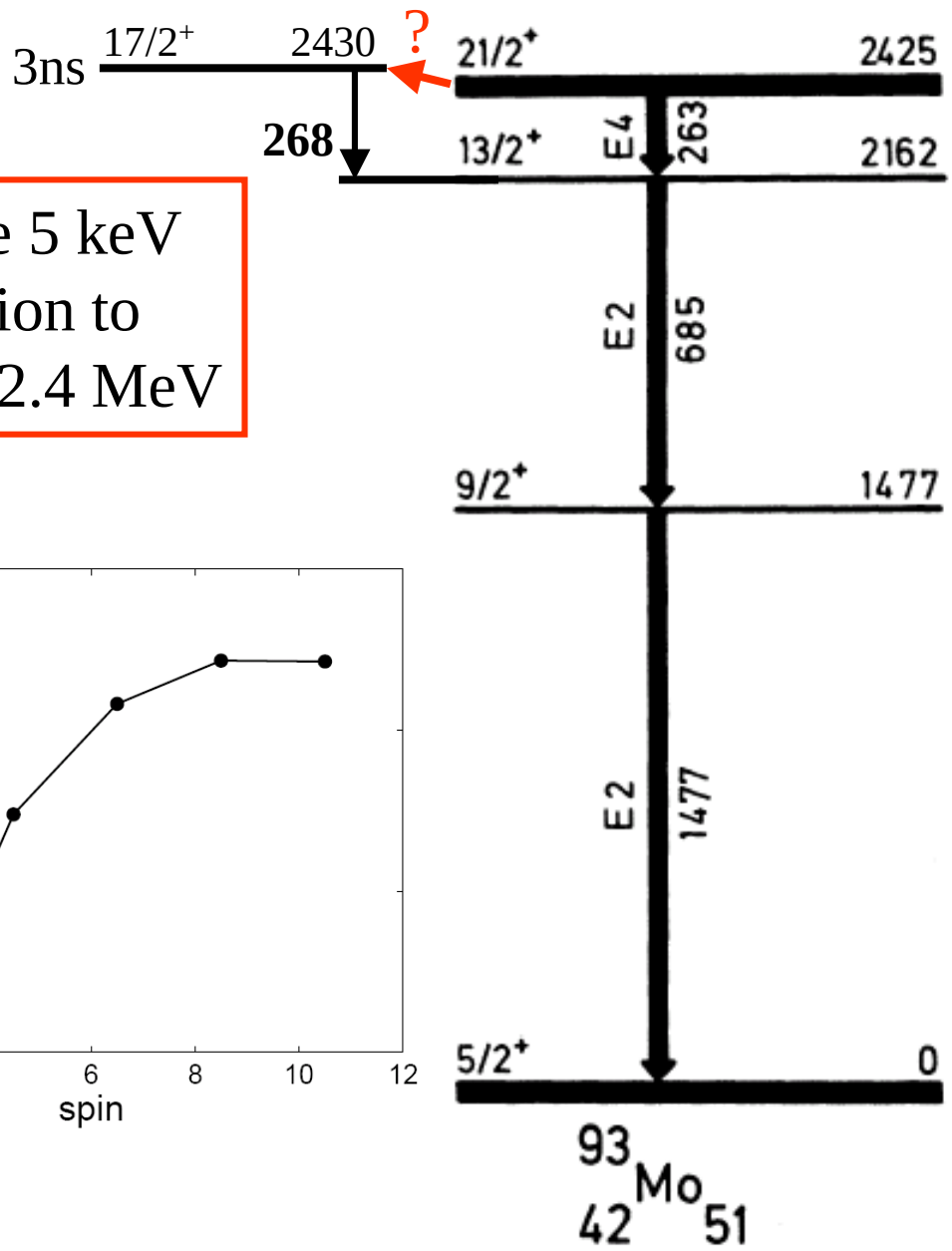
Seniority coupling scheme

example: $(g_{9/2})^2$



[Ressler et al., Phys. Rev. C69 (2004) 034317]

^{93}Mo



$(\pi g_{9/2})^2, \nu d_{5/2}$

possible isomer beam

possible 5 keV transition to release 2.4 MeV

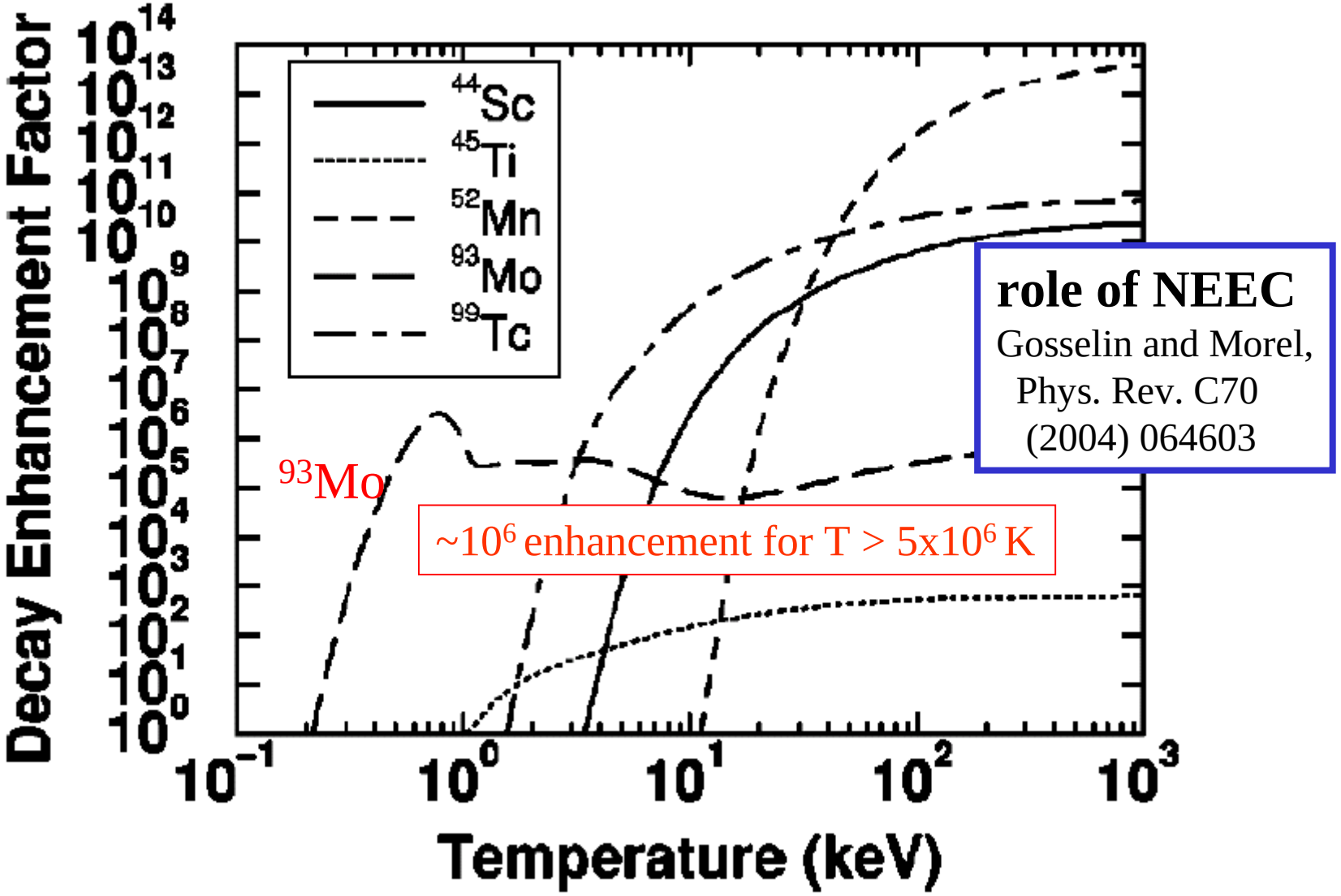
role of NEEC

Gosselin and Morel, Phys. Rev. C70 (2004) 064603

4000y

[Hagn et al., Phys. Rev. C23 (1981) 2252]

“Enhanced nuclear level decay in hot dense plasmas”

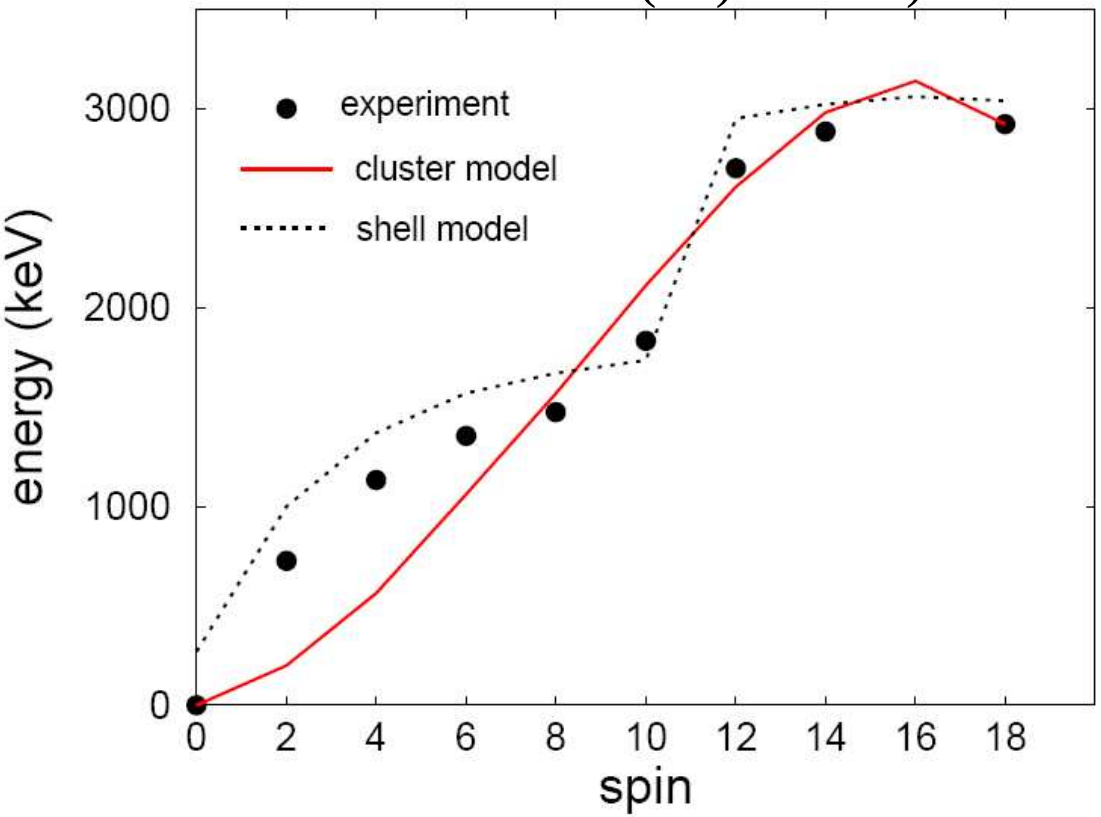


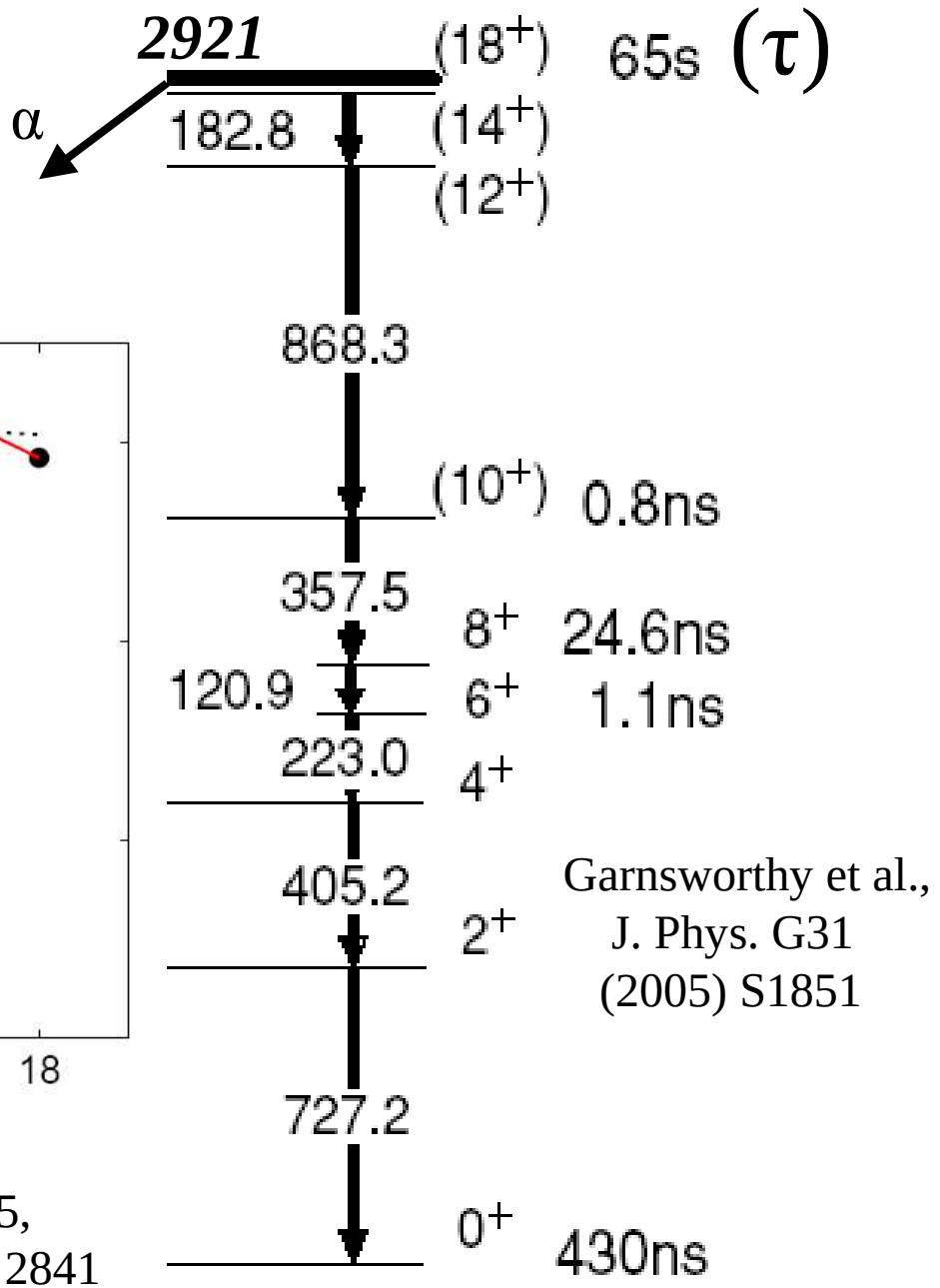
role of NEEC

Gosselin and Morel, Phys. Rev. C70 (2004) 064603

^{212}Po

Coulex 18^+à 16^+: ~20 keV (shell model)
~200 keV (cluster model
B(E2) ~ 5 Wu)



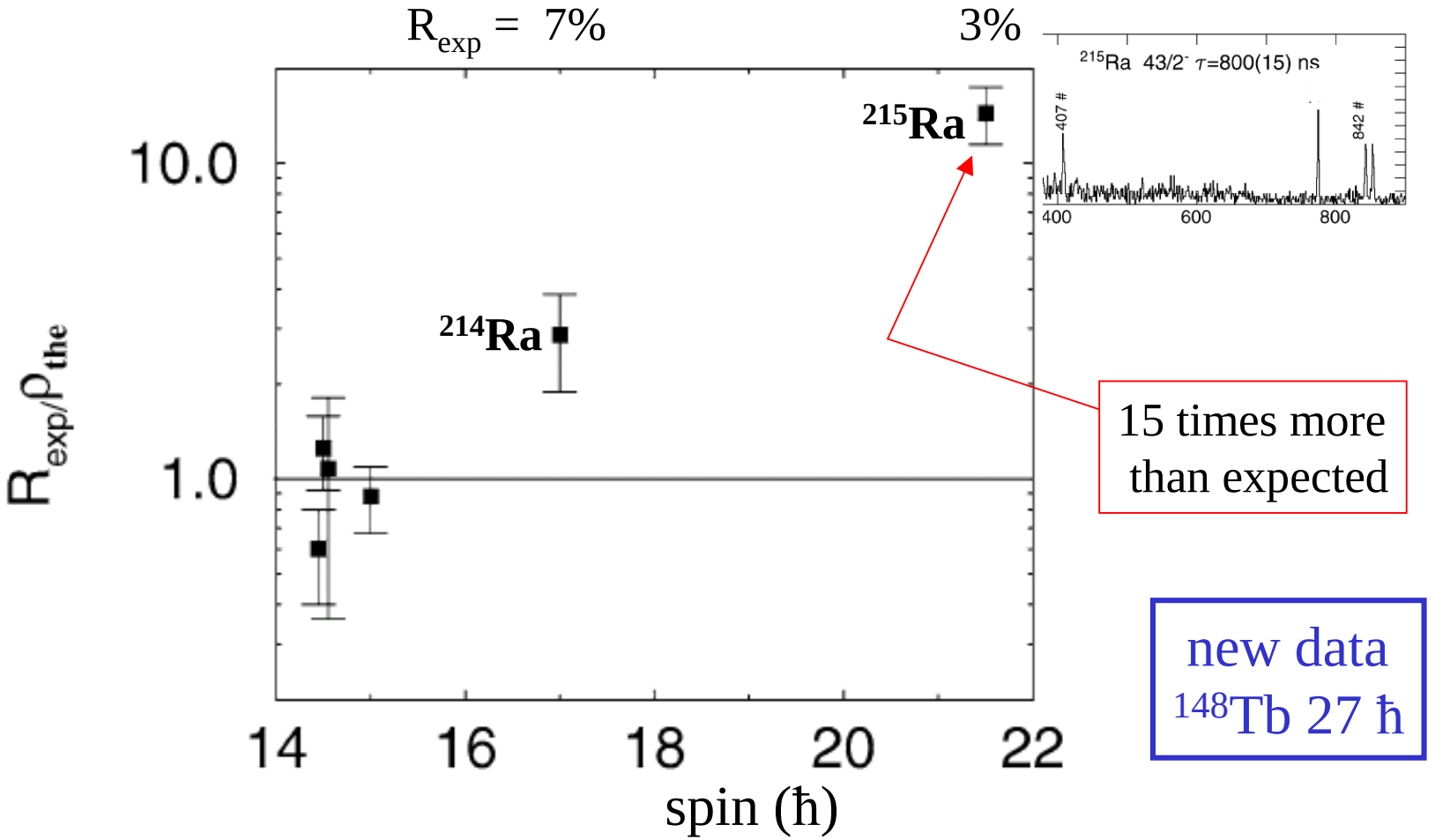


Garnsworthy et al., J. Phys. G31 (2005) S1851

Cluster model: Buck et al., J. Phys. G30 (2004) 65,
Phys. Rev. C53 (1996) 2841

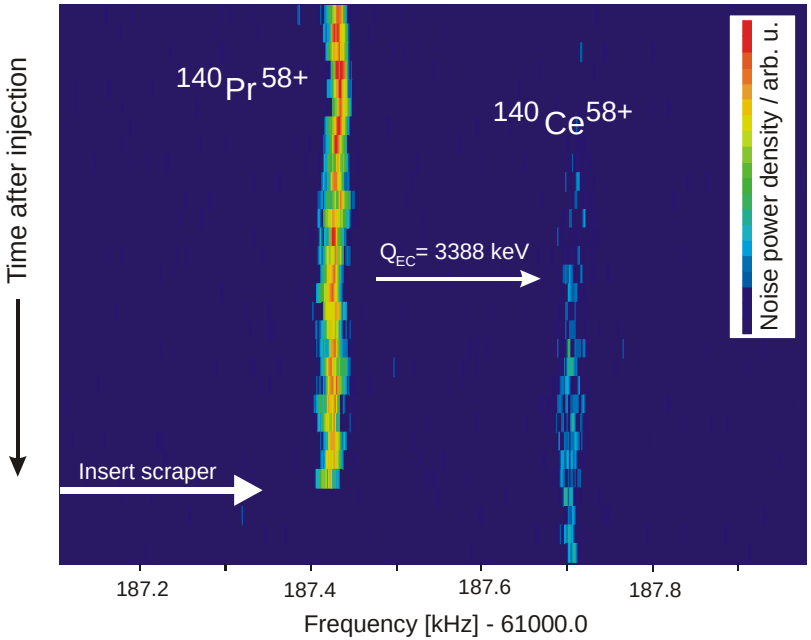
Shell model: Poletti et al., Nucl. Phys. A473 (1987) 595

the angular-momentum dimension
with ^{238}U projectile fragmentation

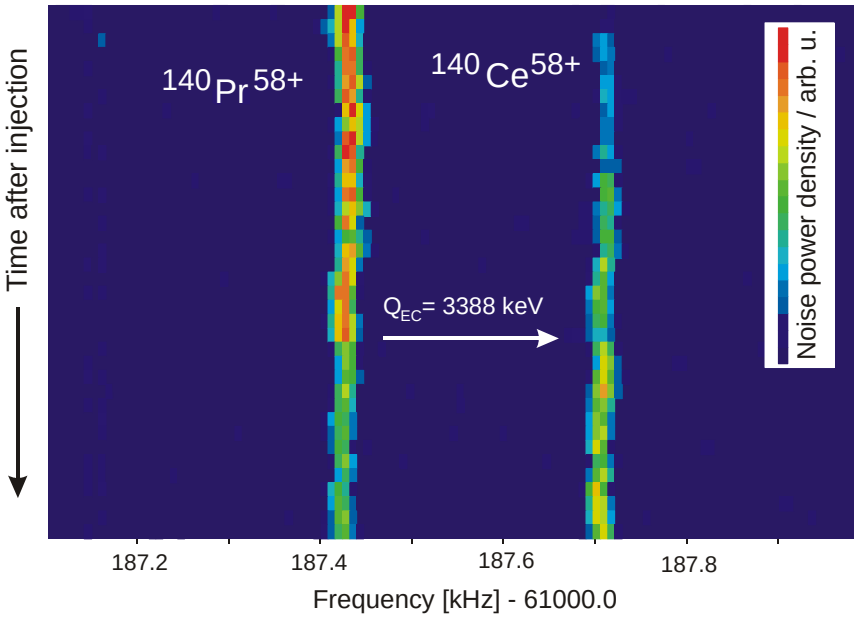


[Podolyak et al., Phys. Lett. B632 (2006) 203]

isomer beam purification



Injection length 170 s



Injection length 520 s

[Y. Litvinov, private comm.]

summary

many isomers with $T_{1/2}$ > 500 ns

opportunities to explore exotic physics

neutron radioactivity

induced isomer decay

. . . . . and many reactions

Special thanks to: Zsolt Podolyak (Surrey), Furong Xu (Beijing), Jeff Carroll (Youngstown), Pete Thompson (AWE), Yuri Litvinov (GSI)