NUCLEAR STRUCTURE (PART II--lectures):
viewed from afar (from stability)

The foundational models of the nucleus were developed based on structure studies of stable and near-stable nuclei

Far-from-stability studies of nuclear structure can test these models in regions of proton/neutron number far away from their point of origin

Reference: “Shape coexistence in atomic nuclei”,
Kris Heyde and John L. Wood, Rev. Mod. Phys. 83 1467 (2011)

LECTURE 3: Simple (?) structures in nuclei
--seniority; quadrupole collectivity

- Illustration of the two types of nuclear structure on which there is consensus (?)

  seniority (pair-dominated) structures

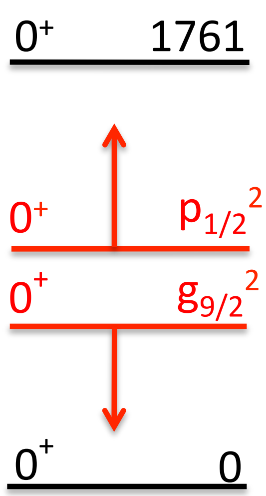
  quadrupole (shape-dominated) structures

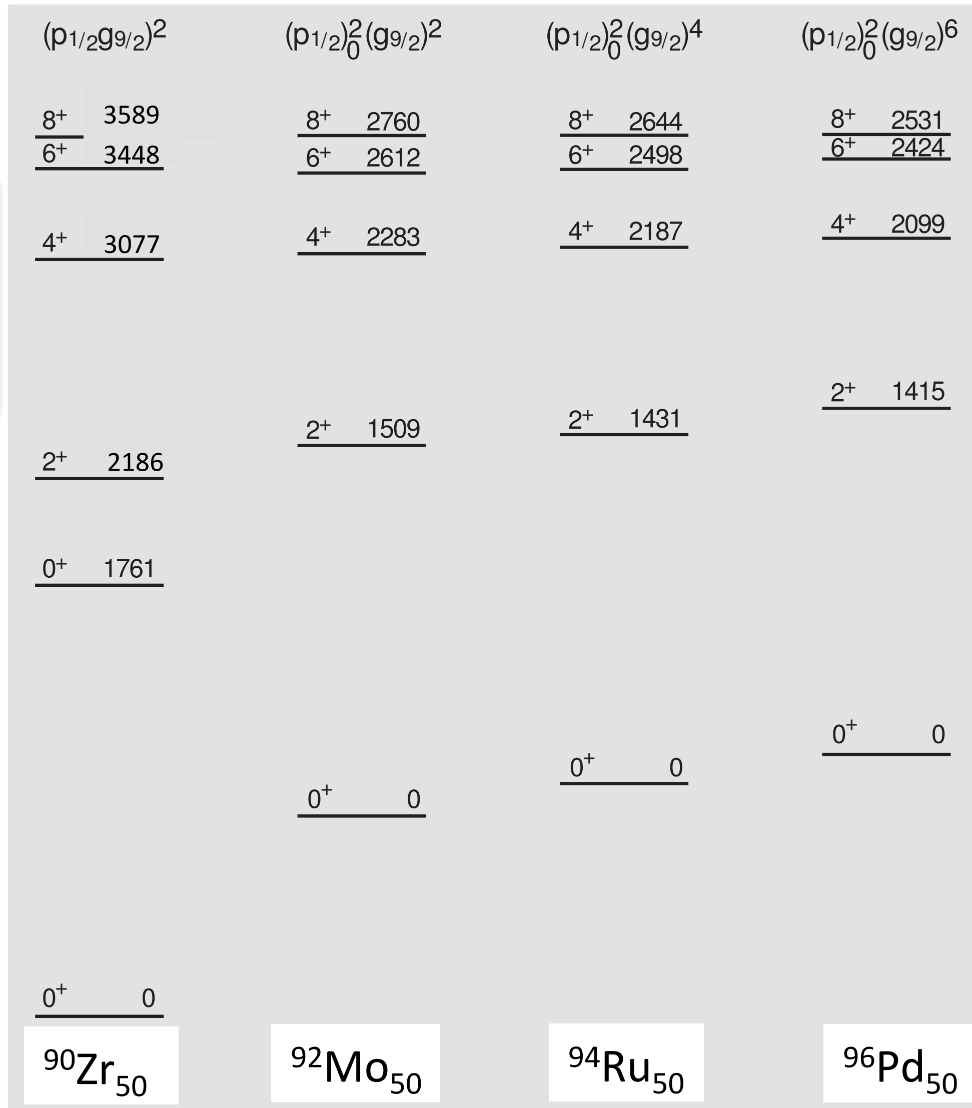
- Illustration of isomer and Coulex spectroscopy

Excited 0^+ states at closed shells: mixing and repulsion of pair configurations in ^{90}Zr

N=50: $g_{9/2}$ seniority structure

E(2_1^+): in some cases it appears high, implying a closed (sub)shell, but is due to a *depression* of the ground-state energy





Neutron-rich Ni isotopes probably dominated by a $\nu g_{9/2}$ seniority structure

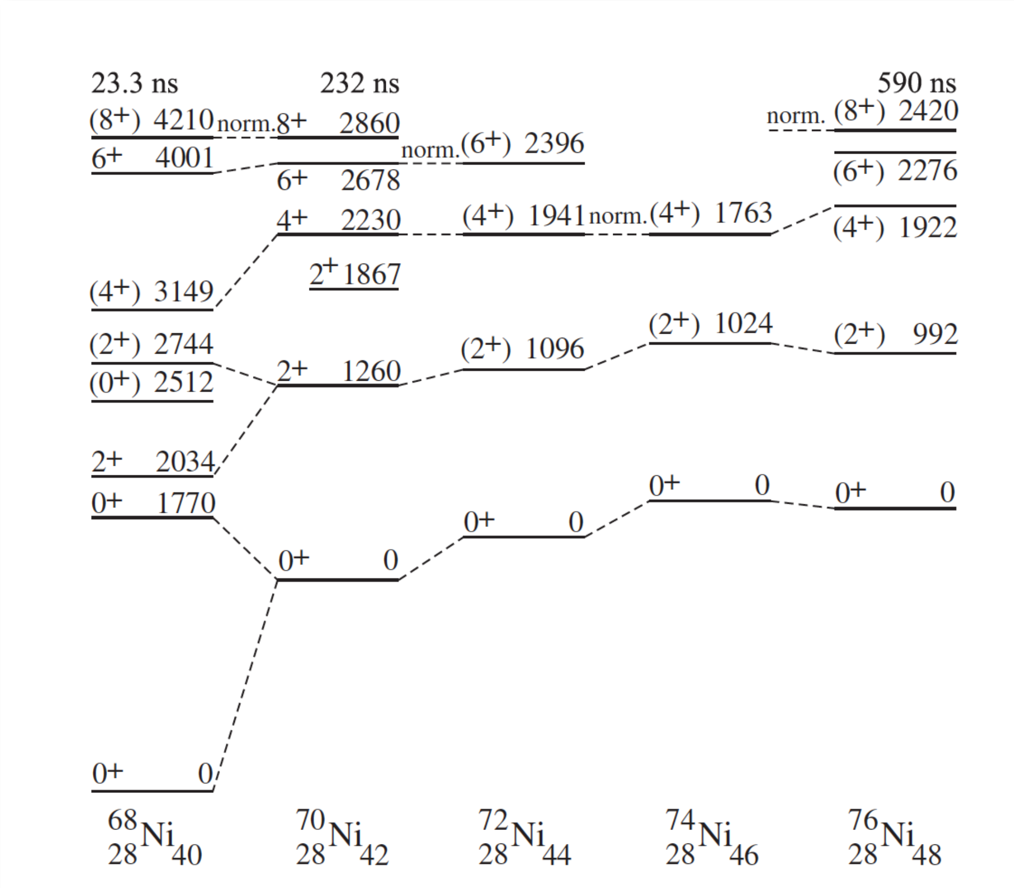


Figure from Heyde & Wood

The relatively high $E(2_1^+)$ value in ^{68}Ni is probably not indicative of a doubly closed shell

^{68}Ni has a structure which is similar to ^{90}Zr, i.e., a seniority structure that is dominated by $g_{9/2}$ and $p_{1/2}$; but the additional states indicate that $f_{5/2}$ and $p_{3/2}$ (and, possibly, proton pair excitations* across the Z = 28 shell) are active.

*See D. Pauwels et al., PR C82, 027304 (2010)

The $g_{9/2}$ seniority structure persistence near the doubly closed shell ^{78}Ni, ^{100}Sn, and ^{132}Sn nuclei

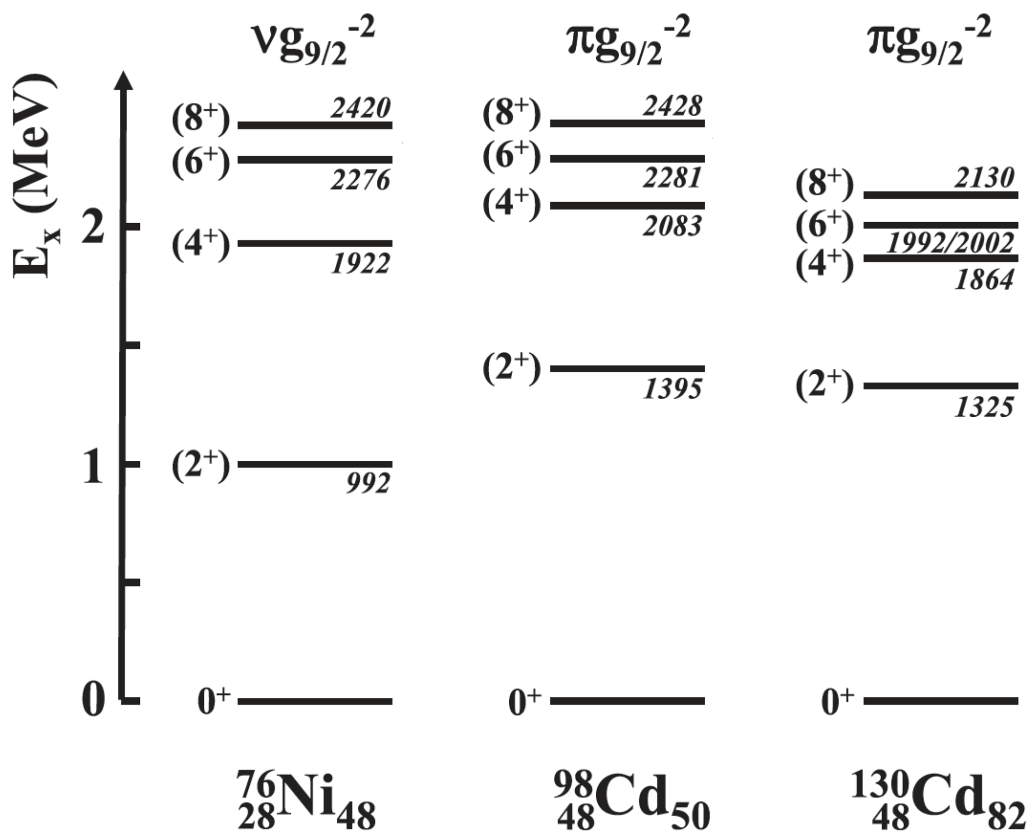


Figure taken from A. Jungclaus et al., PRL 99 132501 (2007)

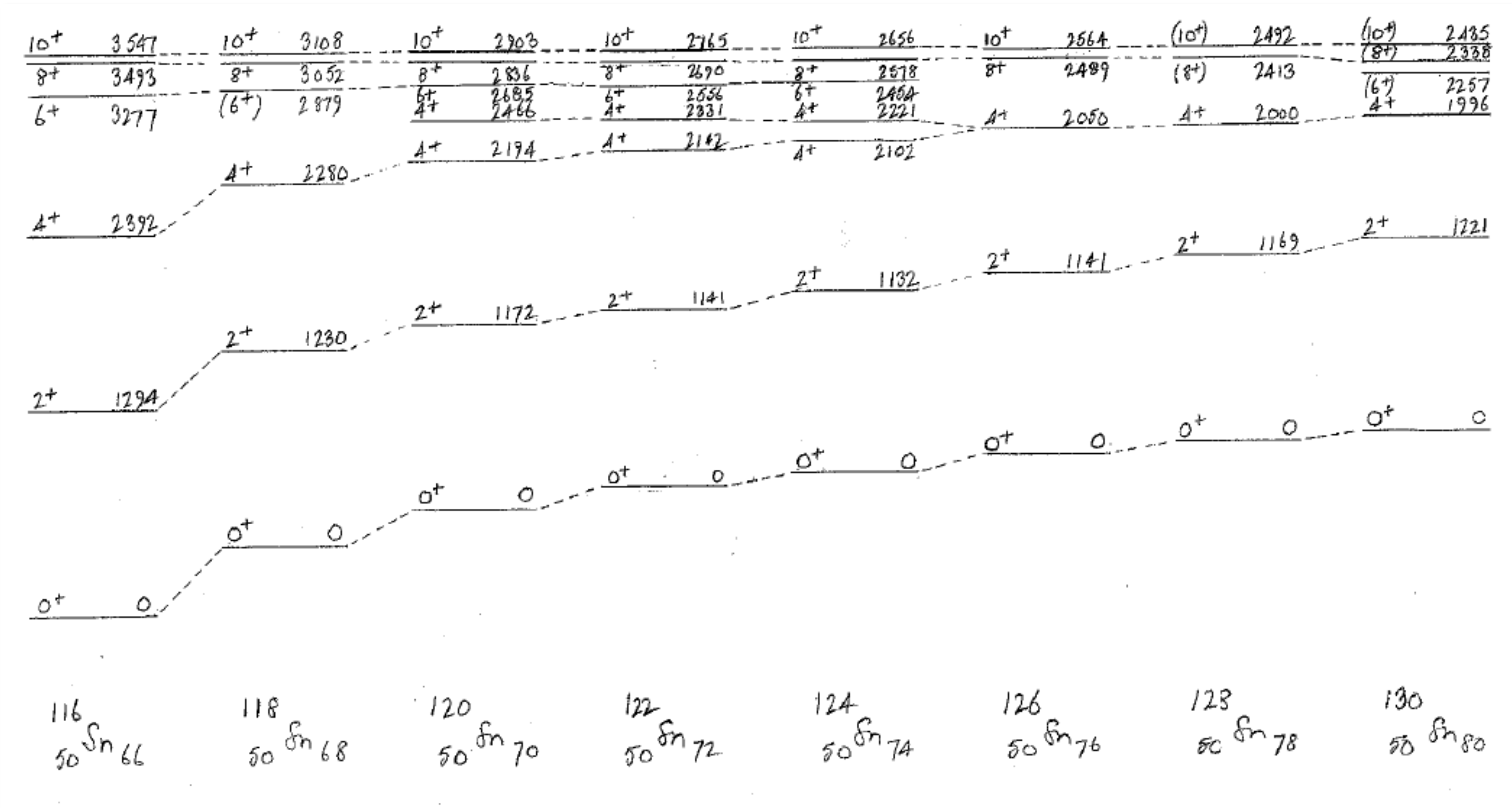
The 8+ states are isomeric:

	$T_{1/2}$ (ns)	Eγ (keV)	B(E2) W.u.
^{76}Ni	590	144	0.71
^{98}Cd	480	147	0.46
^{130}Cd	220	128/138*	1.7/1.3*

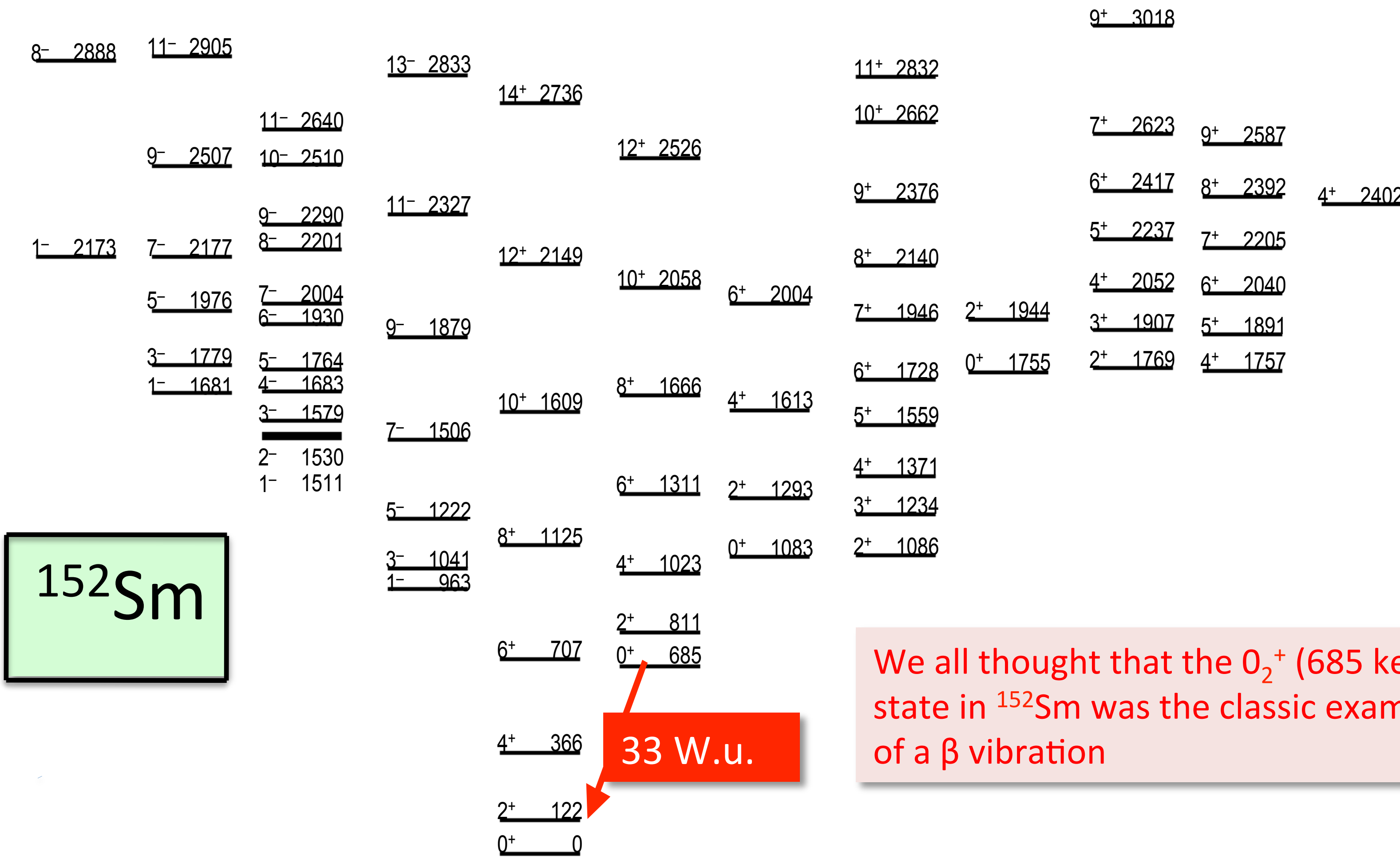
*In ^{130}Cd the ordering of the 128/138 keV γ-ray cascade is not certain

The constancy of the B(E2) values , independent of whether the structures are dominated by protons or neutrons and independent of mass, is remarkable and shows the simple nature of seniority structures.

Neutron-rich Sn isotope structure dominated by $\nu h_{11/2}$ seniority structure



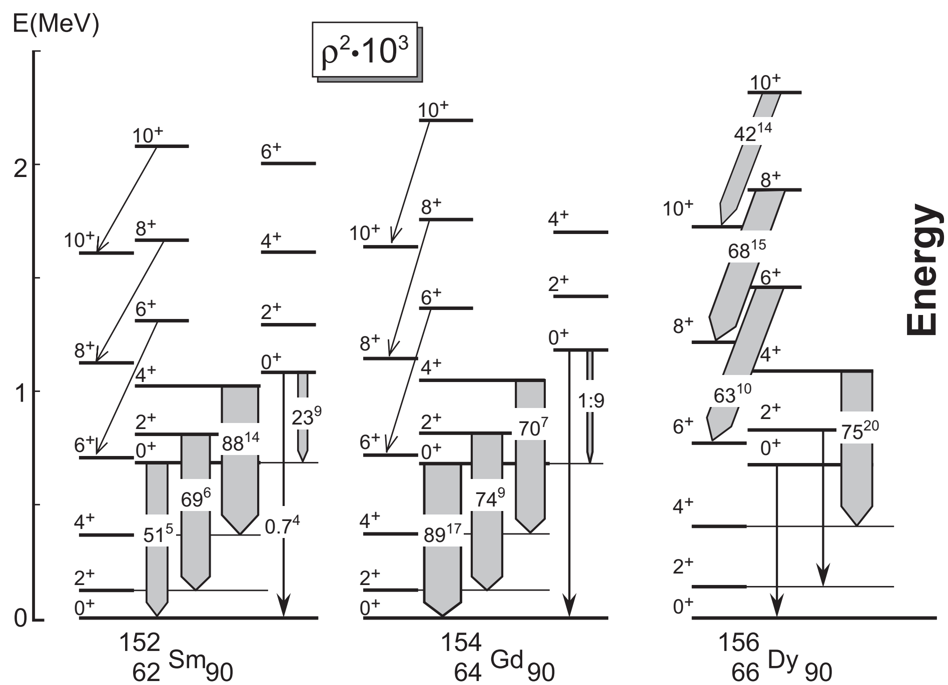
^{152}Sm: what is the nature of the 0_2^+ (685 keV) state?

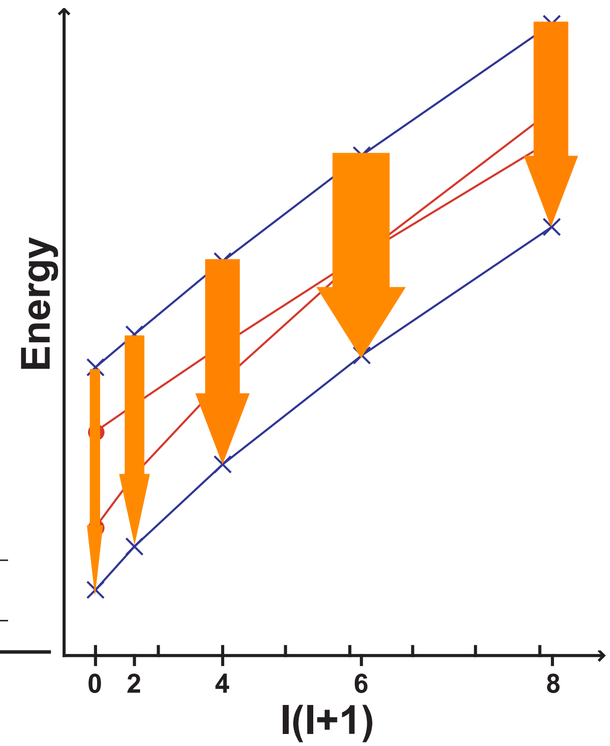


We all thought that the 0_2^+ (685 keV) state in ^{152}Sm was the classic example of a β vibration

Shape coexistence in the N = 90 isotones: explains the E0 transition strengths

Electric monopole transitions are a *model-independent* signature of shape coexistence and mixing--J.Kantele et al., Z. Phys. A289 157 (1979).





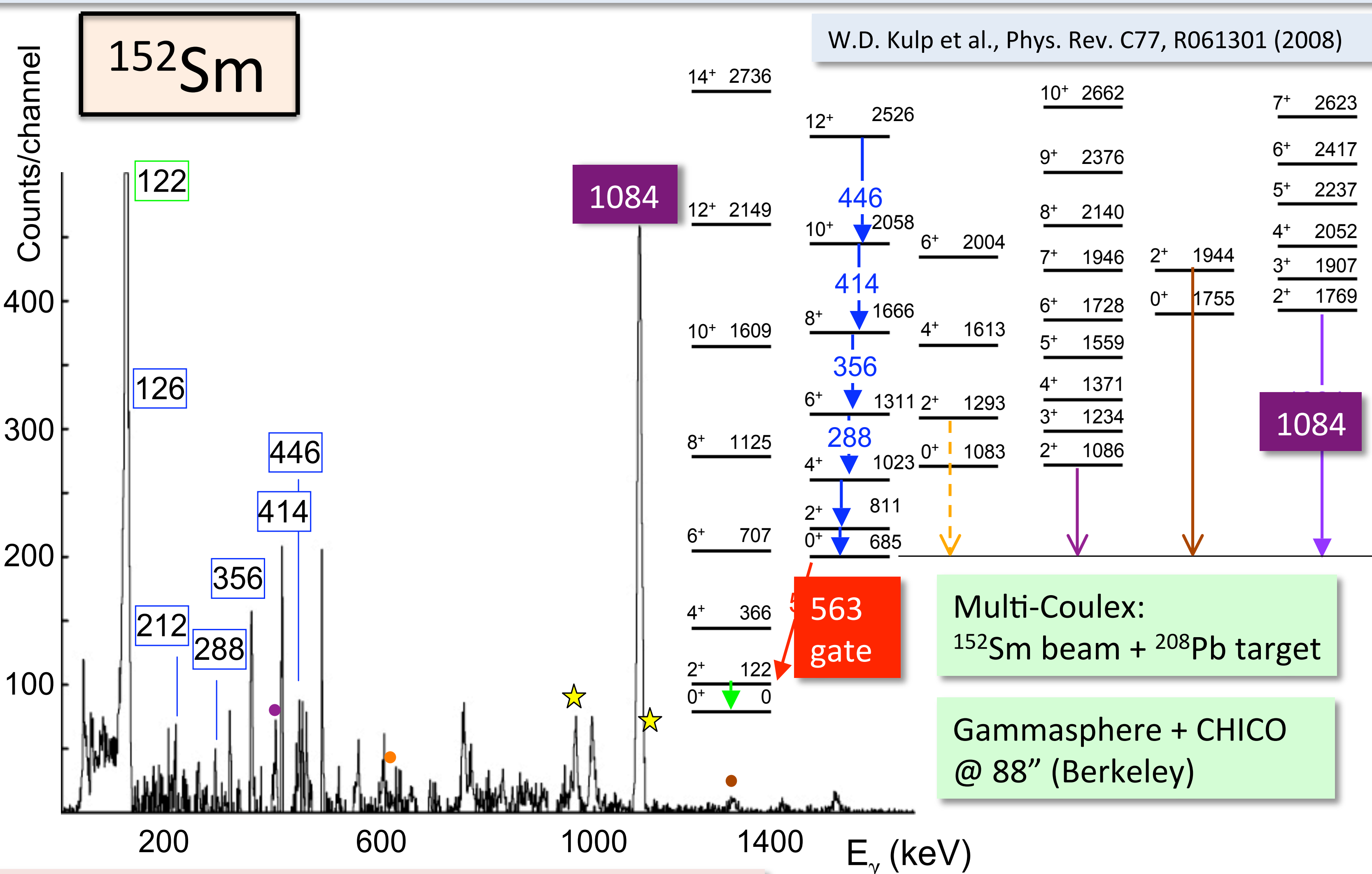
$$\rho^2 \cdot 10^3 = \alpha^2\beta^2 \left(\Delta\langle r^2\rangle\right)^2 \cdot 10^3 \frac{Z^2}{R_0^4}$$

$$R_0 = 1.2A^{1/3} \text{ fm}$$

E0 strength is a function of mixing.

Multi-Coulex of ^{152}Sm 0_2^+(685 keV): strongest response is to head of K=2$^+$ band at 1769 keV

W.D. Kulp et al., Phys. Rev. C77, R061301 (2008)



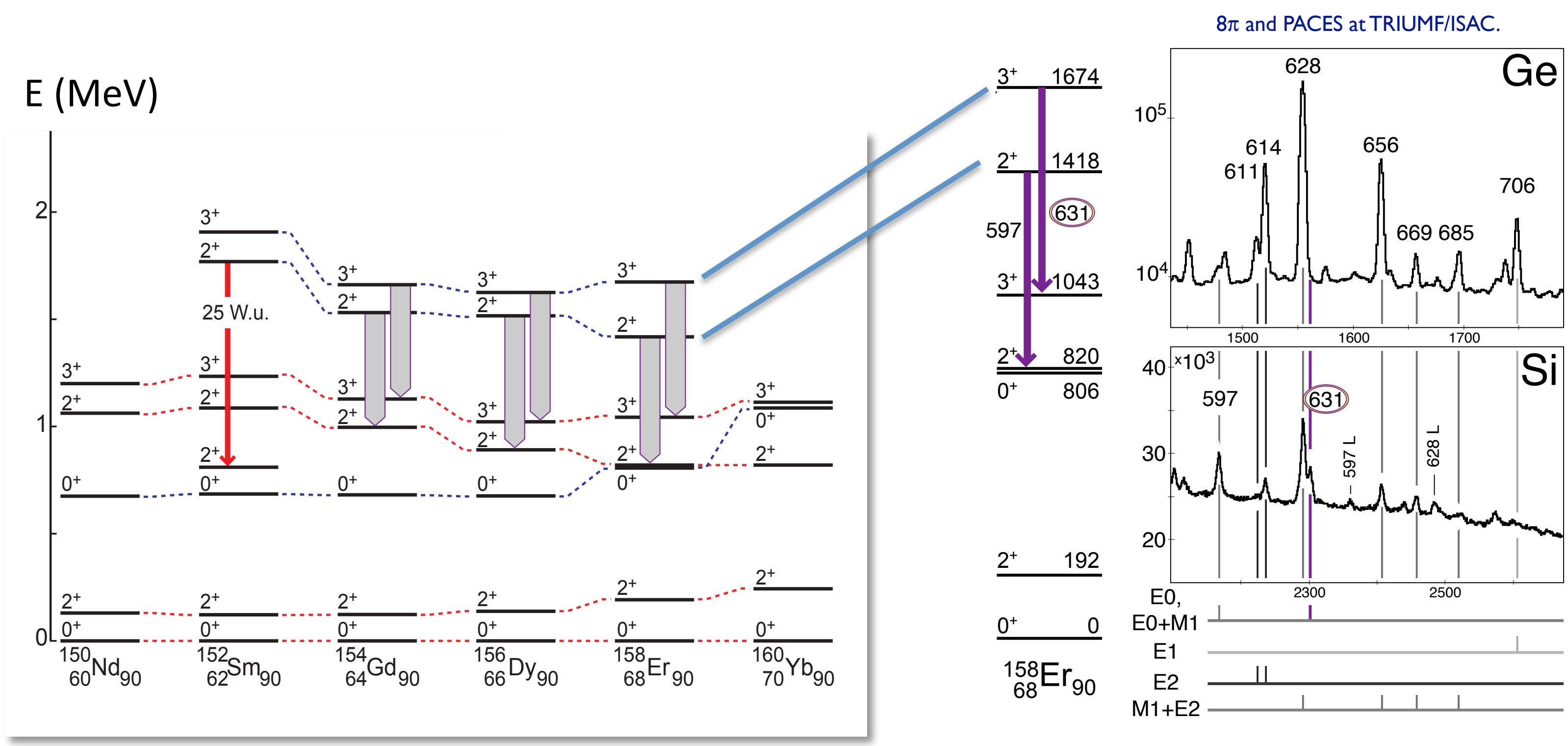
Multi-Coulex:
^{152}Sm beam + ^{208}Pb target

Gammasphere + CHICO @ 88" (Berkeley)

in-band response attenuated by 99.7% decay out @ 811 level

Shape coexistence in the N = 90 isotones: coexisting K = 2 bands revealed by E0 transitions

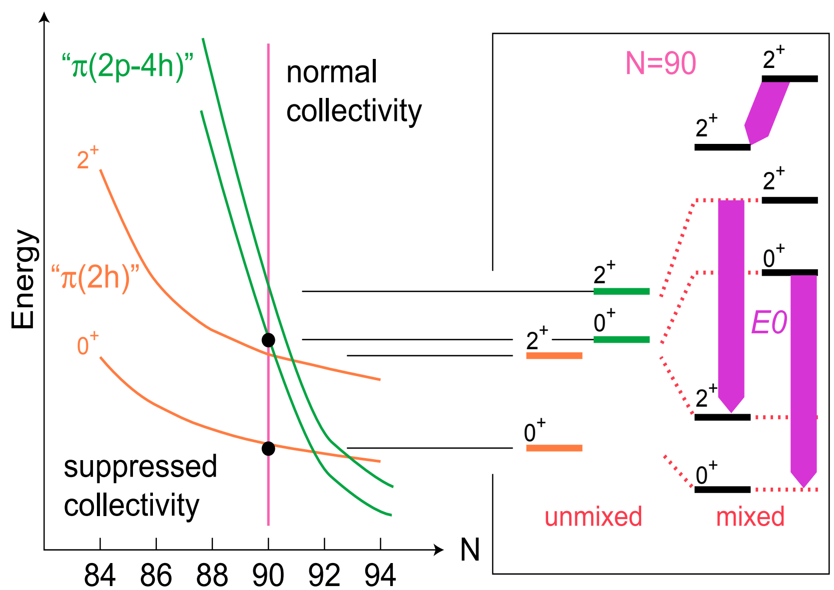
3^+, K = 2 ➔ 3^+, K = 2: 631 keV transition in ^{158}Er has no observable γ-ray strength, only ce's
[$3K^2$ − I(I+1) = 0] are observed --accidental cancellation of E2; M1 is very weak.



Kulp, Wood, Garrett, Zganjar and others

^{152}Sm and the neighboring N = 90 isotones are a manifestation of shape coexistence

Proton particle-hole excitations across the *Z* = 64 gap may be the source of the coexisting shapes.



Less-deformed 2h and more-deformed 2p-4h structures coexist at low energy at *N*=90.

Strong mixing obscures the energy differences that are indicative of different shapes.

Strong *E0* transitions are a key signature of the mixing of coexisting structures.

As observed, the *K*=2 bands will also mix strongly, resulting in *E0* transitions.

Ground state properties, S_{2n} and $\delta\langle r^2\rangle$, in the regions of N = 60, 90 are very similar

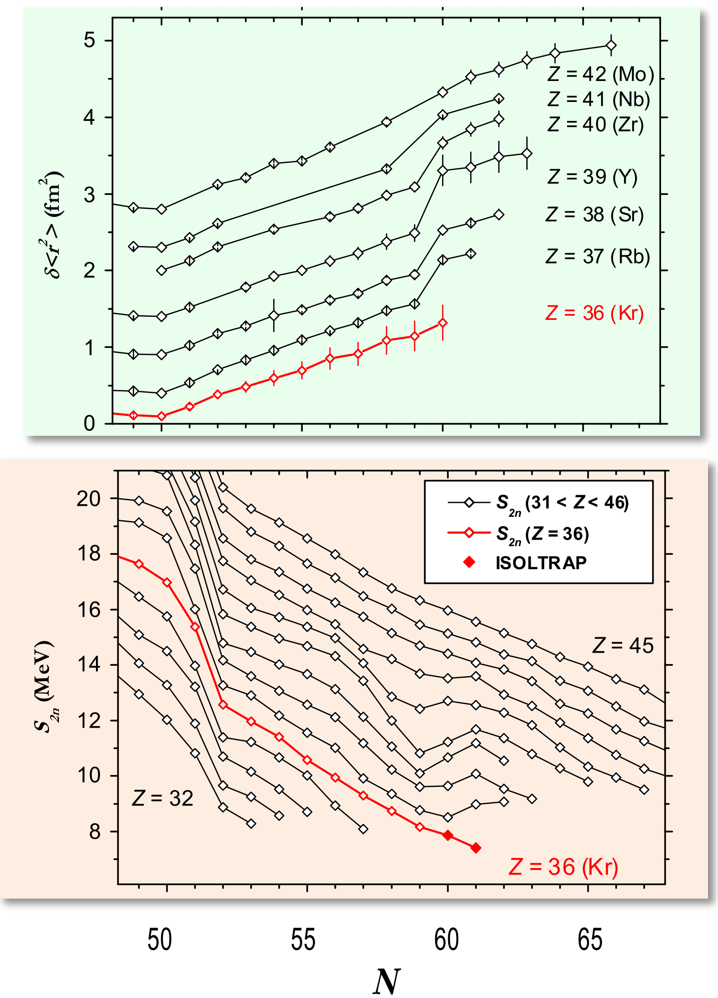


Figure from S. Naimi et al. Phys. Rev. Lett. 105 032502 (2010)

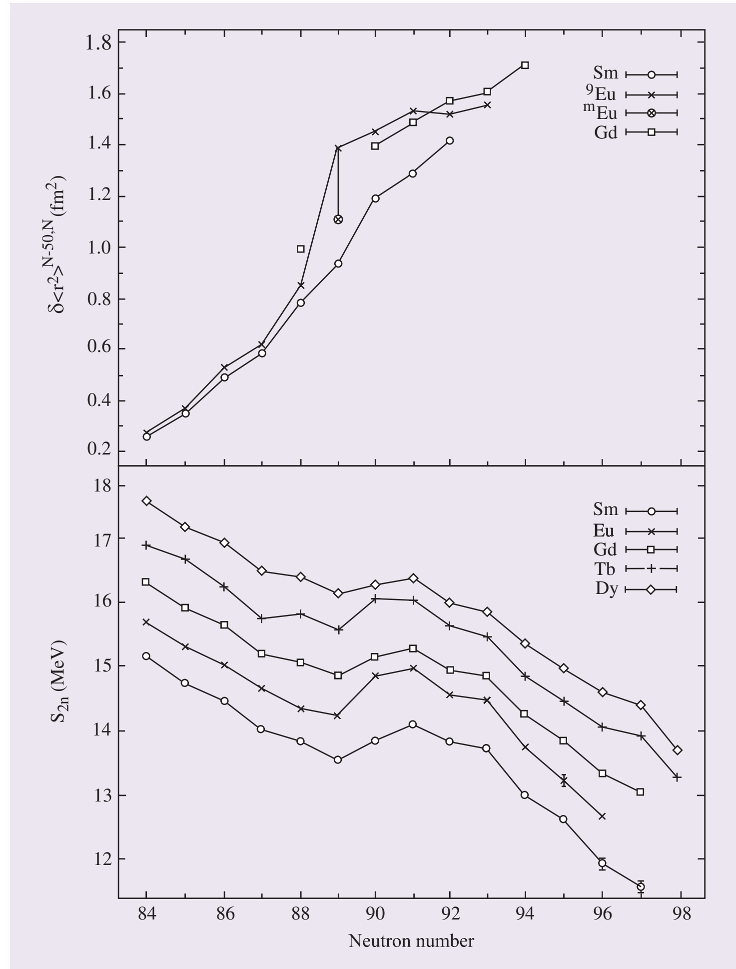


Figure from Heyde & Wood

Universal rotor B(E2)'s

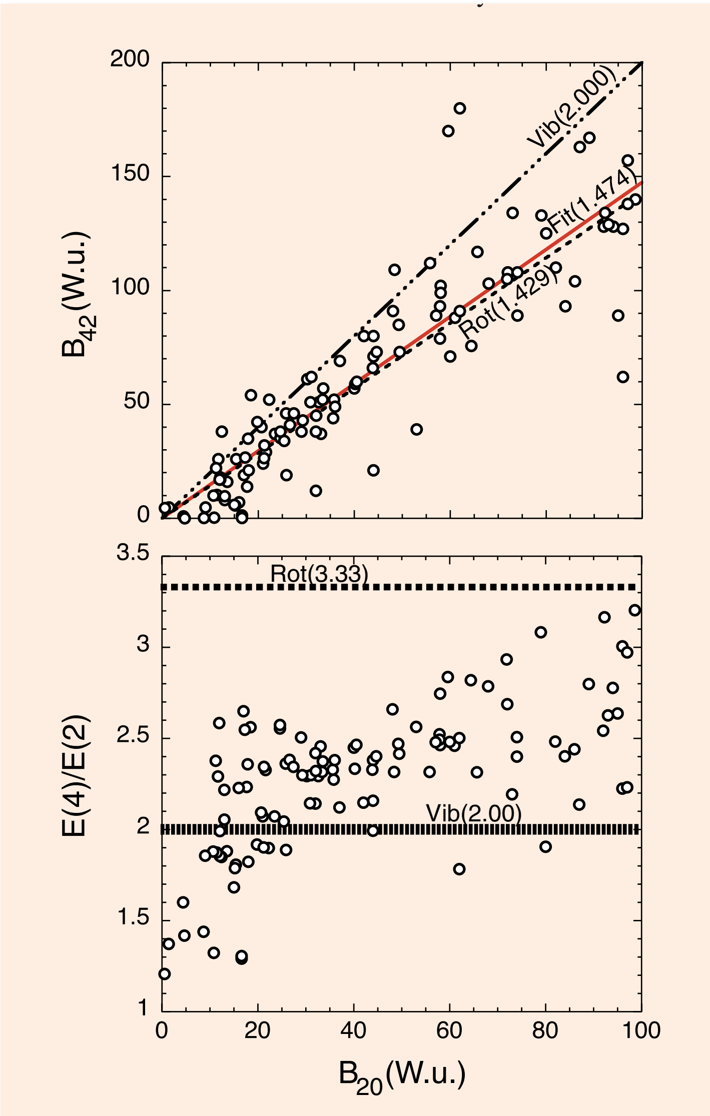


Figure from Heyde & Wood

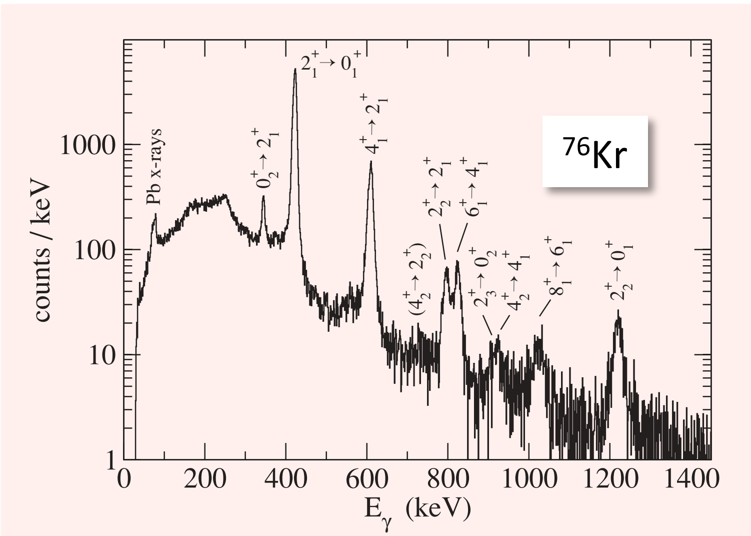
$$B(\mathrm{E2}; 2 \to 0) = \frac{1}{16\pi}\left(\overline{Q}_0^{(e)}\right)^2,$$

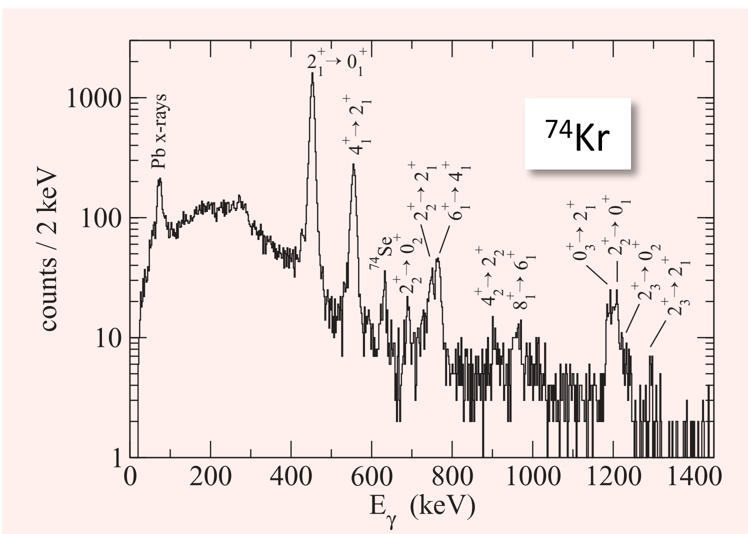
$$B(\mathrm{E2}; I \to I-2) = \frac{15I(I-1)}{2(2I-1)(2I+1)} B(\mathrm{E2}; 2 \to 0)$$

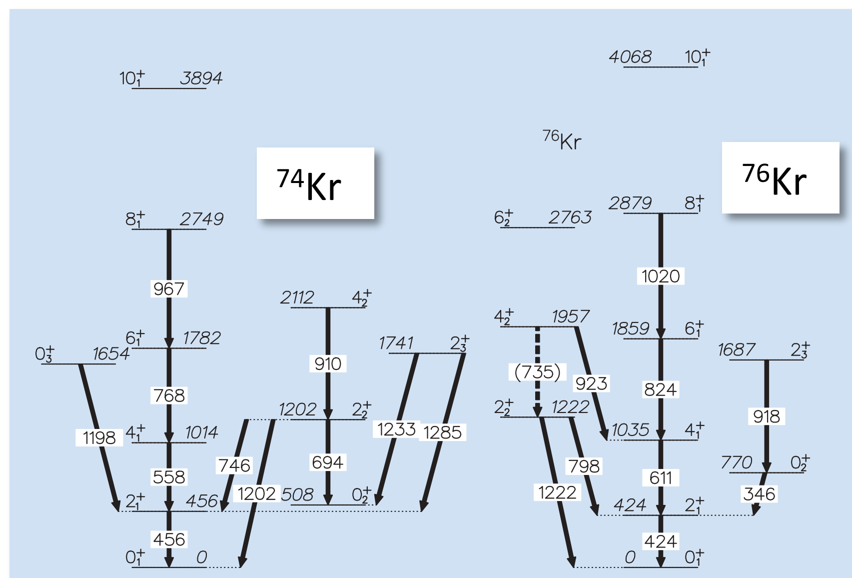
$$E_I = E_0 + \frac{\hbar^2}{2\Im} I(I+1)$$

Multistep Coulomb excitation of ^{74,76}Kr using radioactive beams of Kr on a ^{208}Pb target

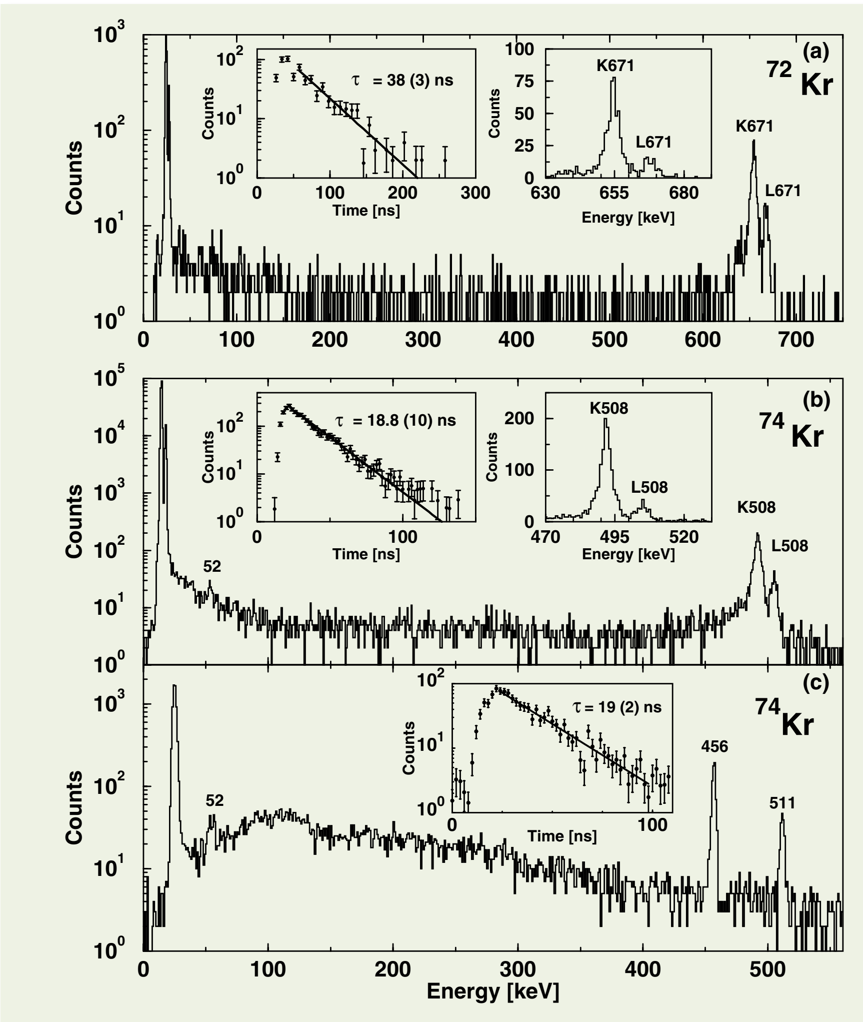
E. Clement et al., Phys. Rev. C75 054313 (2007)

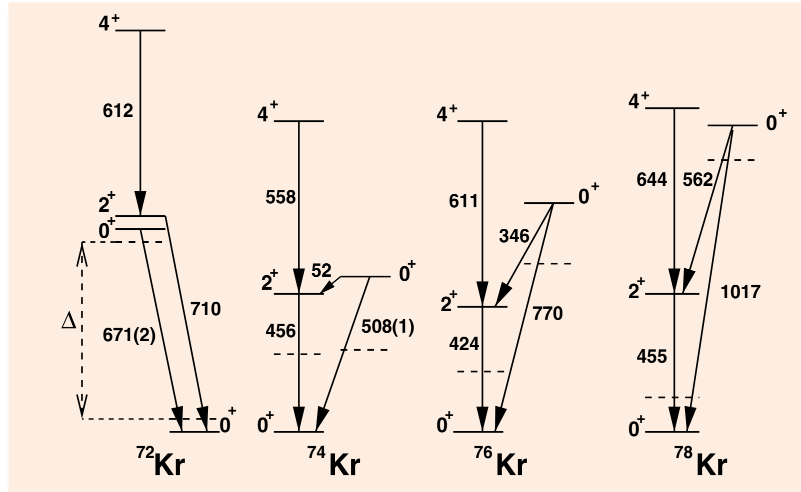






^{72,74}Kr: 0_2^+ states observed by conversion electron spectroscopy via IT decay of ^{72m,74m}Kr





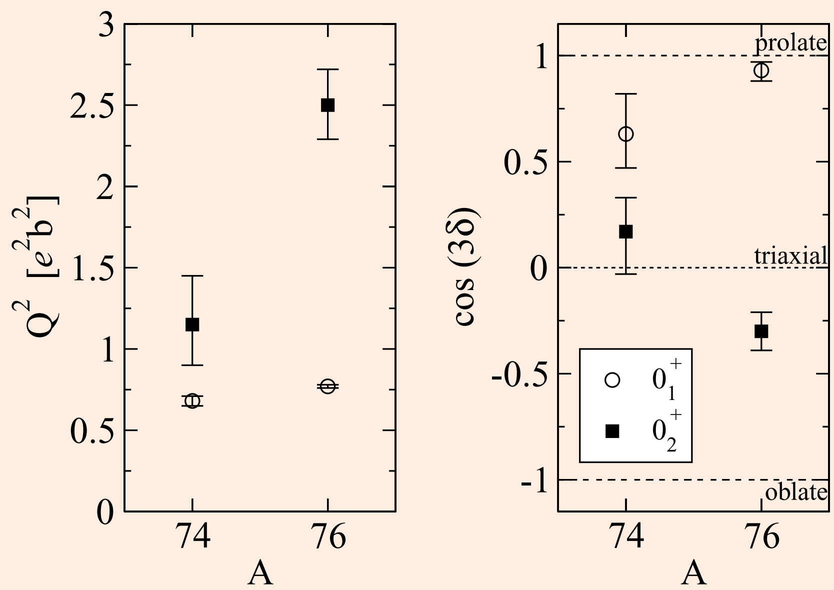
horizontal dashed lines show energies (Δ) of unmixed 0^+ configurations

	72	74	76	78
ρ^2 (E0)•10^3	72^{6}	85^{19}	79^{11}	47^{13}

E. Bouchez et al., PRL 90, 082502 (2003)

J.L. Wood et al. NP A651 323 (1999)

Quadrupole shape invariants constructed from E2 matrix elements for ^{74,76}Kr



E. Clement et al., Phys. Rev. C75 054313 (2007)

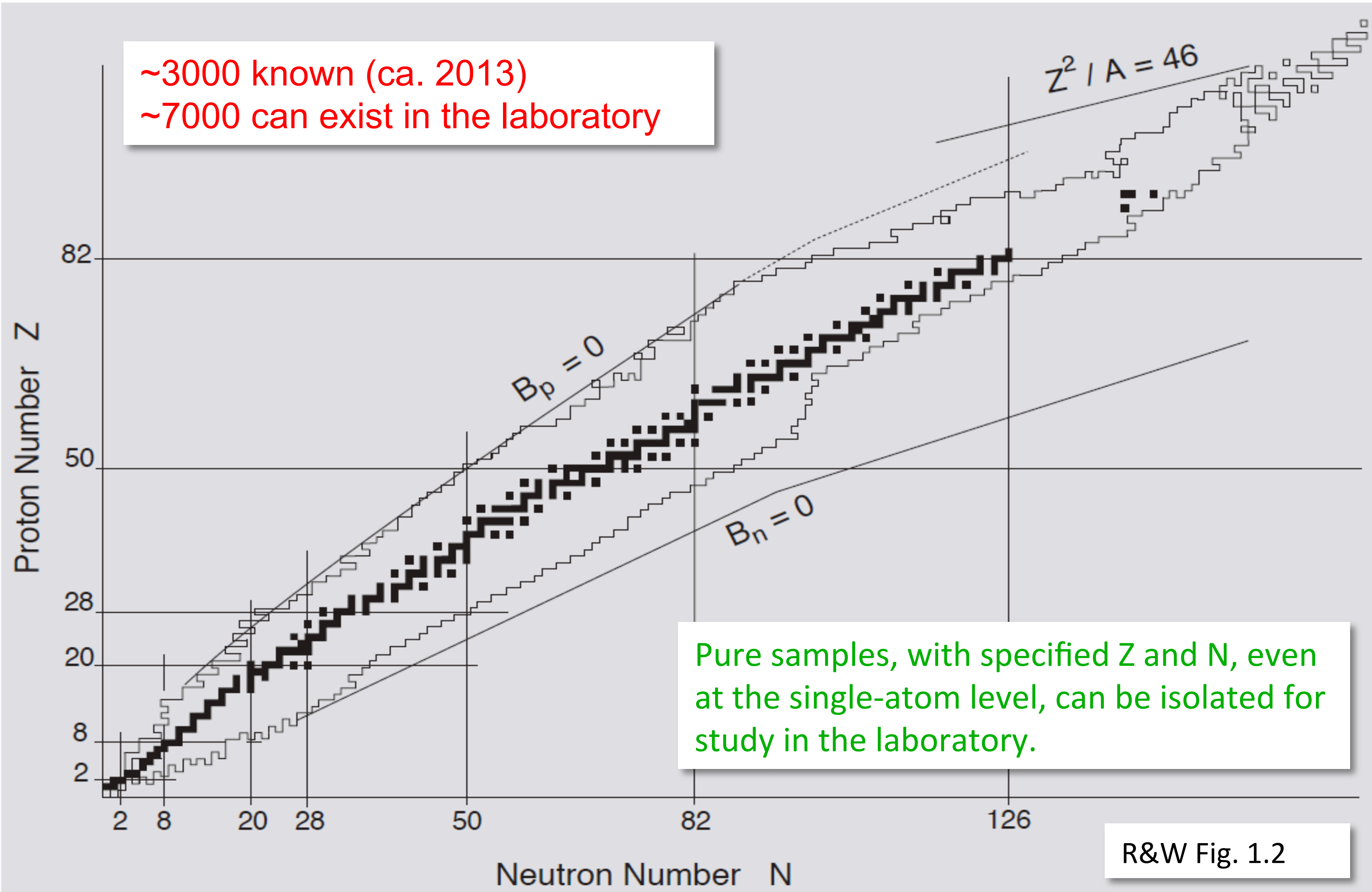
$$\langle q^2\rangle \equiv \langle 0_1^+\|\hat{Q}\|2_1^+\rangle\langle 2_1^+\|\hat{Q}\|0_1^+\rangle + \langle 0_1^+\|\hat{Q}\|2_2^+\rangle\langle 2_2^+\|\hat{Q}\|0_1^+\rangle$$

for the ground state

$$\langle q^3 \cos 3\delta\rangle \equiv \sum_{r,s=1,2} \langle 0_1^+\|\hat{Q}\|2_r^+\rangle\langle 2_r^+\|\hat{Q}\|2_s^+\rangle\langle 2_s^+\|\hat{Q}\|0_1^+\rangle .$$

Nuclear shapes studied by Coulomb excitation
D. Cline, Ann.Rev,Nucl.Part.Sci. 36, 683 (1986)

Go forth and explore!



R&W Fig. 1.2