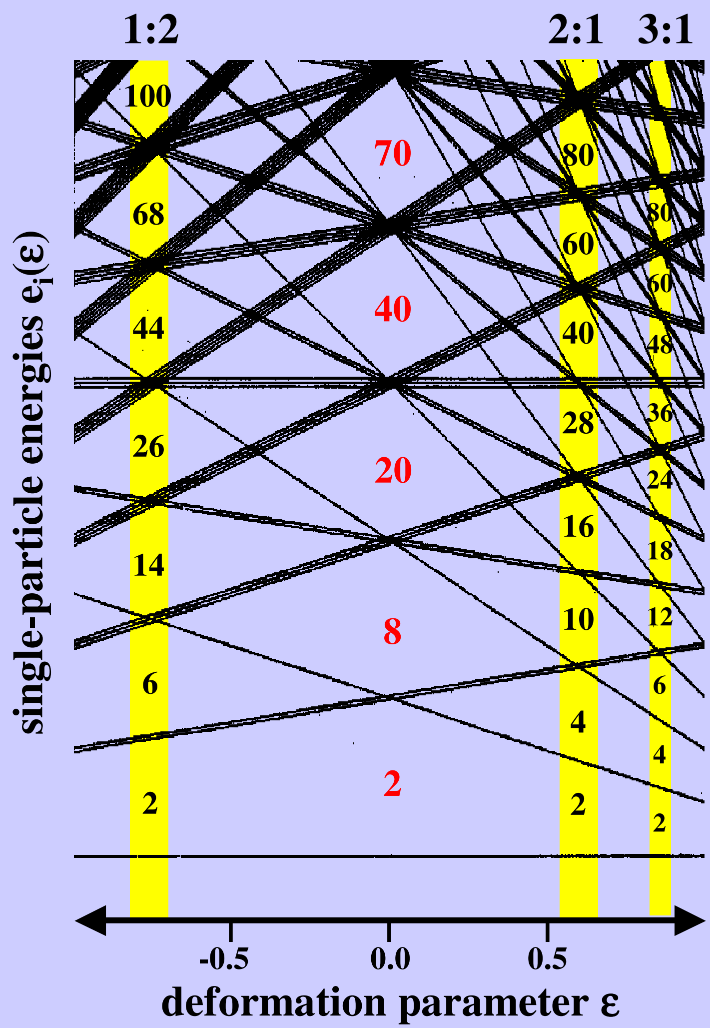
Single-particle energies in deformed harmonic oscillator potential

$$V = \frac{1}{2} M \left[\omega_{x,y}{}^2 (x^2 + y^2) + \omega_z{}^2 z^2 \right]$$

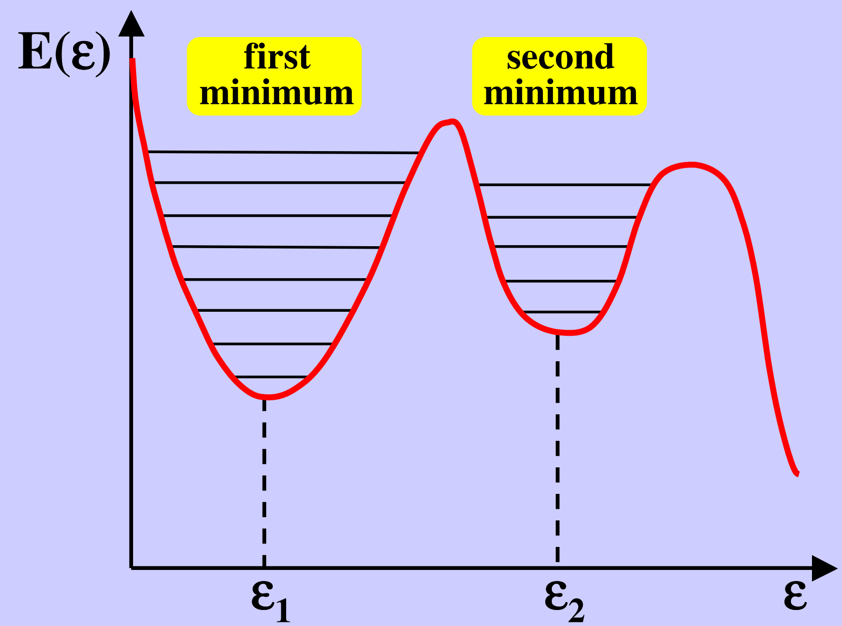


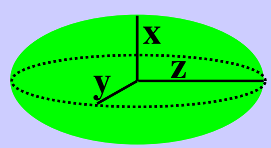
Potential energy of the nucleus as a function of the deformation:

$$E(\varepsilon) = \sum e_i(\varepsilon)$$

sum over the single-particle energies of all A nucleons

Due to the different slopes of the single-particle orbitals there might be more than one minimum for certain nucleon numbers !

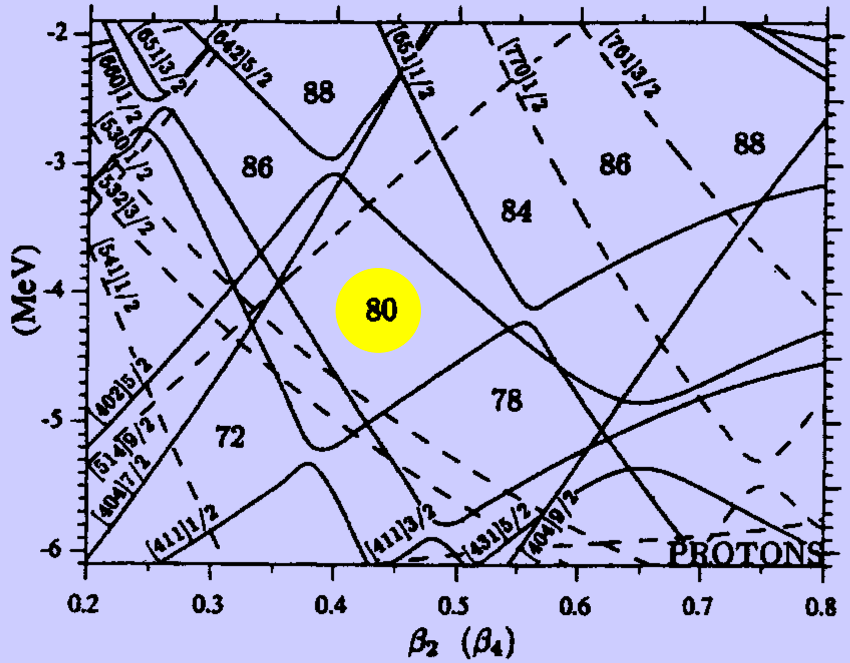


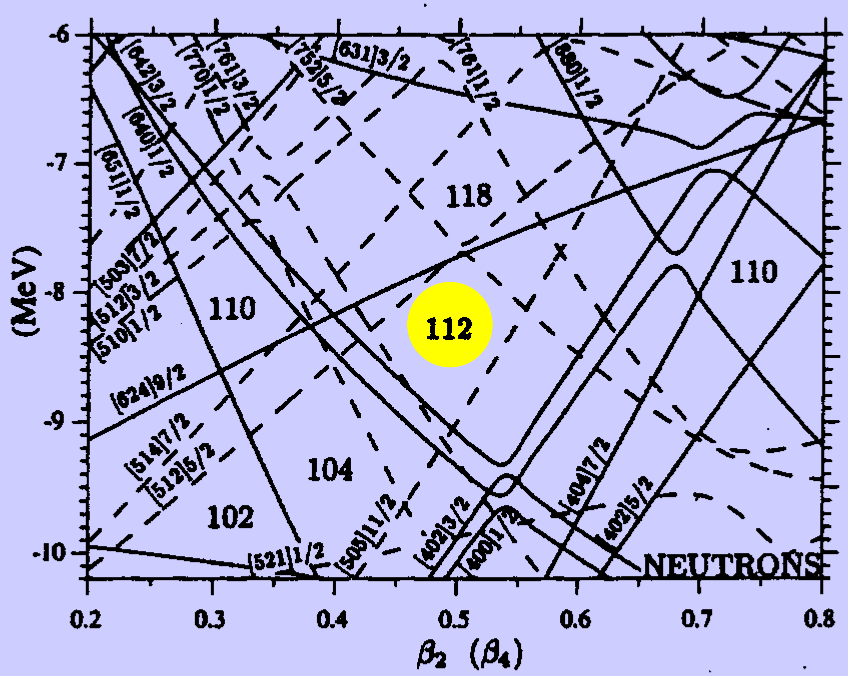


$$x = y = R(1+\varepsilon)$$

$$z = \frac{R}{\sqrt{1+\varepsilon}} \approx R(1 - \frac{1}{2}\varepsilon) \qquad \varepsilon = (\omega_{x,y} - \omega_z)/\omega_0$$

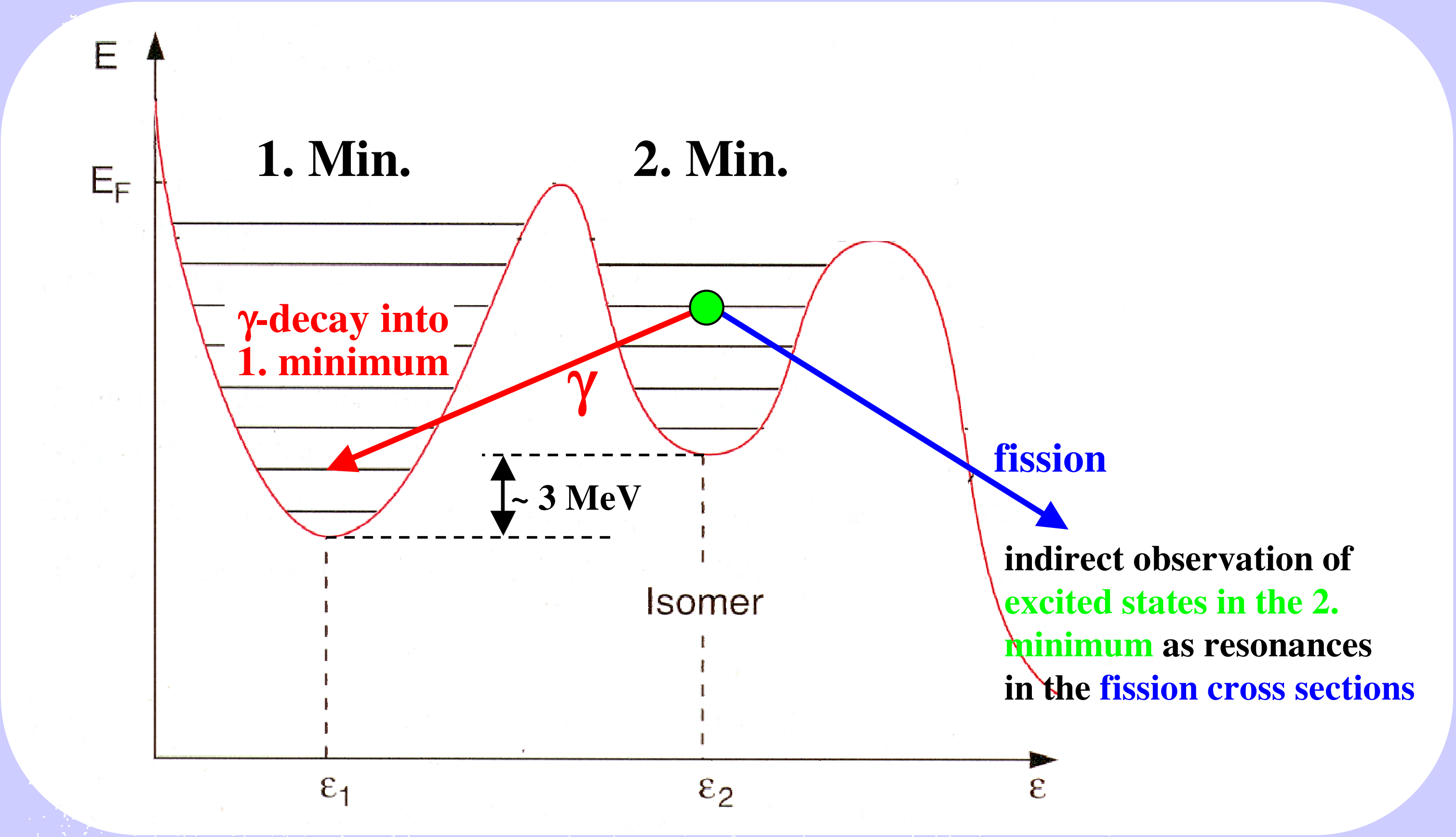
Single-particle energies in an anisotropic Woods-Saxon potential





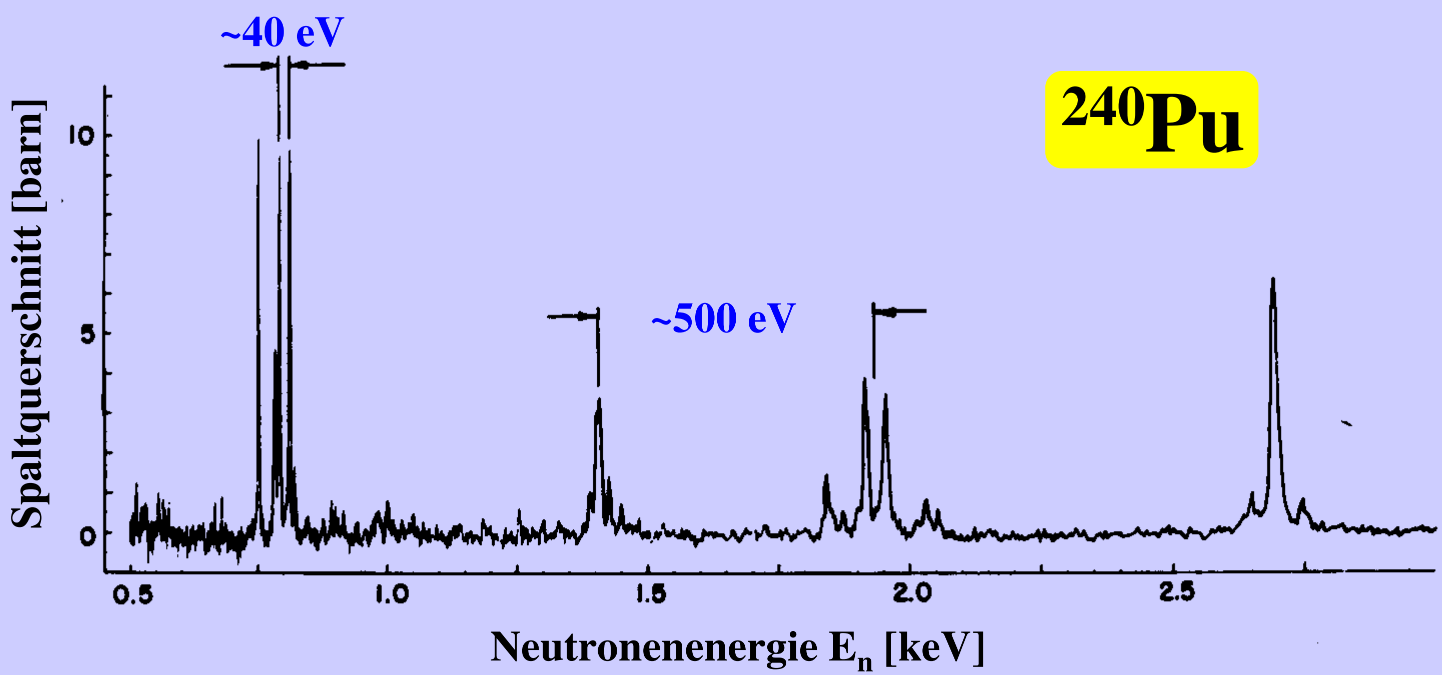
e.g.: Z = 80, N = 112 ➡ **^{192}Hg**

Possible decays out of the second minimum



An example: ^{240}Pu

Subbarrier fission cross section as function of the neutron energy:

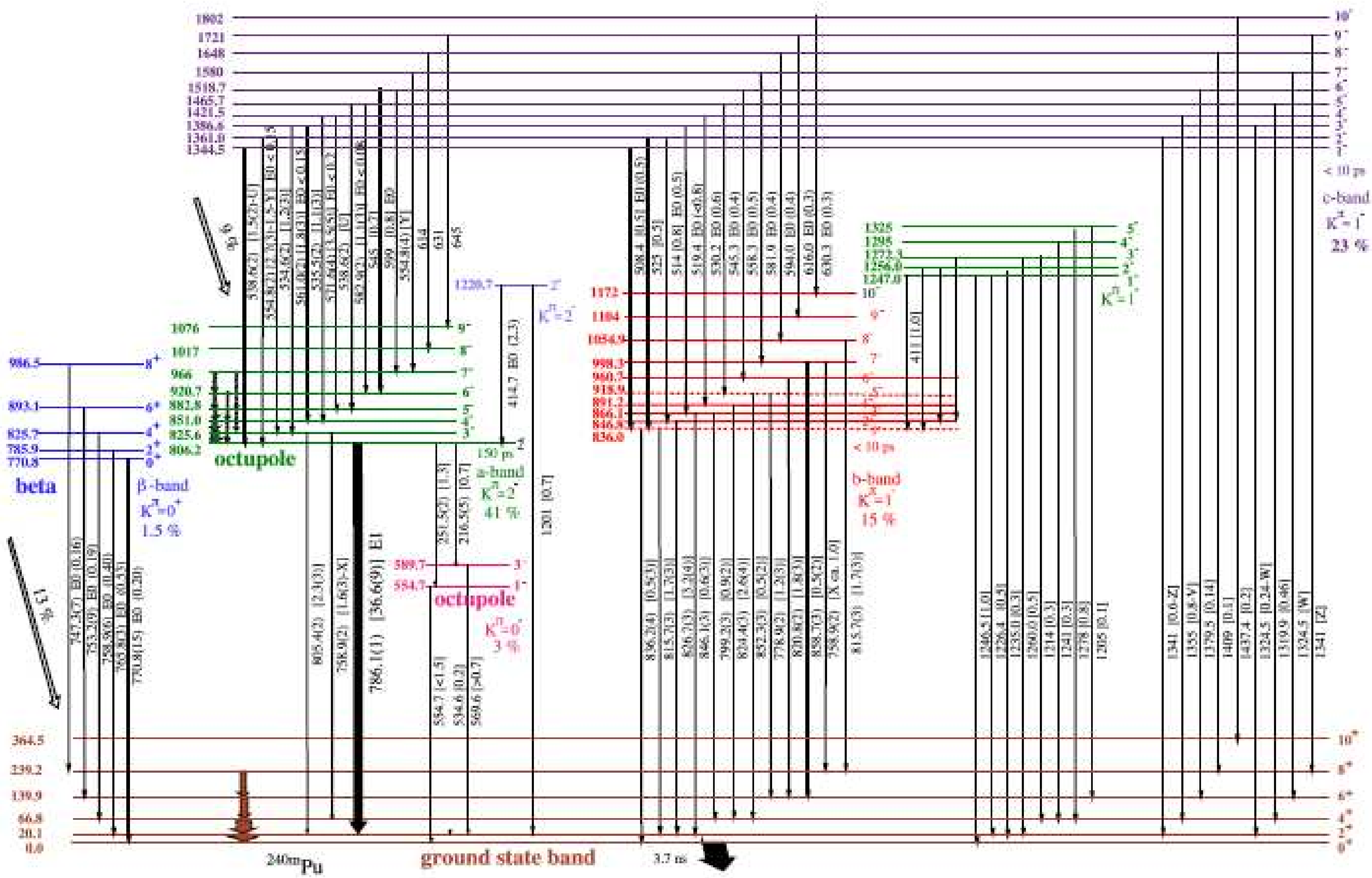


Double structure at energies far below the barrier !

No explanation in 1-barrier-picture, but ...

Spectroscopy in the Superdeformed Minimum of ^{240}Pu

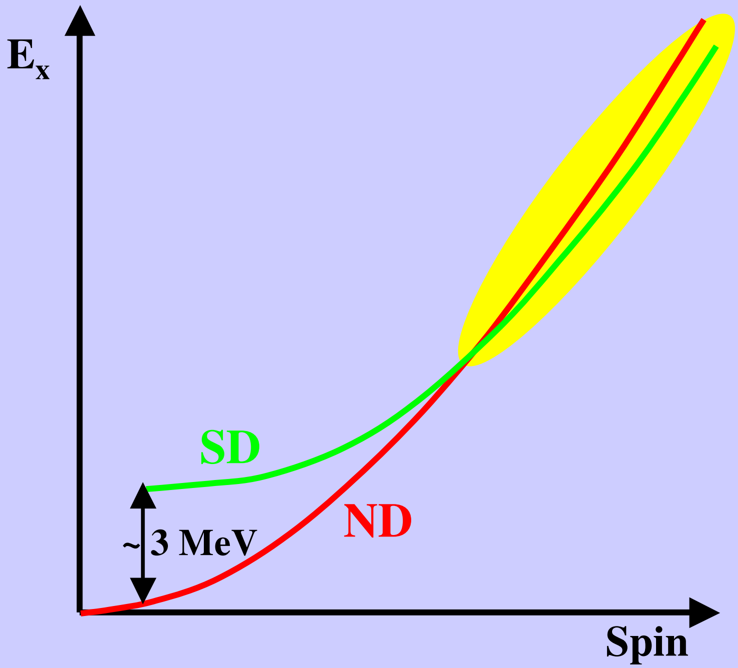
Pansegrau et al., Phys. Lett. 484B (2000) 1



γ-ray spectroscopy

moment of inertia larger for larger deformation

⇨ superdeformed rotational states energetically favoured and therefore observable at high spin !



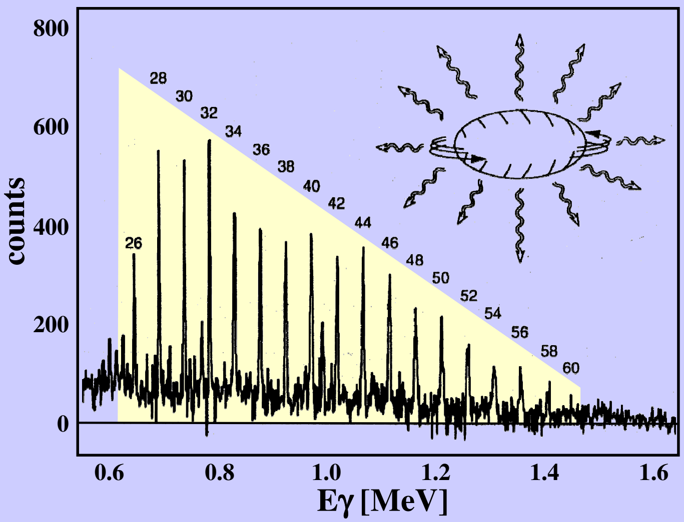
Rotational band:

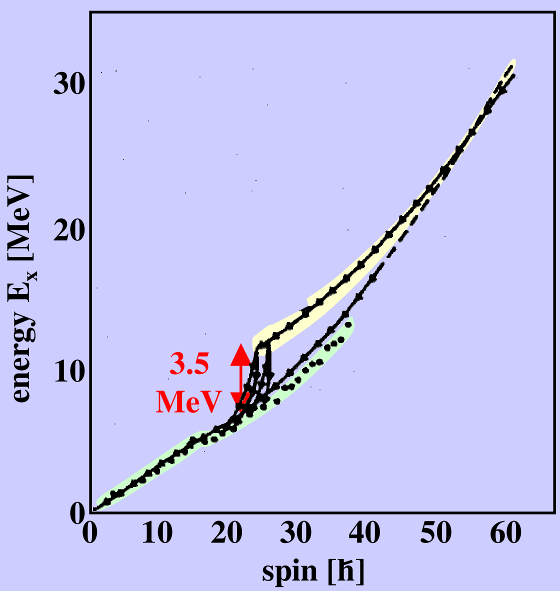
$$E_x = \frac{\hbar^2}{2J} I(I+1)$$

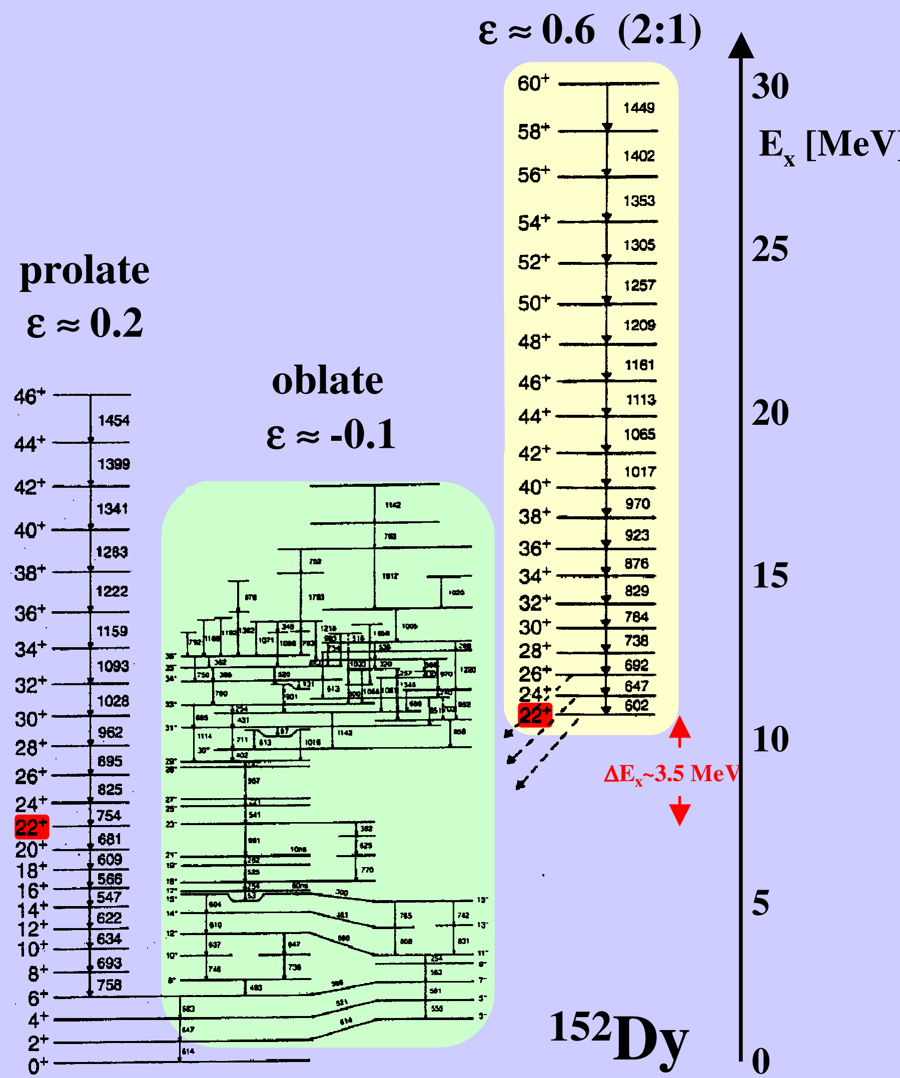
J **: moment of inertia**

$$J_{SD} > J_{ND}$$

Discovery of superdeformation in $^{152}Dy_{86}$





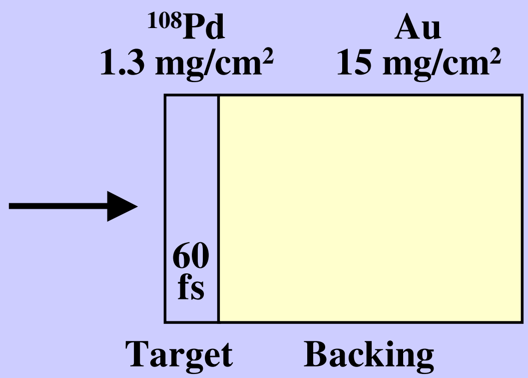


1986

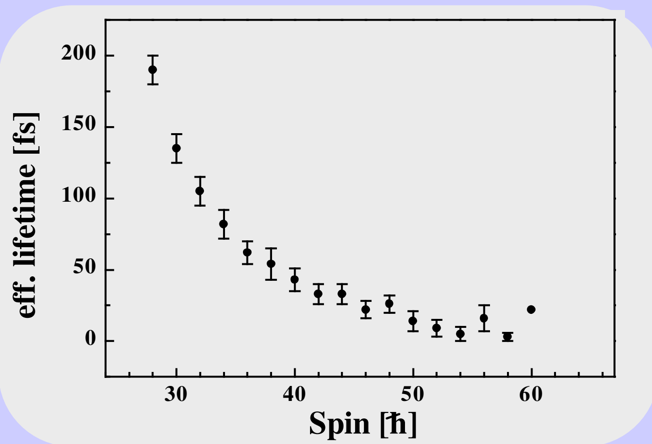
How to determine the deformation ?

Example: superdef. band in ^{152}Dy

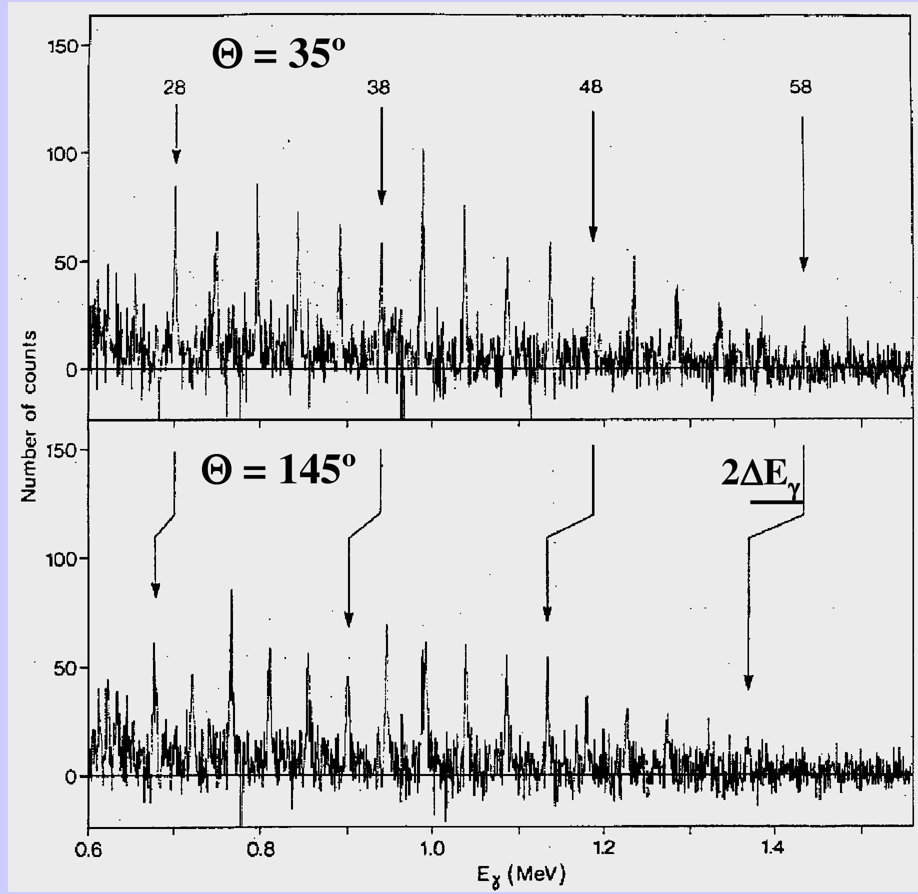
^{108}Pd (^{48}Ca,4n) ^{152}Dy @ 205 MeV



v_{rec}/c = 2.84 - 2.97 % (target thickness !)



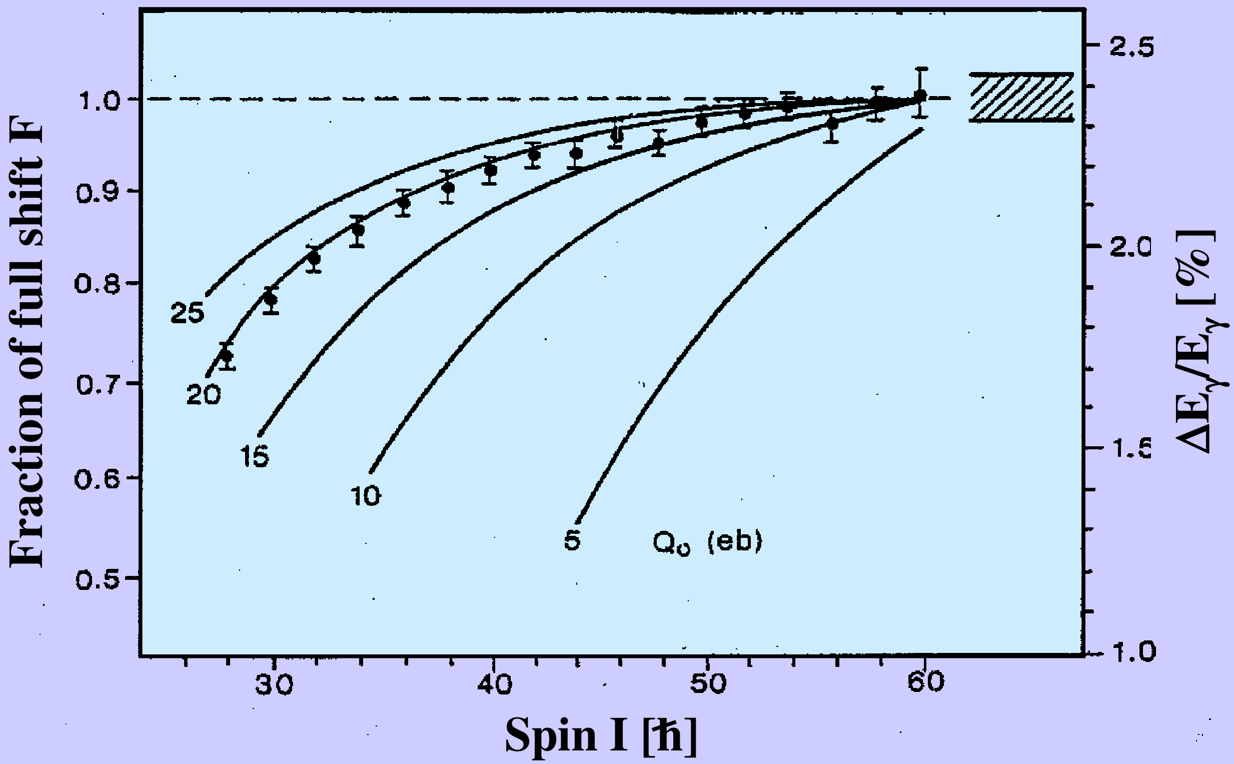
Spectrum of superdef. band



$$\Delta E_\gamma(v) = E_\gamma \cdot v/c \cos\theta = E_\gamma \cdot F(\tau)\, v_{max}/c \cos\theta$$

$$\text{mit} \quad F(\tau) = \int_0^\infty \frac{1}{\tau}\frac{v(t)}{v_{max}} \cdot e^{-t/\tau}$$

Energy shifts as function of spin



Assuming constant deformation ←→ constant Q_0

- **calculation of F(I) for different Q_0**
- **comparison with exp. values**

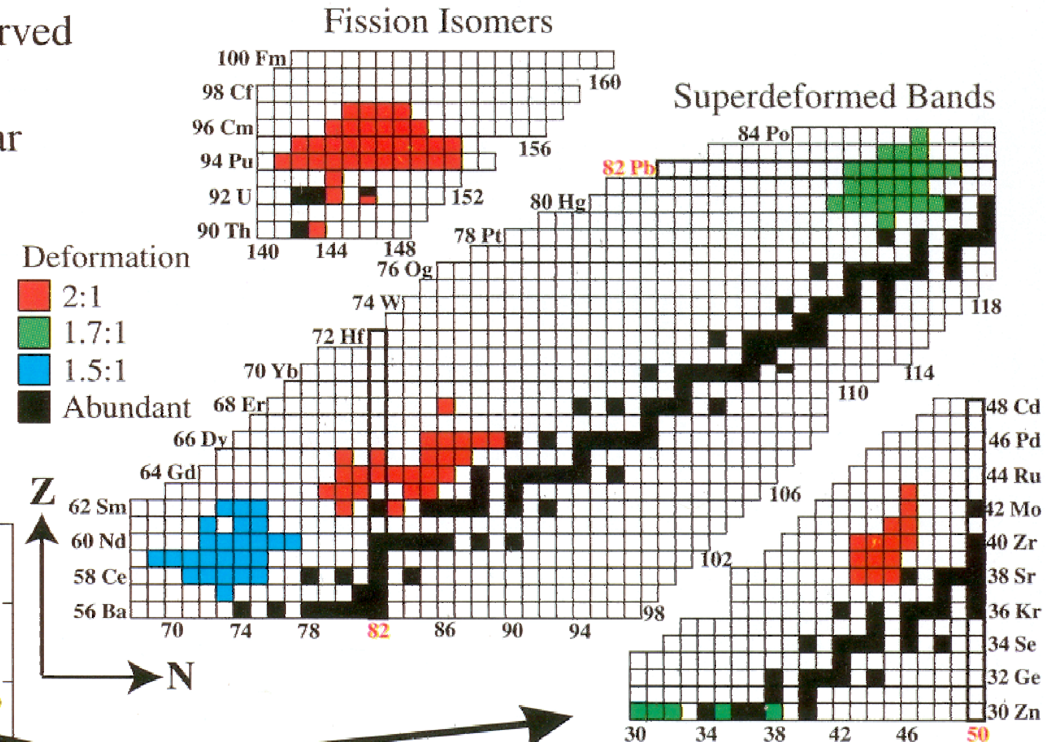
➡ **Q_0 = 19(3) e·b** **β ~ 0.82** **Proof of superdef. !**

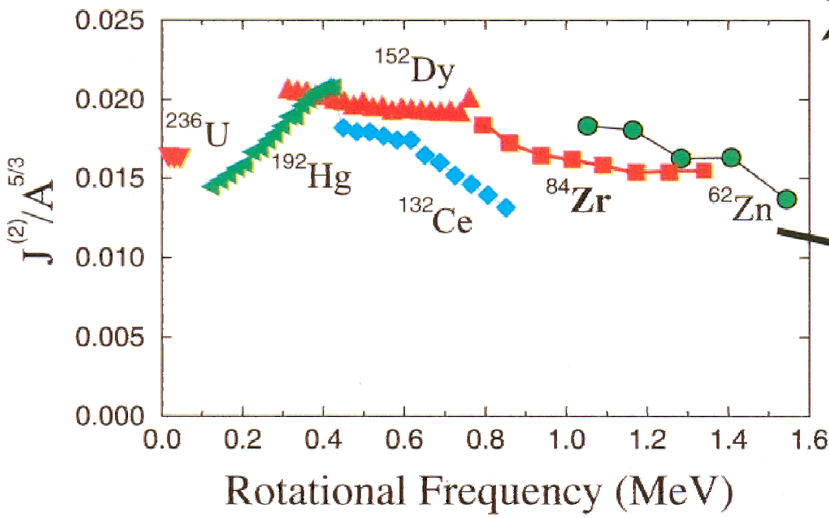
B(E2) ~ 2660 W.u.

$$Q_0 = \frac{3}{\sqrt{5\pi}} Z R_0^2 \beta (1 + 0.16\beta)$$ mit $R_0 = 1.2 \cdot A^{1/3} \mathrm{fm}$

The Regions of Superdeformation

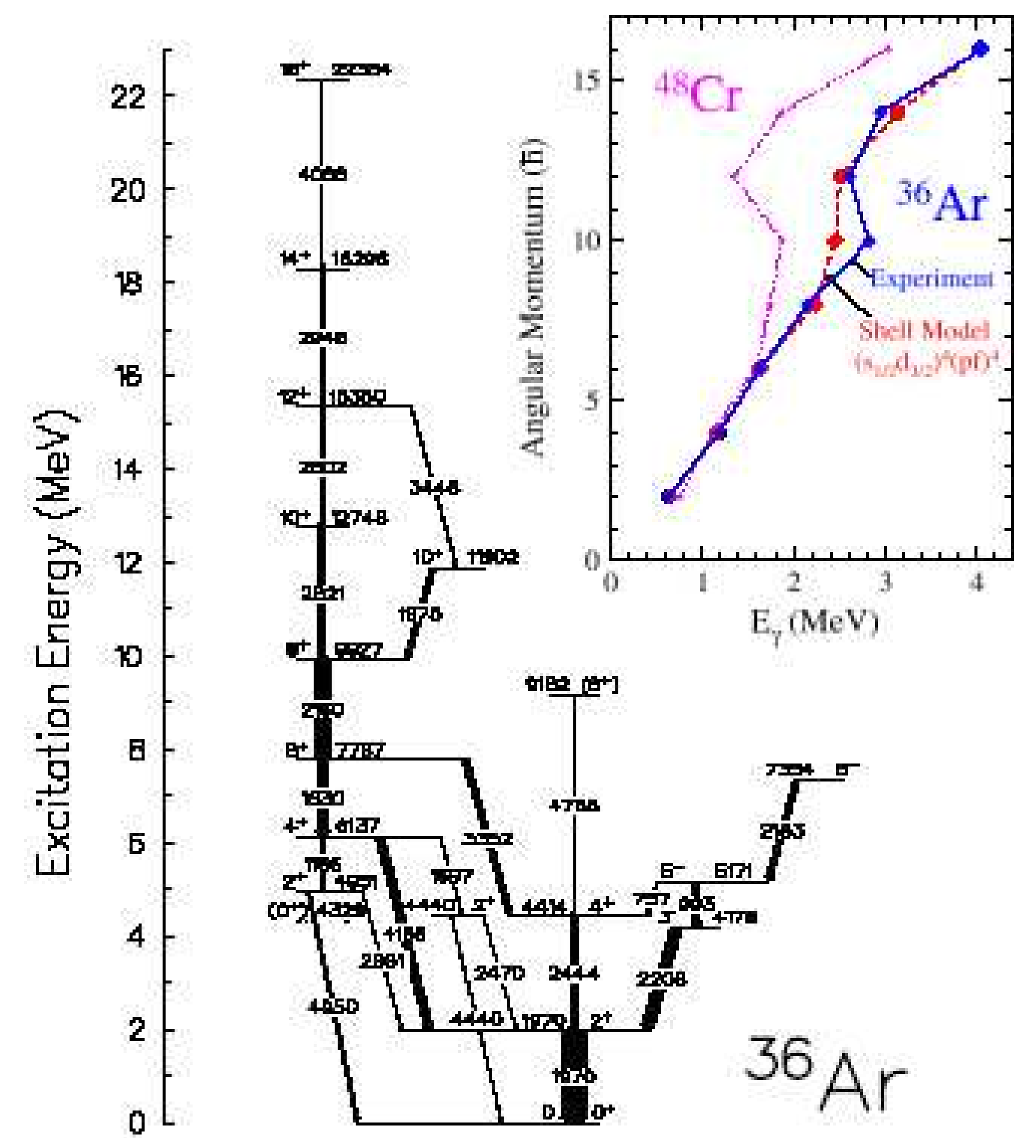
Superdeformed (SD) bands have been observed throughout the nuclear chart. The moments of inertia, after scaling to $A^{5/3}$, are all similar due to the fact that the shape (deformation) of a SD band is largely independent of the mass. The shell gaps, which define the SD shape, depend on the underlying symmetry of the nucleus, and occur at near-integer axis ratios.





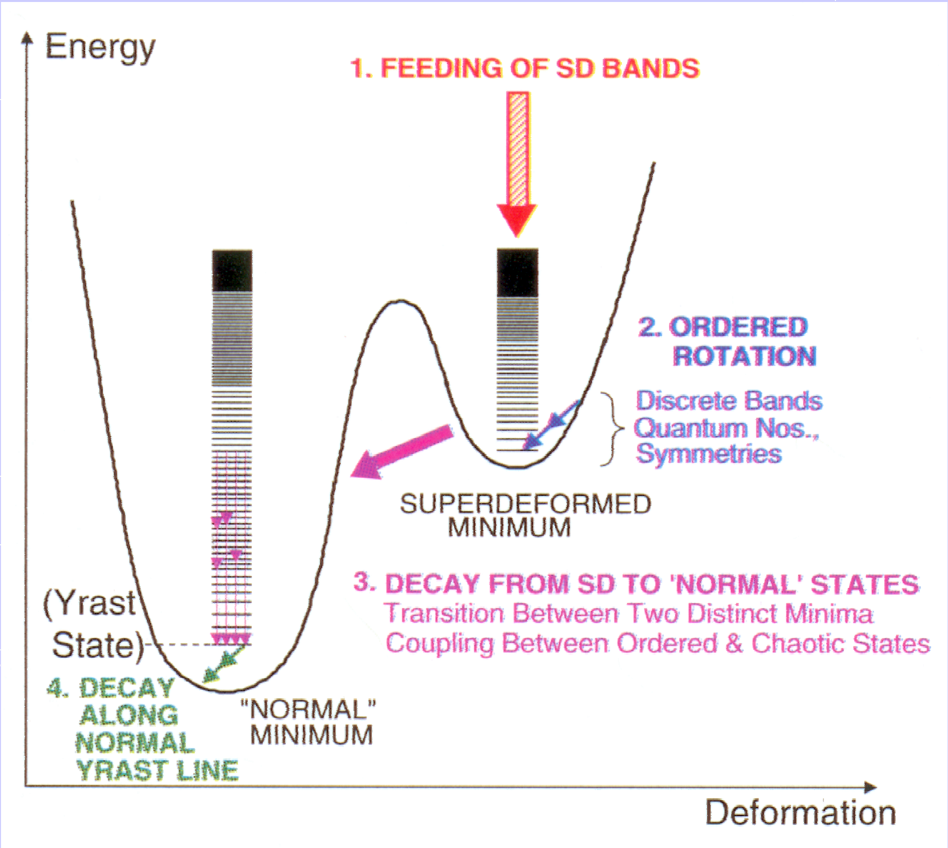
The recent observation with GAMMASPHERE of a new region of superdeformation (N~Z~30) opens up many exciting opportunities, including the possibility to study the most collective states known with a "Shell Model" description.

C. Svensson et al., Phys. Rev. Lett. 85 (2000) 2693



The γ-decay of superdeformed bands

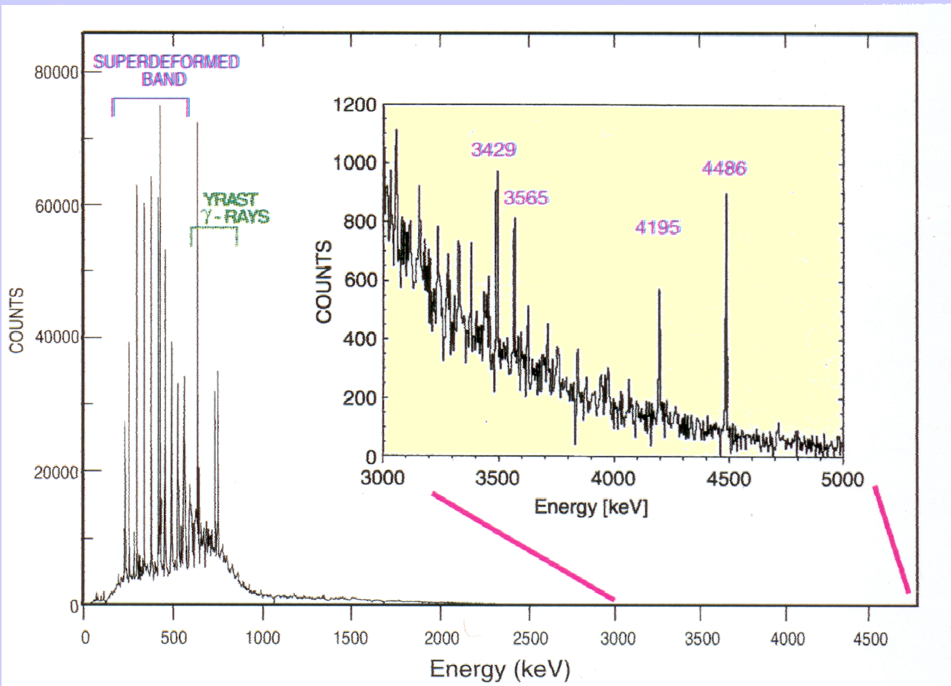
Why is it so difficult to observe ?

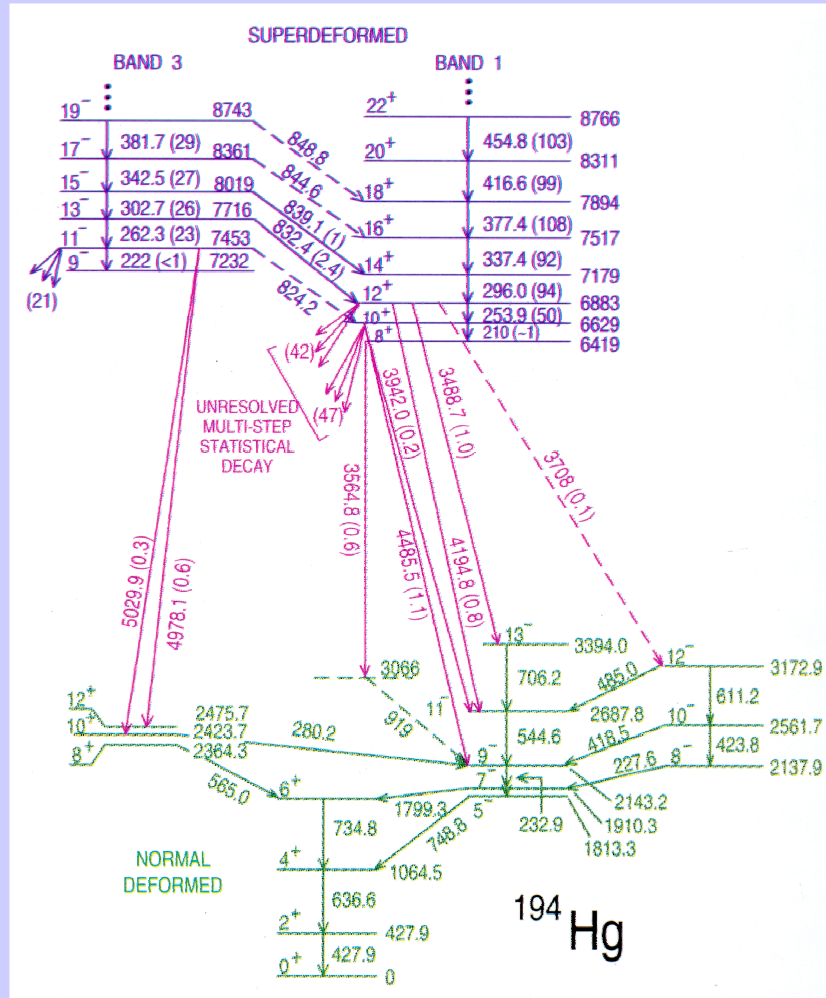


- **high level density**
  $\rightarrow$ fragmentation, low γ-intensities
- **high γ-ray energies**
  $\rightarrow$ low detection efficiency
- **very different structure of the states in the two minima**
  $\rightarrow$ low transition strengths

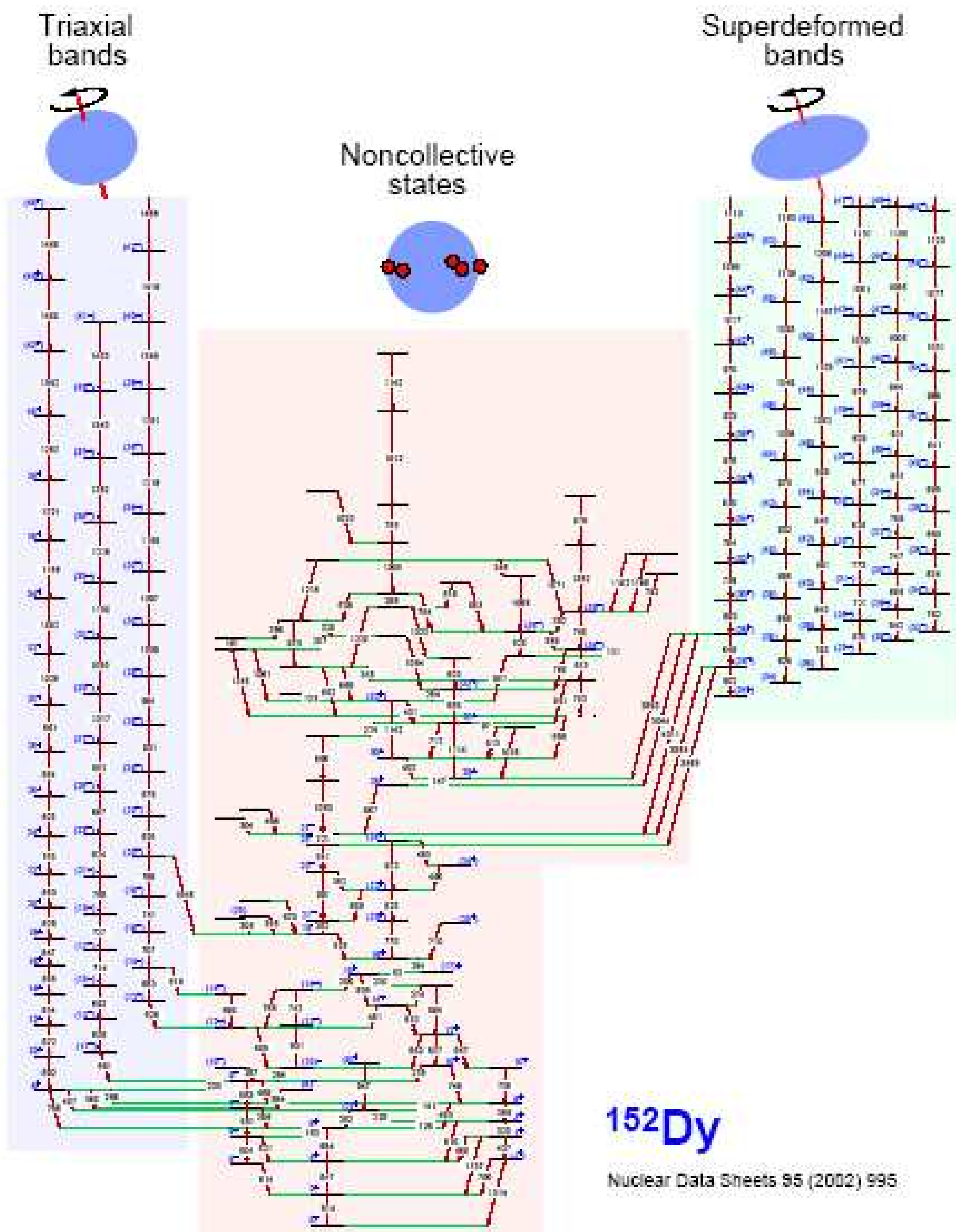
First observation of discrete linking γ-decays into the first minimum: The nucleus ^{194}Hg

Gammasphere-Experiment





Coexistence of collective and noncollective motion



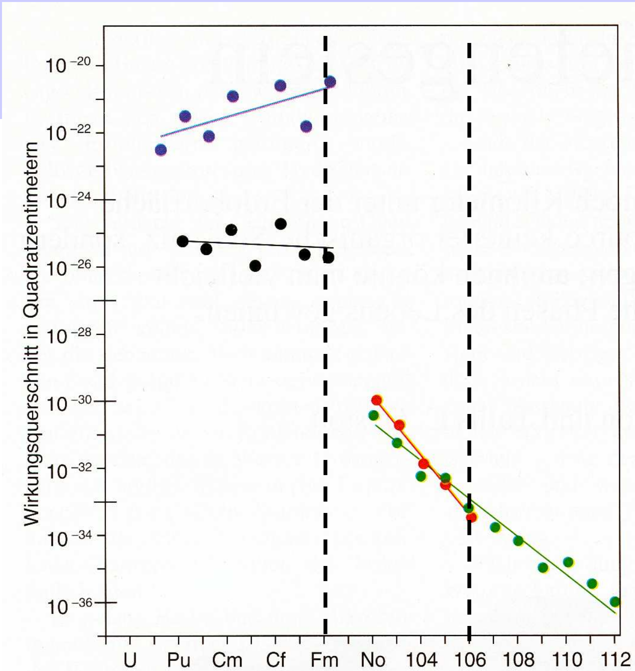
^{152}Dy

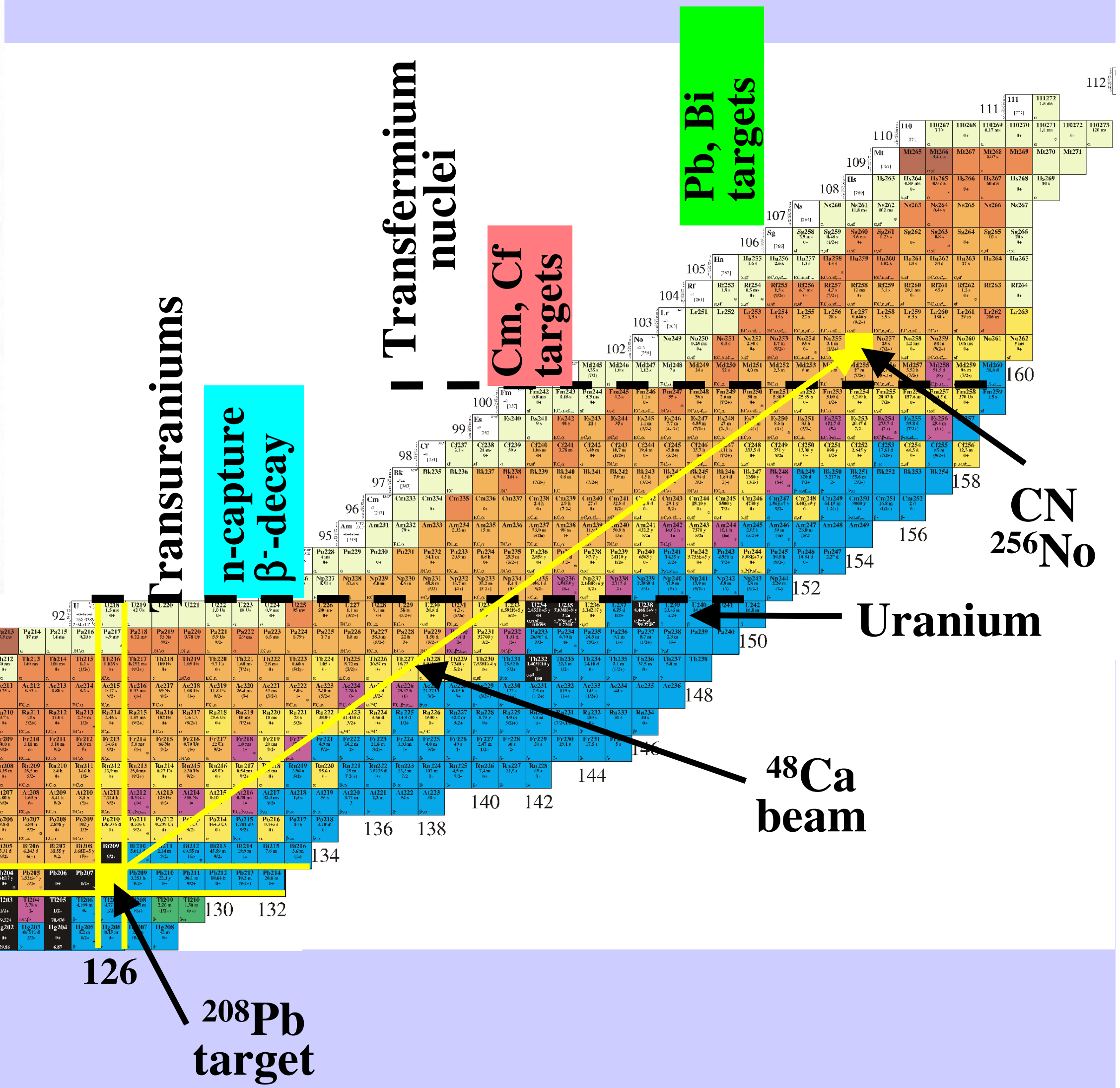
Nuclear Data Sheets 95 (2002) 995

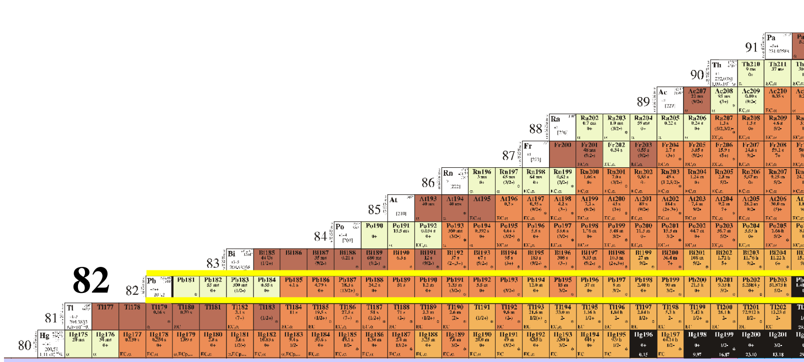
Some recent examples …

- Prompt particle decay from deformed excited states
- Superdeformed bands all over the chart of nuclides
- Spectroscopy of transfermium nuclei: Towards the SHE's …
- Ground state proton decay: spectroscopy beyond the dripline

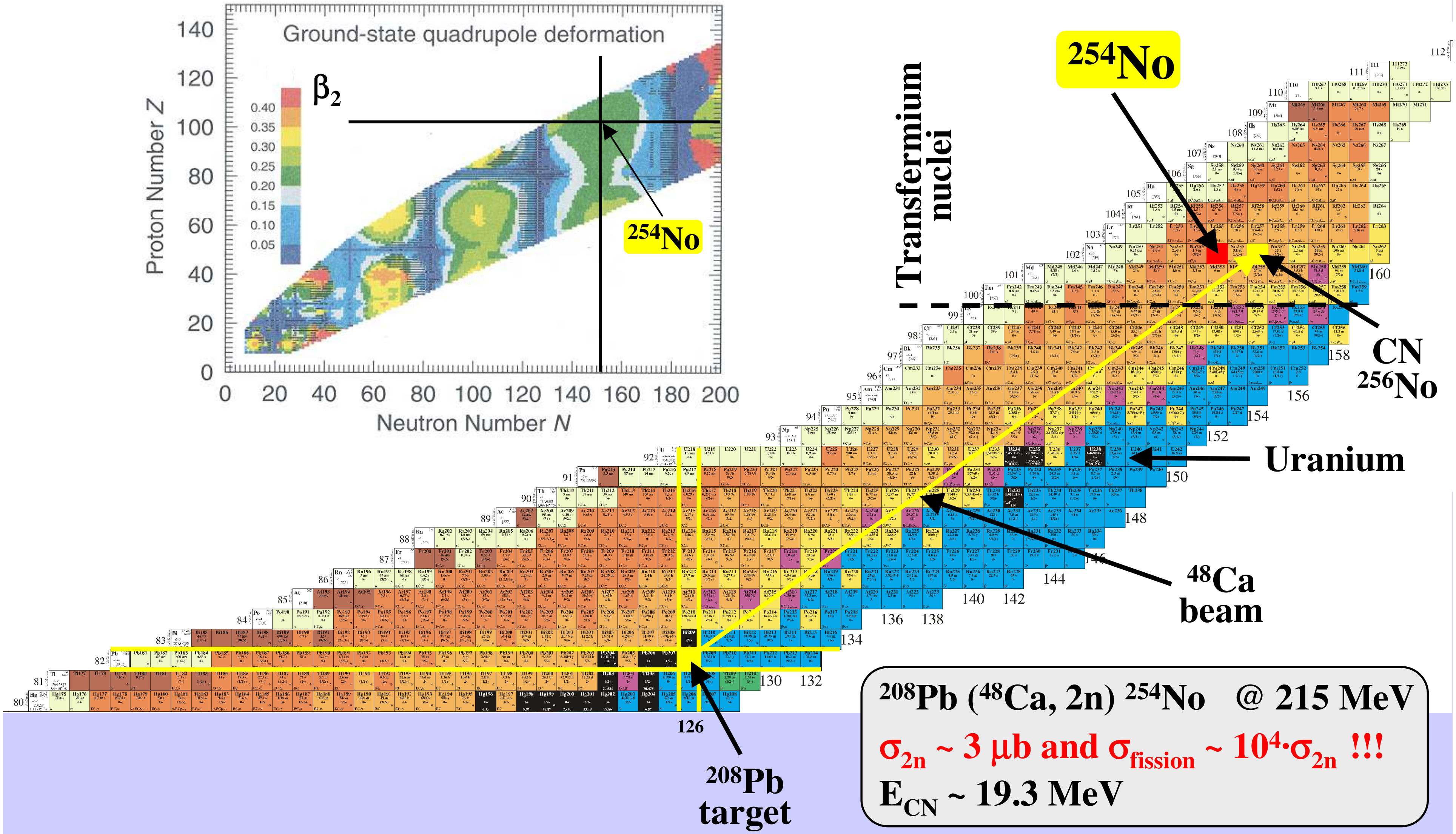
Possible reactions for the synthesis of heavy elements







Where is ^{254}No ?

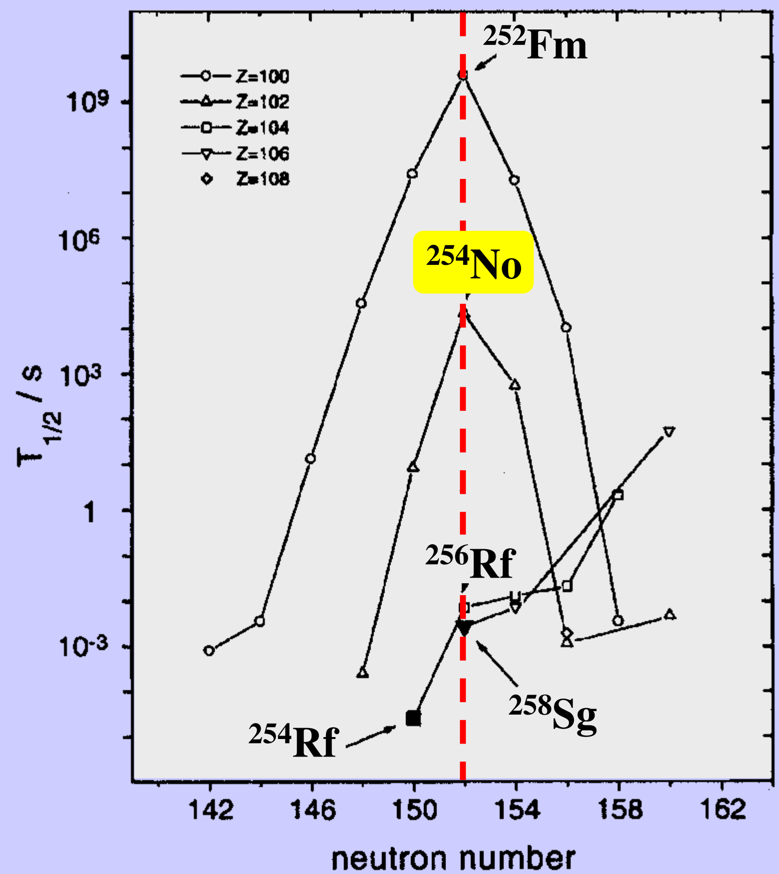


^{208}Pb (^{48}Ca, 2n) ^{254}No @ 215 MeV

σ_{2n} ~ 3 μb and $\sigma_{fission}$ ~ $10^4 \cdot \sigma_{2n}$!!!

E_{CN} ~ 19.3 MeV

Fission halflives of transfermium nuclei

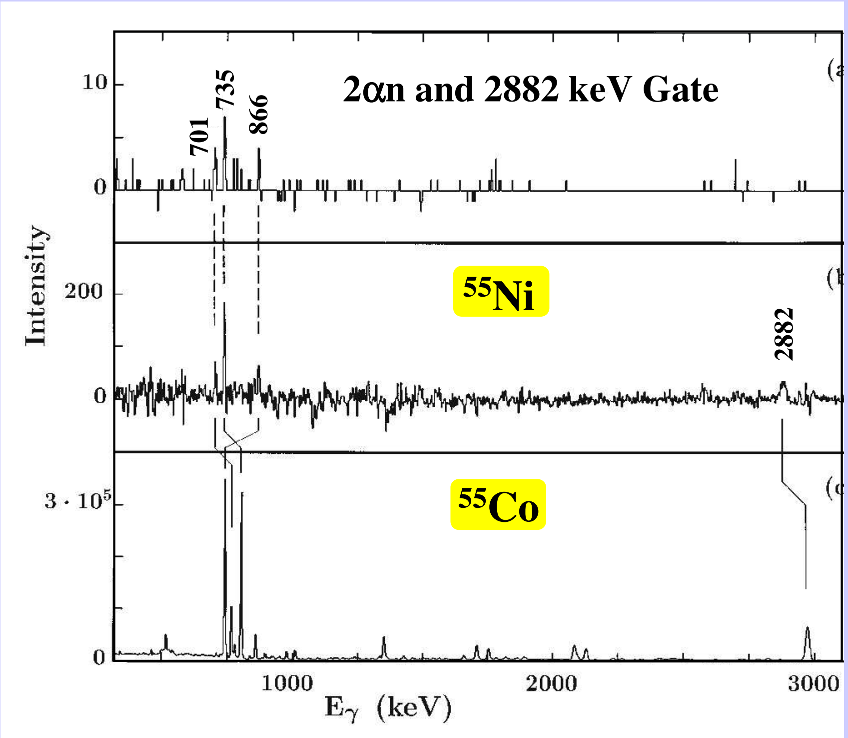


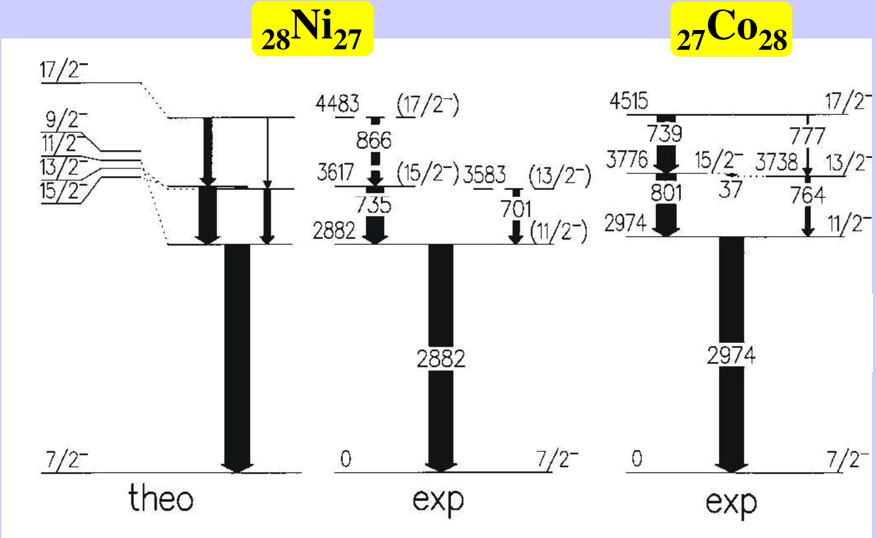
relatively long fission halflive

better chances to observe α-decay

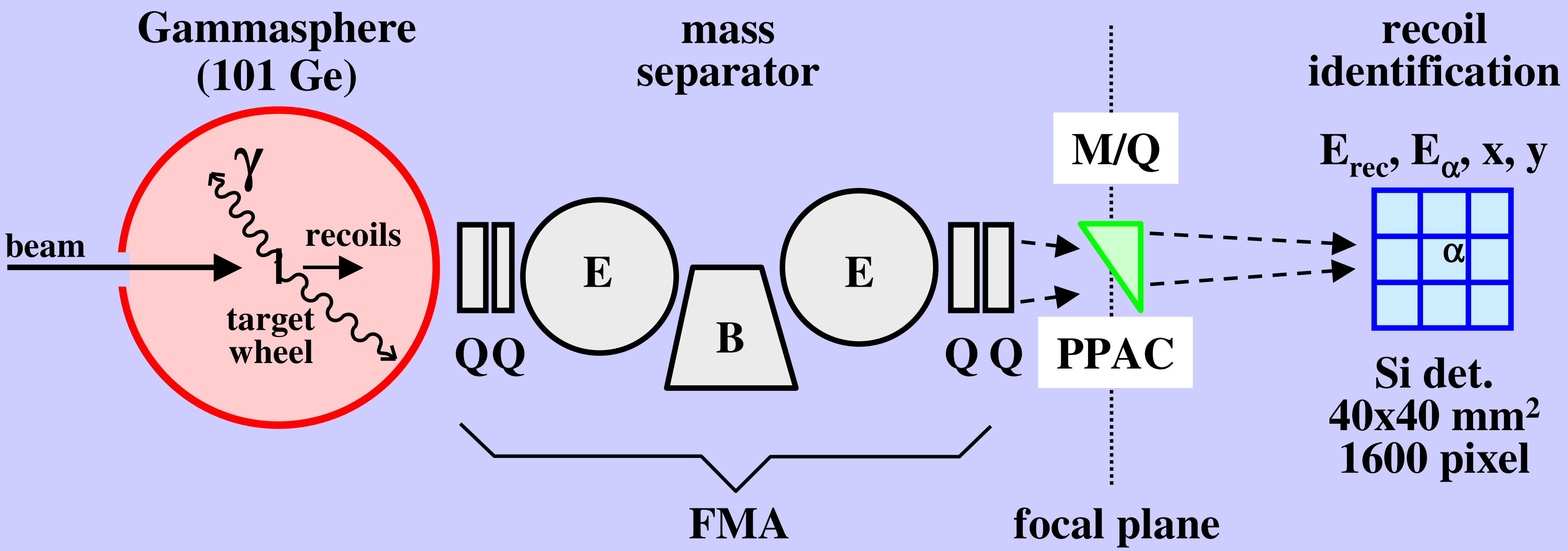
Reminder …

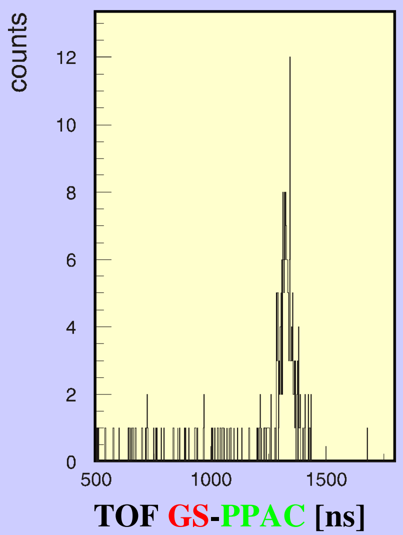
At the limit: ^{55}Ni with σ ~ 0.004 % ≅ 40 μb

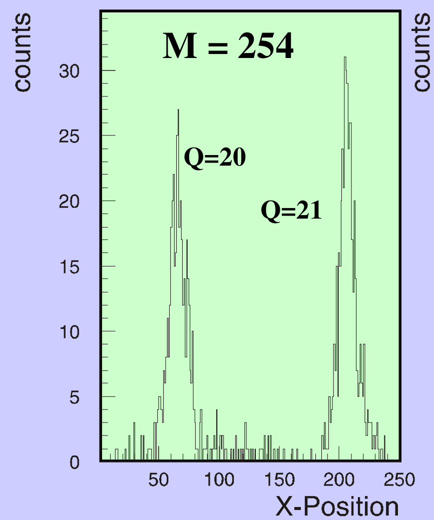


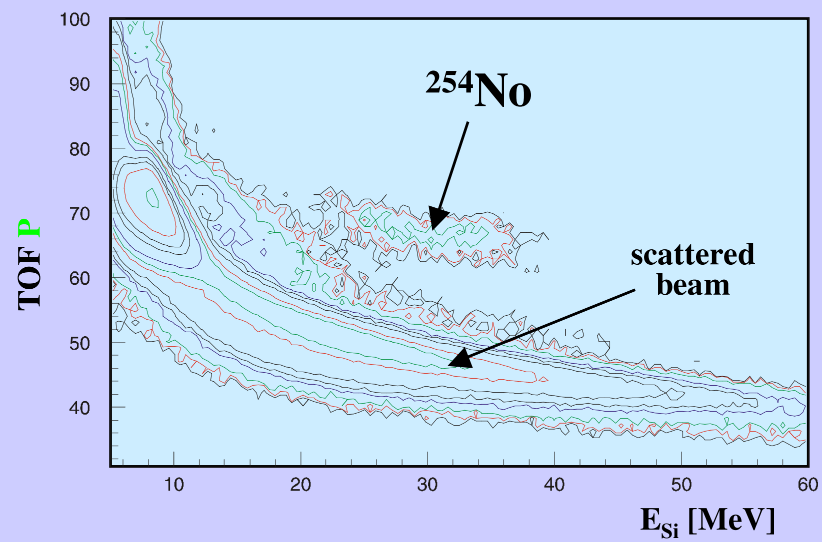


The experimental setup to study ^{254}No

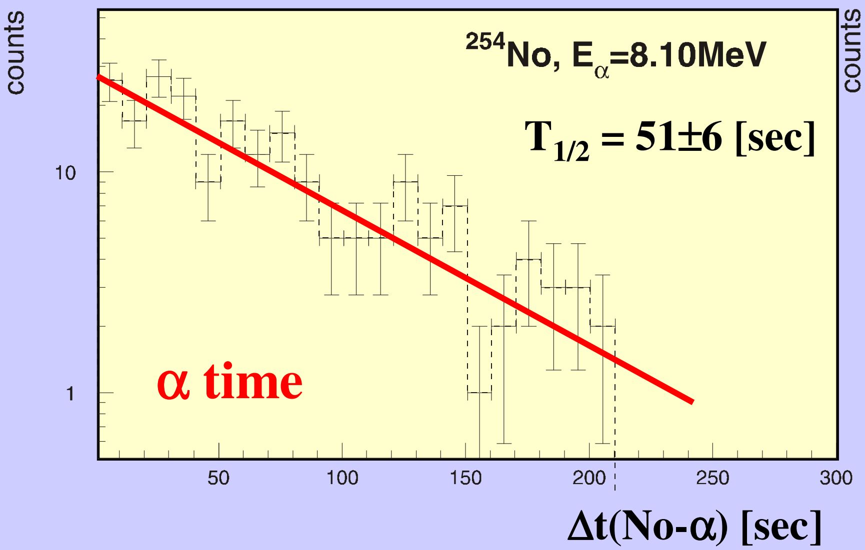


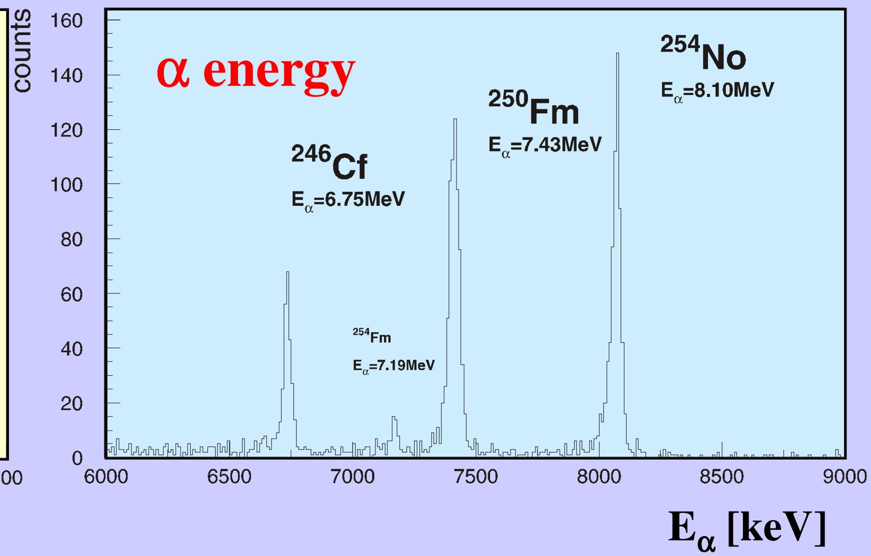




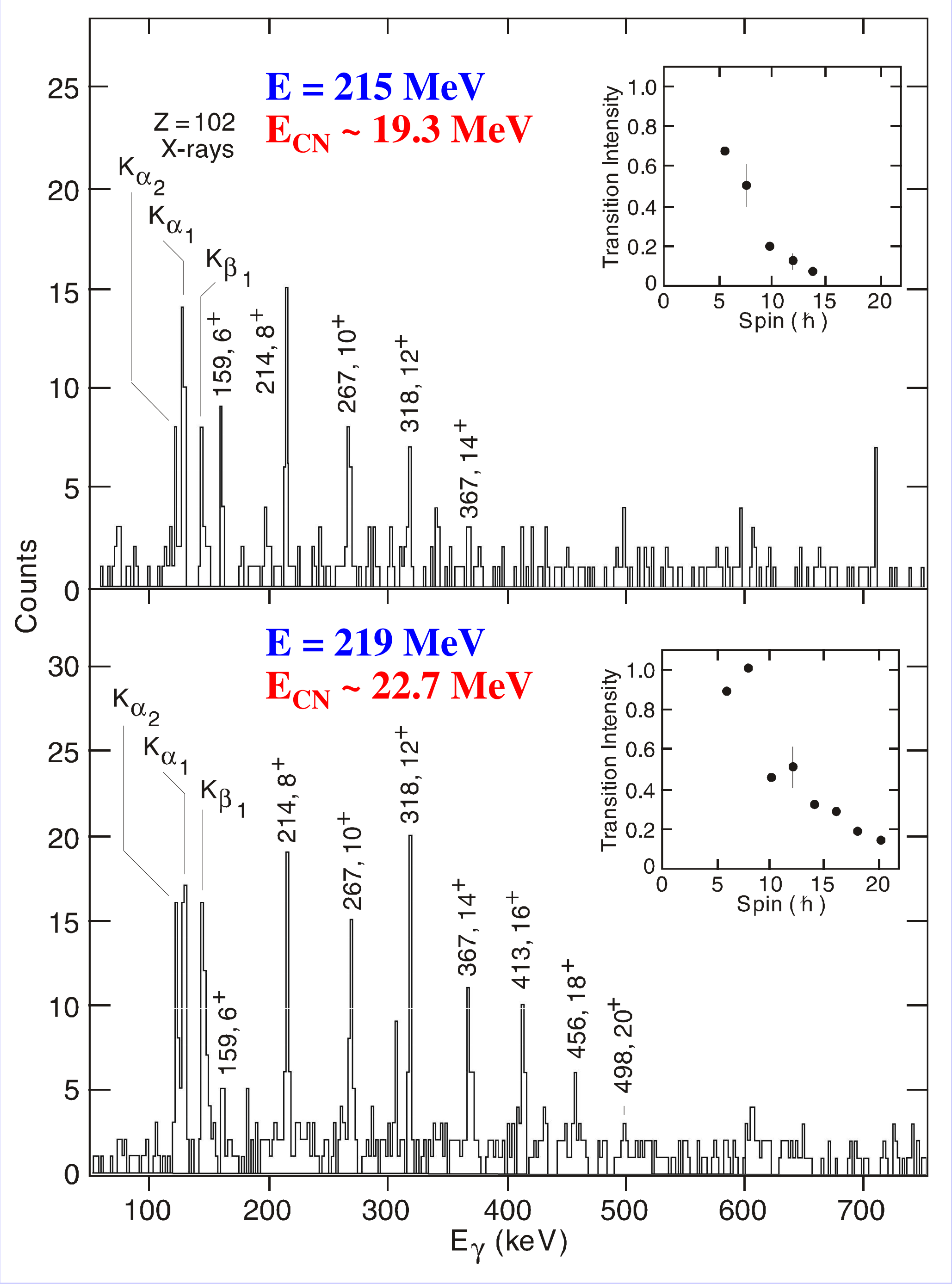


Unequivocal identification of ^{254}No: α-decays in the same Si pixel

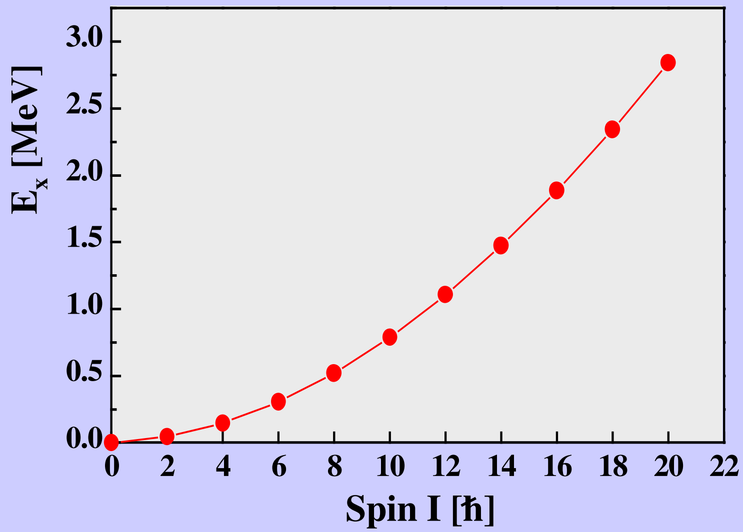




^{254}No γ spectra from Gammasphere

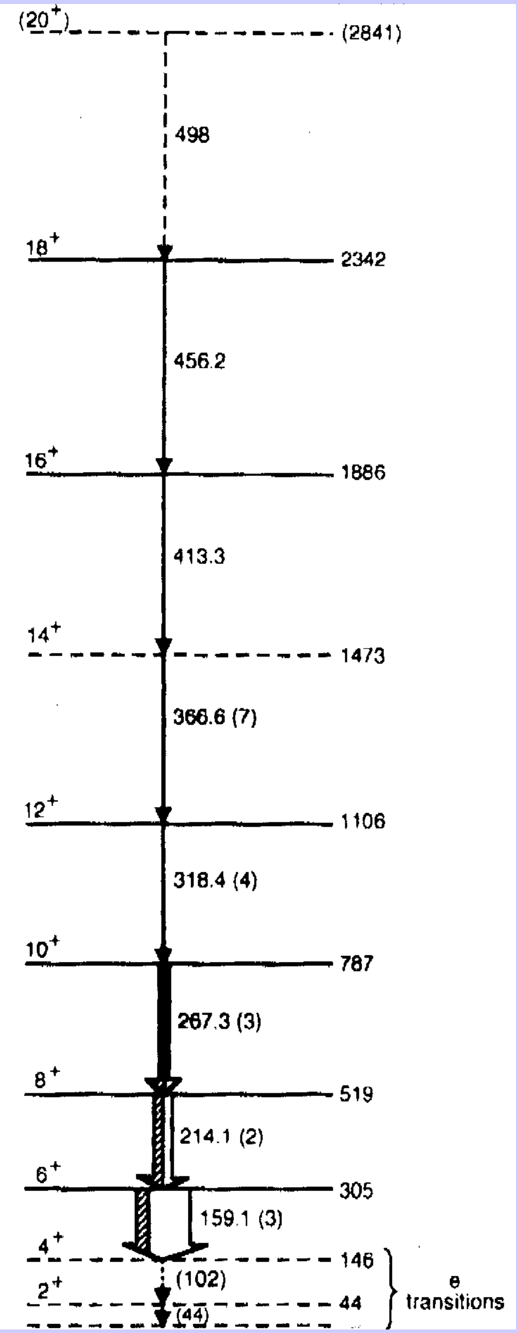


Rotational band and deformation of ^{254}No



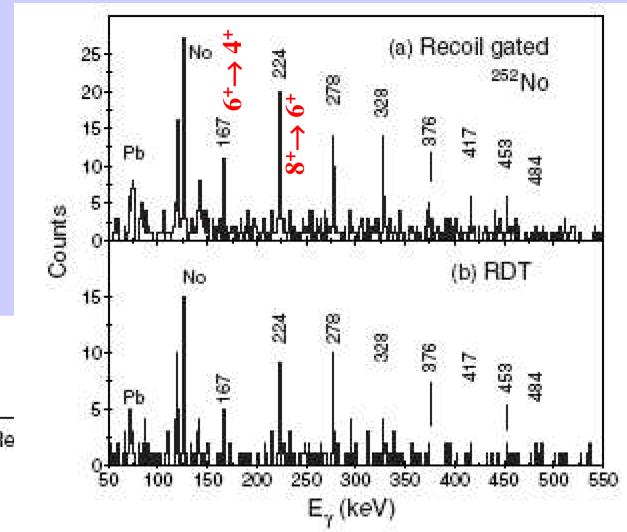
Using an empirical formula to deduce the deformation from the energy of the first 2^+ state:

$$\beta = 0.27(2)$$



More transfermium spectroscopy …

^{252}No (220 nb)



^{250}Fm