Mini−Workshop on Future In−Beam Conversion Electron Spectroscopy

ISKP Bonn, 23./24. January 2003

Conversion Electron Spectroscopy in the Second Minimum of Actinides

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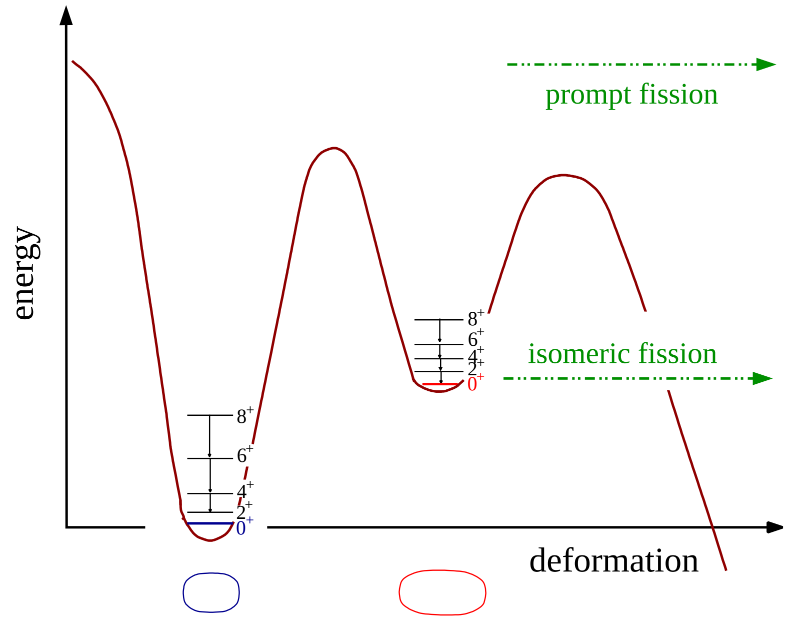
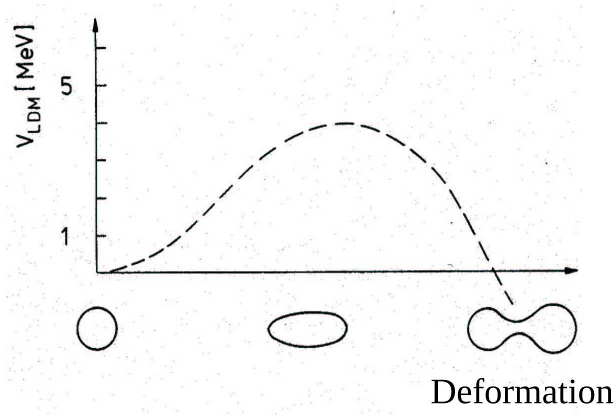


- Introduction: double−humped fission barrier, fission isomers
- Experiments in the superdeformed 2. minimum: ^{240f}Pu
  - − γ −spectroscopy
  - − conversion electron spectroscopy
- Predictions from phenomenological systematics
- Summary and Outlook

2. minimum and fission isomers

- double-humped fission barrier:



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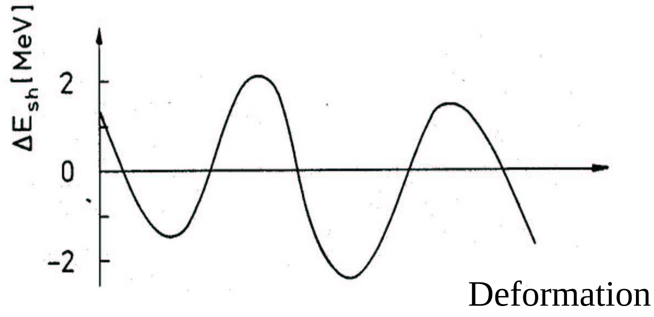
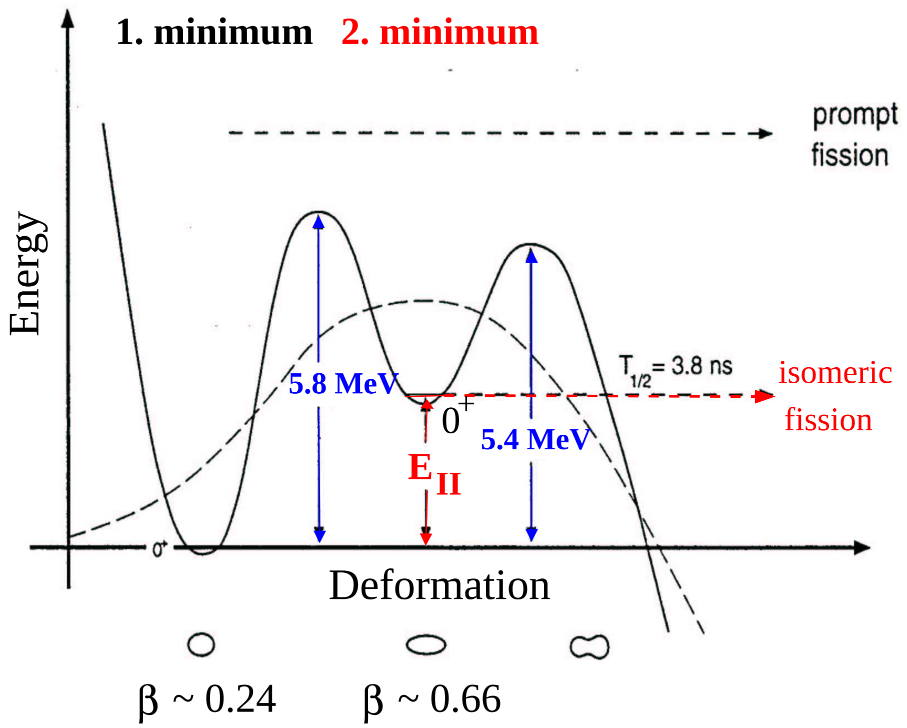


(macroscopic)
droplet model

+

(microscopic)
shell corrections
(Strutinsky, 1967)

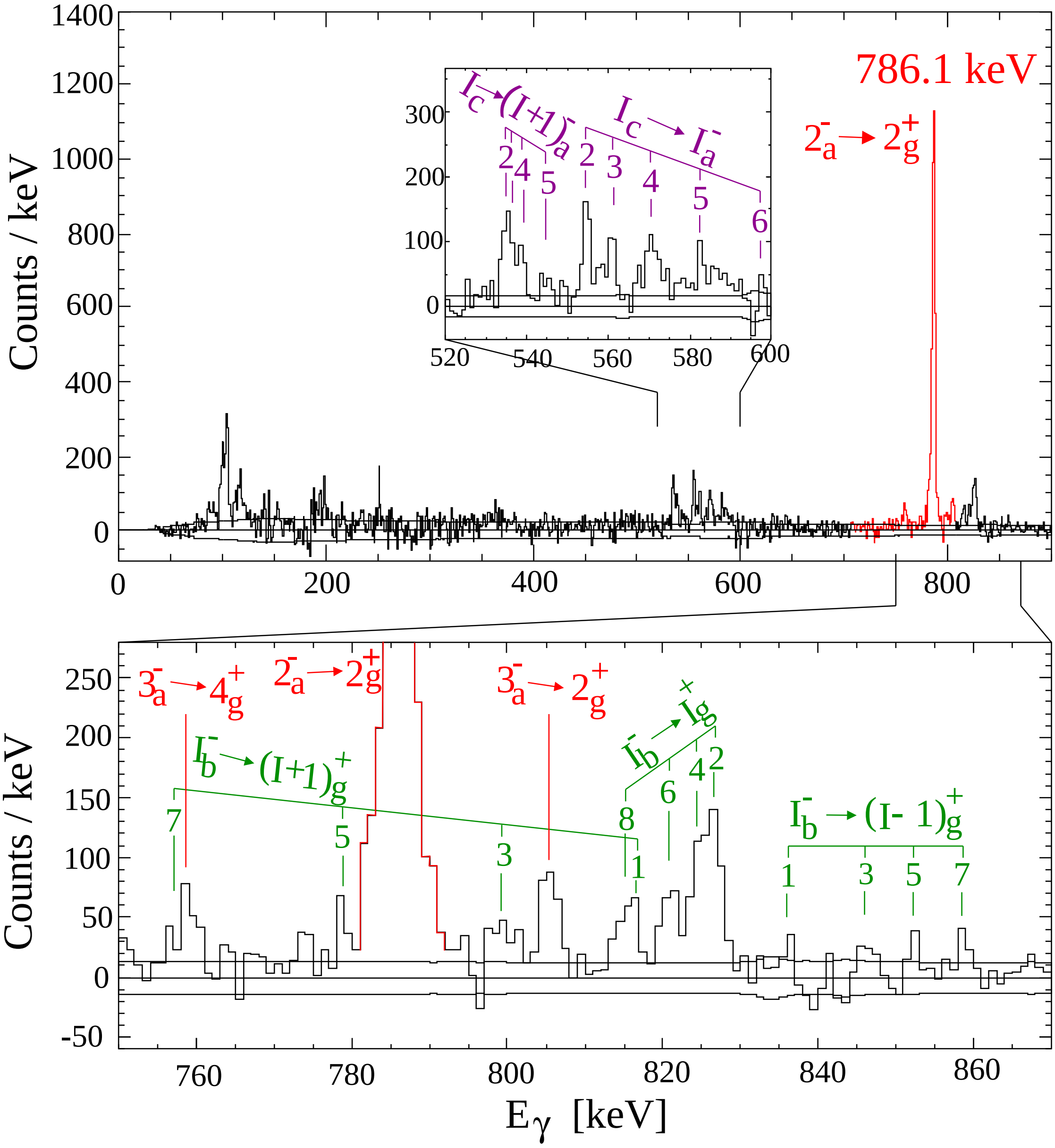
- ^{240}Pu:



- magic neutron number N=146 , fission isomer: $t_{1/2}$ = 3.8 ns
- pioneer experiment by Specht et al. (1972) :
  conversion electron spectroscopy after ^{238}U(α,2n) ^{240}Pu
  first identification of fission isomeric ground state rotational band

γ *spectroscopy in* ^{240f}Pu

- 6 Ge-CLUSTER of German EUROBALL Collaboration: 42 detectors
- $^{238}U(\alpha, 2n)\ ^{240f}Pu$ ($t_{1/2}$ =3.8 ns), 440 hrs. beamtime
- delayed coincidence with fission fragments

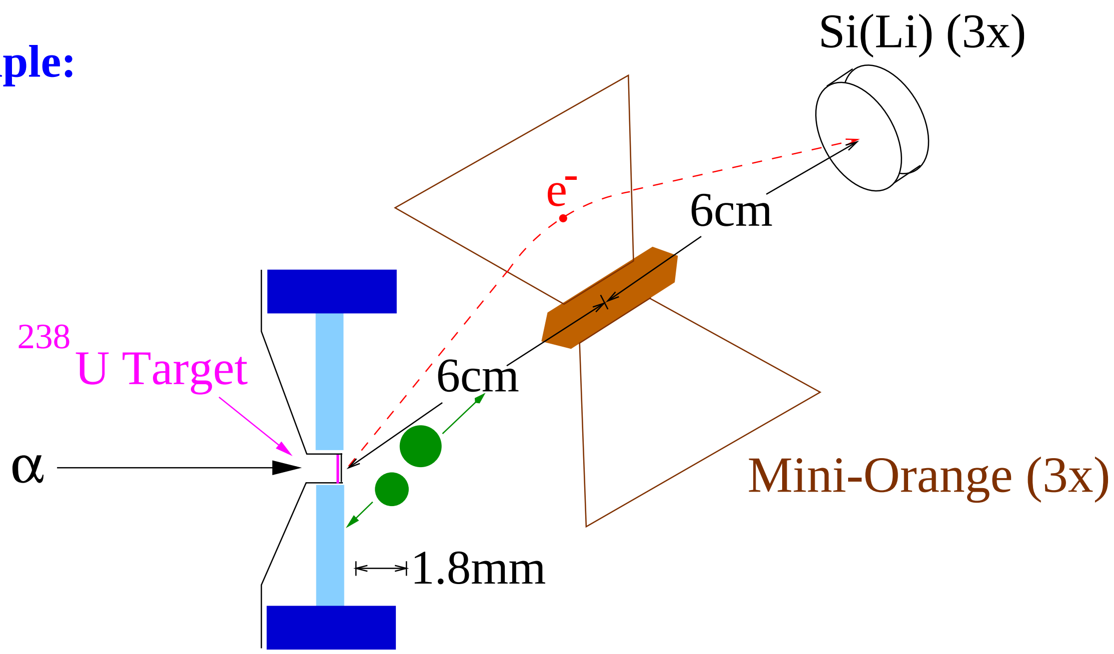


- single intensive γ- line (786.1 keV, 36.6 %) + weaker lines
- regular rotational band structure: starting point for level scheme

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

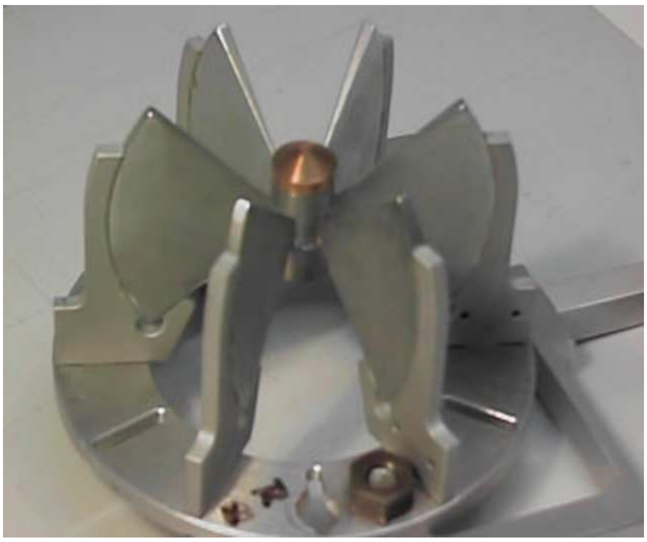
Mini Orange setup for conversion electron spectroscopy

Principle:



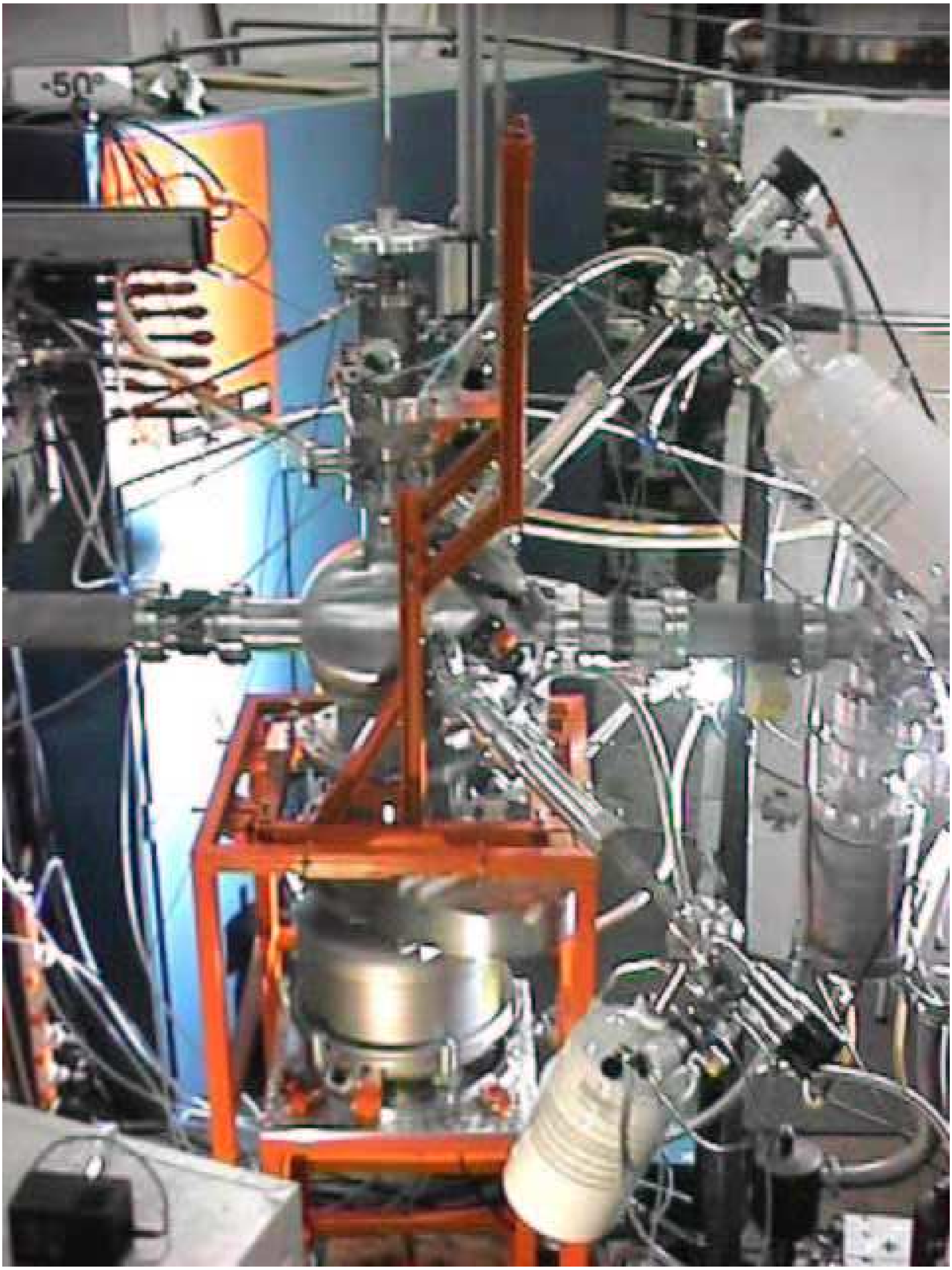
annular Si detector
(delayed fission)

Mini-Oranges:



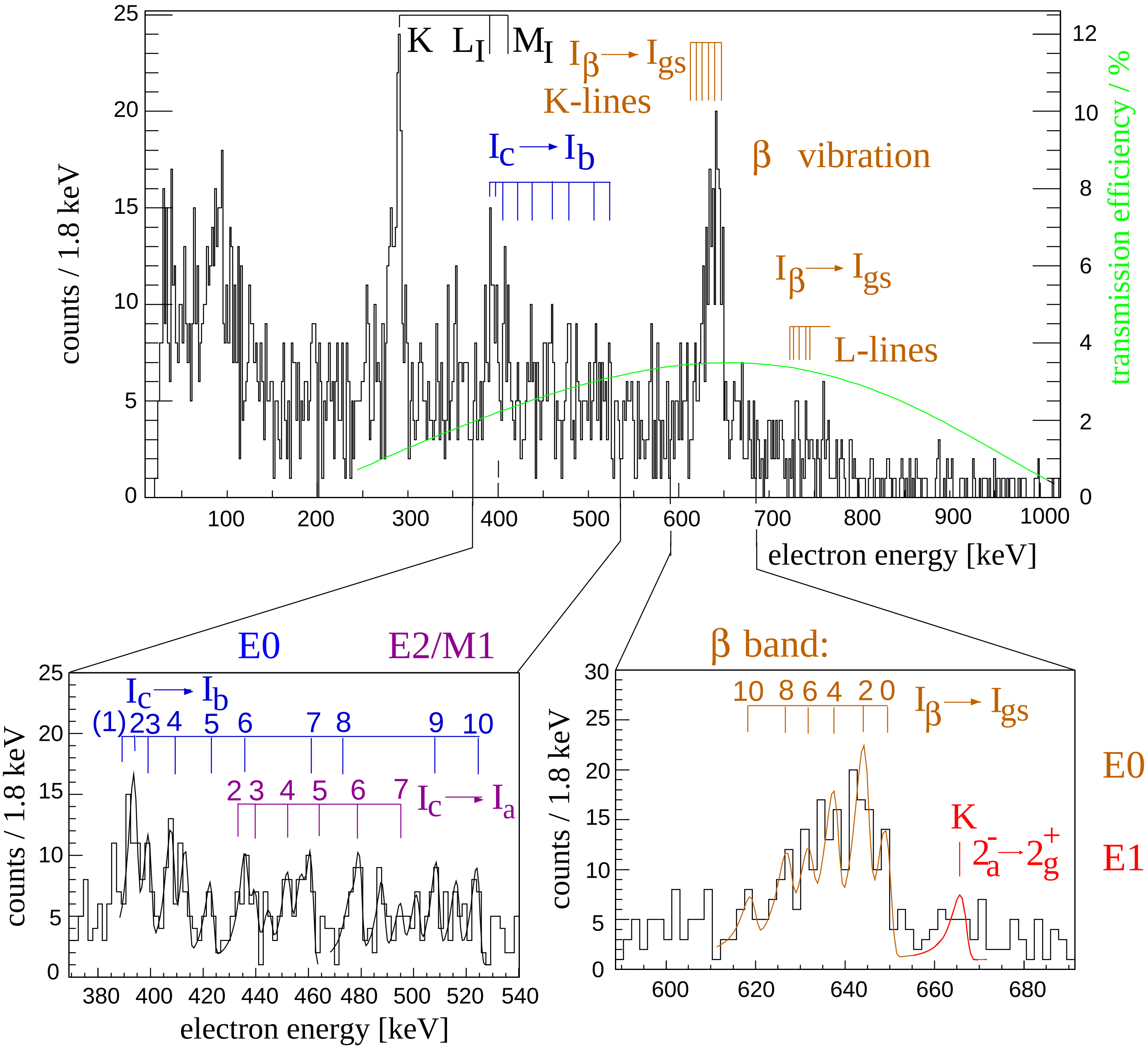
- wedge-shaped permanent magnets around central Pb absorber
- toroidal magnetic field
- 2 configurations:
  300 <= E_e(keV) <=600
  600 <= E_e(keV) <=800
- Si(Li)-detectors: Δ E~ 3.1 keV
- total efficiency: 5.4 % (625 keV)

Experimental Setup for Conversion Electron Spectroscopy



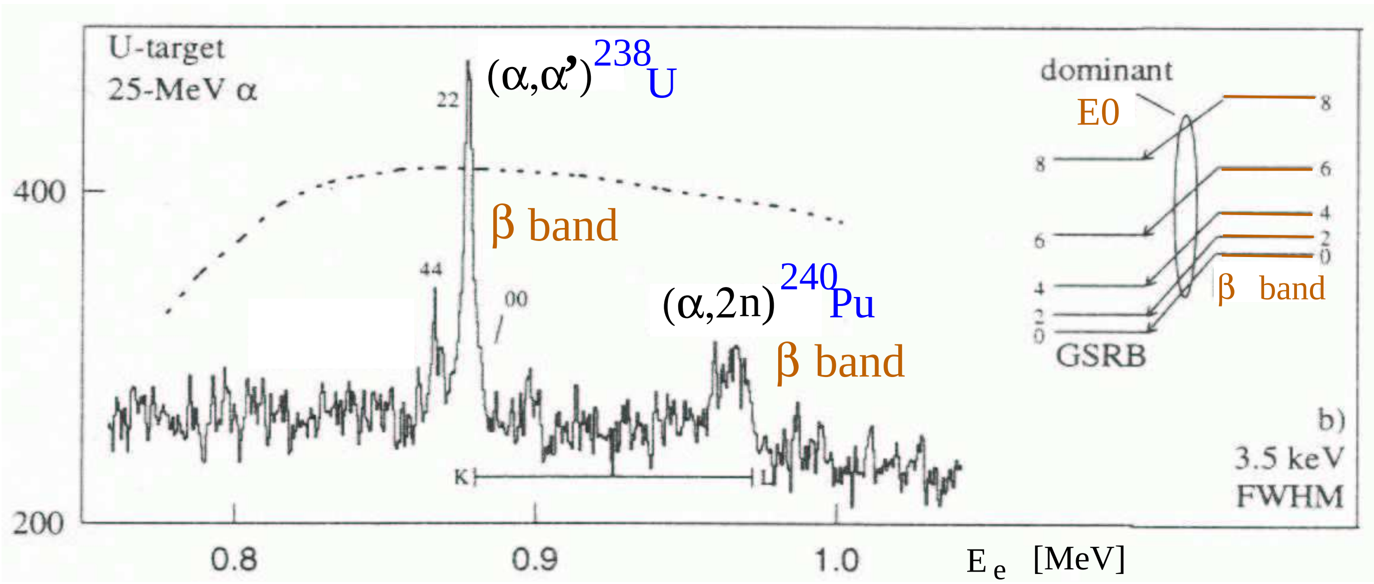
Conversion electrons from ^{240f}Pu

- from 2 series of experiments (ca. 570 hrs. beamtime): transmission optimized for 300-600 keV, 600-800 keV
- reaction: $^{238}U(\alpha,2n)\,^{240f}Pu$ $E_\alpha = 25$ MeV
- electrons in delayed coincidence with fission fragments



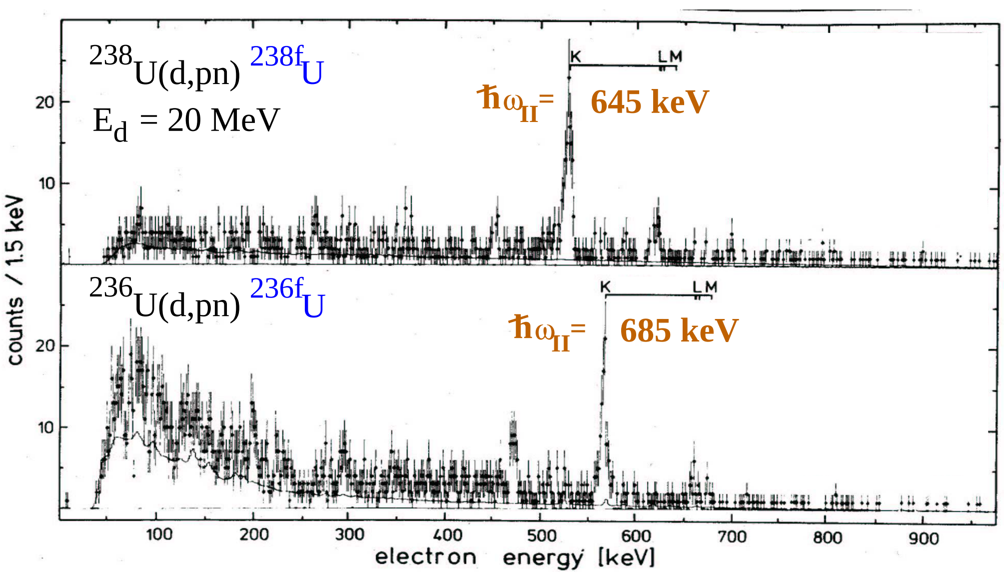
β bands in $^{236f,238(f)}$U and ^{240}Pu

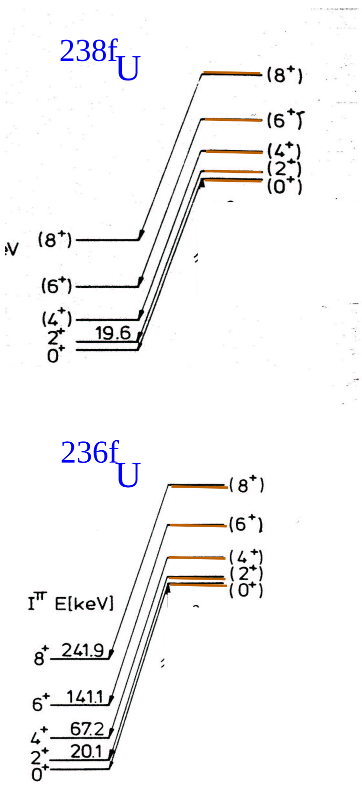
- 1. minimum:



J.M. Hoogduin et al. Phys. Lett. B 384 (1996) 43

- 2. minimum:

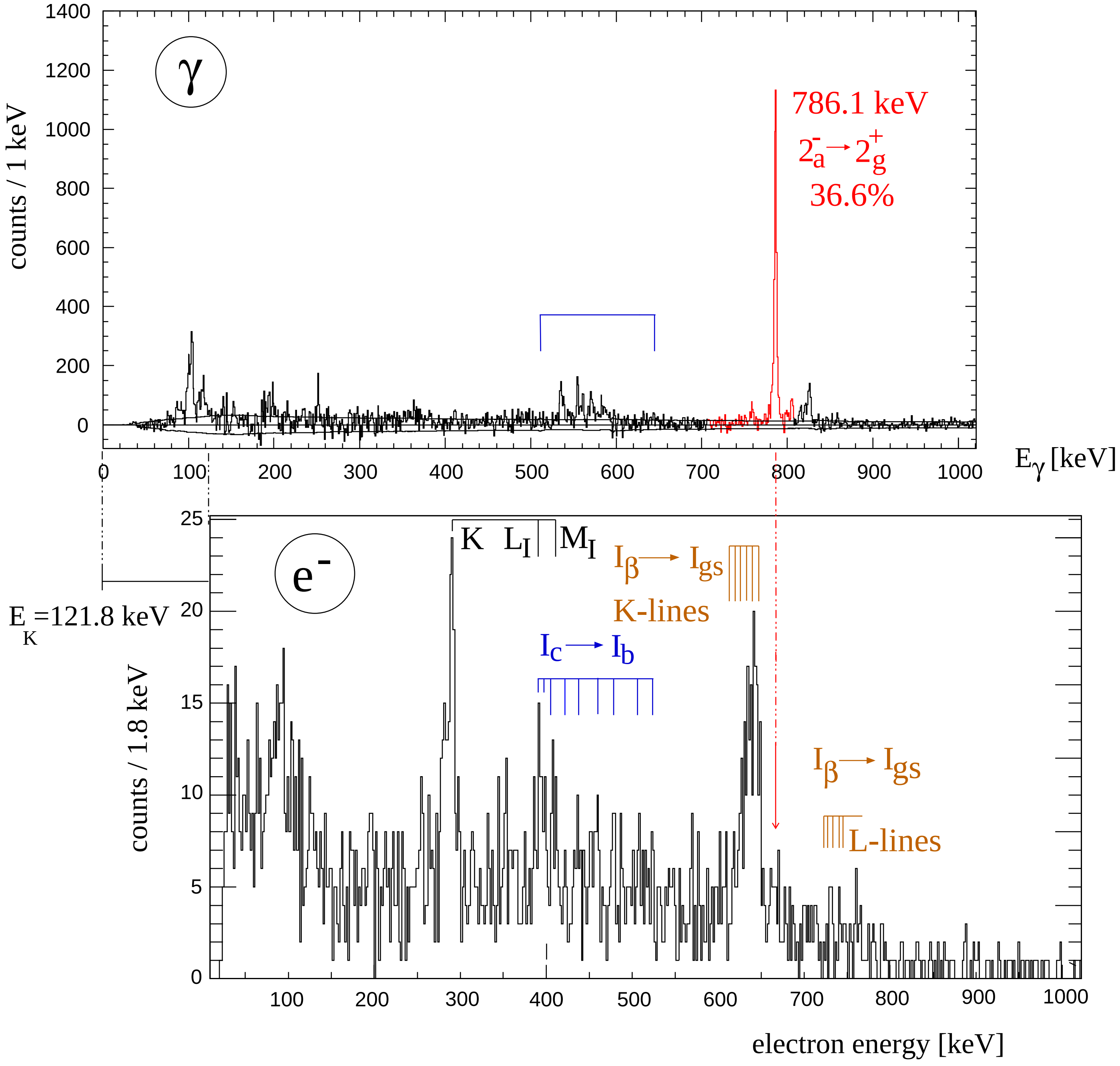




U. Goerlach et al., Phys. Rev. Lett. 48 (1982) 1160

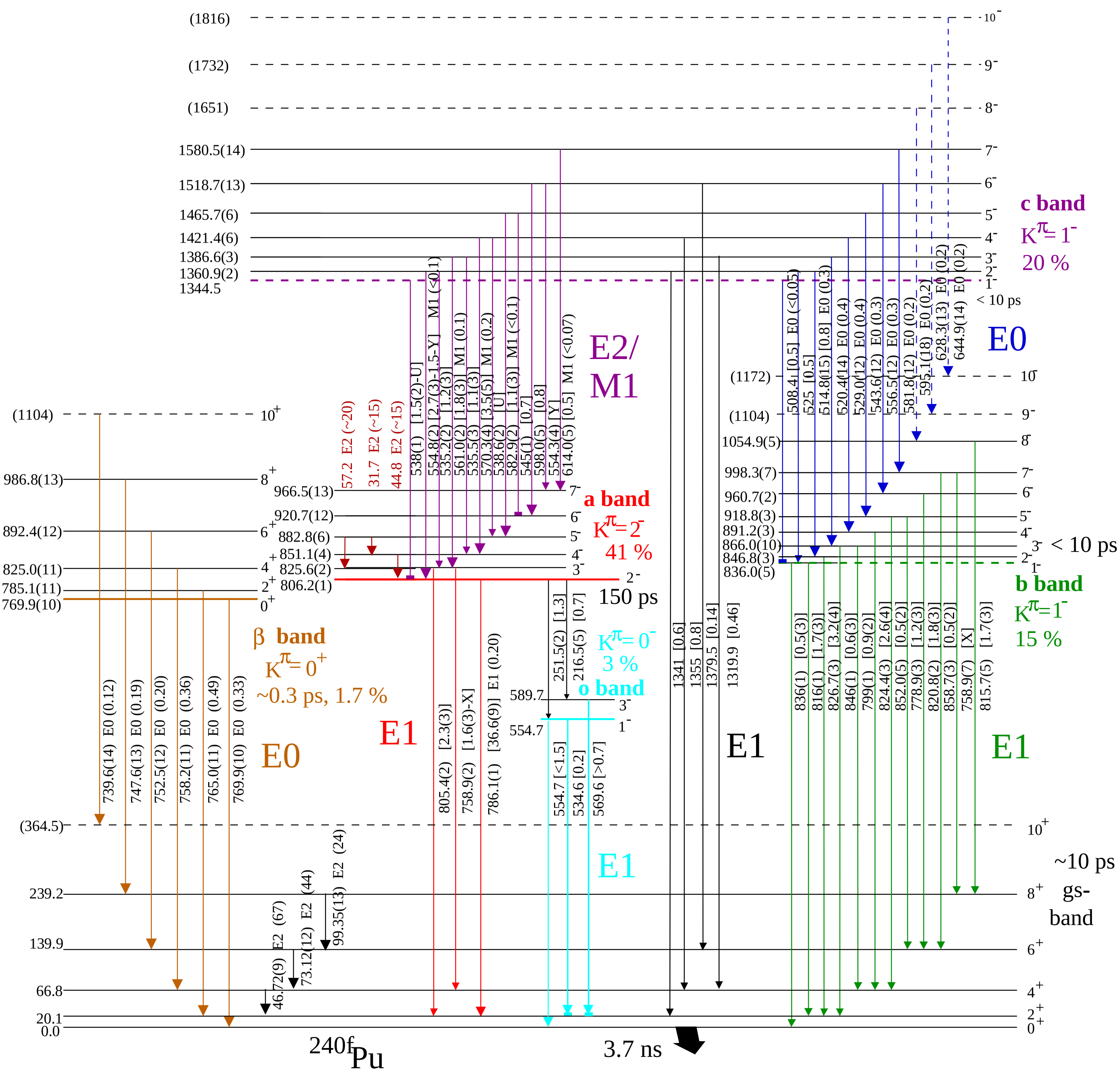
- I_β - I_g - degeneracy removed

Combined analysis: γ's + conversion electrons



- all strong electron lines are E0 transitions
- conversion coefficient of 786.1 keV transition: E1
- first excited β-vibrational phonon: 769.9 keV
- connecting E0 transitions between excited rotational bands

Level scheme of ^{240f}Pu



- excited states in 2. minimum: ca. 98% negative parity

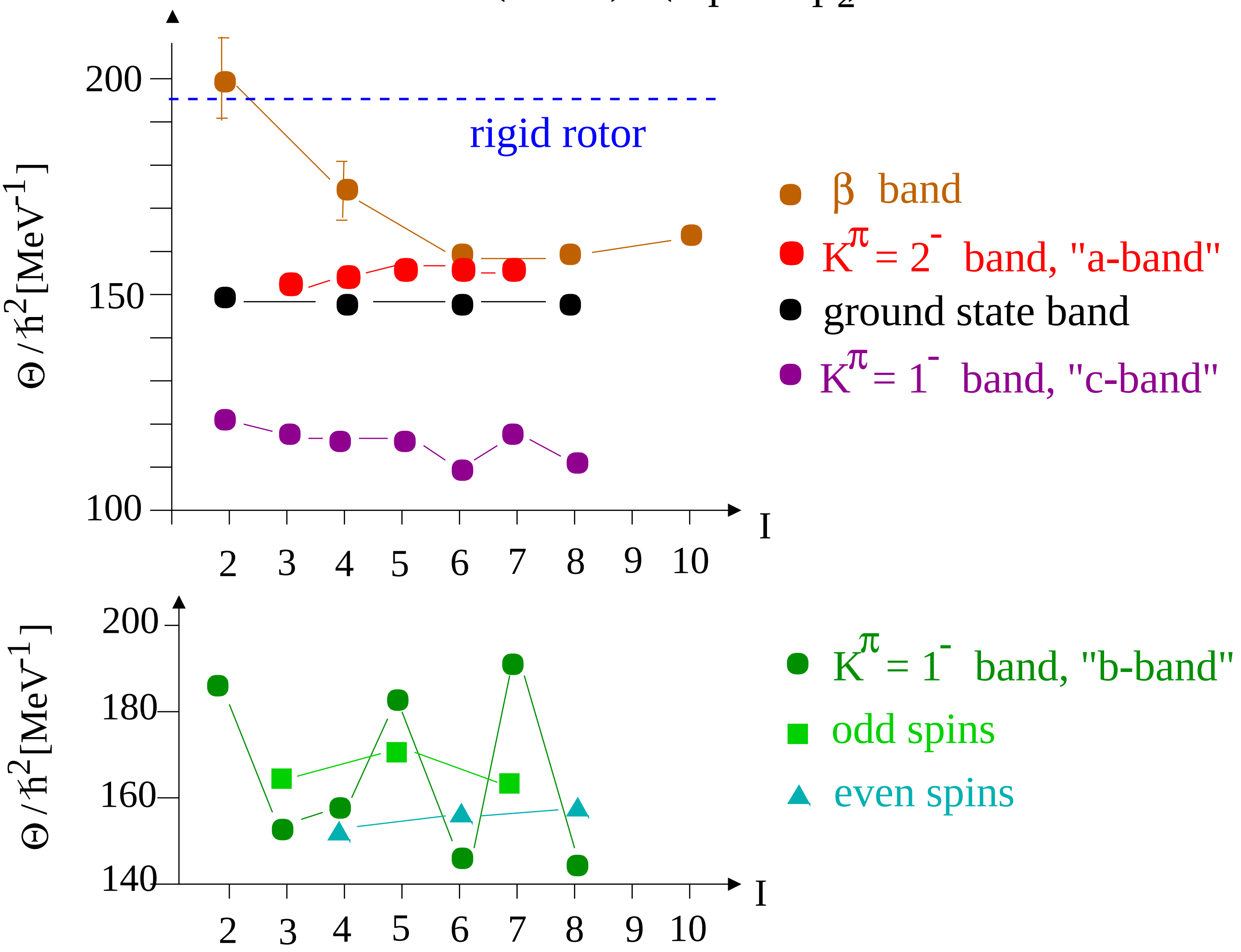
D. Gassmann et al., Phys. Lett. B 497 (2001) 181

Moments of Inertia

- (dynamical) moments of inertia:

$$E = (\hbar^2 / 2\Theta)\ (I\,(I+1))$$

$$\Theta/\hbar^2 = (2I - 1) / (E_I - E_{I-2})$$

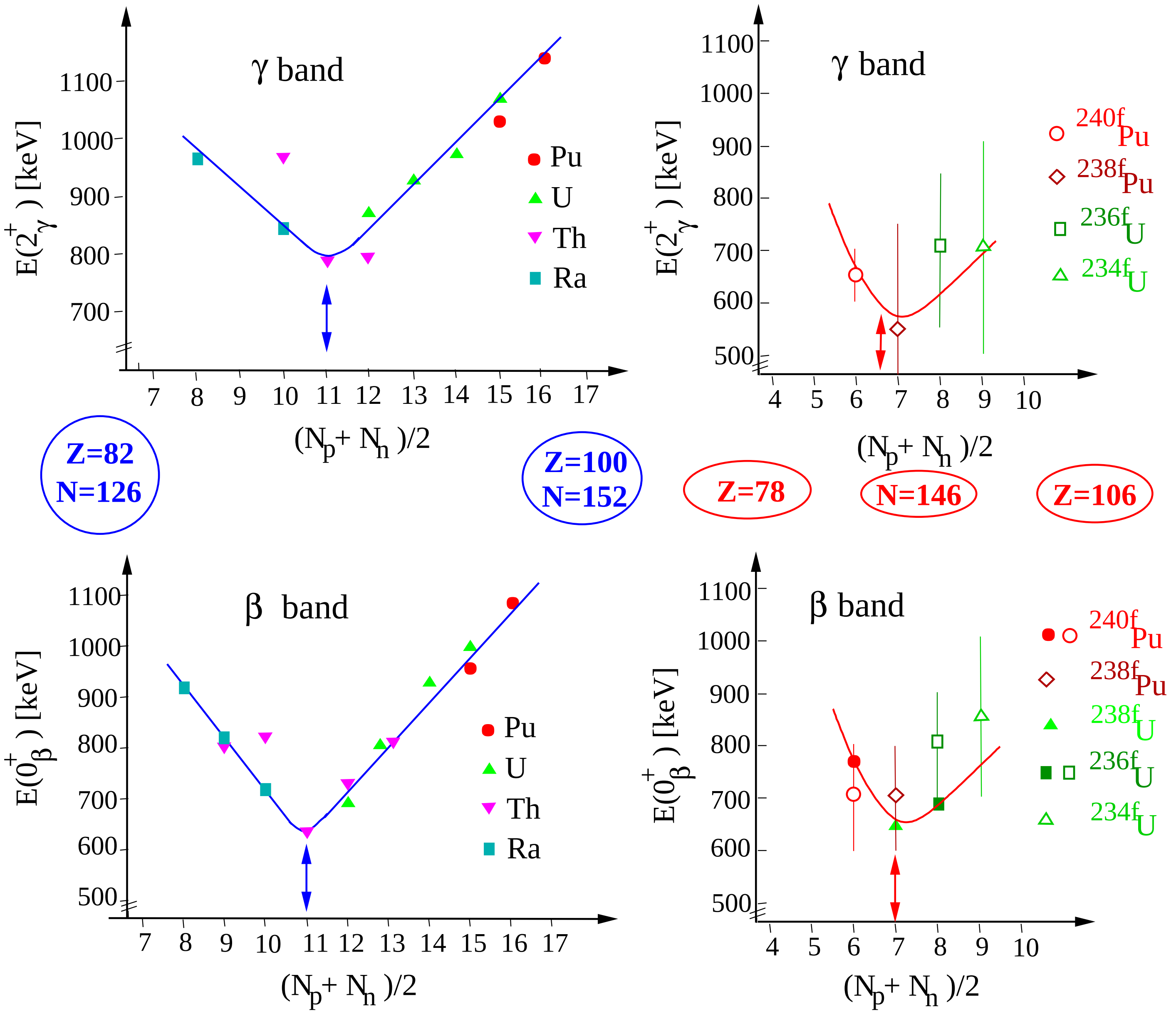


- Variation of moments of inertia:
  - in β band from rigid rotor limit (low I) to value of gs band (high I)
  - odd-even staggering in b band known from $K = 1^-$ bands in 1. minimum of actinides
  - separately smooth behaviour for even/odd spins in b band

Systematics of collective excitations

- VCS: 'Valence Correlation Scheme':
  Sum of valence nucleon pairs as ordering scheme

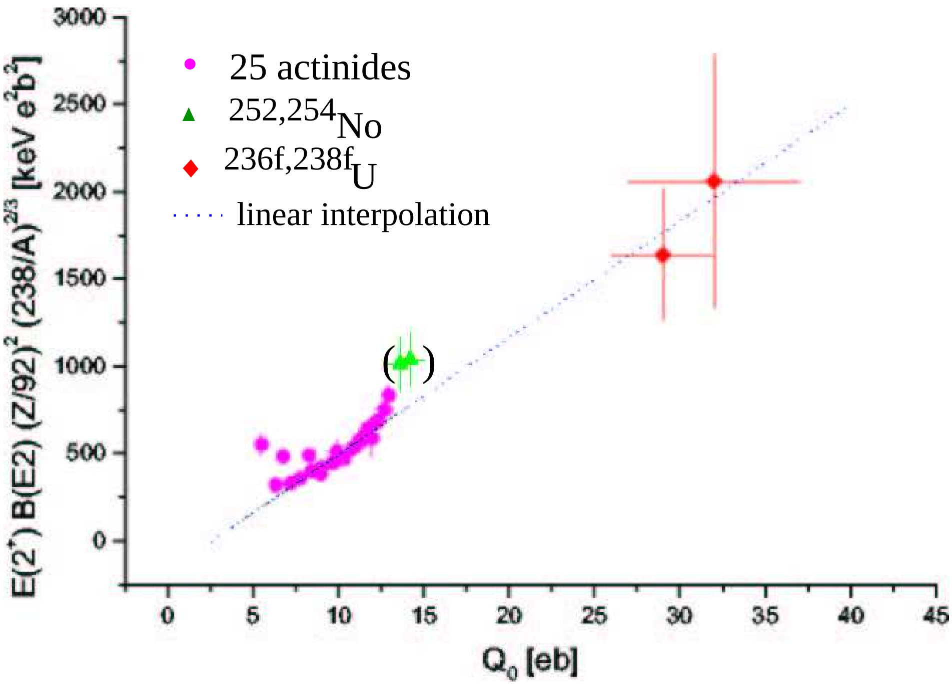
1. Minimum: 2. Minimum:



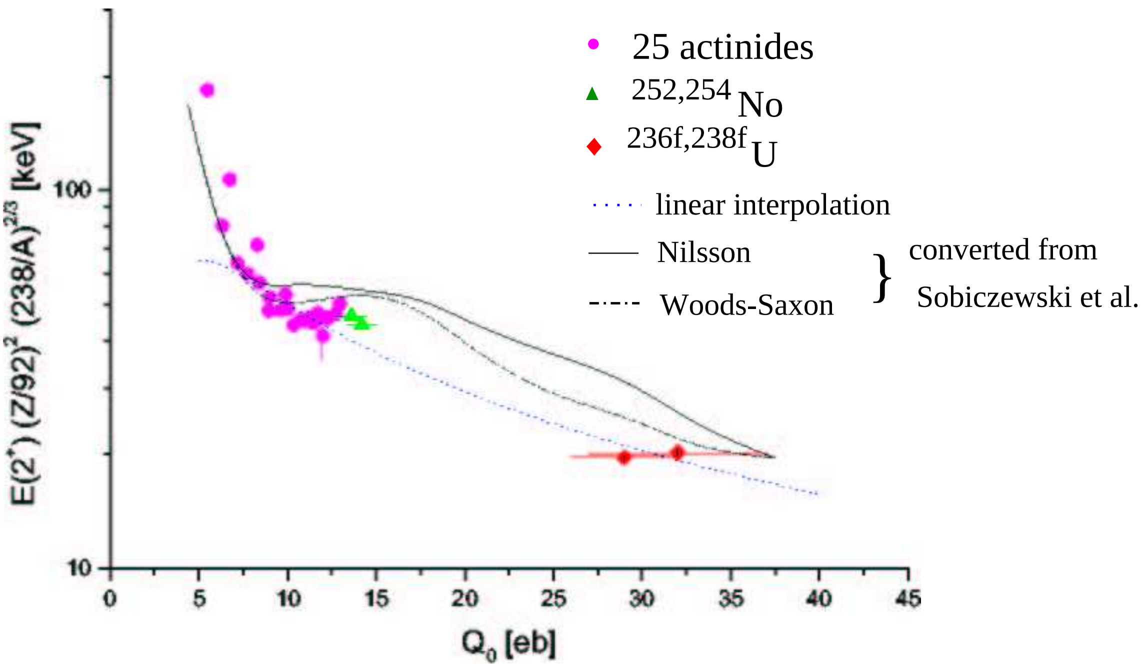
- enables prediction of phonon energies in 2. minimum
- exp. determination of new magic numbers in 2. minimum

Extension of the Grodzins Systematics

- Grodzins (/Raman): $B(E2)\,E(2^+) = 2.6\,Z^2 A^{-2/3}$
- Actinide region: data plotted as function of quadrupole moment Q_0



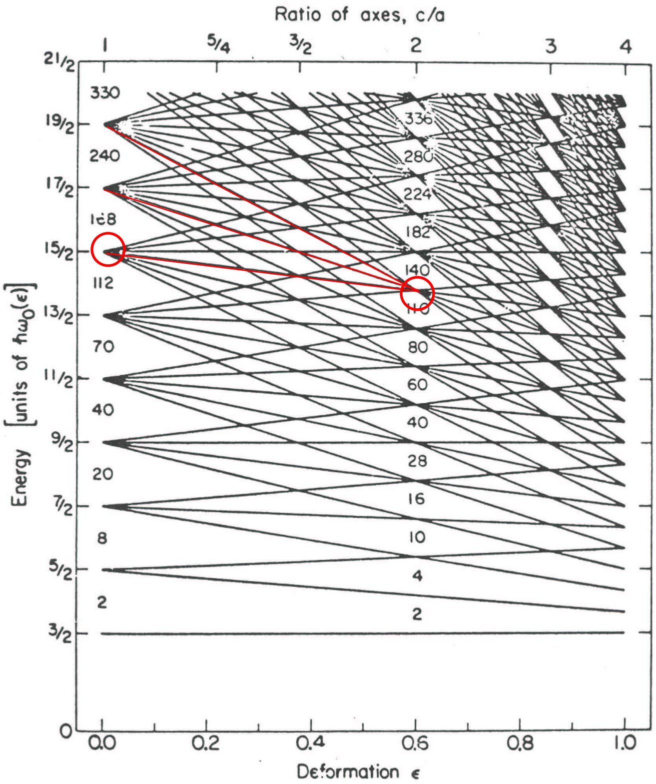
$$B(E2) = 5/16\pi \; |e\,Q_0|^2$$ (Single shell asymptotic Nilsson model)



Outlook:

- Study of a fission isomer with odd neutron number

  − measurement of single particle energies



γ − spectroscopy:

− measurement of Nilsson orbitals in odd fission isomer ^{237f}Pu

→ MINIBALL (new Germanium spectrometer)

Conversion electrons:

− identification of β−vibrational bands in ^{237f}Pu

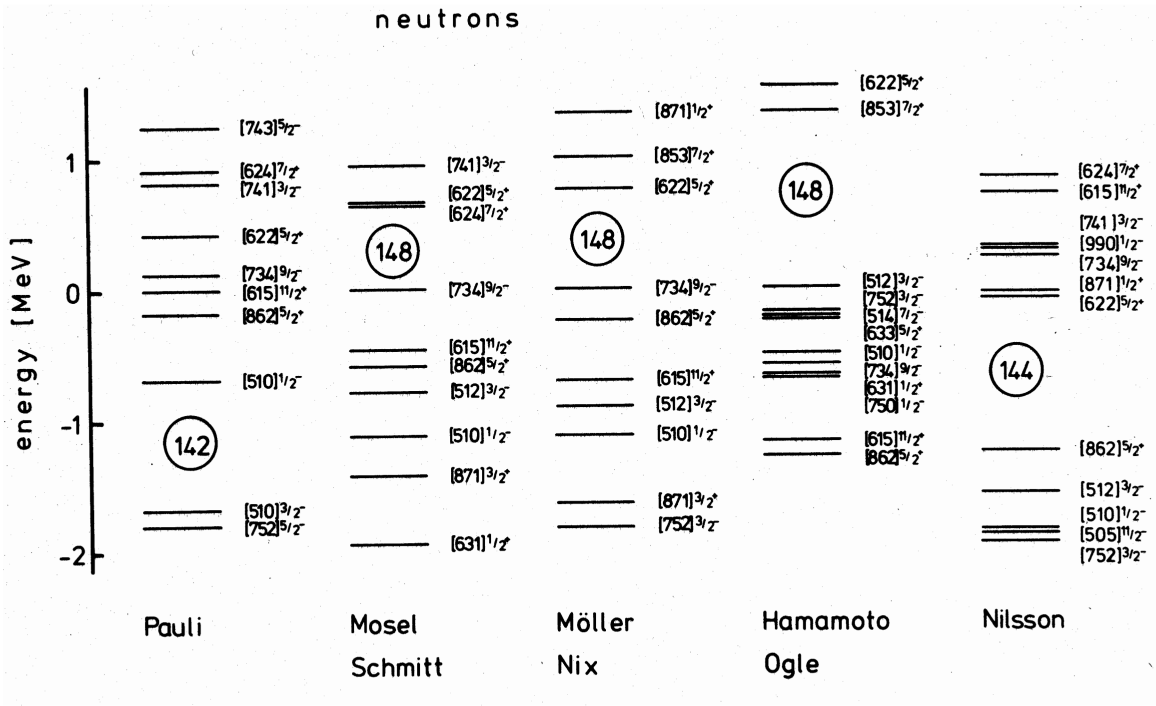
→ Mini Oranges

- Improvement of models for description of superheavy elements

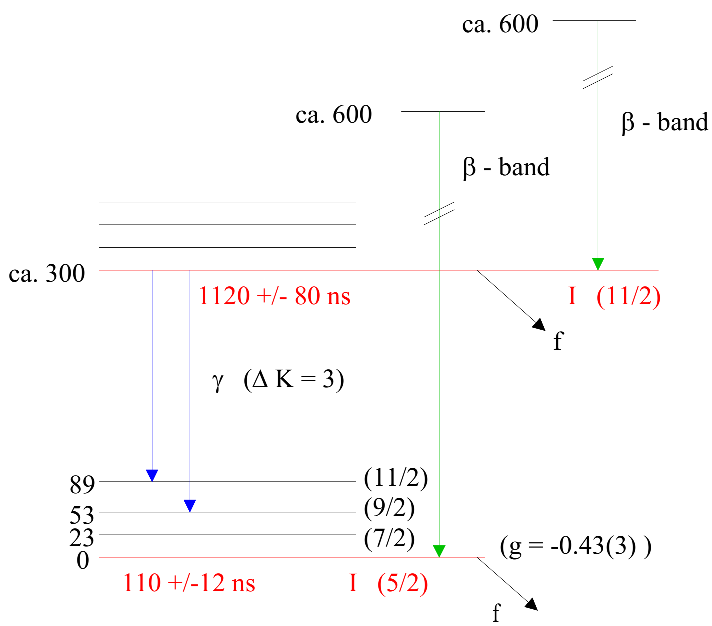
  − main objective of MAFF project at new research reactor FRM−II

Expected Properties of ^{237f}Pu

- Single Particle structure: for neutrons at deformation of second well



- Decay properties:



conversion electron spectroscopy

(prepared at Garching)

γ-ray spectroscopy

(MINIBALL)

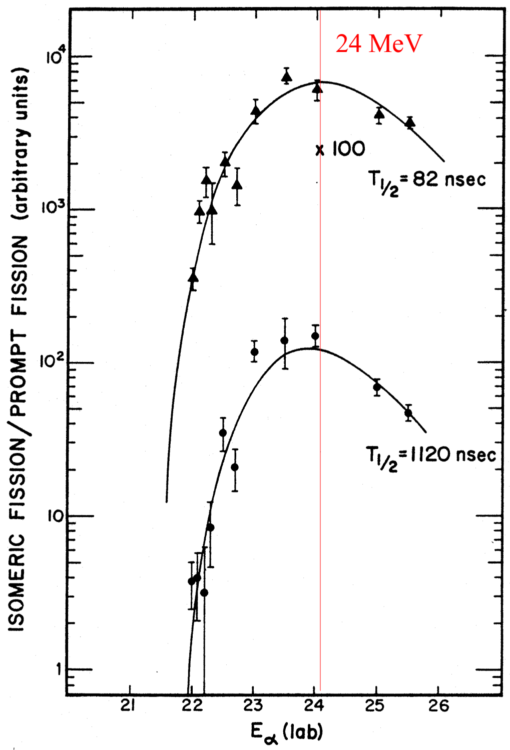
R. Vandenbosch et al., Phys. Rev. C8 (1973) 1080
M.H. Rafailovich et al., PRL 48 (1982) 982

Population of the Second Minimum

- Excitation function:

Reaction:

$^{235}U(\alpha,2n)^{237}Pu$



- Isomeric cross section:

^{237f}Pu:	^{240f}Pu:
$^{235}U(\alpha,2n)^{237f}Pu$ $E_\alpha = 24$ MeV	$^{238}U(\alpha,2n)^{240f}Pu$ $E_\alpha = 24$ MeV
$\sigma_{delay} = 1\text{-}2\ \mu b$	$\sigma_{delay} = 10\ \mu b$
$\frac{\sigma_{delay}}{\sigma_{prompt}} = 1.2 * 10^{-5}$	$\frac{\sigma_{delay}}{\sigma_{prompt}} = (6\text{-}8) * 10^{-5}$
$\frac{\sigma_{short}}{\sigma_{long}} = 1.1$	

R. Vandenbosch et al., Phys. Rev. C 8 (1973) 1080
P.A. Russo et al., Phys. Rev. C 3 (1971) 1595
S. de Barros et al., Z. Phys. A 323 (1986) 101

Summary/Outlook

- Advantage of fission isomers:
  - low angular momenta, few K mixing
  - clear separation between vibrational and rotational excitations

- Conversion electron spectroscopy indispensable tool:
  - complementary to γ −ray spectroscopy: removal of ambiguities

- Superdeformed 2. minimum:
  - identification of superdeformed collective bands
  - determination of β phonon energy
  - detailed level scheme
  - predictive power for phonon energies in 2. minimum
  - exp. determination of new magic numbers in 2. minimum
  - extension of the Grodzins systematics

- Outlook:
  - identification of Nilsson single particle states
    candidate: ^{237f}Pu with conversion electron, γ spectroscopy
  - (in beam) identification of the fission isomer in ^{239}U

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