Nuclear Structure from Gamma-Ray Spectroscopy

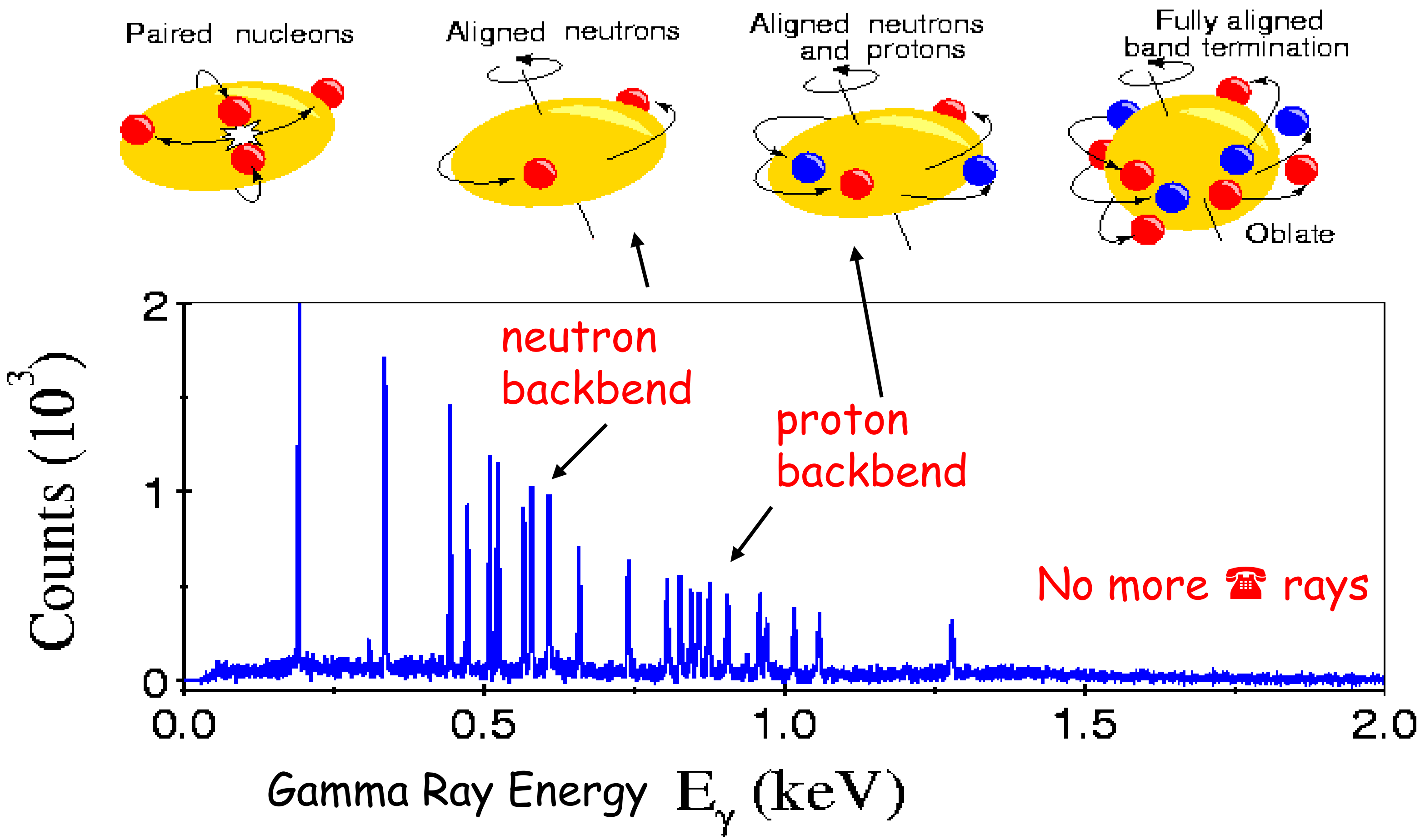
2019 Postgraduate Lectures

Lecture 8: Band Termination

Introduction: Band Termination

- A deformed prolate nucleus can increase its angular momentum by collective rotation about an axis perpendicular to its symmetry axis
- However, the nucleus is a many-body quantal system and such collective behaviour must have an underlying microscopic basis
- There is a limiting angular momentum that a given configuration can generate
- Successive alignments occur until all the valence particles are aligned and move in equatorial orbits giving the nucleus an oblate appearence

Band Termination: ^{158}Er



- A band 'terminates' when all valence particles outside a doubly magic (spherical) core are aligned

Band Termination in ^{158}Er

- When the valence np protons and nn neutrons align, the total spin is: $I = \sum_i^{np} j_i(p) + \sum_i^{nn} j_i(n)$
  and the rotational band is said to 'terminate'

- At termination ^{158}Er can be considered as a spherical ^{146}Gd core plus 4 protons and 8 neutrons, generating a maximum spin 46ħ

- The configuration is: $\pi(h_{11/2})^4 \otimes \nu(i_{13/2})^2(h_{9/2})^3(f_{7/2})^3$

- The terminating spin value of $I_{max}= 46$ is generated as:
  (11/2+9/2+7/2+5/2) + (13/2+11/2) + (9/2+7/2+5/2) + (7/2+5/2+3/2)

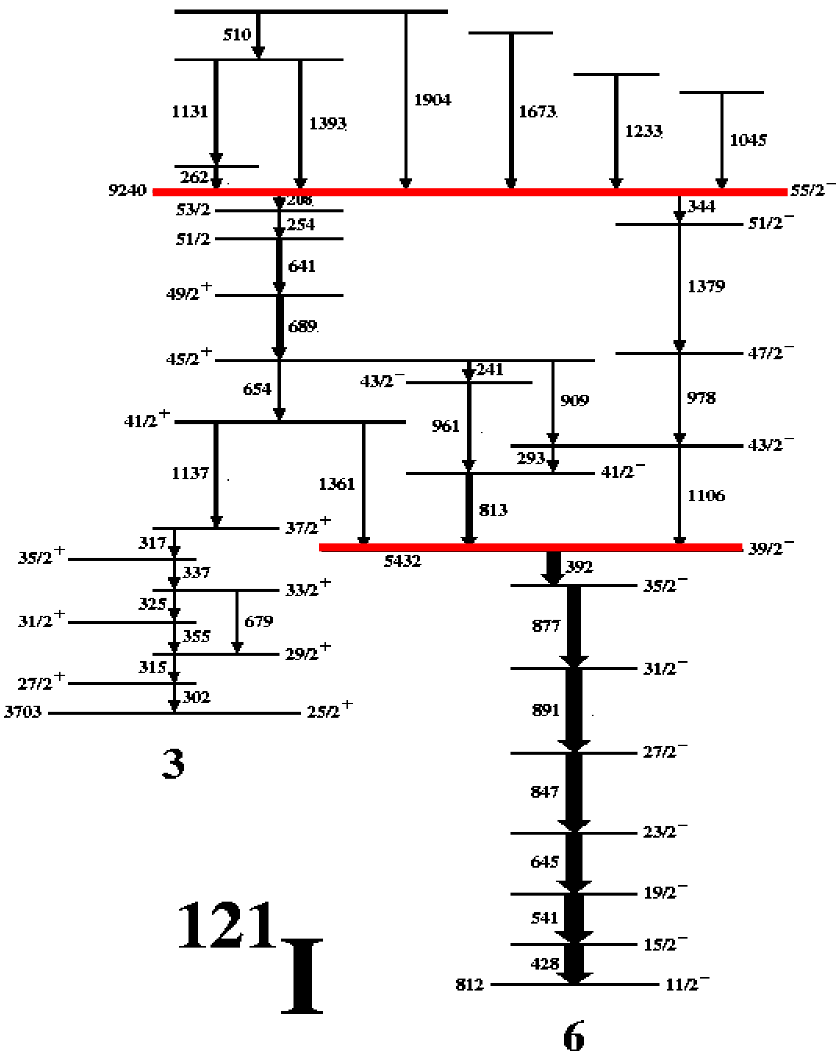
Favoured Oblate States

- Full termination represents the maximum alignment of all the valence particles outside a doubly magic core, consistent with the Pauli Exclusion Principle

- Certain noncollective states representing maximal alignment of a subset of the valence particles may be yrast leading to the observation of (energetically) favoured noncollective oblate states at a certain spin

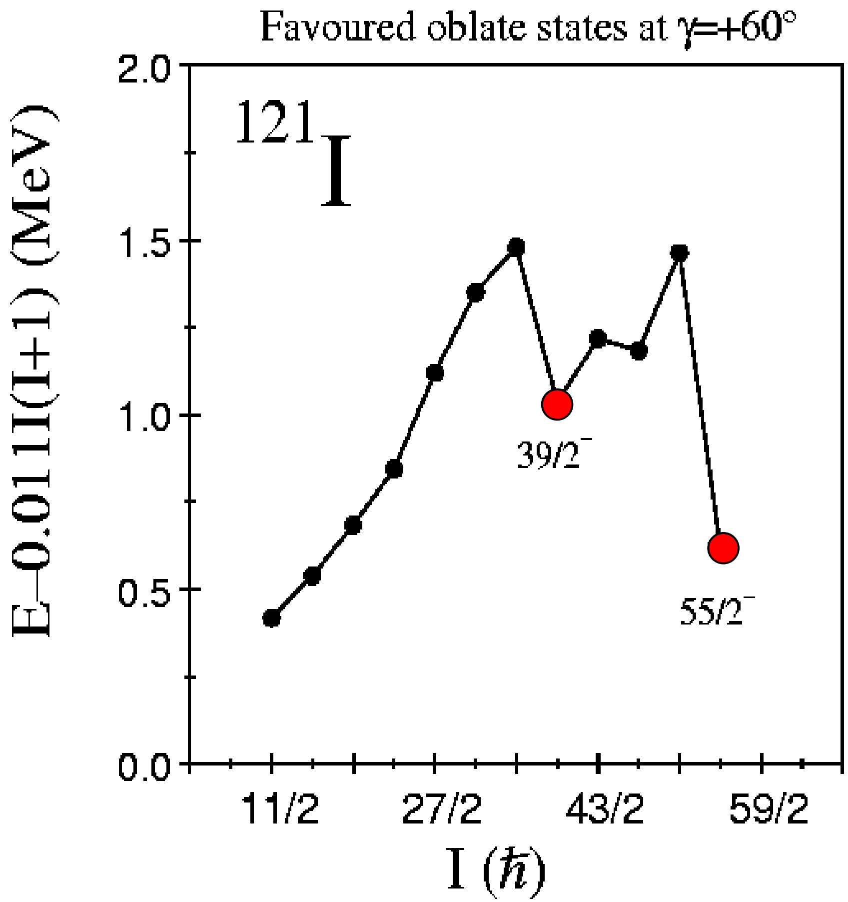
- Example: In ^{157,158}Er energetically favoured states are seen at $(I_{max} - 6)$, corresponding to two $f_{7/2}$ neutrons still being paired, i.e. they contribute 0 spin rather than $7/2 + 5/2 = 6$

Noncollective Oblate States in ^{121}I



- Low-lying states are seen at $I = 39/2$ and $55/2$
- ^{121}I can be considered as a core (^{114}Sn) plus 3 valence protons and 4 valence neutrons
- The configuration is
  $\pi\ \{h_{11/2}g_{7/2}{}^2\}\ \nu\ \{h_{11/2}{}^4\}$
  with maximum spin 55/2
- If two of the protons remain paired we get the 39/2 state

Rigid Rotor Plot

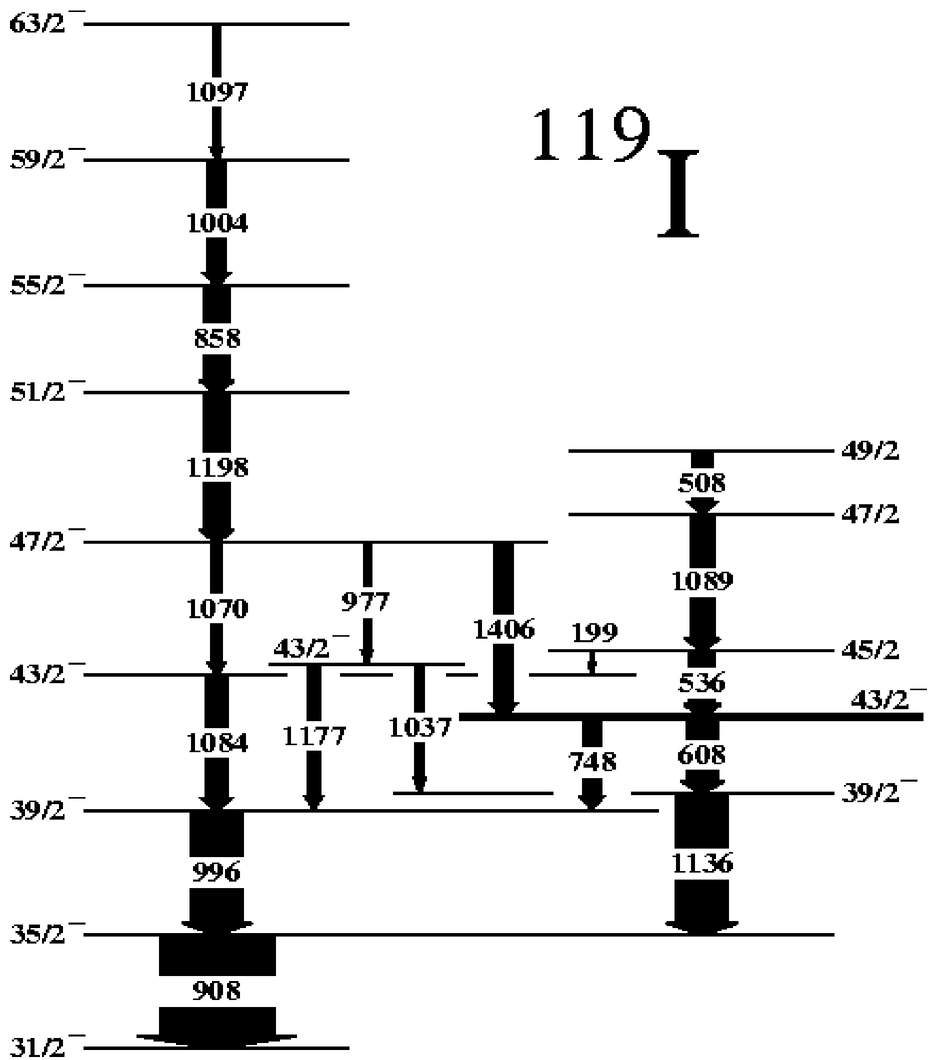


- The favoured nature of noncollective oblate states can be seen by plotting energy levels against spin
- A rotating liquid-drop energy reference is subtracted:

$$E_{LD} = (\hbar^2/2\mathfrak{I}_{rig})\ I(I+1)$$

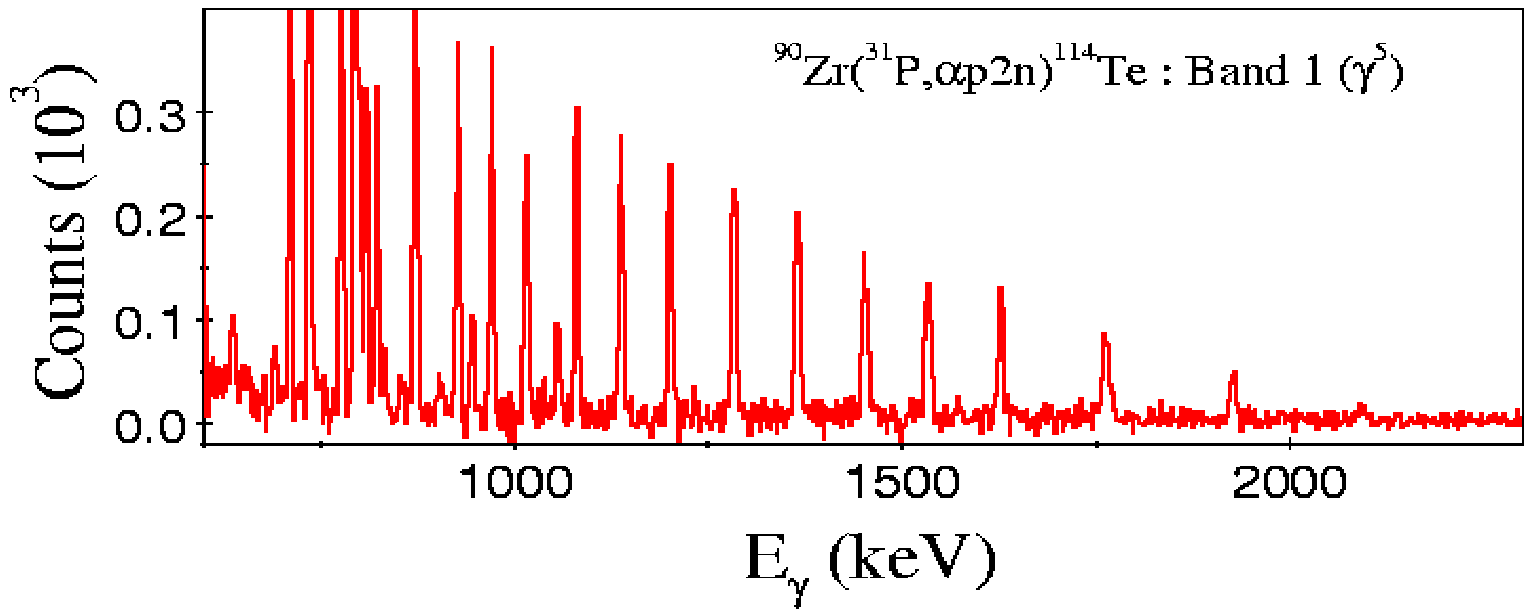
$\mathfrak{I}_{rig}$ scaled to ^{158}Er, i.e. $\boxed{(\hbar^2/2\mathfrak{I}_{rig}) = 0.007\ \{158/A\}^{5/3}\ \text{MeV}}$

Shape Coexistence



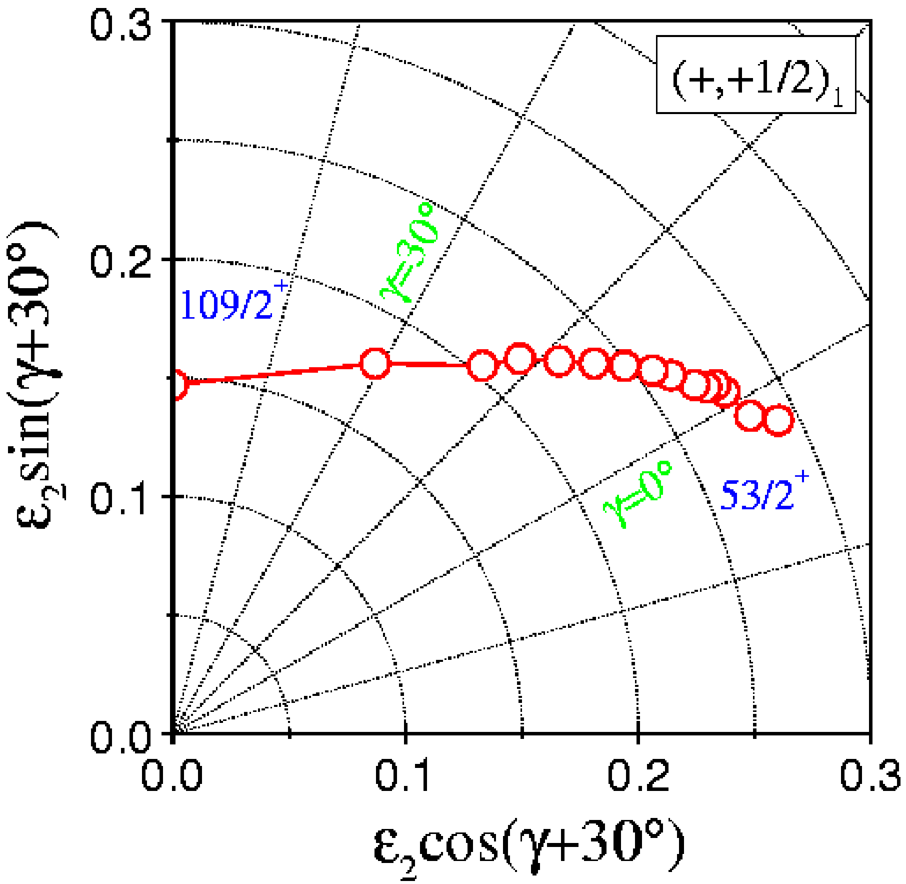
- Noncollective oblate states may coexist with collective rotational structures
- In ^{119}I, collective structures are seen to the left and oblate states to the right

Smooth Band Termination



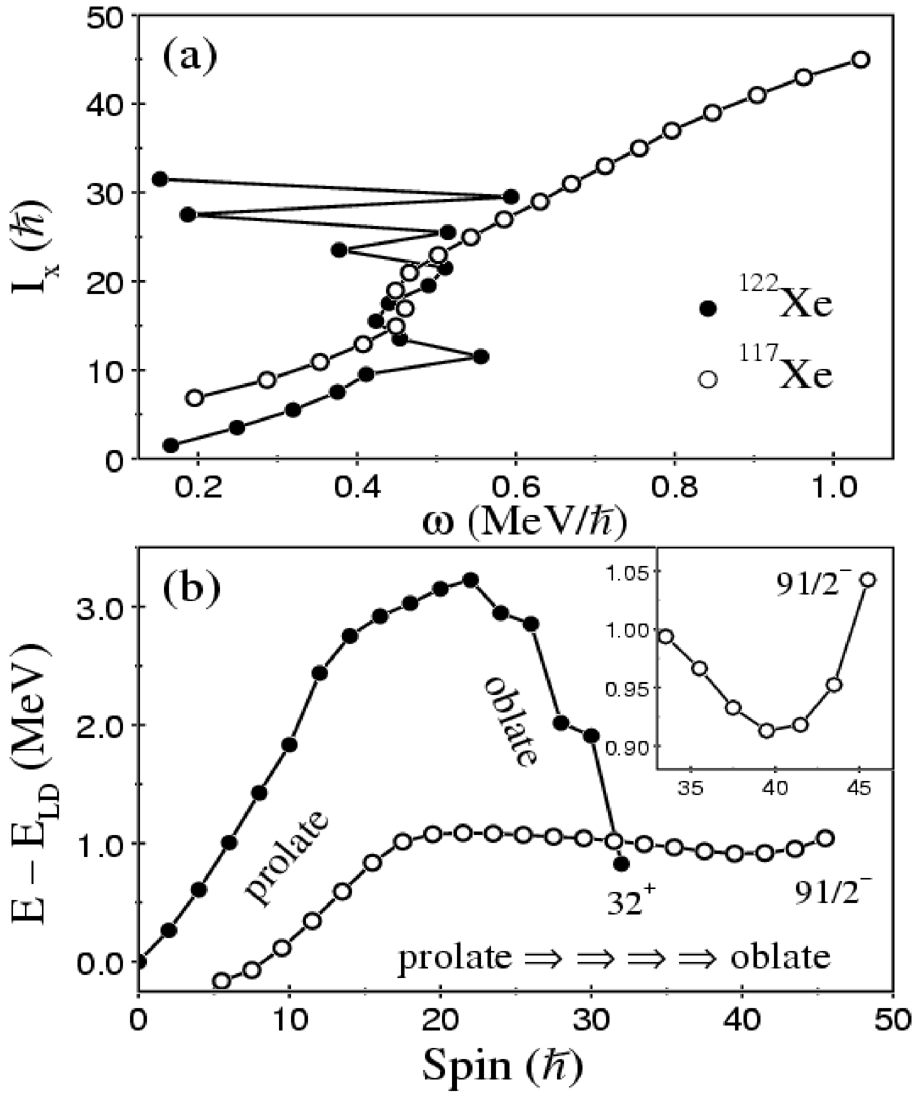
- A novel type of '<u>smooth</u>' band termination has been observed in several nuclei of the mass A = 110 region
- Bands extend to very high energy (frequency) and the spacings between the γ rays increase (moment of inertia decreases)

Drift Through the γ Plane



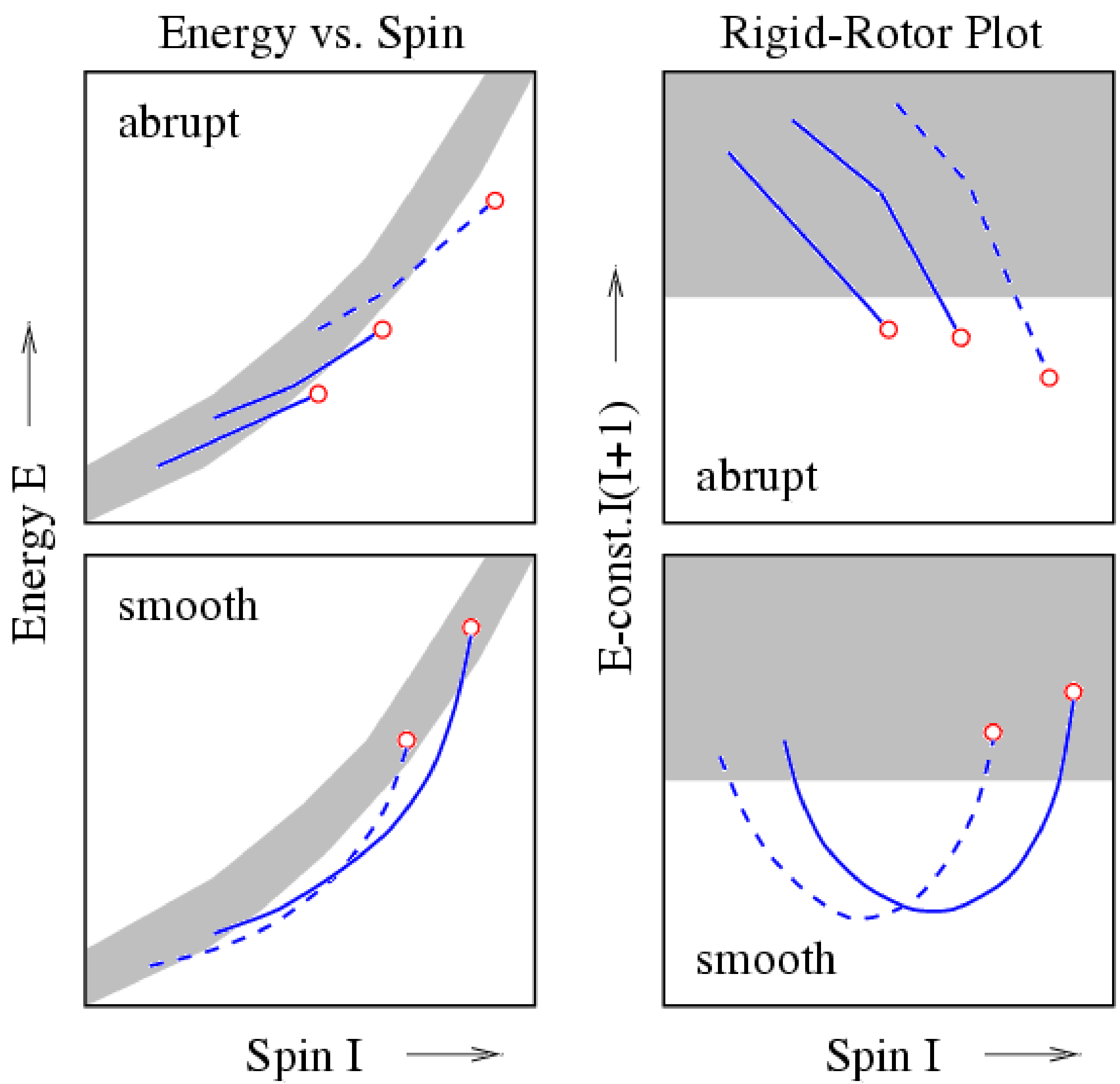
- Smooth termination has been interpreted in the framework of the Cranked Nilsson Strutinsky method
- It represents a gradual shape change from collective prolate (γ = 0°) to noncollective oblate (γ = 60°) over a wide spin range

Abrupt and Smooth Termination



- The contrasting high-spin behaviour of ^{117}Xe and ^{122}Xe is shown here
- The rotational nature of ^{122}Xe abruptly breaks down above $I = 22\ \hbar$
- The behaviour of ^{117}Xe appears more smooth

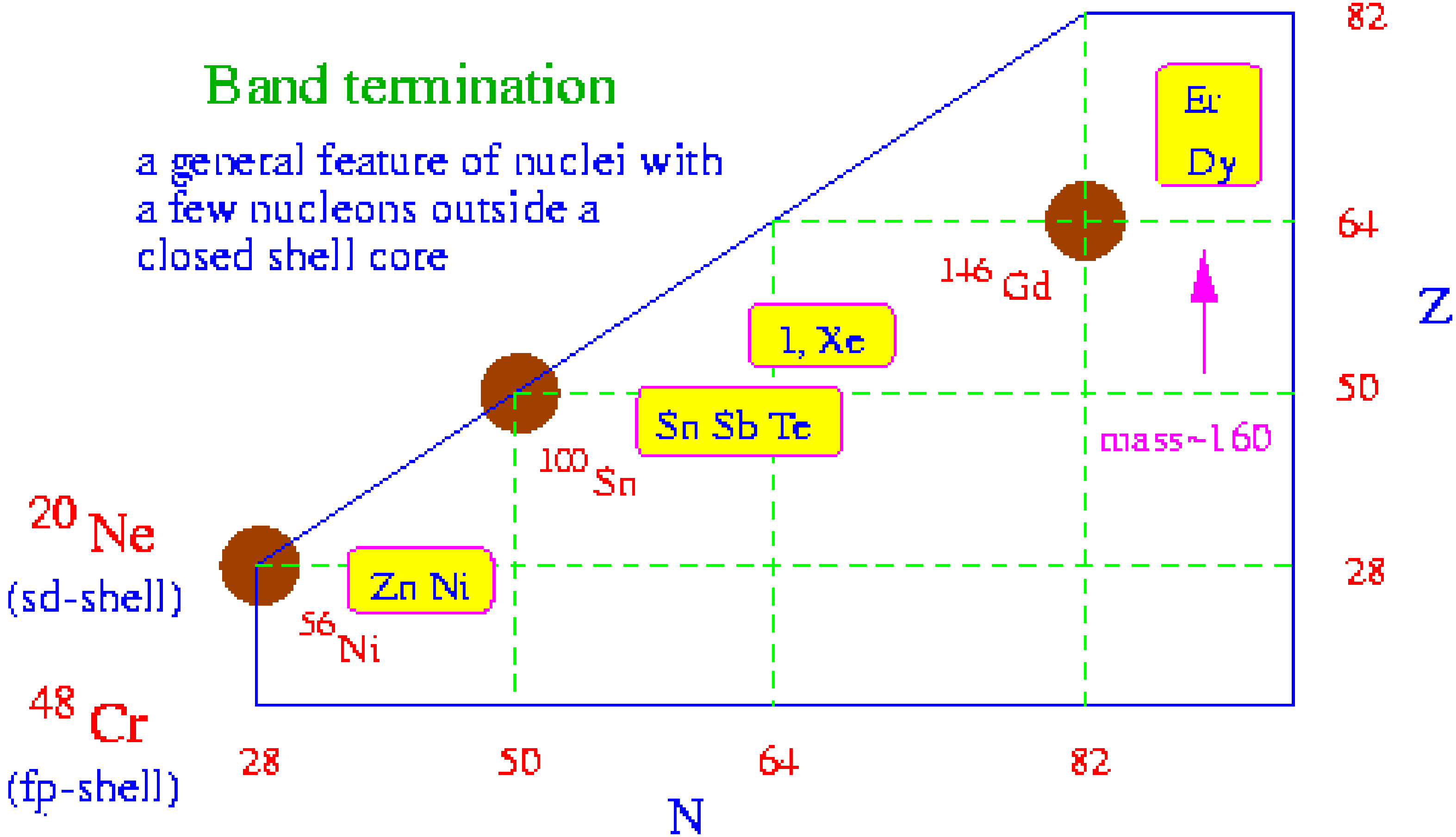
Termination Modes



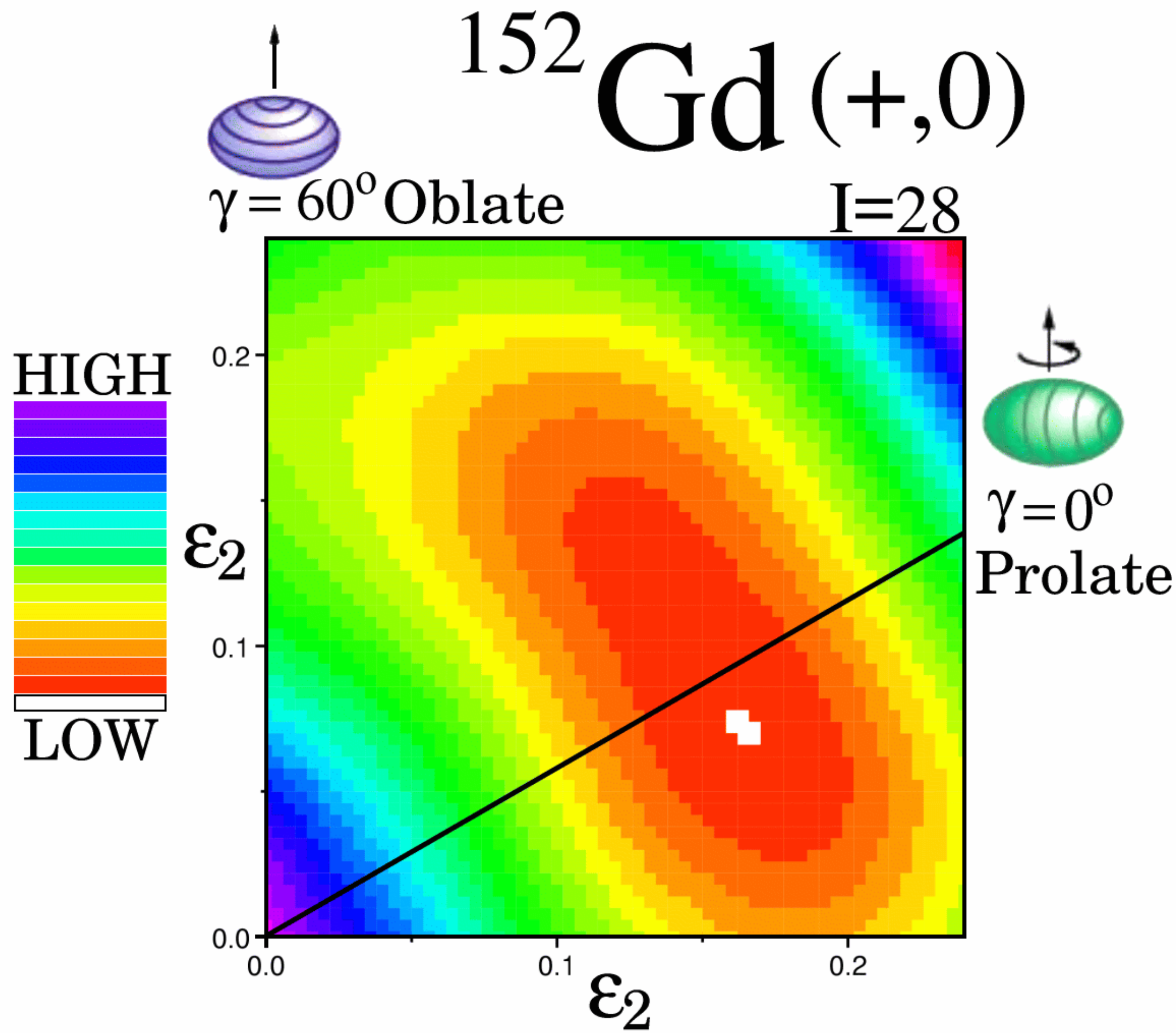
- Abrupt or favoured termination is shown at the top
- Smooth or unfavoured termination is shown at the bottom

Termination Systematics

Nucleus at the extreme of angular momentum



Band Termination in ^{152}Gd



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Beyond Termination

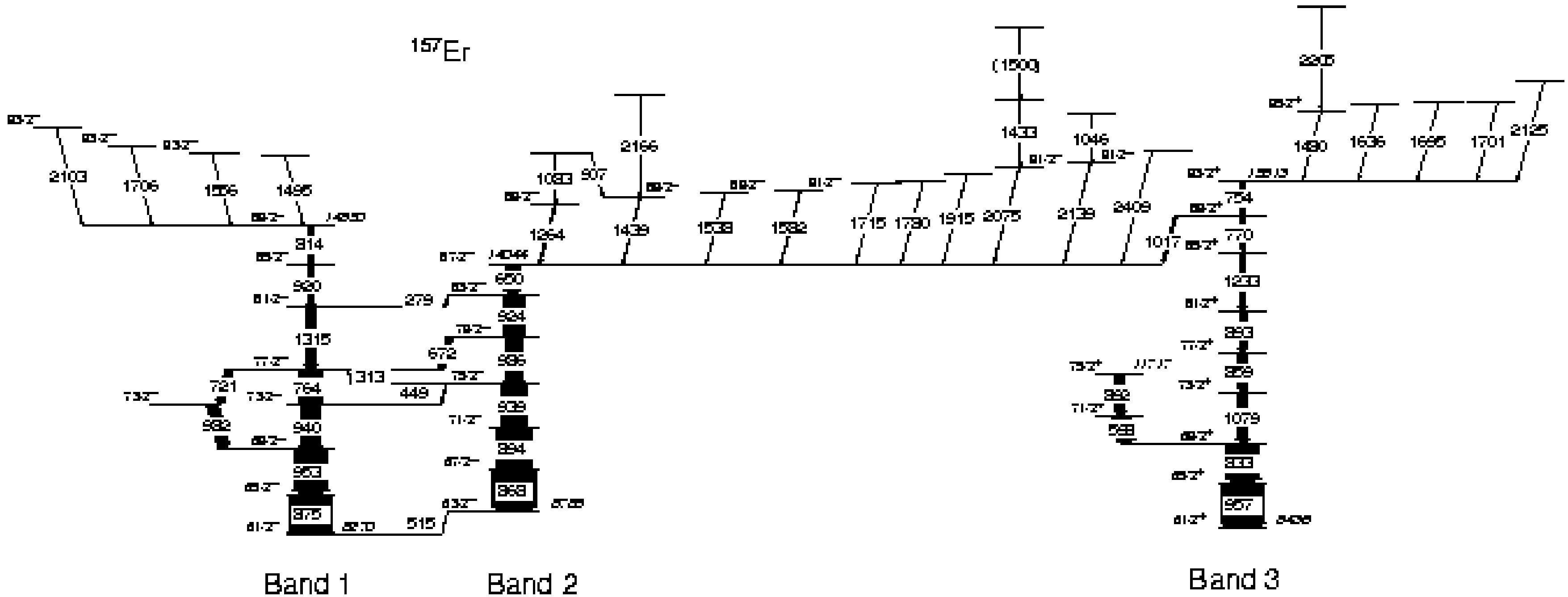
- At termination, several valence particles are aligned with the 'rotation' axis outside an 'inert' closed core ('doubly magic' spherical core)

- How do we generate higher spin states?

- We must break the core and form energetically expensive particle-hole excitations across the magic shell gaps of the core

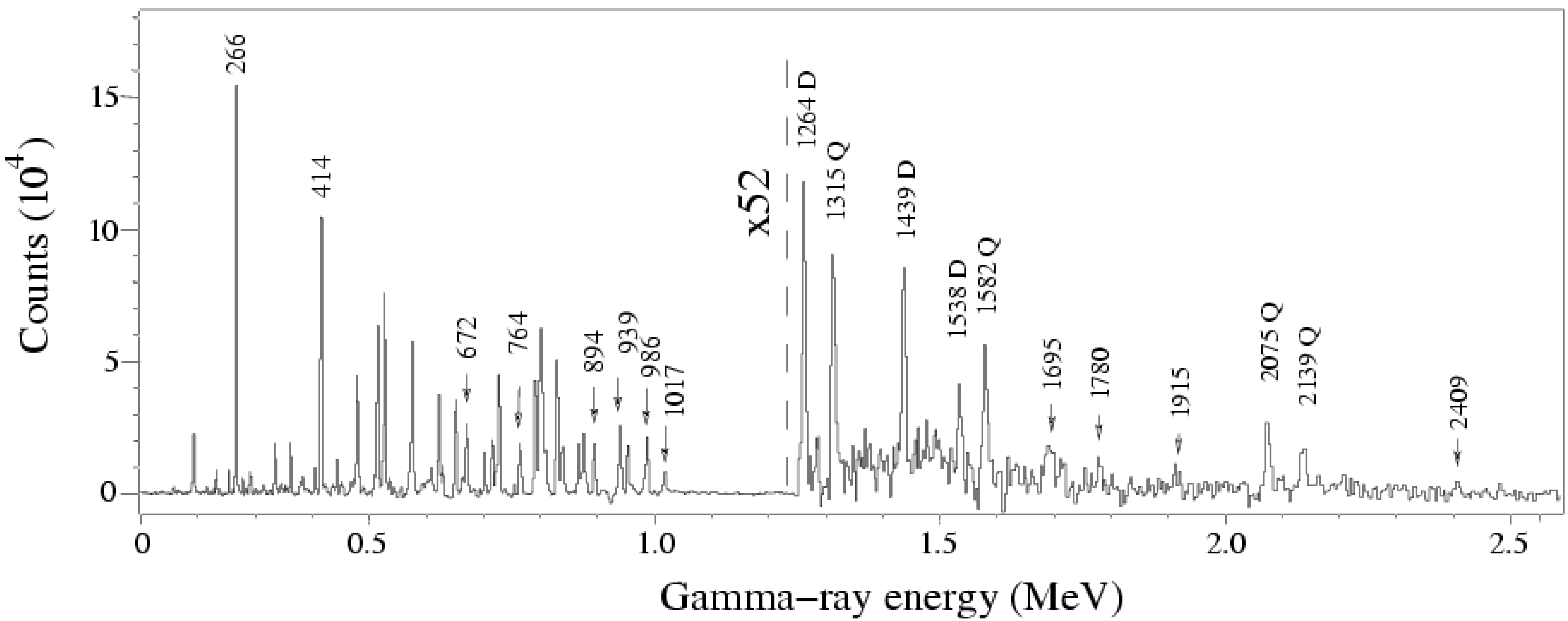
- A classic (state-of-the-art) case is the nucleus ^{157}Er which was studied with the Gammasphere spectrometer in Berkeley

^{157}Er at High Spin



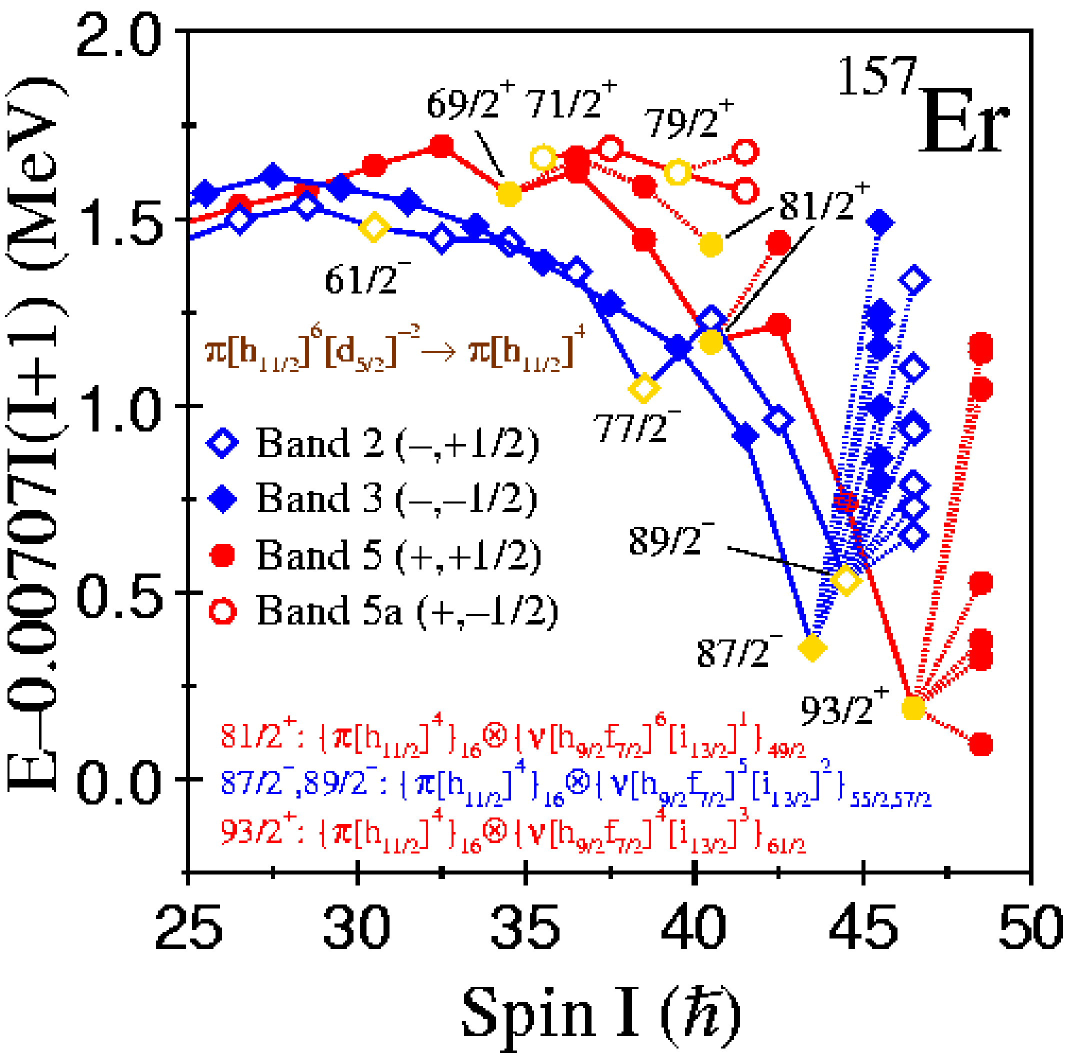
- New high-energy (1.5-2.5 MeV), high-spin transitions have been identified above I^{π} = 87/2^{-}, 89/2^{-} and 93/2^{+} (new) terminating states

^{157}Er Spectrum



Several (weak) transitions are seen in the energy range 1.0 – 2.5 MeV. Measured $\Delta I=2$ transitions are labelled as Q (quadrupole) and $\Delta I=1$ transitions as D (dipole)

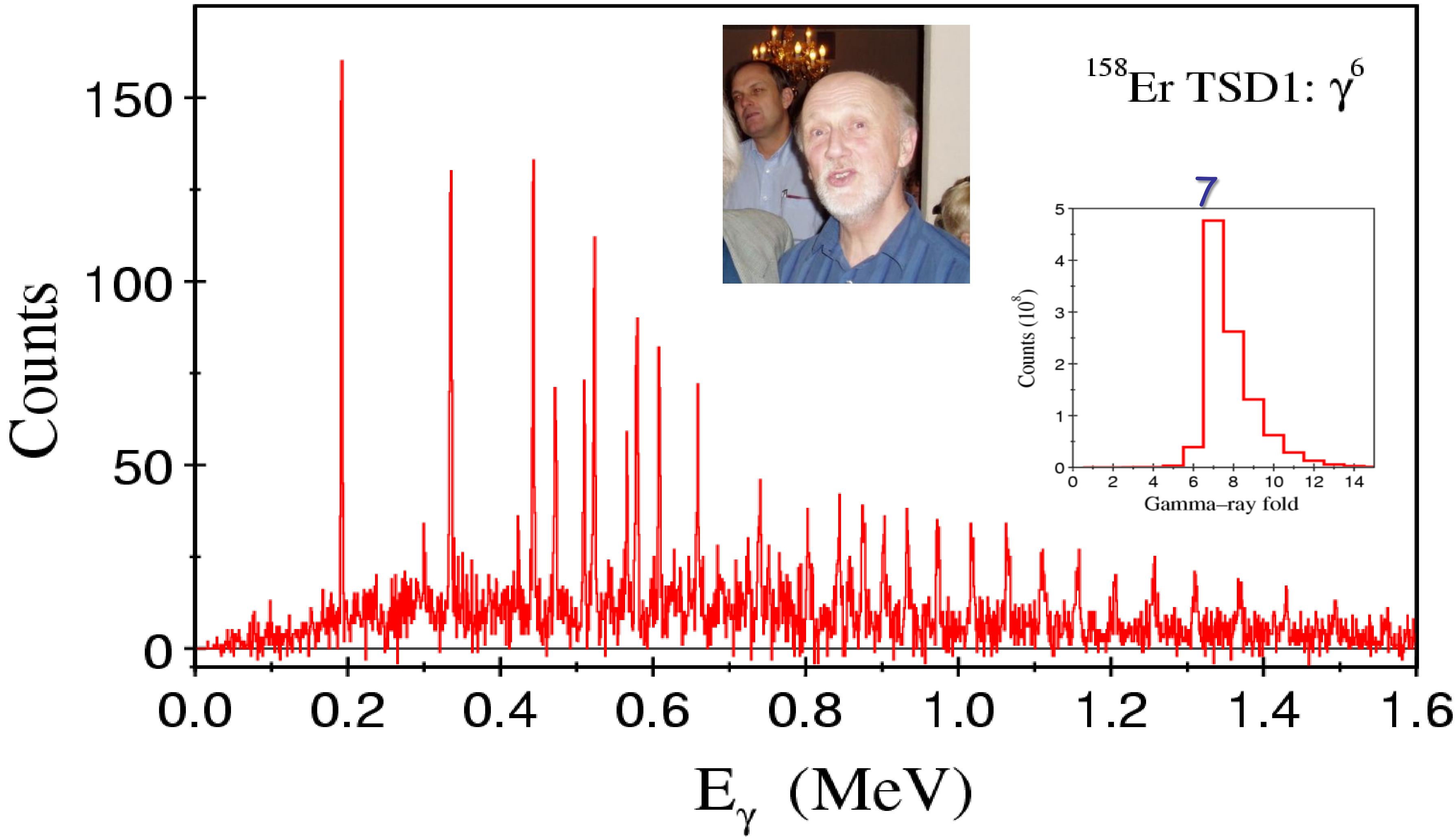
^{157}Er Rigid-Rotor Plot



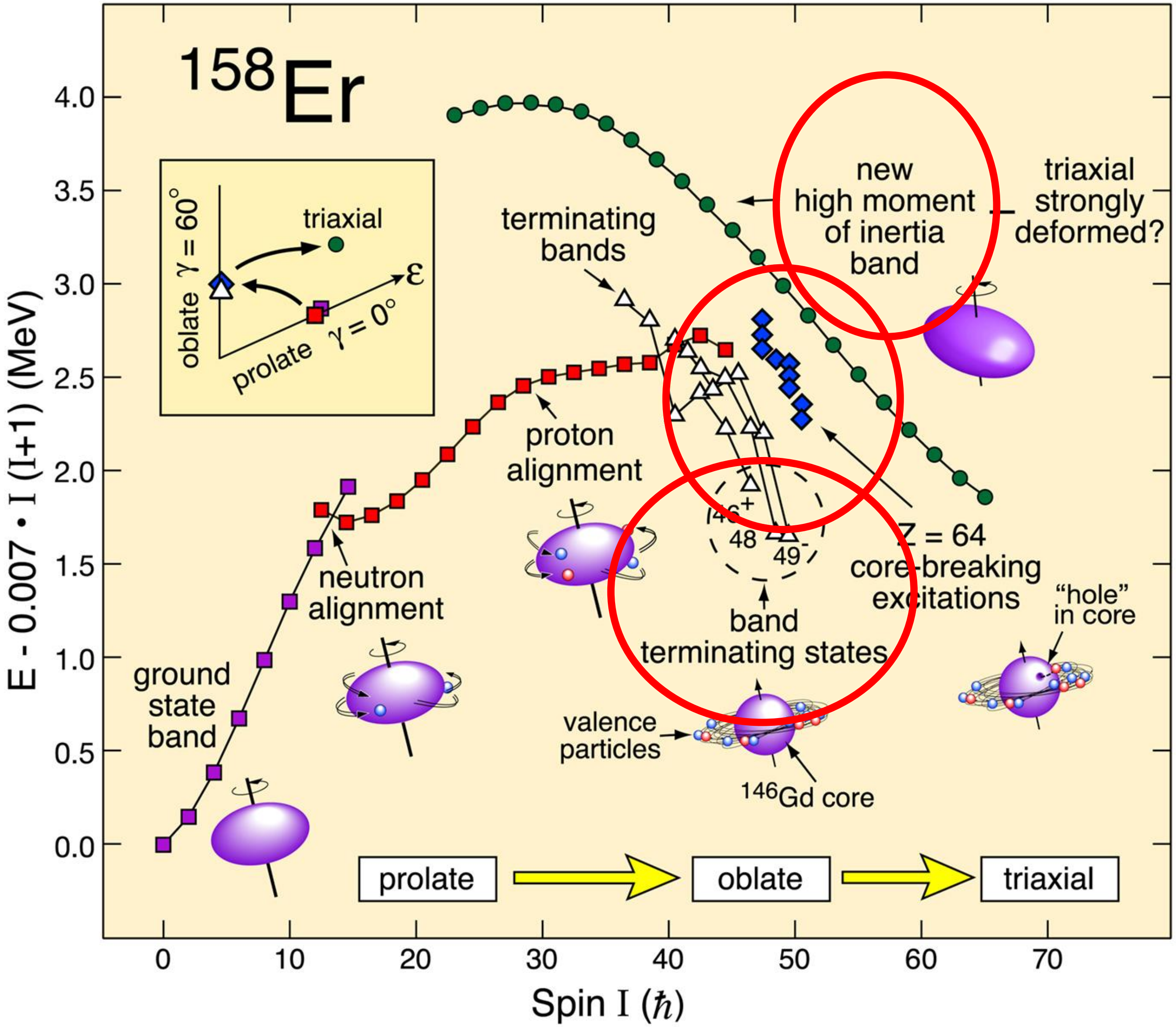
- Favoured oblate states are shown in gold
- It costs a lot of energy to generate states of higher spin
- The Z=64 proton core has to be broken to generate the highest spins

High-Fold (Spikeless) Sorting

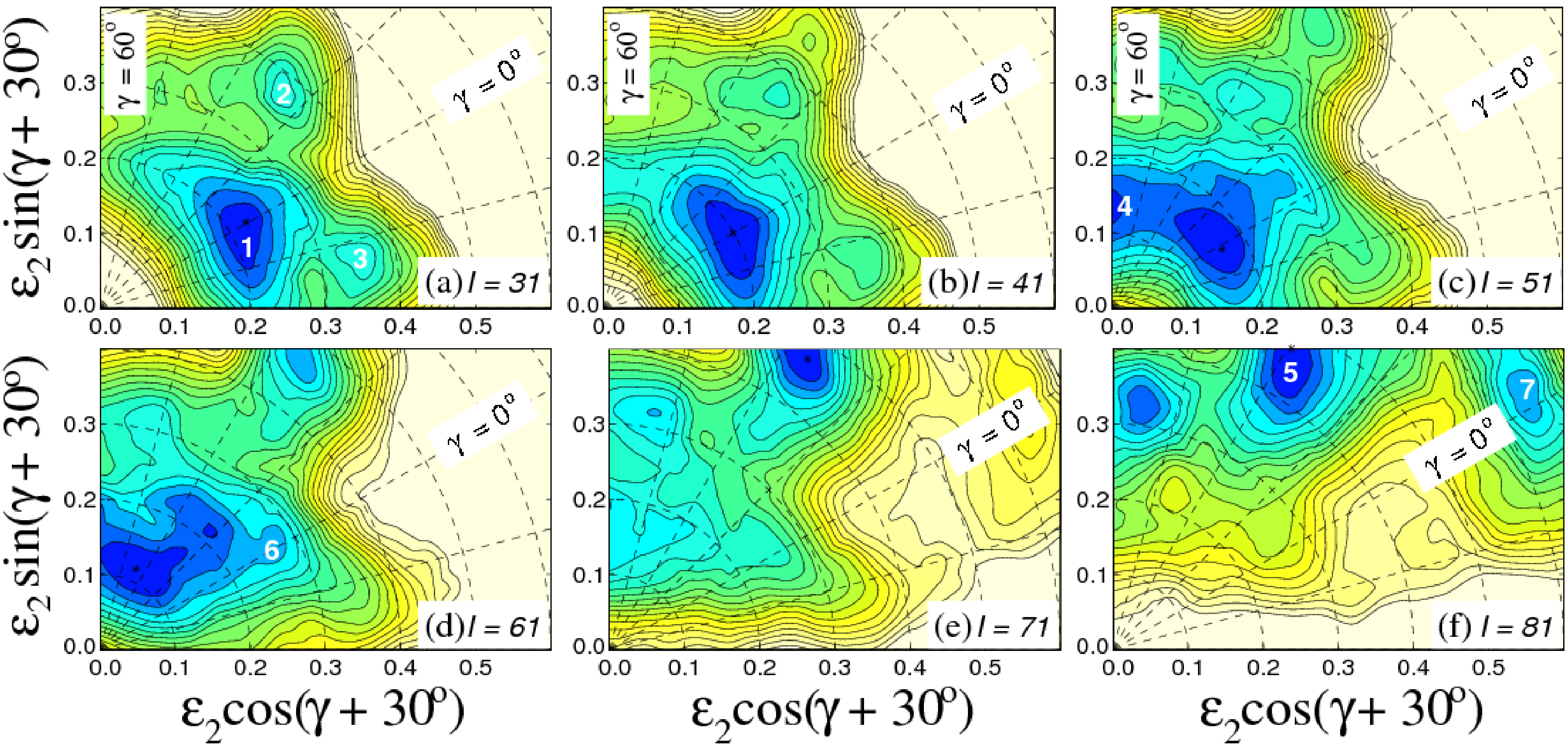
100 times weaker than SD band in ^{152}Dy



Structural Evolution in ^{158}Er



What Shape Are the Bands?



- Do the TSD bands correspond to positive (+20°) or negative (-20°) gamma deformation?
- Theoretically, positive gamma is favoured at high spin

Quadrupole Moments

- DSAM lifetime measurement
- The slowing down in the Au acts as our clock