Formkoexistenz

Ein paar Gedanken zur Einführung …

- Restwechselwirkung zwischen Protonen und Neutronen treibt Deformation
- Art und Stärke der Restwechselwirkung hängt von der Konfiguration ab

⇒ verschiedene Konfigurationen in einem Kern können verschiedene Deformation haben

⇒ Formkoexistenz

Kerndeformation

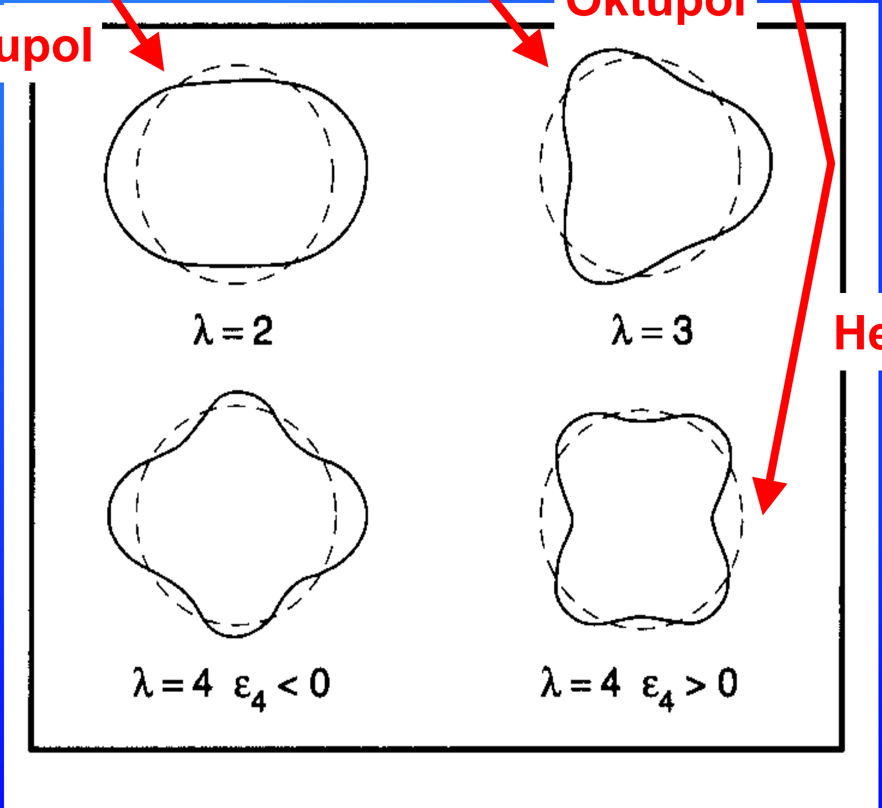
- ^{32}Mg, ^{56}Ni
- Super- und Hyperdeformation
- Spaltisomere
- Isotopenverschiebung in Hg
- Formisomere und -koexistenz in ^{186,188}Pb

Kerndeformation 1

Entwicklung der Kernoberfläche in Kugelfächenfunktionen

Laborsystem

$$R = R_0\left[1+\sum_{\mu}\alpha_{2\mu}Y_{2\mu}(\theta,\Phi)+\sum_{\mu}\alpha_{3\mu}Y_{3\mu}(\theta,\Phi)+\sum_{\mu}\alpha_{4\mu}Y_{4\mu}(\theta,\Phi)+\ldots\right]$$



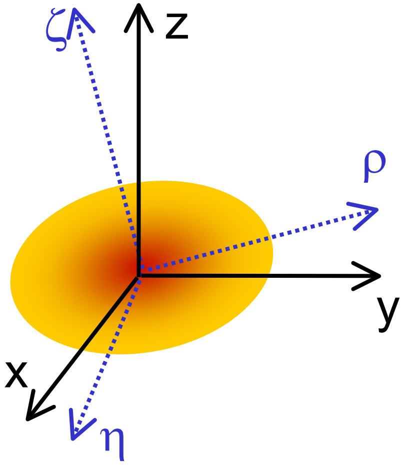
Quadrupol

Oktupol

Hexadekapol

Kerndeformation 2

Laborkoordinaten
(x,y,z)
⇔
intrinsische Koordinaten
(η,ρ,ζ)



Transformation zwischen Labor- und intrinsischem Koordinatensystem wird mittels der 3 Euler-Winkel $\Theta_{1,2,3}$ durchgeführt!

Beschränkung auf Quadrupoldeformation

$$\alpha_{2\mu} = \sum_{\nu} a_{2\nu} D^{(2)}_{\mu\nu}$$

D: Drehmatrix

$$D^{I\,*}_{MK}(\theta_1, \theta_2, \theta_3) = \langle IM | e^{-i\theta_3 I_z} e^{-i\theta_2 I_y} e^{-i\theta_1 I_z} | IK \rangle$$

- Wahl der Achsen des intrinsischen Koordinatensystems identisch zu den Hauptträgheitsachsen der Ladungsverteilung ($a_{21} = a_{2-1} = 0$)
- Guter Drehimpuls I der Zustände bleibt erhalten und intrinsische Projektion K wird in Projektion im Labor M transformiert ... bzw. umgekehrt

Kerndeformation 3

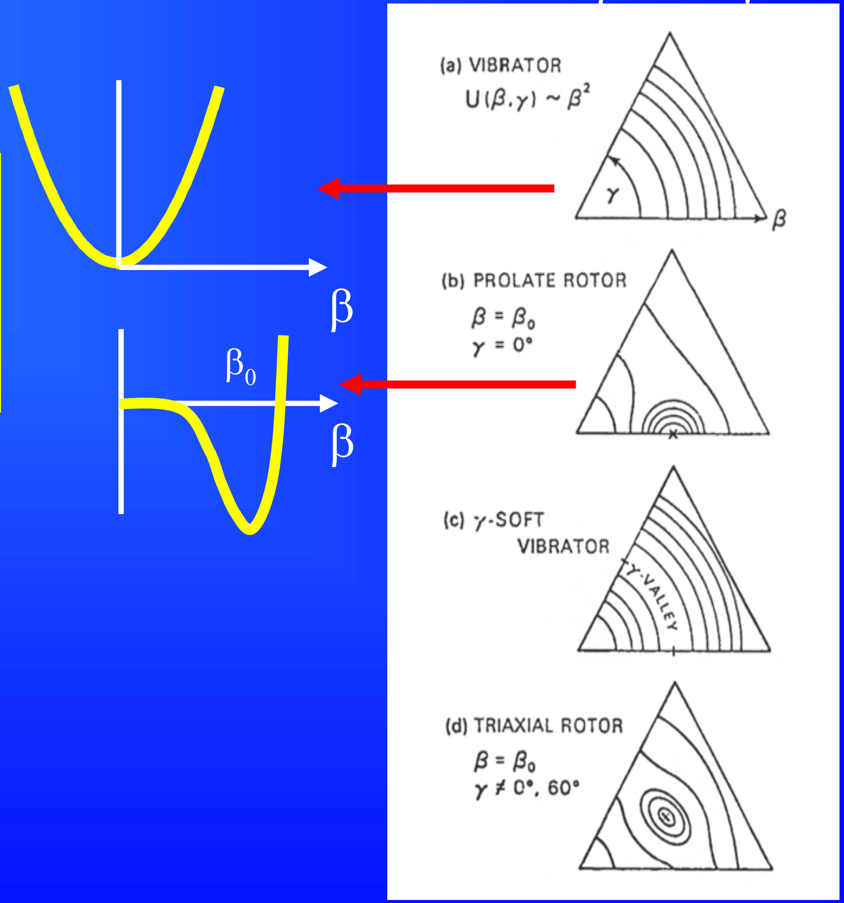
$$a_0 = \beta \cdot \cos\gamma$$

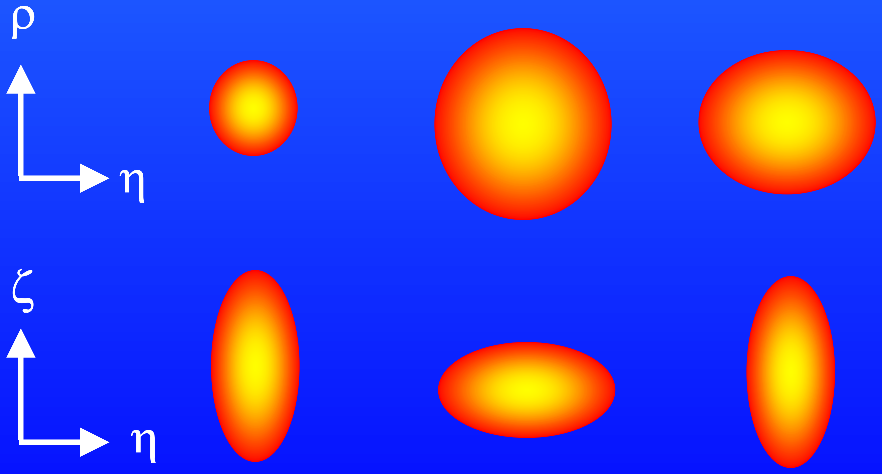
$$a_2 = a_{-2} = \frac{1}{\sqrt{2}}\beta \cdot \sin\gamma$$

β – Quadrupoldeformation
γ – Grad der Abweichung von axialer Deformation

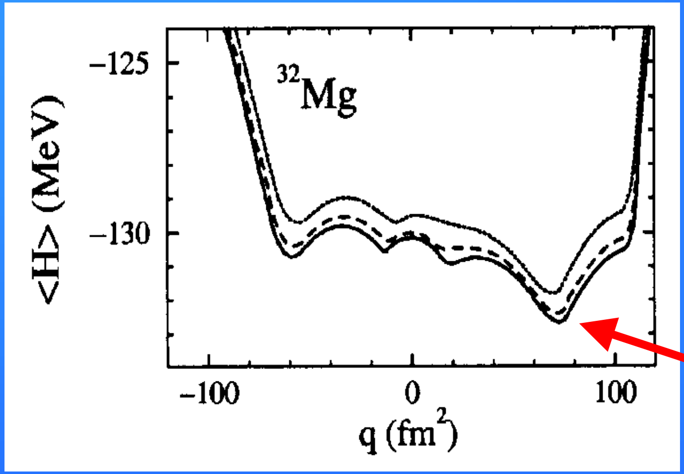
Total Energy Surface (TES)
Theoretisch berechnete totale Energie des Kerns als Funktion von β und γ

prolat	oblat	triaxial
$\beta > 0$	$\beta < 0$	$\beta > 0$
$\gamma = 0^\circ$	$\gamma = 60^\circ$	$\gamma = 30^\circ$

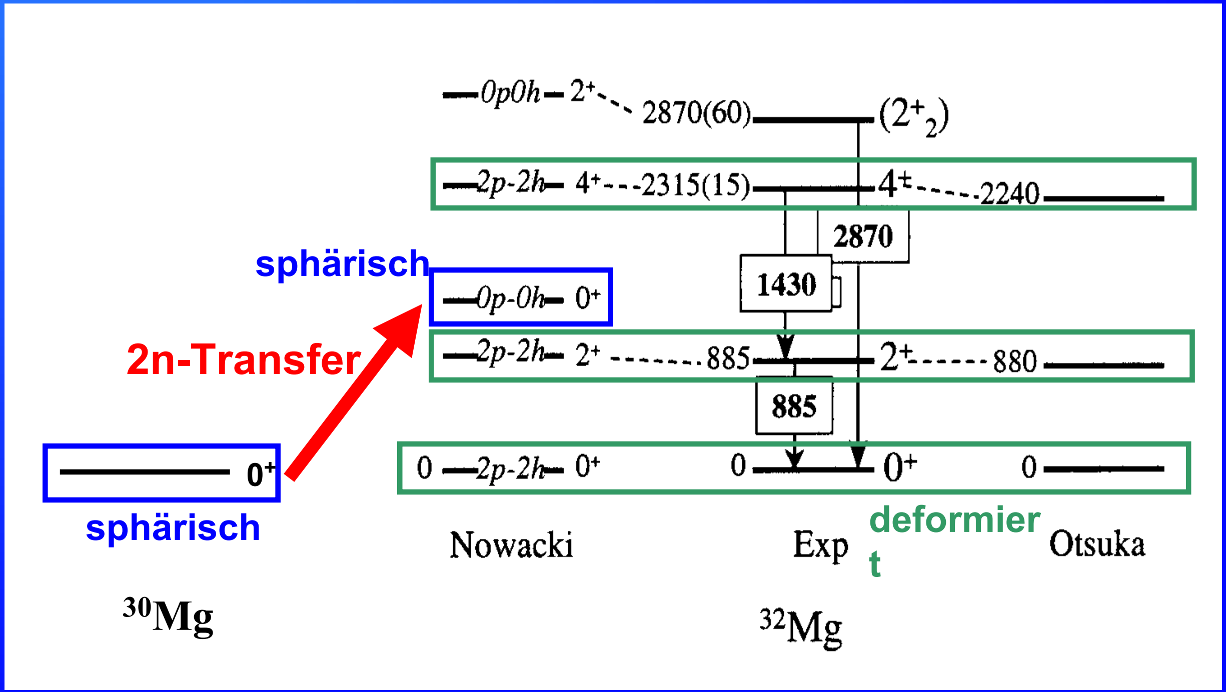




Formkoexistenz in ^{32}Mg



deformiert



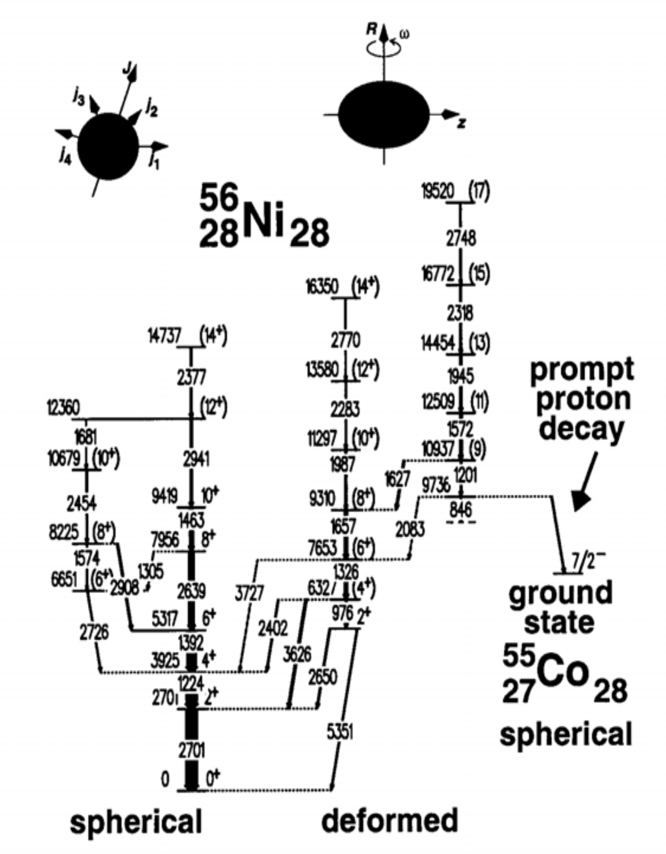
sphärisch

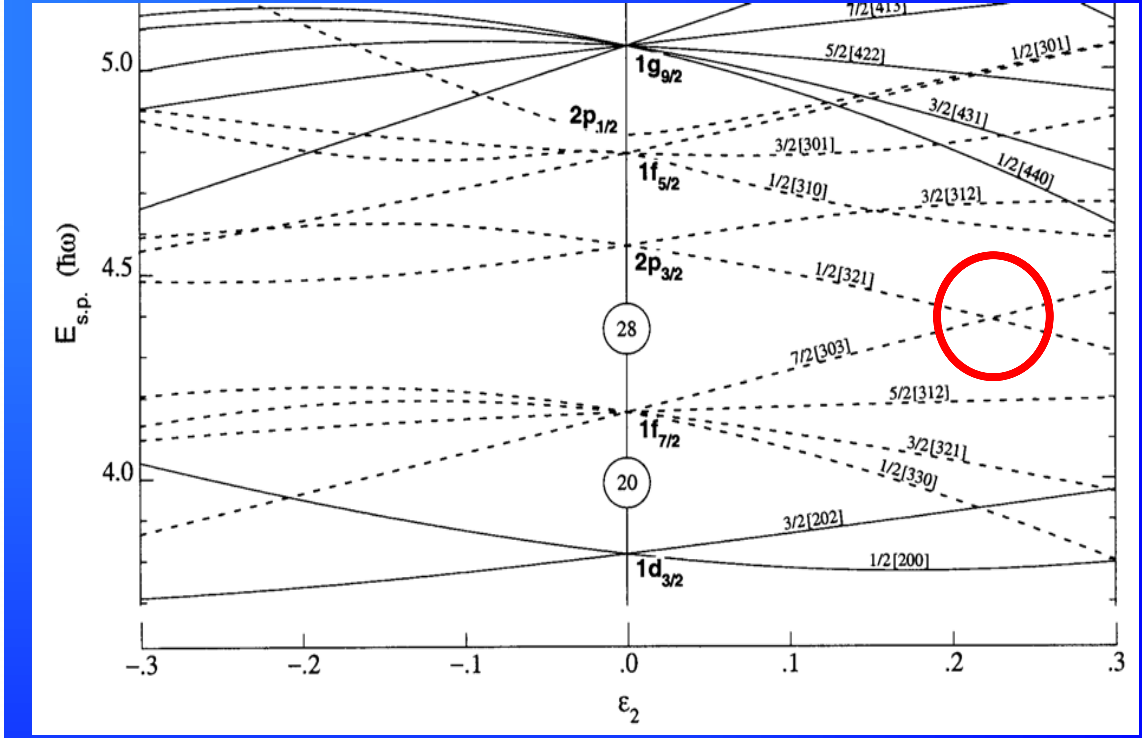
2n-Transfer

sphärisch

deformiert

Formkoexistenz in ^{56}Ni



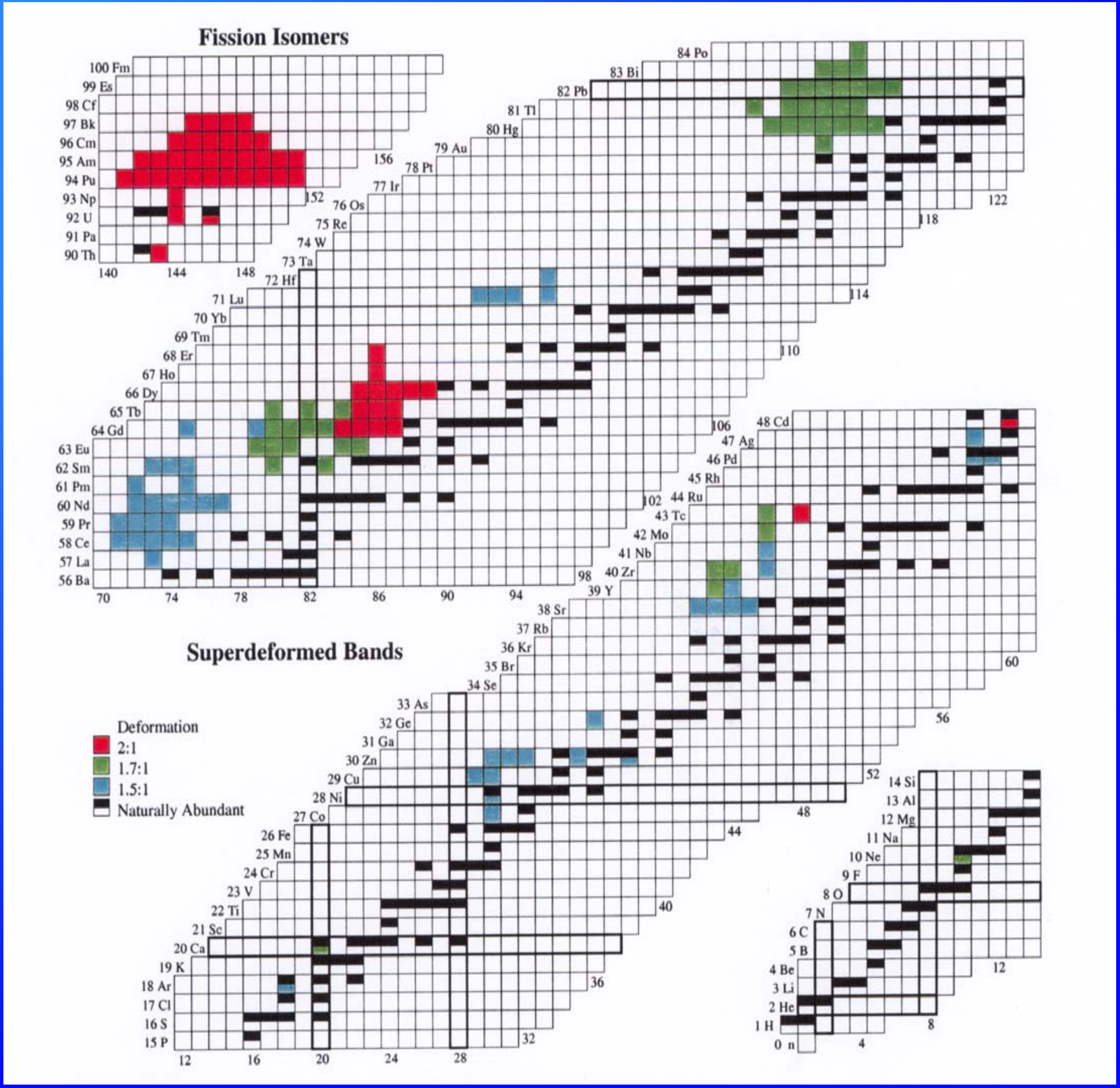


← oblat **prolat →**

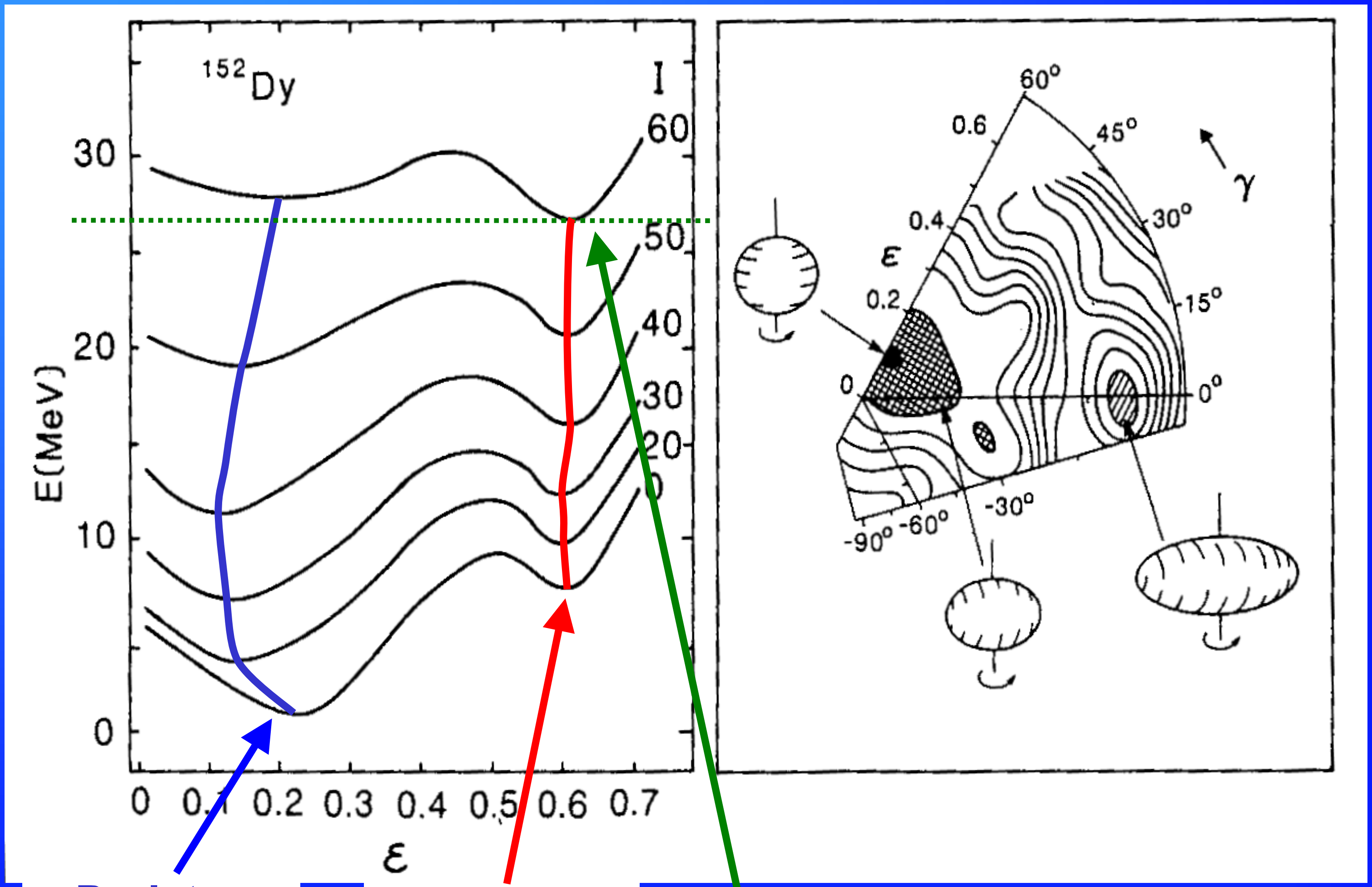
Superdeformation

Superdeformation
Kerne mit
Achsenverhältnis
von ≈ 2:1

Bisher wurden rund 250 superdeformierte Banden beobachtet



Formkoexistenz in ^{152}Dy



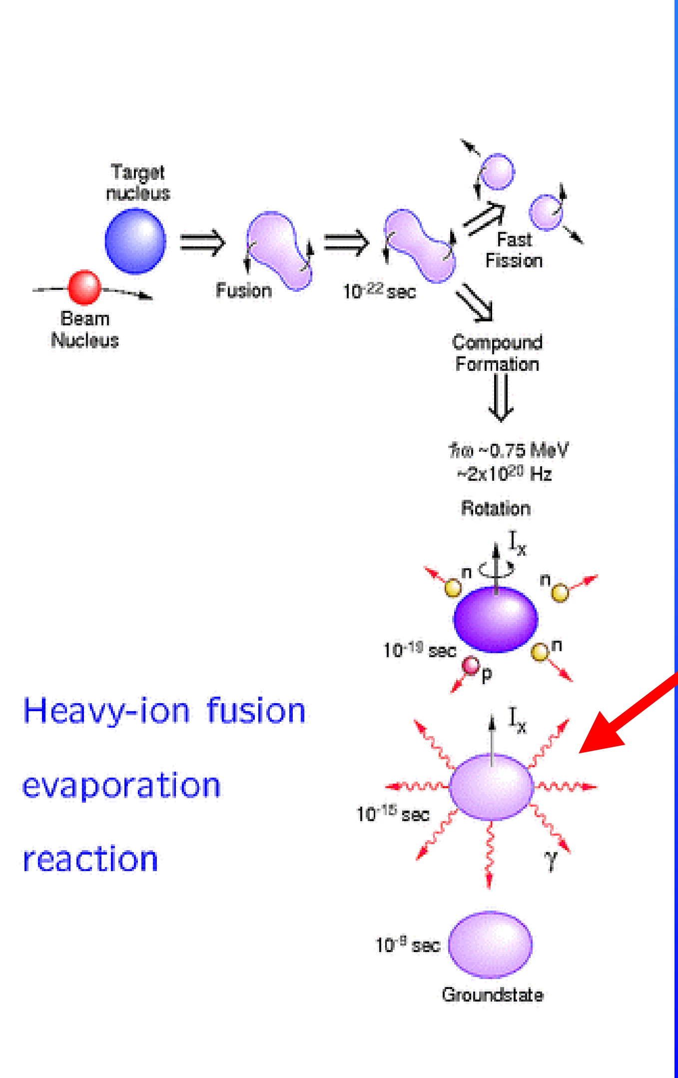
Prolates ND Minimum

SD Minimum

SD Zustände werden bei I ≈ 60ħ „yrast“!!

Hochspin-Spektroskopie

Bevölkerung von Kernen bei hohem Drehimpuls in Fusion-Evaporation-Reaktion



Heavy-ion fusion

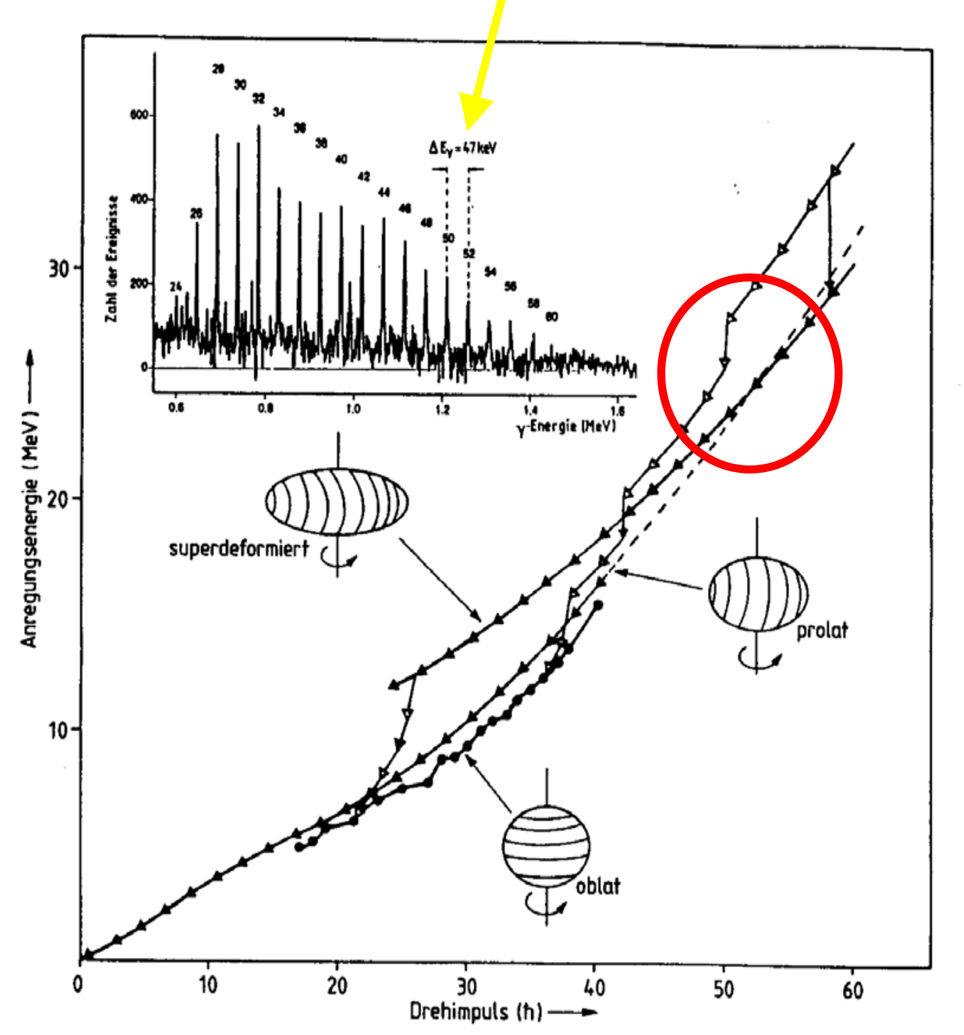
evaporation

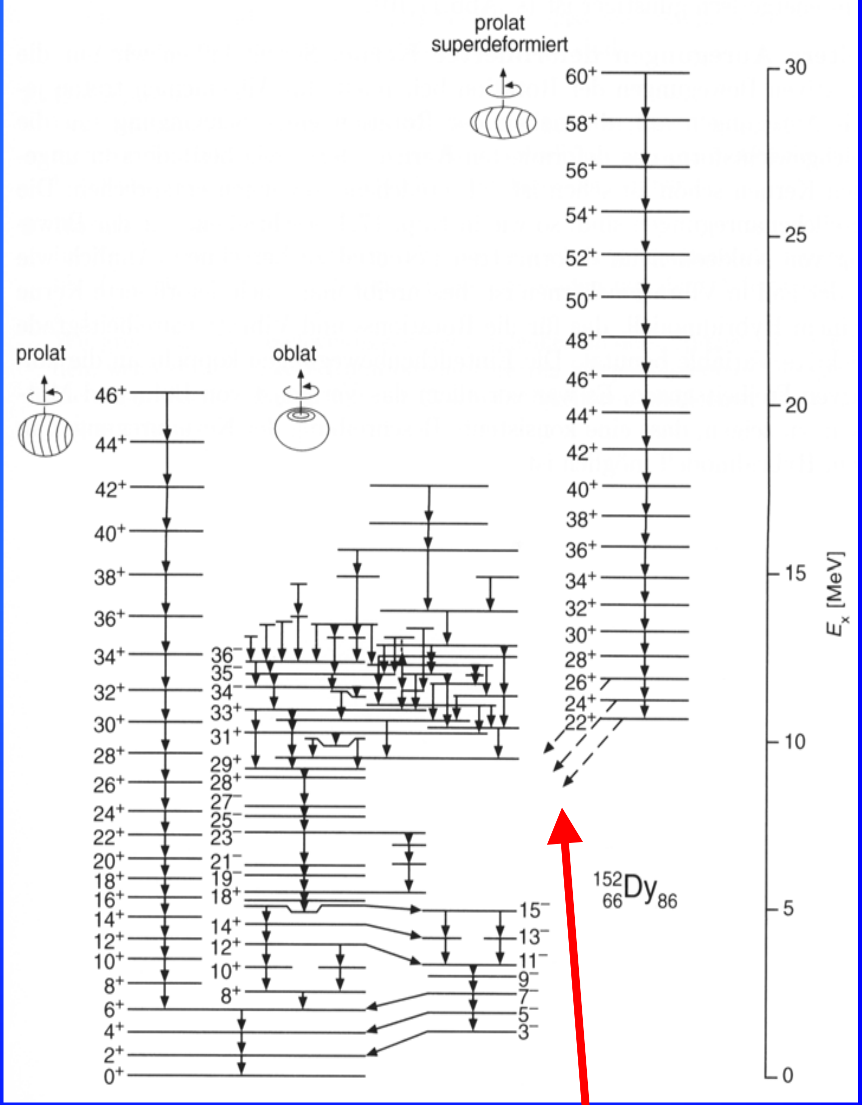
reaction

EUROBALL

Formkoexistenz in ^{152}Dy

$$\Delta E_\gamma = E_\gamma(I+2) - E_\gamma(I) = const.$$

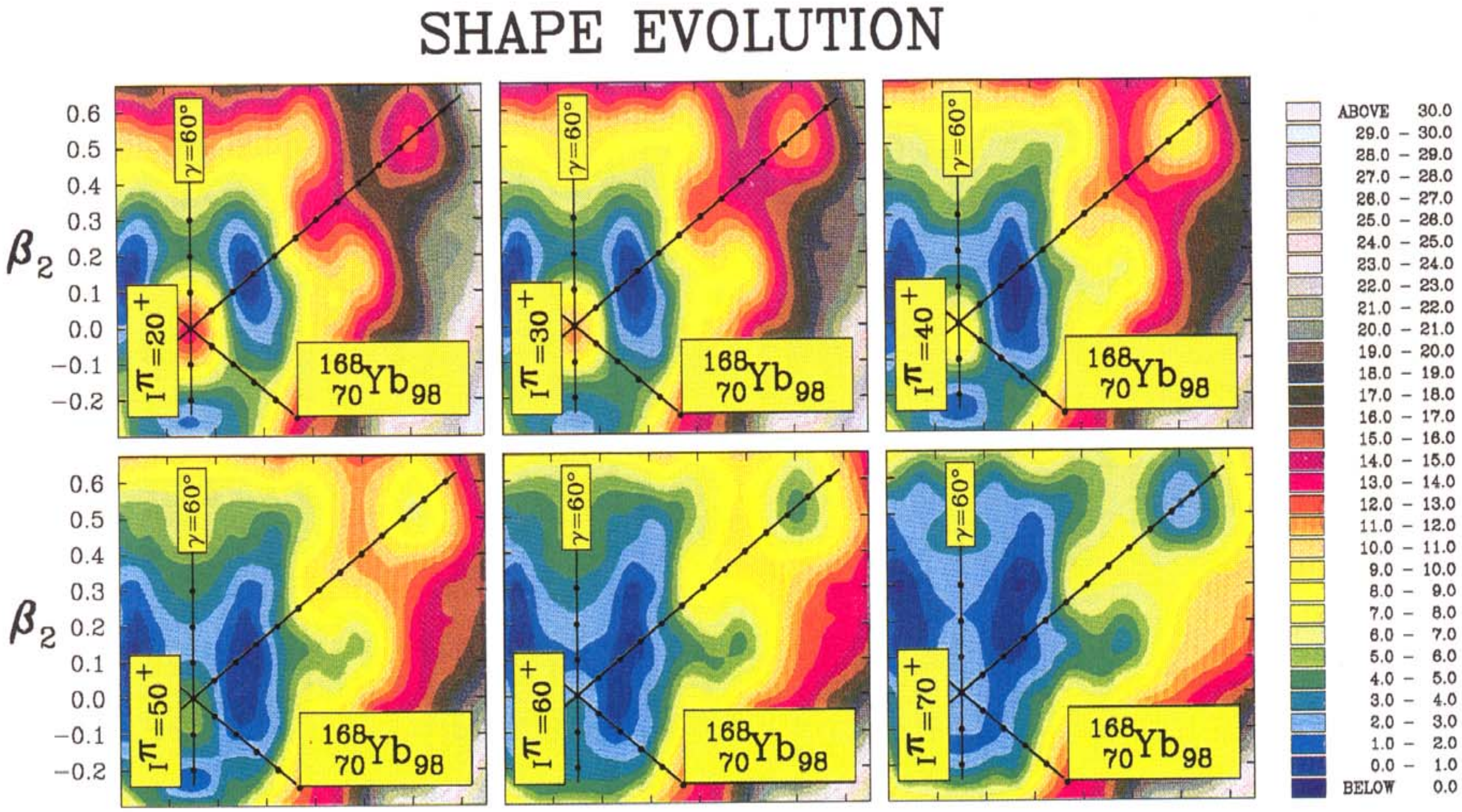




„linking transitions“ unbekannt

Hyperdeformation

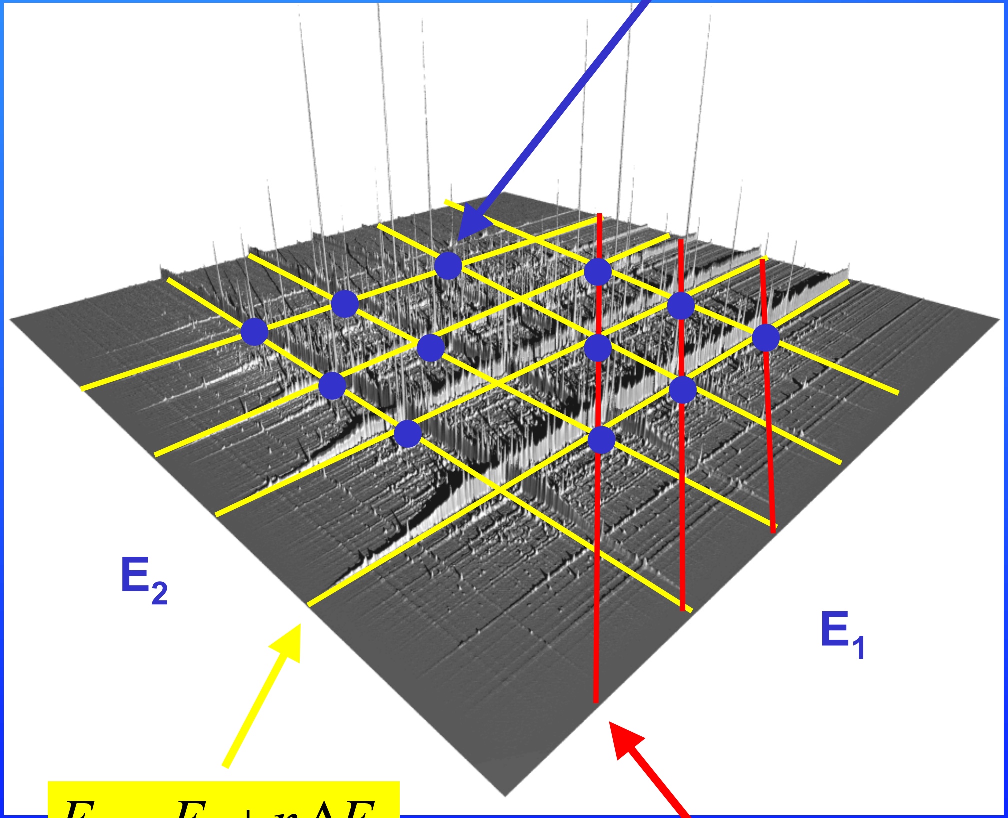
Hyperdeformation - Kerne mit Achsenverhältnis 3:1



Hyperdeformation in ^{152}Dy?

γγ-Matrix

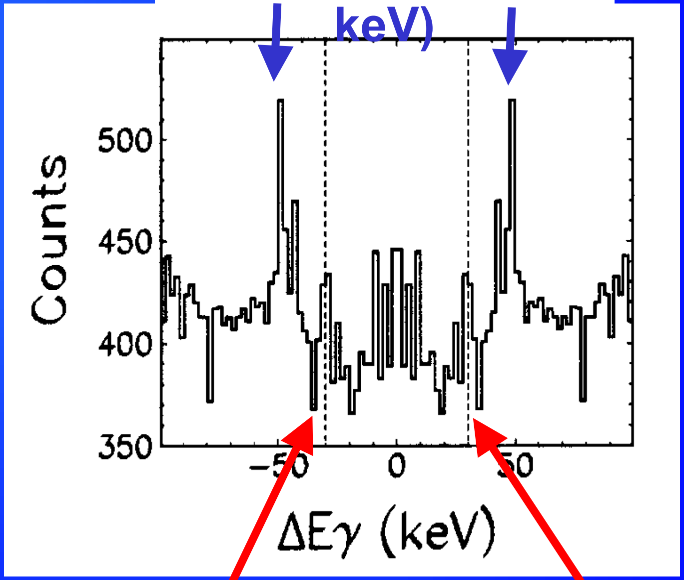
Koinzidenzen zwischen Übergängen innerhalb einer Bande



$$E_\gamma = E_0 + n\Delta E_\gamma$$

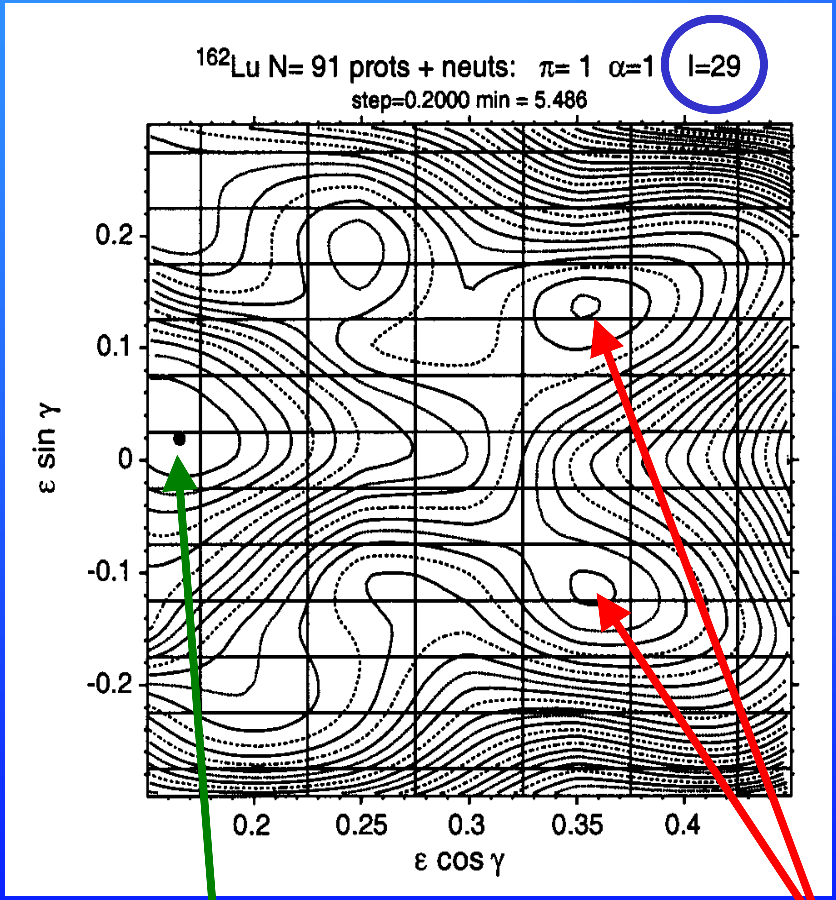
$$E_1 - E_2 = \Delta E_\gamma$$

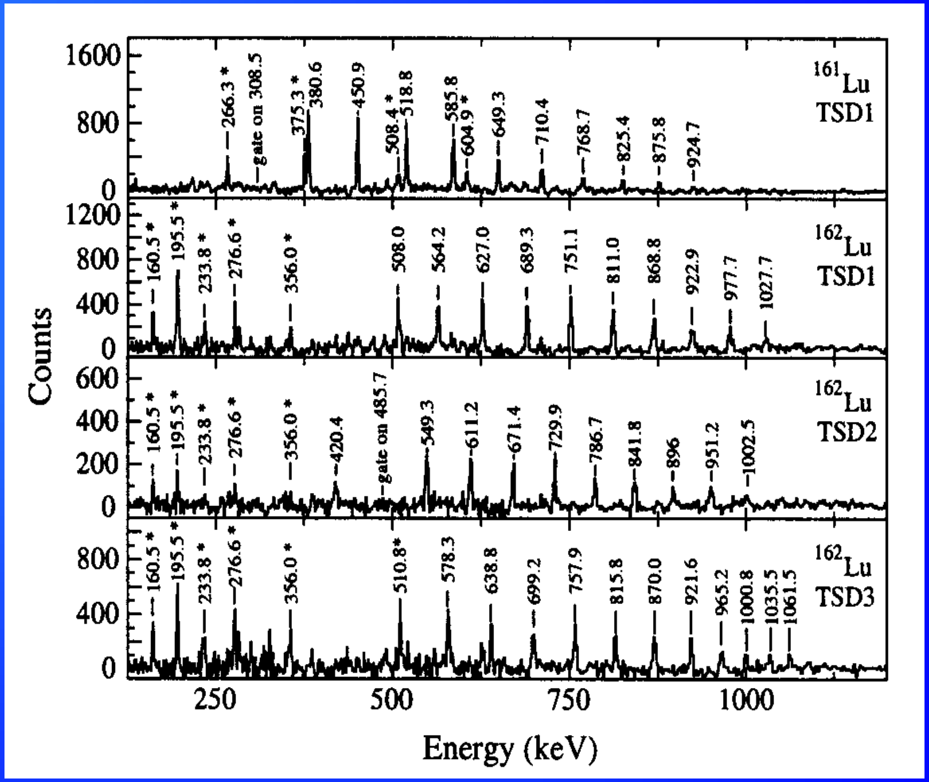
SD Bande (47 keV)



HD Bande (≈ 30 keV)?

Triaxiale Superdeformation in Lu

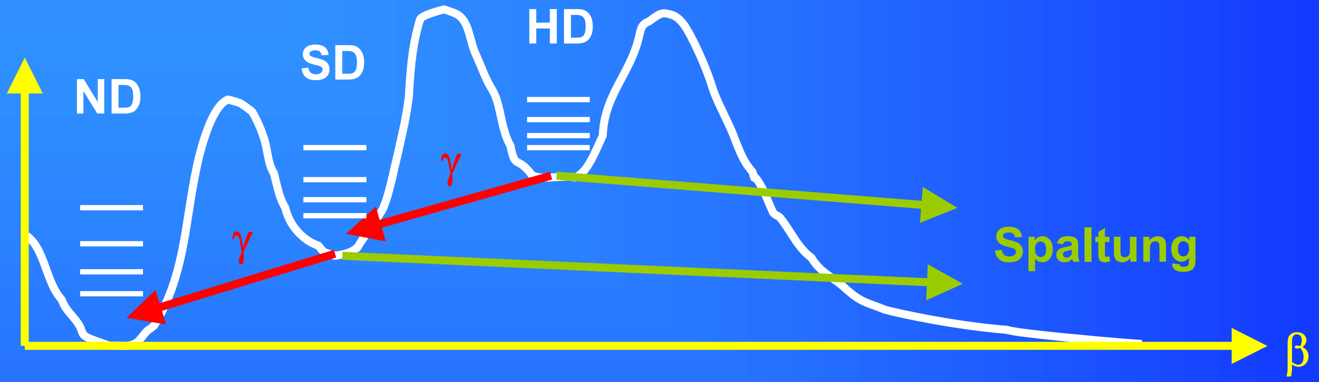


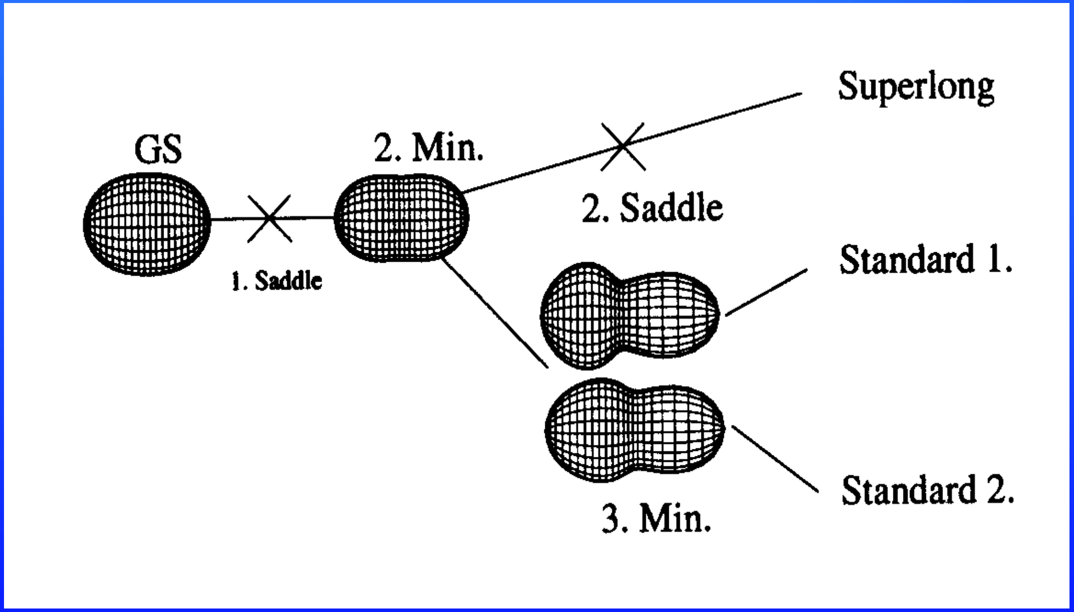


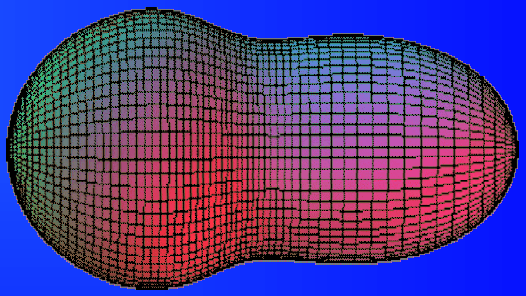
ND Grundzustand $\varepsilon \approx 0.17$

Triaxiale SD (TSD) Minima bei $\gamma \approx \pm 20°$ und $\varepsilon \approx 0.36$

Spaltisomere







^{232}U

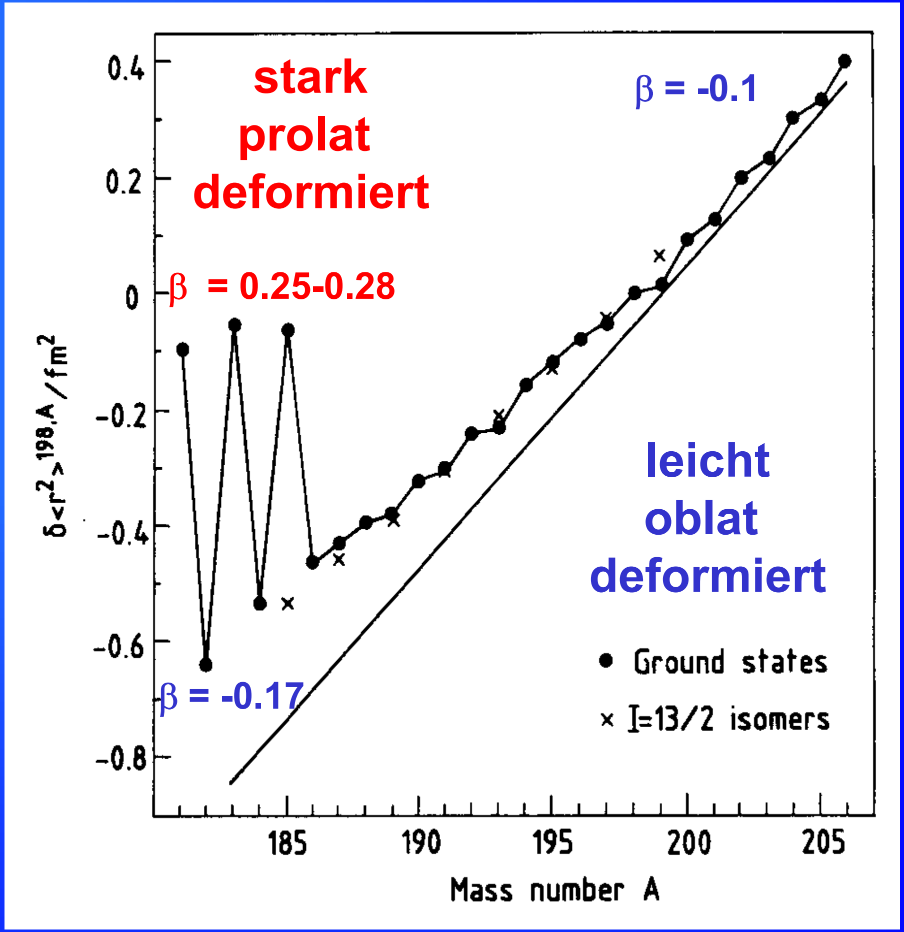
Isotopenverschiebung in Hg

Isotopenverschiebung (IS)
atomarer Übergänge

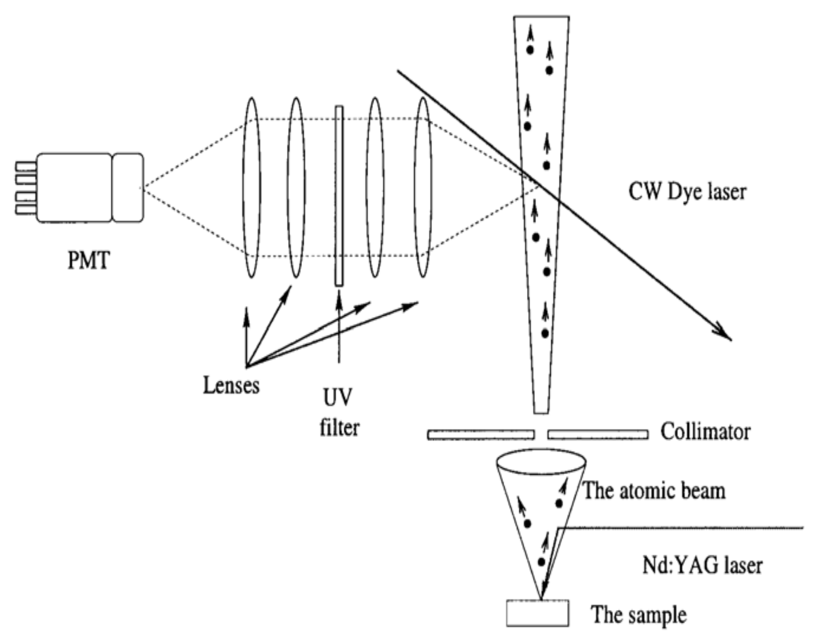
$$\delta\nu_{IS}^{A,A'} = \delta\nu_{Masse}^{A,A'} + \delta\nu_{Feld}^{A,A'} \qquad \delta\nu_{IS}^{A,A'}/\nu \approx 10^{-6}$$

$$\delta\nu_{Feld}^{A,A'} = F_{Elektronen} * \left(\delta\left\langle r^2\right\rangle^{A,A'} + \ldots\right)$$

Mittlerer quadratischer Ladungsradius $\langle r^2 \rangle$

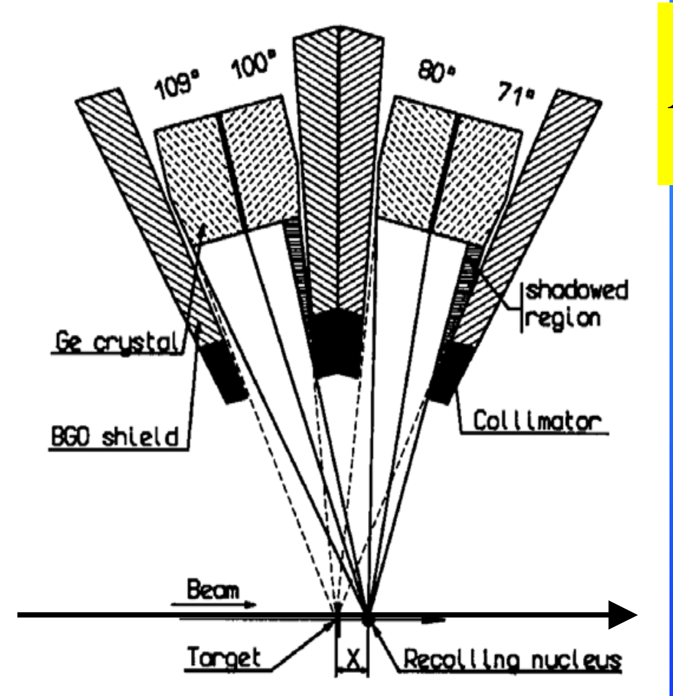


Kollineare Laserspektroskopie

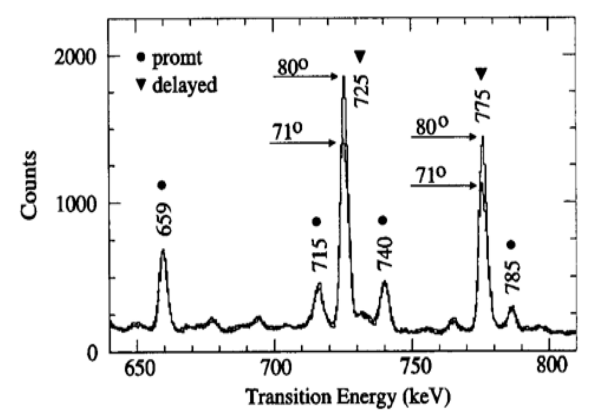


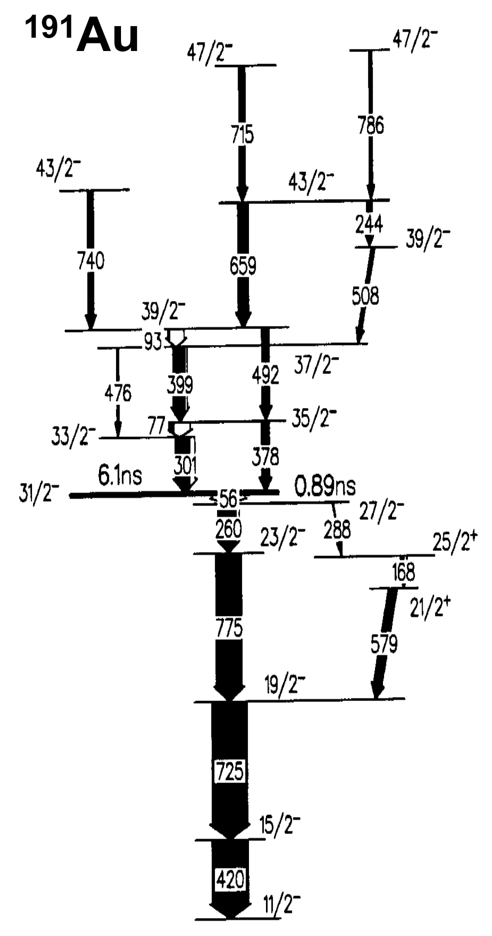
Lebensdauermessung von Isomeren

RSAM
Recoil Shadow Anisotropy Method



$$A = \frac{I_\gamma(80^\circ) - I_\gamma(71^\circ)}{I_\gamma(80^\circ) + I_\gamma(71^\circ)} = f(\tau)$$



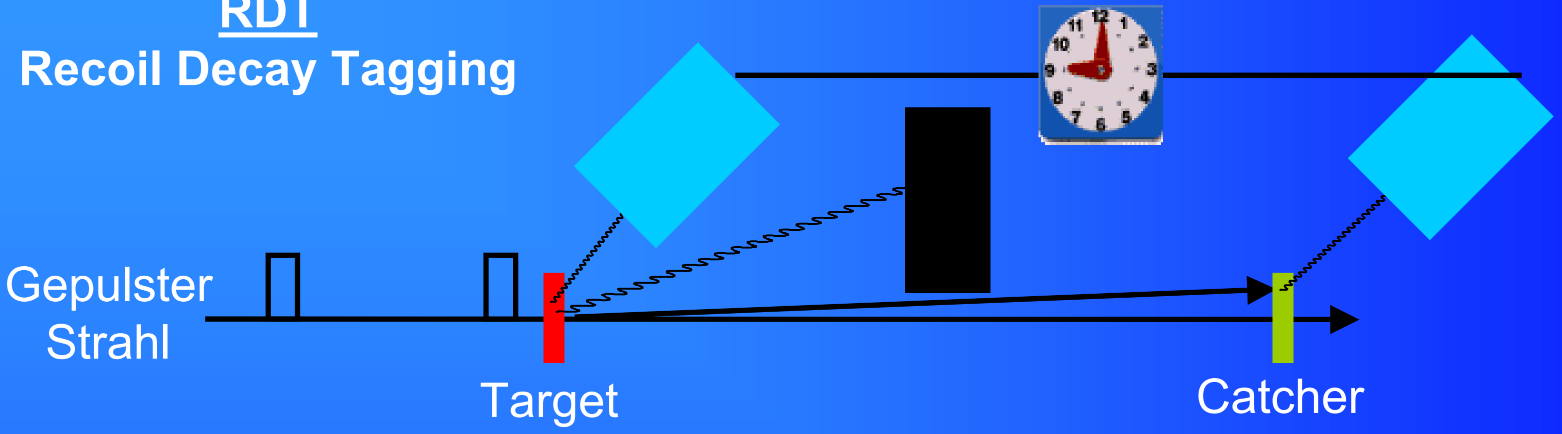


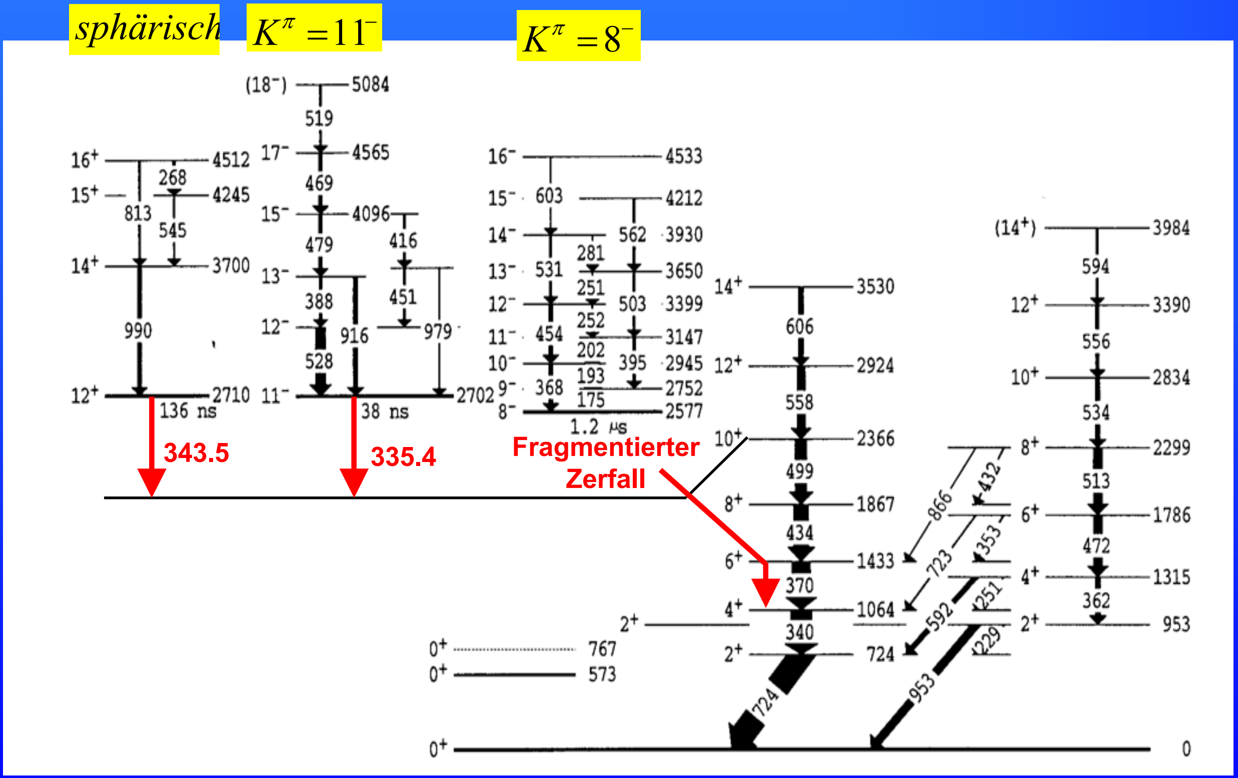
CLOVER

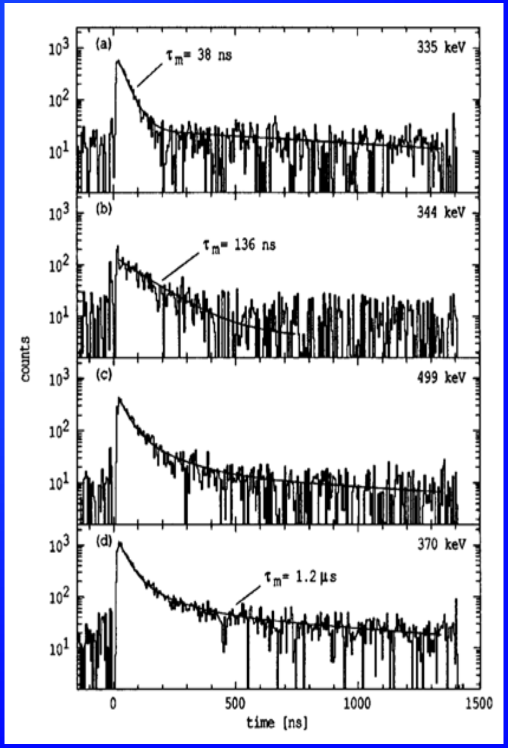
Formisomere in ^{188}Pb

RDT

Recoil Decay Tagging





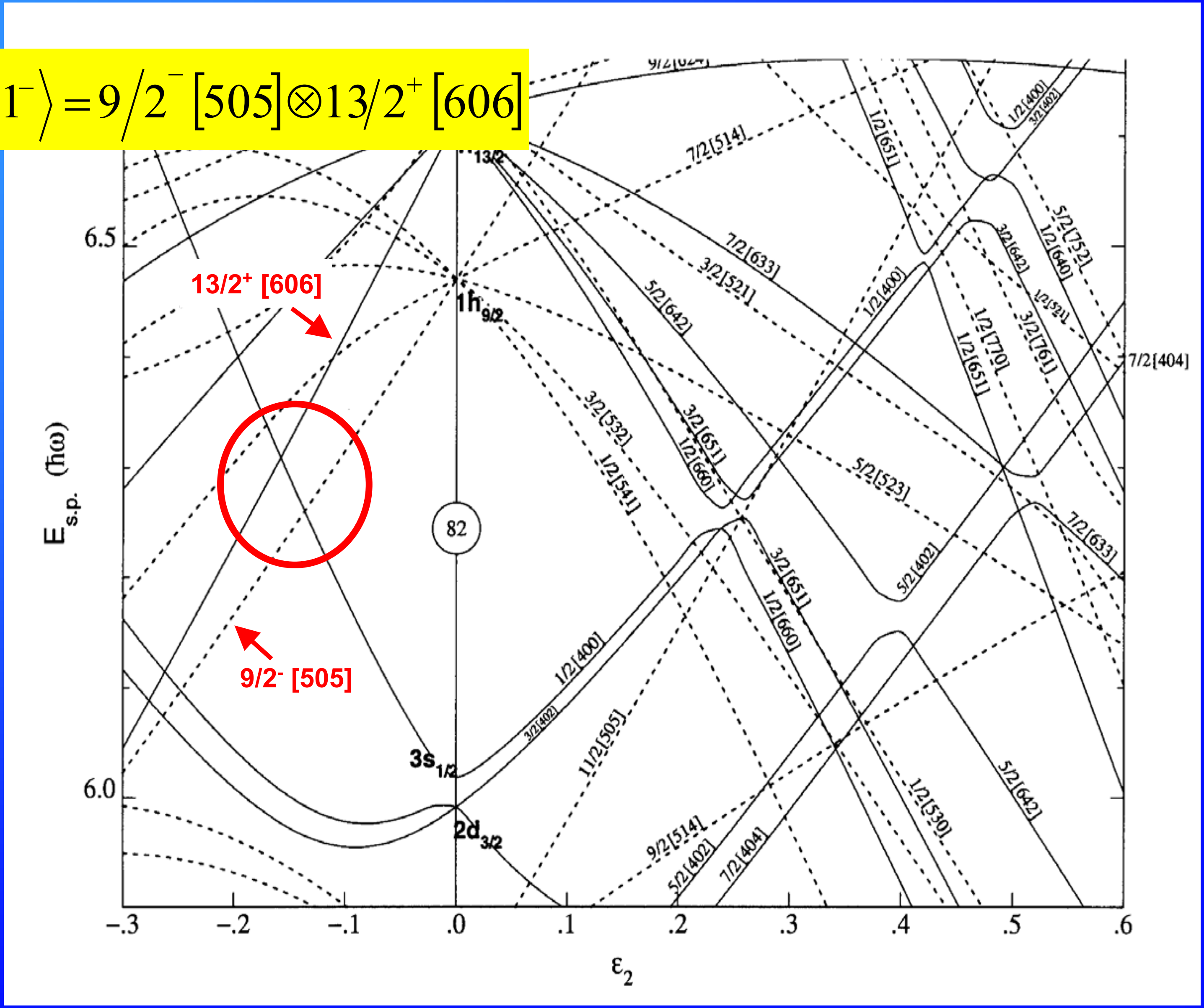


Nilsson-Orbitale für Protonen

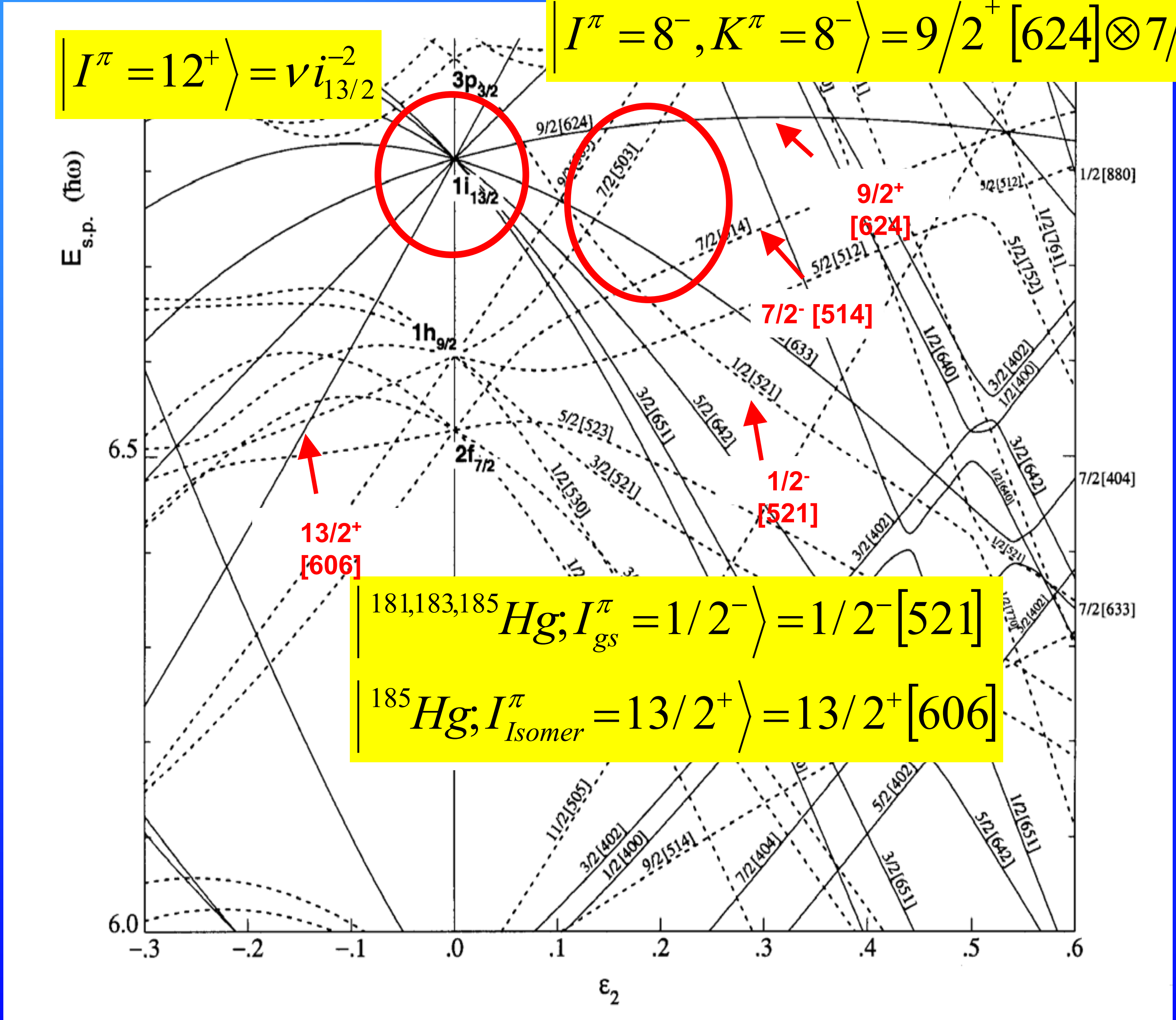
$$\left|I^{\pi}=11^{-},K^{\pi}=11^{-}\right\rangle = 9/2^{-}[505]\otimes 13/2^{+}[606]$$

Nilsson-Quantenzahlen

$j^{\pi}[N,n_z,l_z]$



Nilsson-Orbitale für Neutronen



$$\left|I^\pi = 12^+\right\rangle = \nu i_{13/2}^{-2}$$

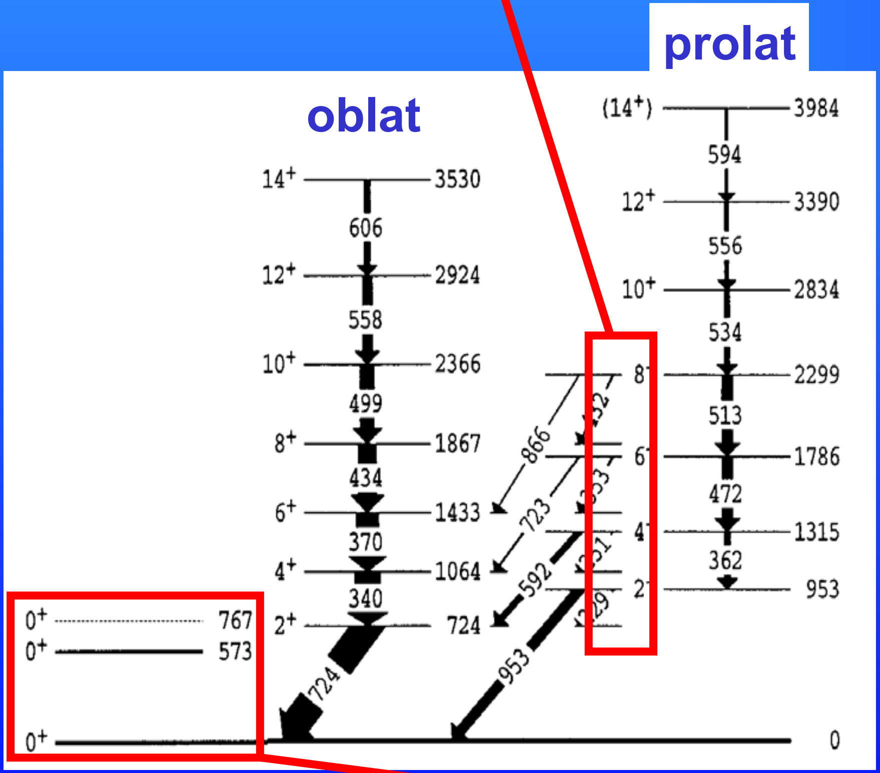
$$\left|I^\pi = 8^-, K^\pi = 8^-\right\rangle = 9/2^+[624] \otimes 7/2^-[514]$$

$$\left|{}^{181,183,185}Hg; I^\pi_{gs} = 1/2^-\right\rangle = 1/2^-[521]$$

$$\left|{}^{185}Hg; I^\pi_{Isomer} = 13/2^+\right\rangle = 13/2^+[606]$$

Formkoexistenz in ^{188}Pb - Rotationsbanden

Intensitäten der Inband-Übergänge in Koinzidenz mit Interband-Übergängen lassen sich nur unter Hinzunahme von E0-Übergängen erklären



Bandenmischung

$$\alpha_{total} = \alpha(E2) + \Gamma_e(E0) / \Gamma_\gamma(E2)$$

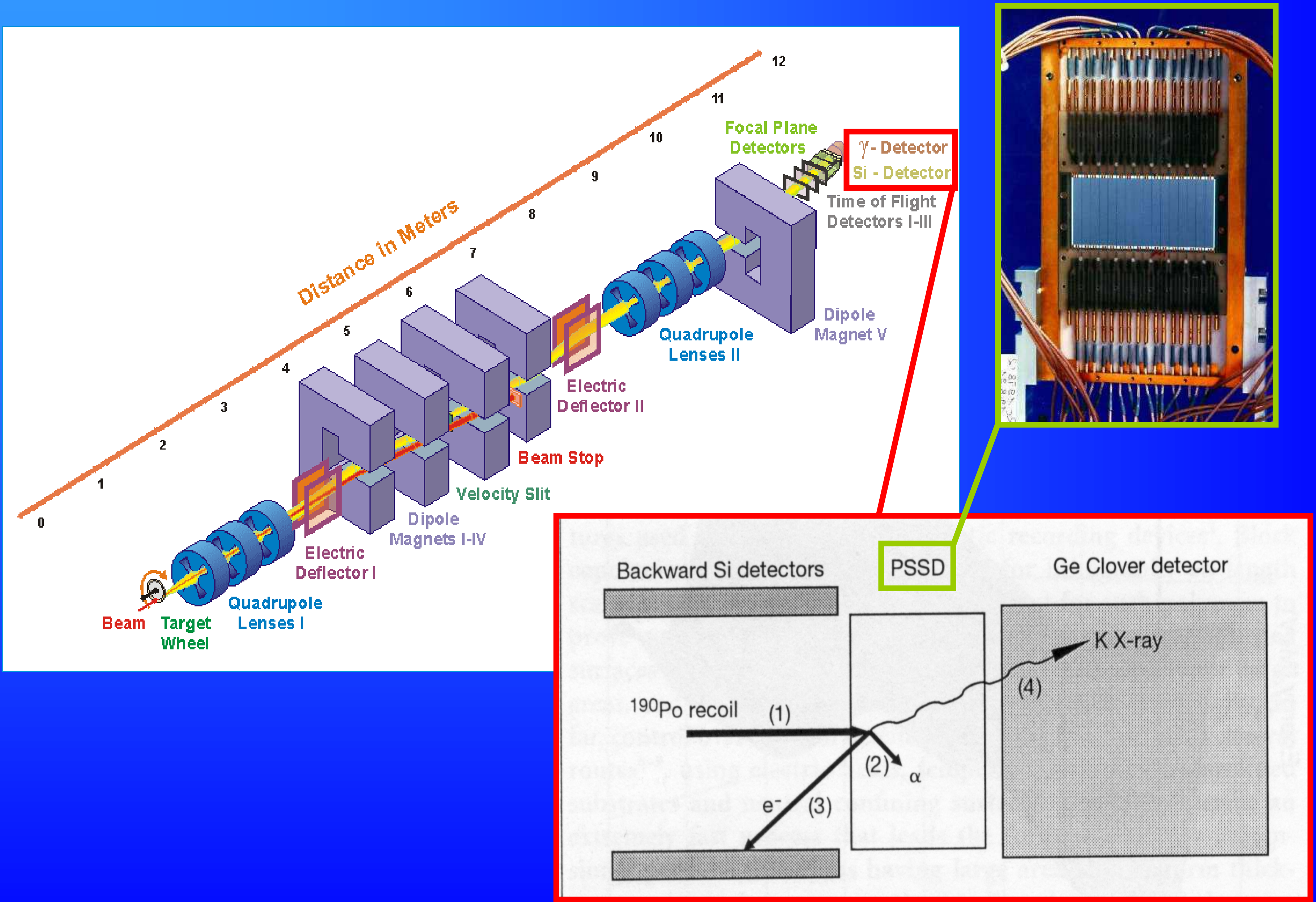
$$\Gamma(E0; J \rightarrow J) \propto \left(a\sqrt{1-a^2}\left[(\beta_1)^2 - (\beta_2)^2\right]\right)^2$$

$$\Gamma(E2; J \rightarrow J) \propto \left(a\sqrt{1-a^2}\left[\beta_1^{\,2} - \beta_2^{\,2}\right]\right)^2$$

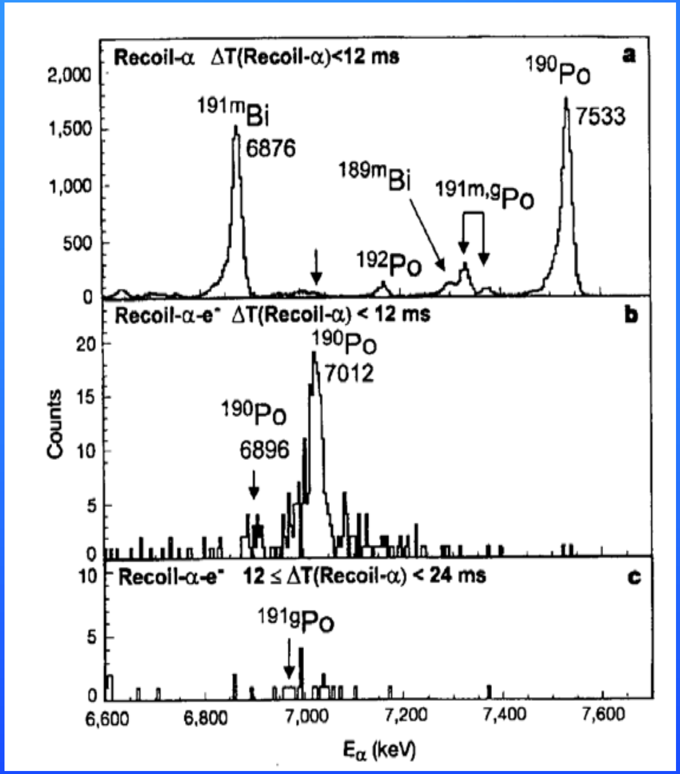
β_1 und β_2 müssen verschieden sein, ergo: Formkoexistenz!!!

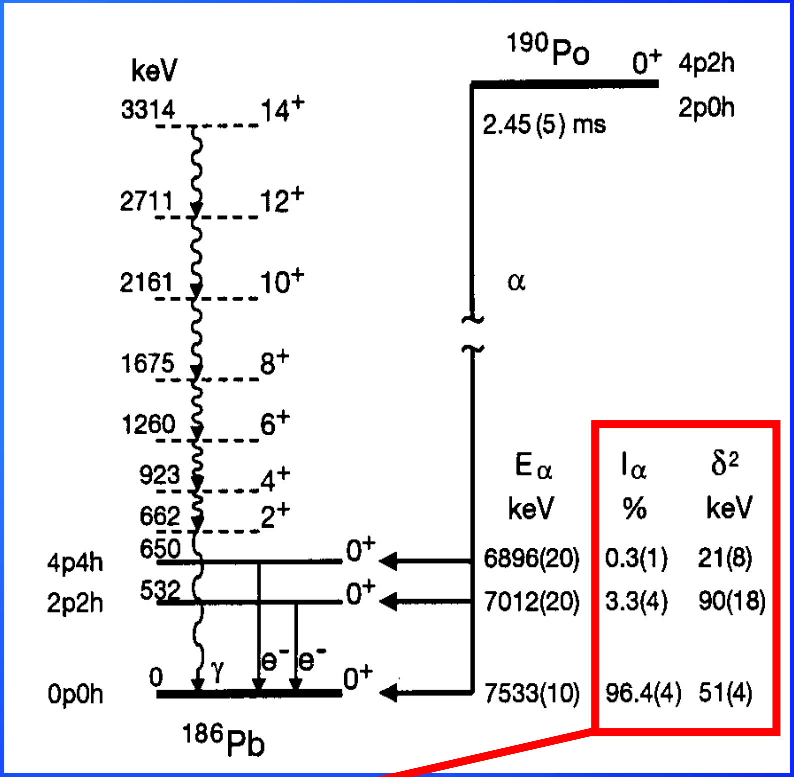
	sphärisch	prolat	oblat
$0^+_{g.s.}$	95%	4%	1%
0^+_2	2%	15%	83%
0^+_3	3%	81%	16%
β	0.0	0.2	-0.13

SHIP@GSI


Distance in Meters
0
1
2
3
4
5
6
7
8
9
10
11
12
Beam
Target Wheel
Quadrupole Lenses I
Electric Deflector I
Dipole Magnets I-IV
Velocity Slit
Beam Stop
Electric Deflector II
Quadrupole Lenses II
Dipole Magnet V
Focal Plane Detectors
γ - Detector
Si - Detector
Time of Flight Detectors I-III
Backward Si detectors
PSSD
Ge Clover detector
K X-ray
(4)
190Po recoil
(1)
(2)
α
e⁻
(3)

Formkoexistenz in ^{186}Pb – α-Spektren





Eα keV	Iα %	δ² keV	
6896(20)	0.3(1)	21(8)	**prolat**
7012(20)	3.3(4)	90(18)	**oblat**
7533(10)	96.4(4)	51(4)	**sphärisch**

Reduzierte α-Breite δ^2:
Maß für Bildung eines
α-Teilchens im Kern
⇔ Konfiguration

$$\delta^2 = \frac{h \ln(2) I_\alpha}{T_{1/2} 100 P}$$

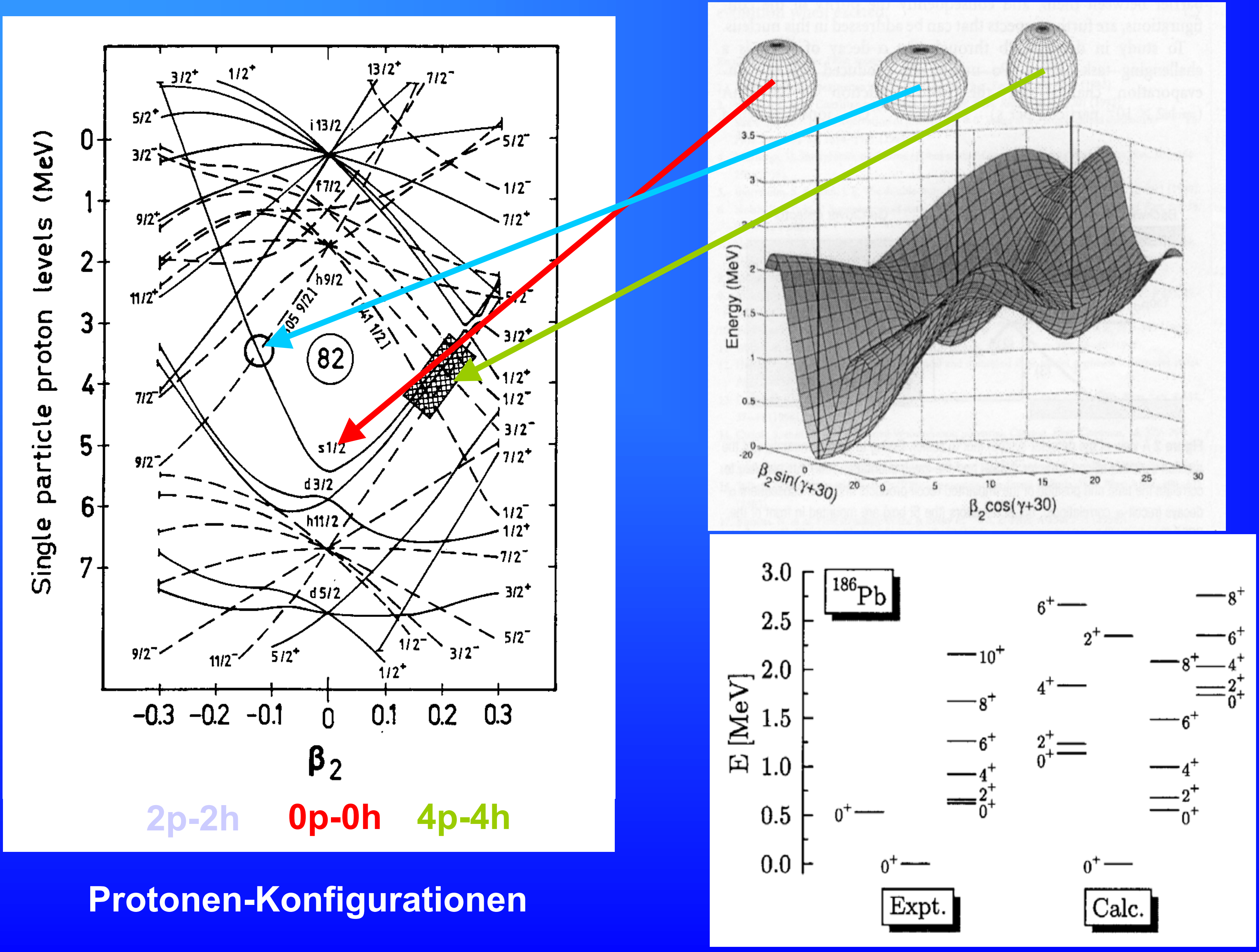
$$\delta \propto \langle Pb \otimes \alpha | A_\alpha^+ | Po \rangle$$

Grosser Überlapp: (nur Protonen)
|Po;2p-0h> → |Pb;0p-0h>
|Po;4p-2h> → |Pb;2p-2h>

“Penetration”-Faktor *P* hängt von Form ab!!!

Analogie: spektroskopische Faktoren

Formkoexistenz in ^{186}Pb



2p-2h 0p-0h 4p-4h

Protonen-Konfigurationen