Oblate nuclear shapes and shape coexistence in neutron-deficient rare earth isotopes

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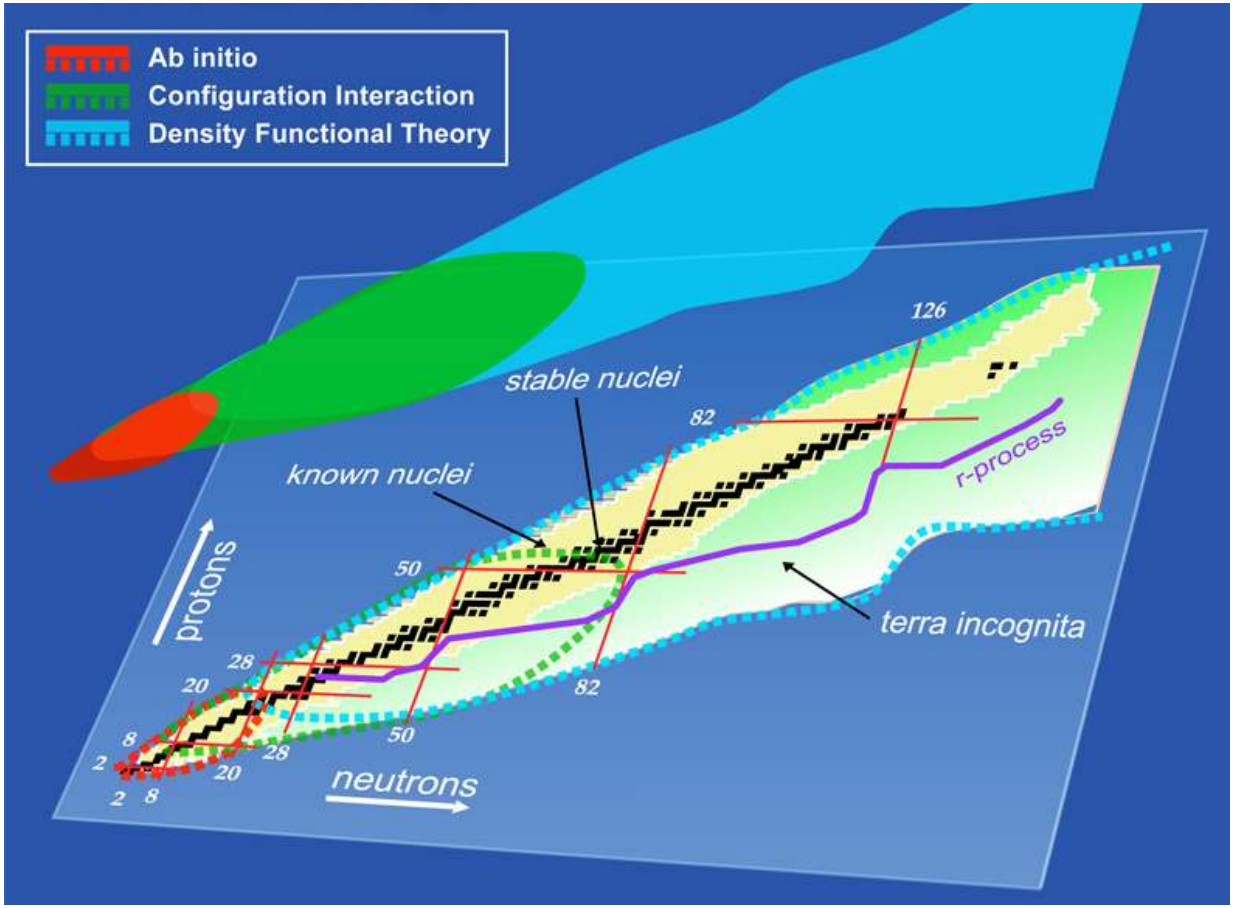
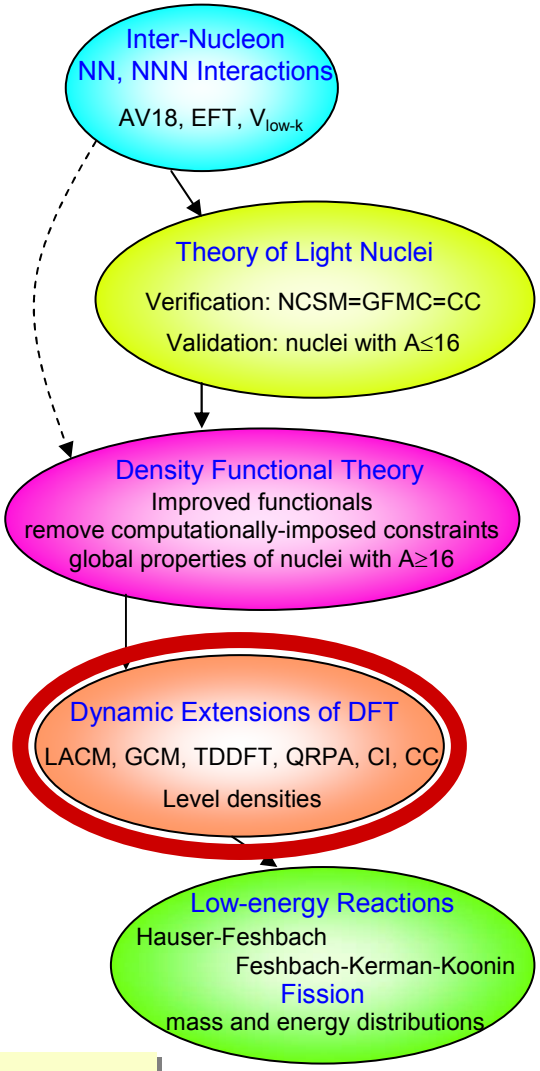
Context





ultimate goal:

comprehensive microscopic description of all nuclei and low-energy reactions from the the basic interactions between the constituent nucleons

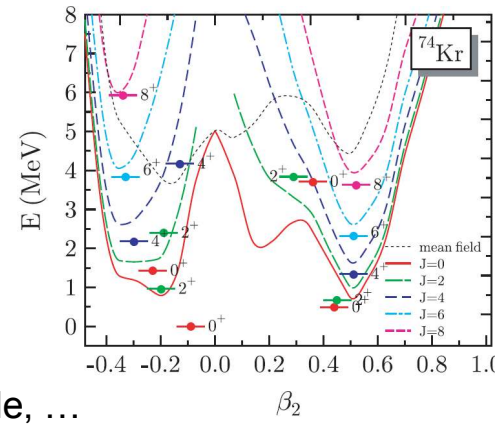
specific goal:

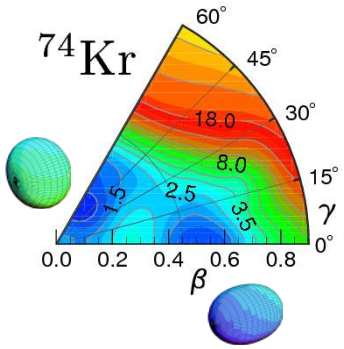
provide experimental data on nuclear shapes and collectivity in a sensitive region of shape transition and shape coexistence for benchmarking

Mean field and beyond: an example

Self-consistent HFB constrained to collective coordinate, e.g. (q_{20},q_{22})

- set of basis states $\left|\Phi_q\right\rangle$
- potential energy surface





M. Bender et al.,
PRC 74, 024312 (2006)

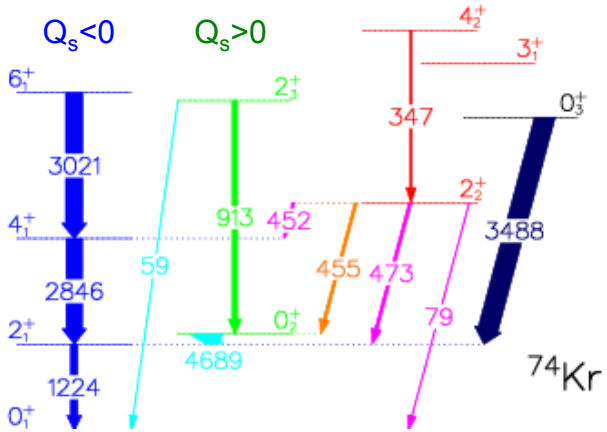
Correlations beyond mean field

- configuration mixing $\left|\Psi_i\right\rangle = \int f_i(q)\left|\Phi_q\right\rangle dq$
- properties of excited states: E_x, Q_s, B(E2), …

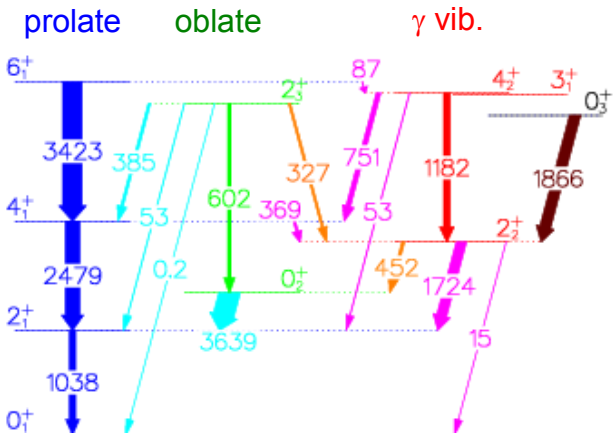
Approaches / choices

- collective coordinates: e.g. axial, triaxial, octupole, …
- relativistic or non-relativistic
- effective interaction: Skyrme, Gogny

Experiment: E_x, Q_s, B(E2) from low-energy Coulomb excitation



experiment

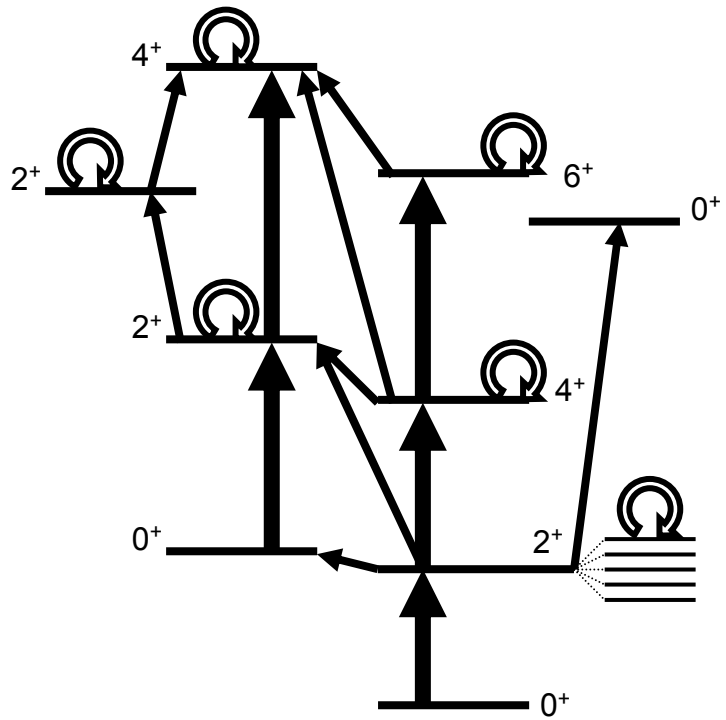


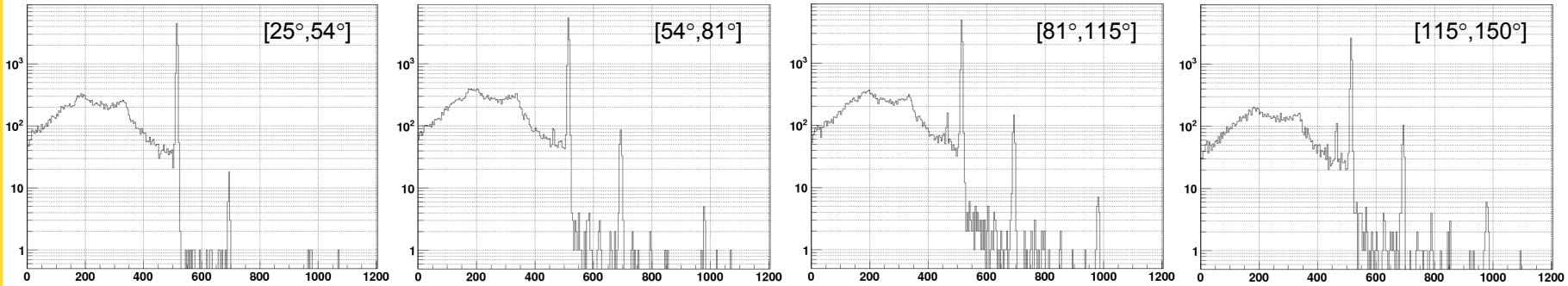
theory

E. Clément et al.,
PRC 75, 054313 (2007)

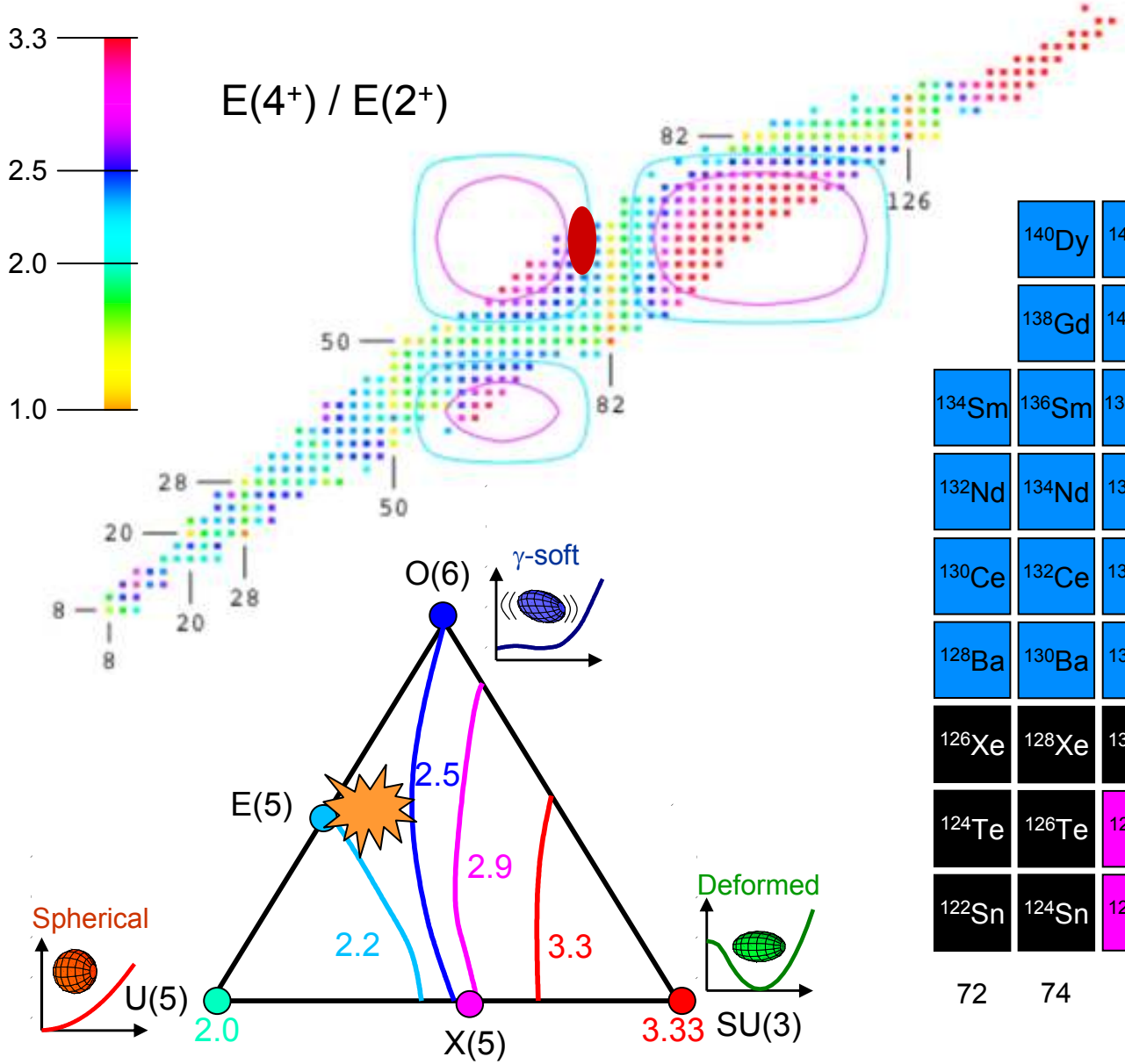
Multi-step Coulomb excitation

- safe energy ⇒ purely electromagnetic excitation
- transitional matrix element ⇒ **B(E2)**
- diagonal matrix element ⇒ **Q_s**
- reorientation effect ⇒ sensitive to nuclear shape
- multi-step excitation
- de-excitation γ-ray yields ⇒ **$d\sigma/d\theta$**
- χ^2 minimization of matrix elements to reproduce experimental γ-ray yields



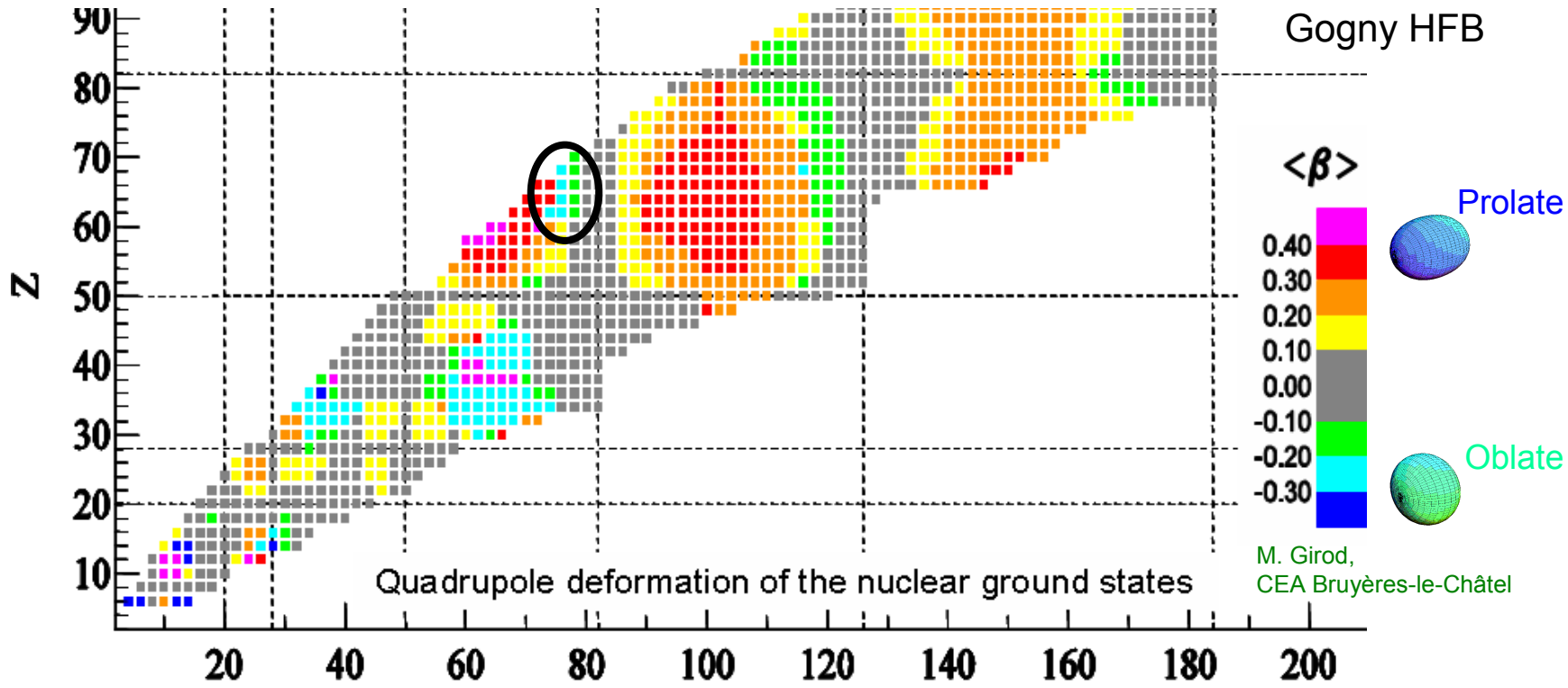


Region of interest

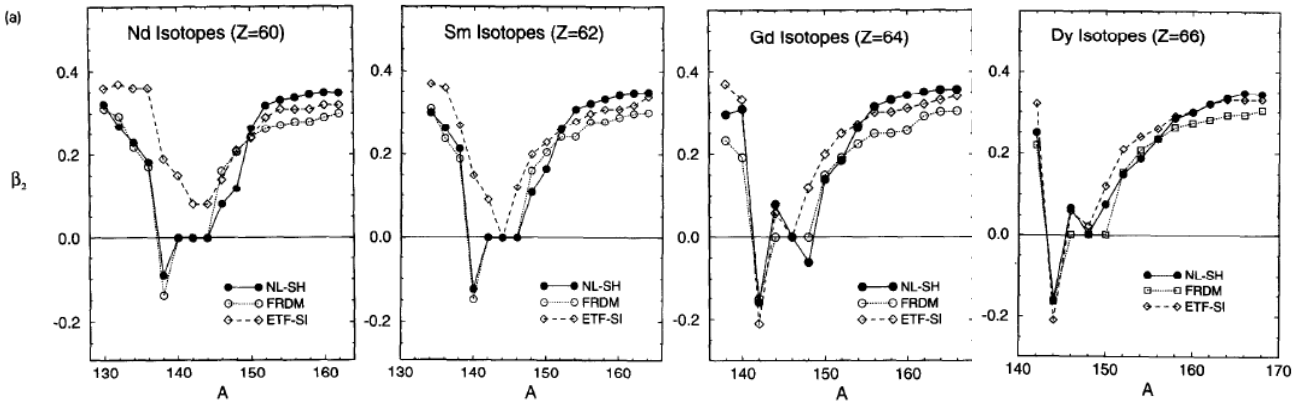


				^{148}Er	^{150}Er	68
	^{140}Dy	^{142}Dy	^{144}Dy	^{146}Dy	^{148}Dy	66
	^{138}Gd	^{140}Gd	^{142}Gd	^{144}Gd	^{146}Gd	64
^{134}Sm	^{136}Sm	^{138}Sm	^{140}Sm	^{142}Sm	^{144}Sm	62
^{132}Nd	^{134}Nd	^{136}Nd	^{138}Nd	^{140}Nd	^{142}Nd	60
^{130}Ce	^{132}Ce	^{134}Ce	^{136}Ce	^{138}Ce	^{140}Ce	58
^{128}Ba	^{130}Ba	^{132}Ba	^{134}Ba	^{136}Ba	^{138}Ba	56
^{126}Xe	^{128}Xe	^{130}Xe	^{132}Xe	^{134}Xe	^{136}Xe	54
^{124}Te	^{126}Te	^{128}Te	^{130}Te	^{132}Te	^{134}Te	52
^{122}Sn	^{124}Sn	^{126}Sn	^{128}Sn	^{130}Sn	^{132}Sn	50
72	74	76	78	80	82	

Nuclear shapes



RMF



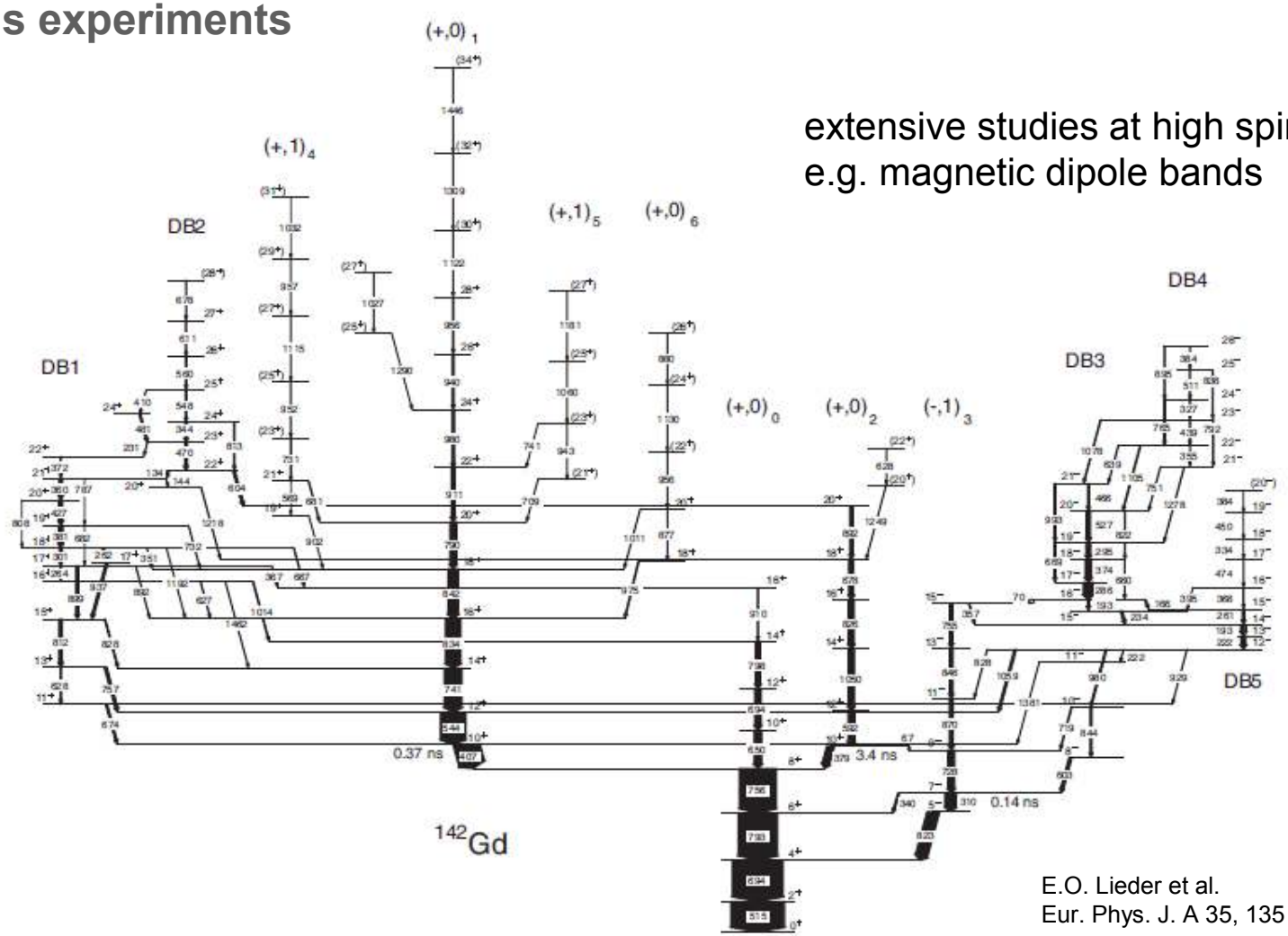
G.A. Lalazissis et al. Nucl. Phys. A 597, 35 (1996)

oblate shapes in medium / heavy nuclei just beneath shell closure
- holes in Ω=1/2 orbitals

region of
- oblate shapes
- rapid shape transition
- shape coexistence ?

Previous experiments

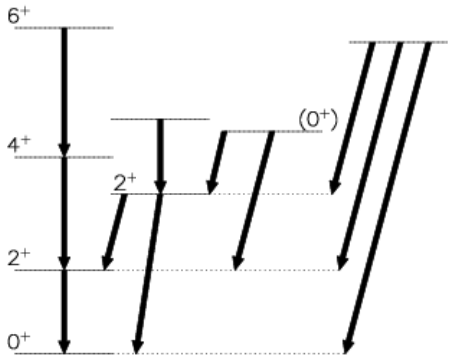
extensive studies at high spin
e.g. magnetic dipole bands

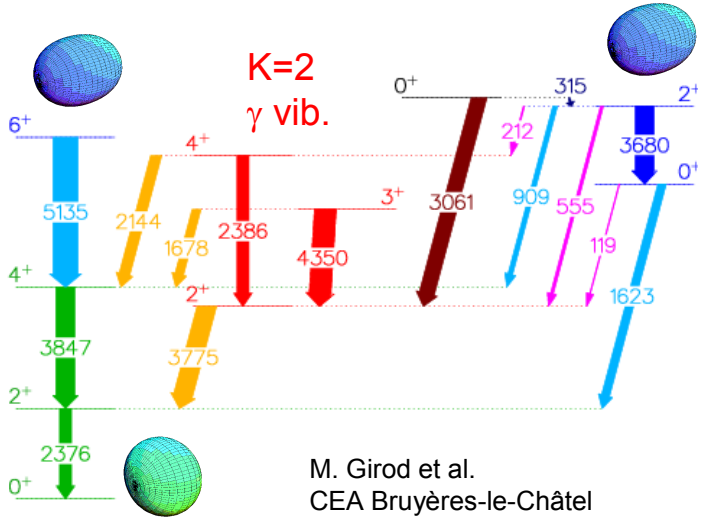


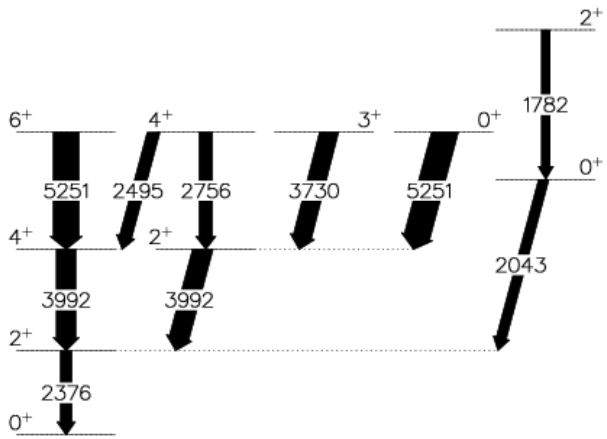
E.O. Lieder et al.
Eur. Phys. J. A 35, 135 (2008)

- **no lifetimes known at low spin**
- **only few non-yrast states from β decay studies**
- **no experimental information on the shape at low spin**

Predictions for ^{142}Gd







M. Girod et al.
CEA Bruyères-le-Châtel

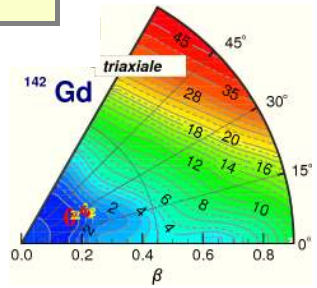
experiment

need B(E2) values and quadrupole moments to test predictions

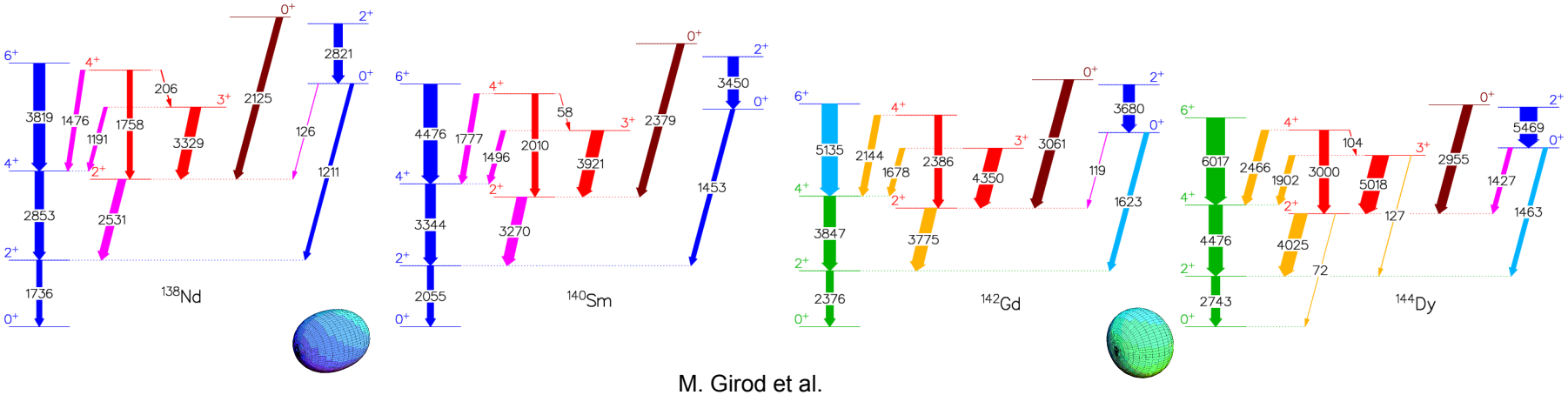
configuration mixing calculation
GCM(GOA)
5-dimensional (q_{20},q_{22},α,β,γ)
Gogny D1S interaction
parameter free

analytic solution of Bohr Hamiltonian
with square-well potential
E(5) symmetry
normalized to experimental $E_x(2^+)$
and B(E2,$2^+ \rightarrow 0^+$) from GCM(GOA)

oblate shape near ground state
transition to prolate at higher spin
γ vibration built on oblate states



Shape transitions



M. Girod et al.
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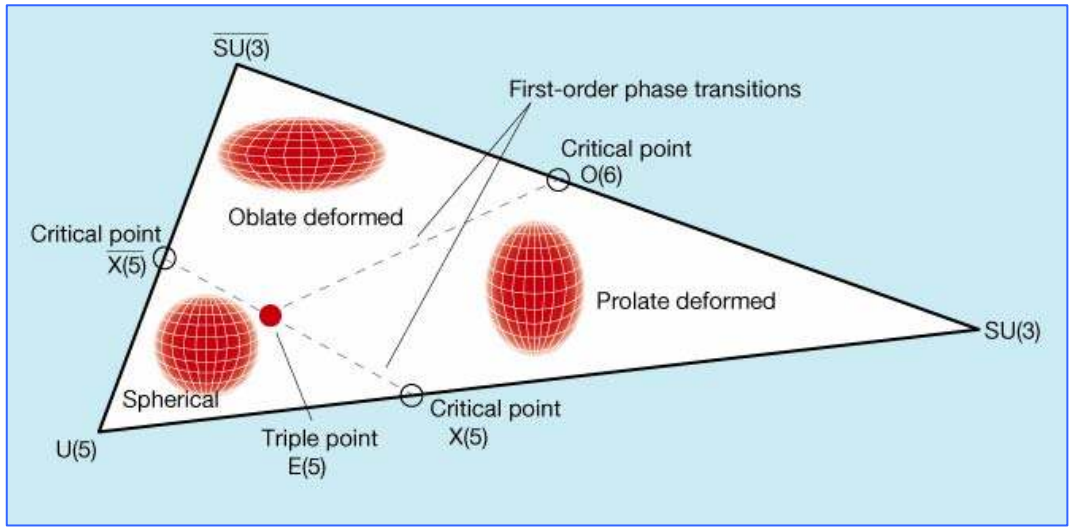
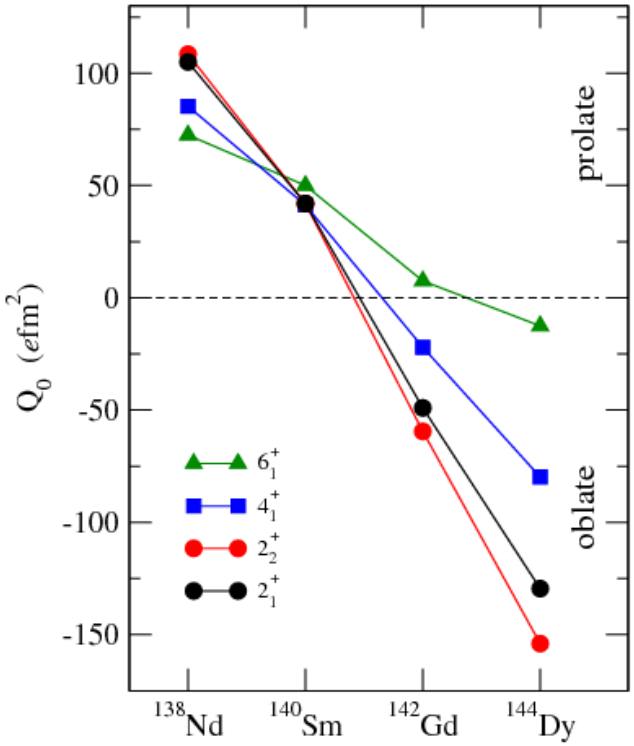
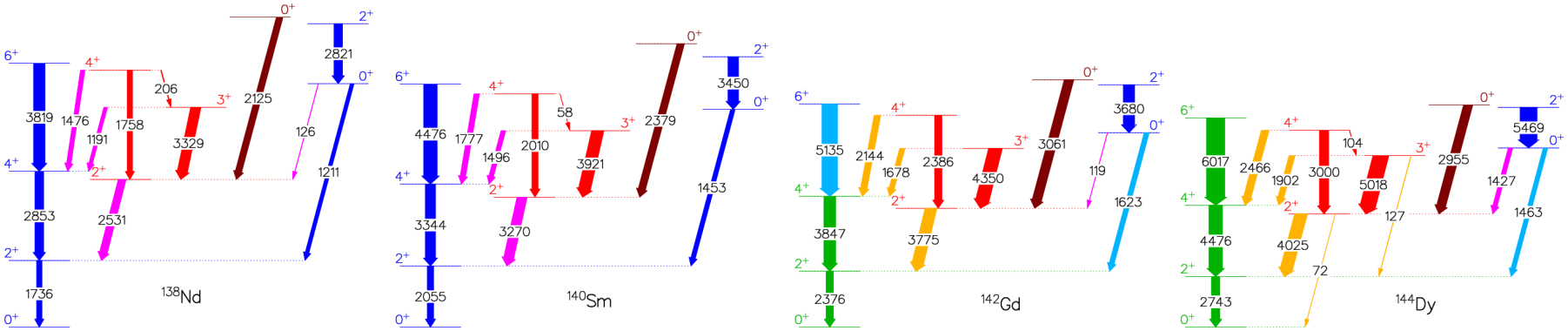




Shape coexistence ?



experiment theory

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shape transitions

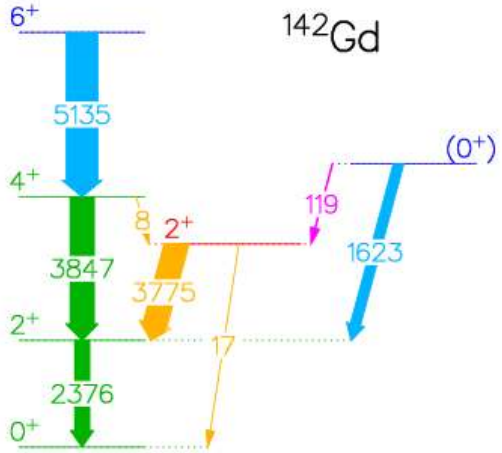
- **neutron number:** spherical (N=82) ⇒ oblate (N=78) ⇒ prolate (N<78)
- **proton number:** prolate (Nd, Sm) ⇒ oblate (Gd, Dy)
- **spin:** oblate near ground state (Gd) ⇒ prolate above 4^+ (Gd)

is there also shape coexistence ?

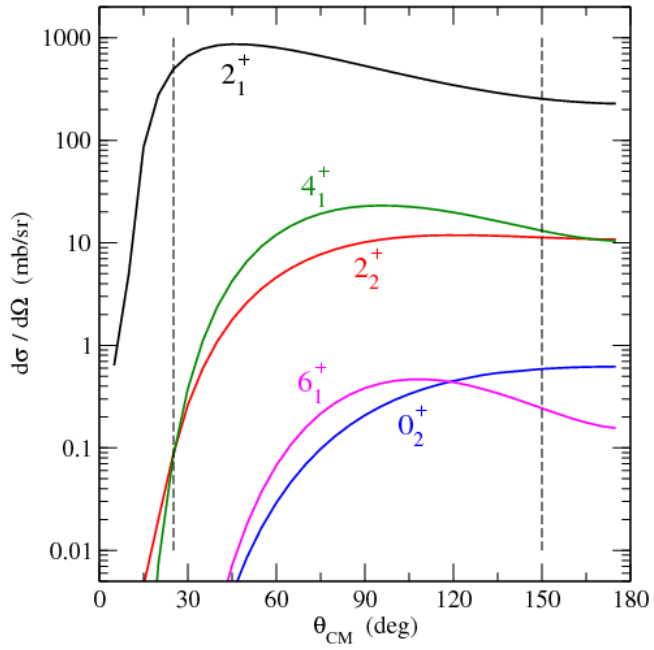
indication: low-lying 0^+ states

(tentative) 0^+ state in ^{140}Sm at 990 keV

Simulation

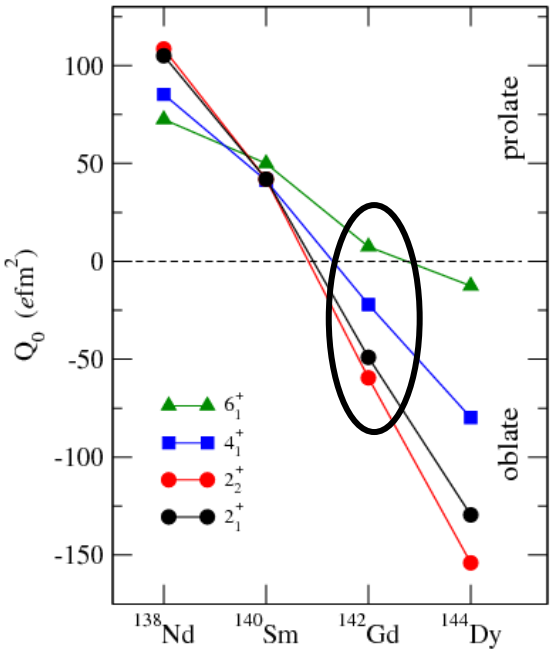


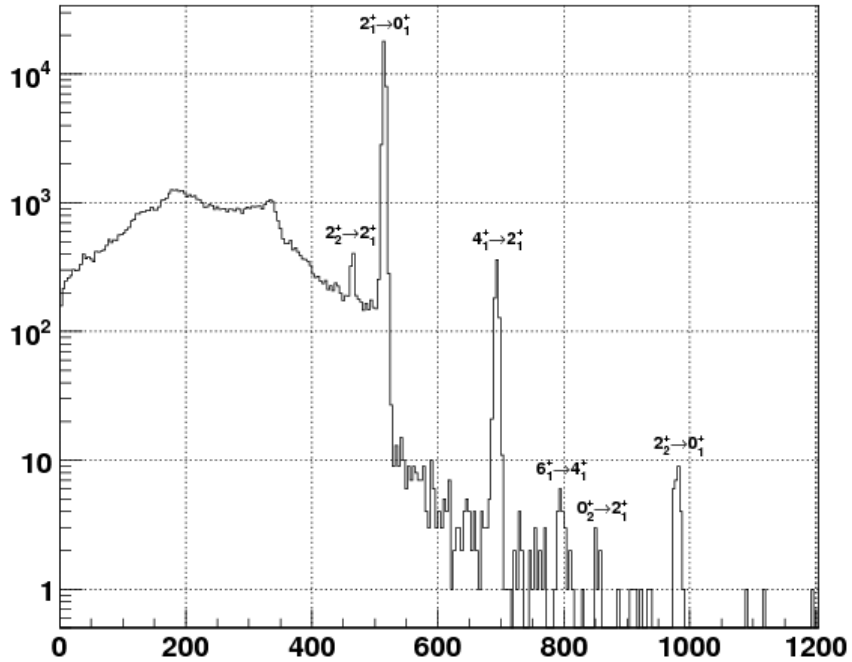
experimental level scheme
theoretical B(E2) and Q_s



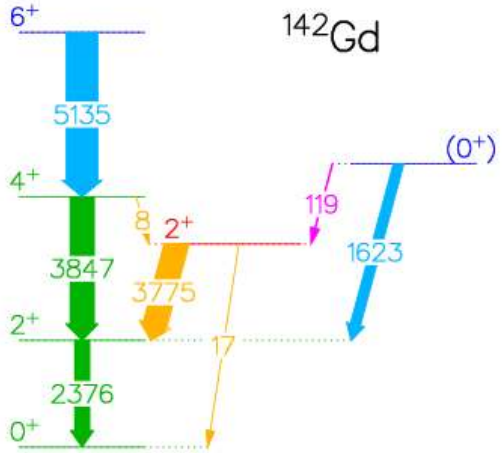
^{142}Gd + ^{208}Pb
2.9 MeV / u

2×10^4 pps
1 mg/cm^2 ^{208}Pb
15 shifts





Differential cross section



experimental level scheme
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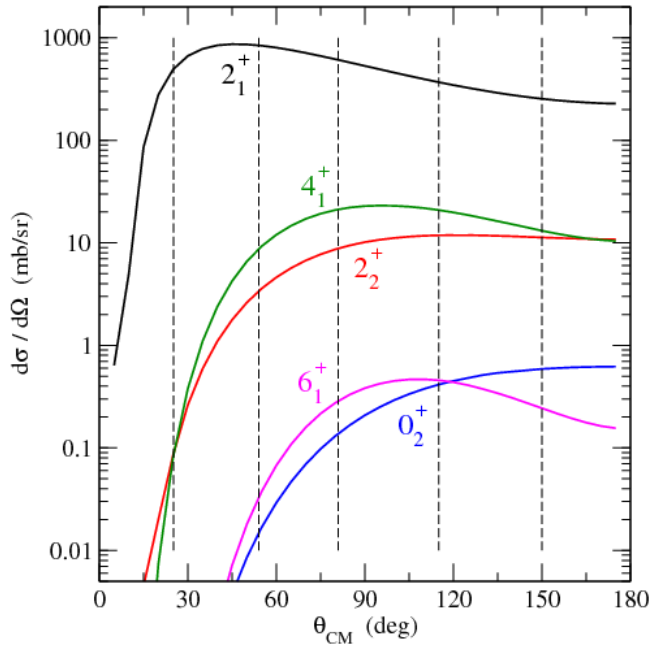

^{142}Gd + ^{208}Pb
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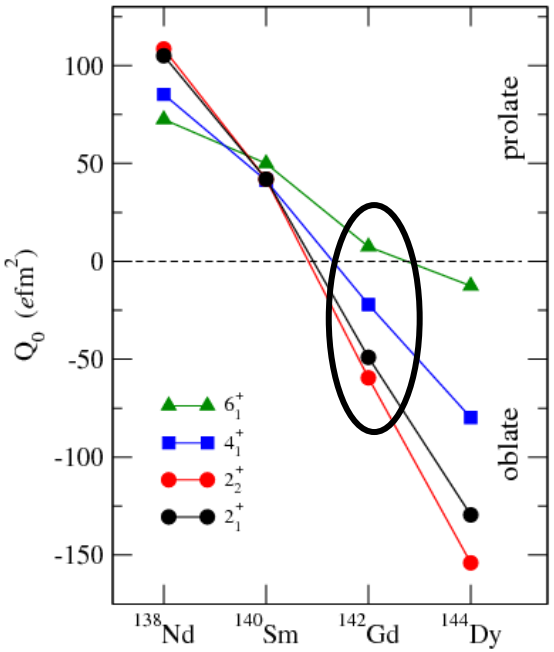
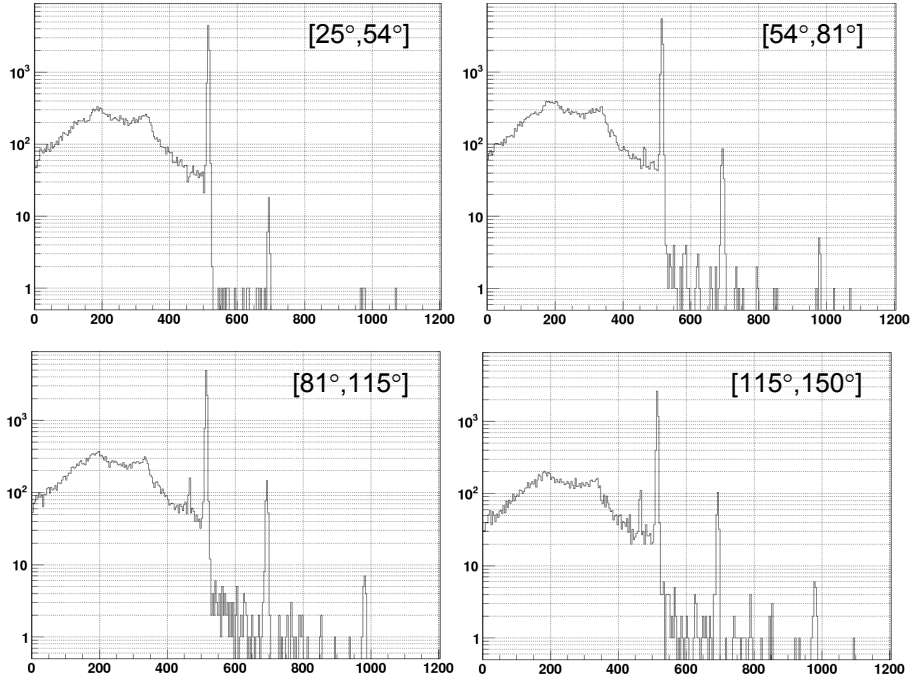
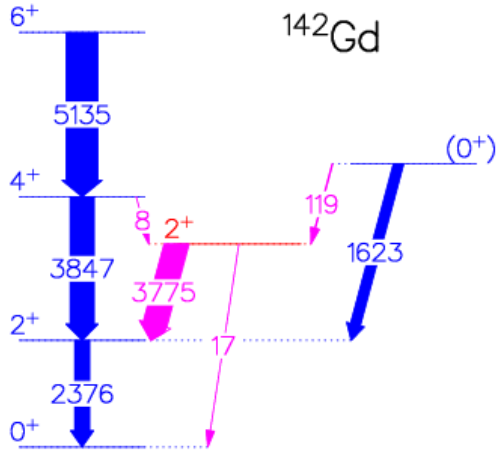
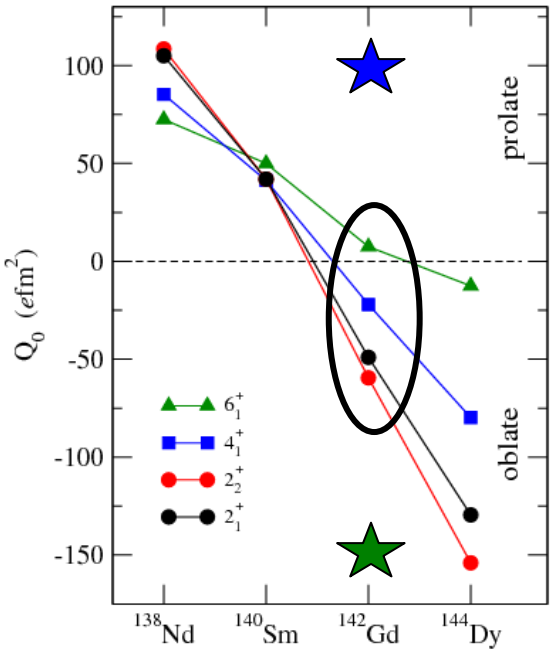


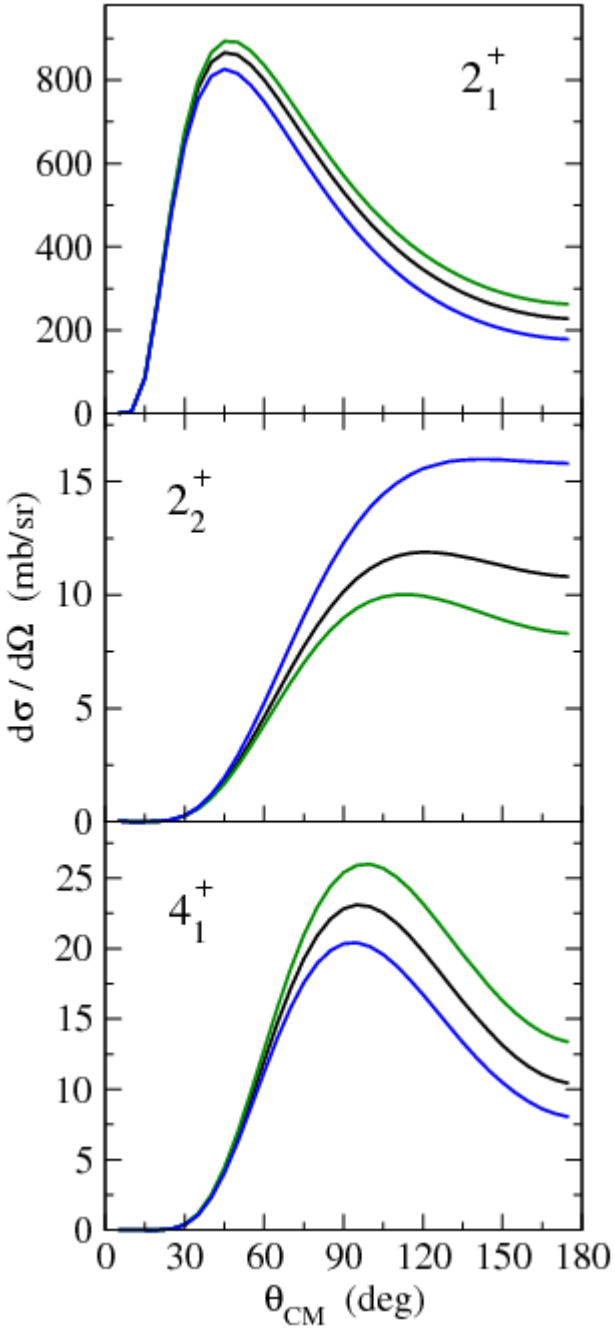


Sensitivity to quadrupole moments



experimental level scheme
theoretical B(E2) and Q_s





Proposed experiment

- REX beams at maximum energy of 2.95 MeV / u
- measured yields / realistic beam intensities
  - ^{138}Nd: ? (large) / ~10^6
  - ^{140}Sm: 2×10^8 / 4×10^5
  - ^{142}Gd: 1.2×10^6 / 2×10^4
  - ^{144}Dy: ? / ?
- RILIS to suppress isobaric contaminants crucial
- ionization schemes exist, Sm and Gd not yet tested at ISOLDE
- Coulomb excitation target: ^{206}Pb or ^{208}Pb (normalization point vs. spectrum simplicity)
- double-sided annular silicon detector and MINIBALL

^{140}Dy	^{142}Dy	^{144}Dy	^{146}Dy	^{148}Dy	66
^{138}Gd	^{140}Gd	^{142}Gd	^{144}Gd	^{146}Gd	64
^{136}Sm	^{138}Sm	^{140}Sm	^{142}Sm	^{144}Sm	62
^{134}Nd	^{136}Nd	^{138}Nd	^{140}Nd	^{142}Nd	60
^{132}Ce	^{134}Ce	^{136}Ce	^{138}Ce	^{140}Ce	58
^{130}Ba	^{132}Ba	^{134}Ba	^{136}Ba	^{138}Ba	56
74	76	78	80	82	

shape transition and coexistence predicted for N=78 isotones

- **measure quadrupole moments for 2_1^+ (2_2^+, 4_1^+) in ^{140}Sm and ^{142}Gd**
- **measure transition rates between all low-lying states**
- **identify low-lying 0^+ states**
- **extend study to ^{144}Dy and N=76 if feasible**

beam time request

- **^{140}Sm: 6+3 shifts**
- **^{142}Gd: 15+3 shifts**

testing required to determine / improve intensity and purity

Collaboration

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