Single-particle and collective excitations in transitional nuclei

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Plan of the talk :

- Physics interest in transitional nuclei
- Role of intruder orbital and triaxiality
- Experiments with INGA
  High spin band structure in Ce and Tl nuclei
- Development of collectivity towards neutron rich nuclei

Shapes and excitation in transitional nuclei

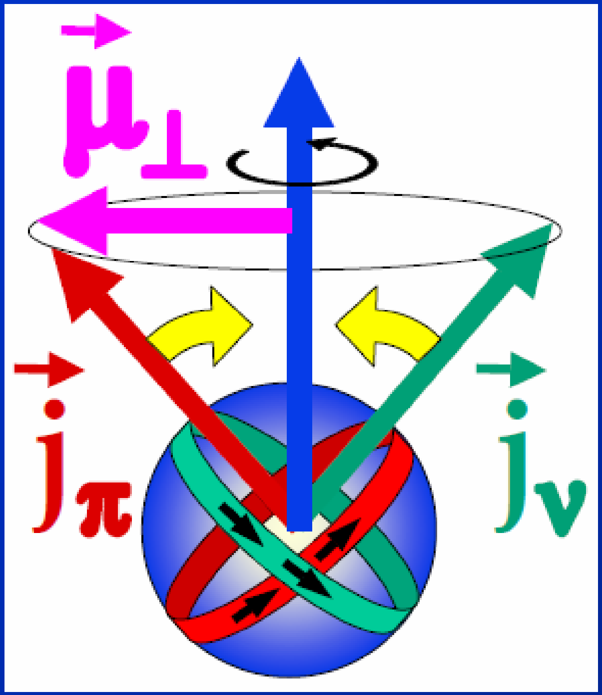
- Interplay of single particle and collective excitation

- Band structures based on multi-quasiparticle excitation

- Role of
  - intruder shape driving orbitals
  - triaxial degrees of freedom

- New modes of excitation
  - Magnetic rotation
  - Chiral bands

Rotation in weakly deformed system : MR band



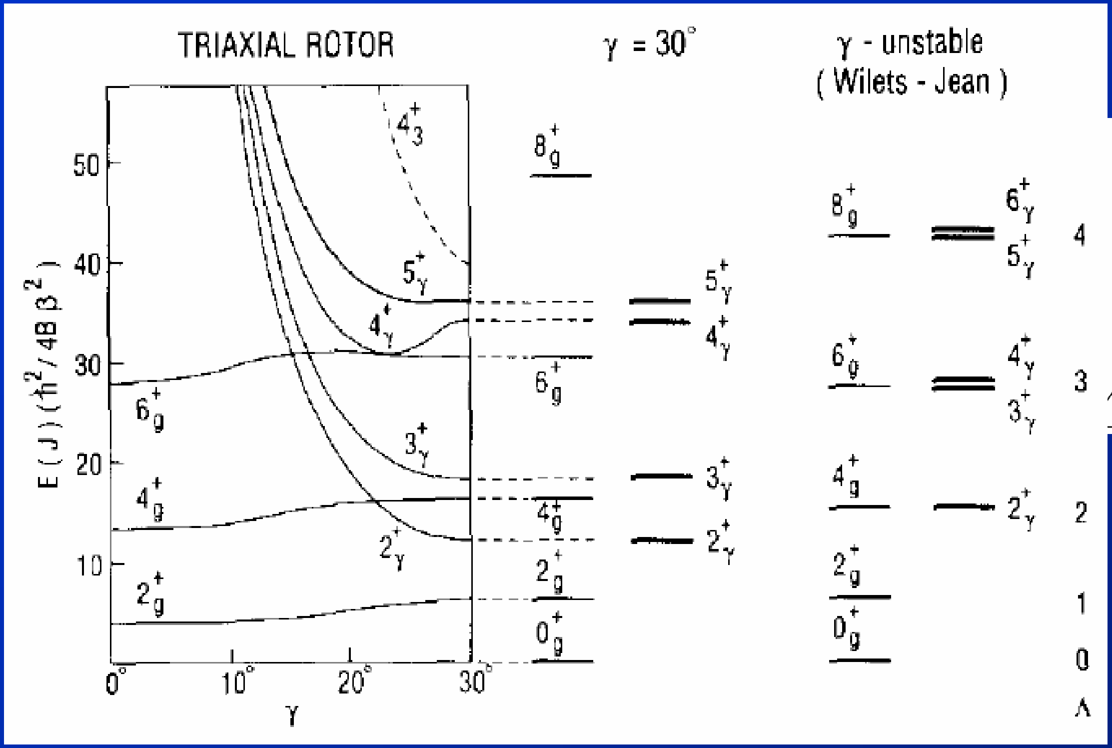
Novel way of generating angular momentum in a weakly deformed system with low quadrupole collectivity.

Tilted Axis Cranking (TAC)

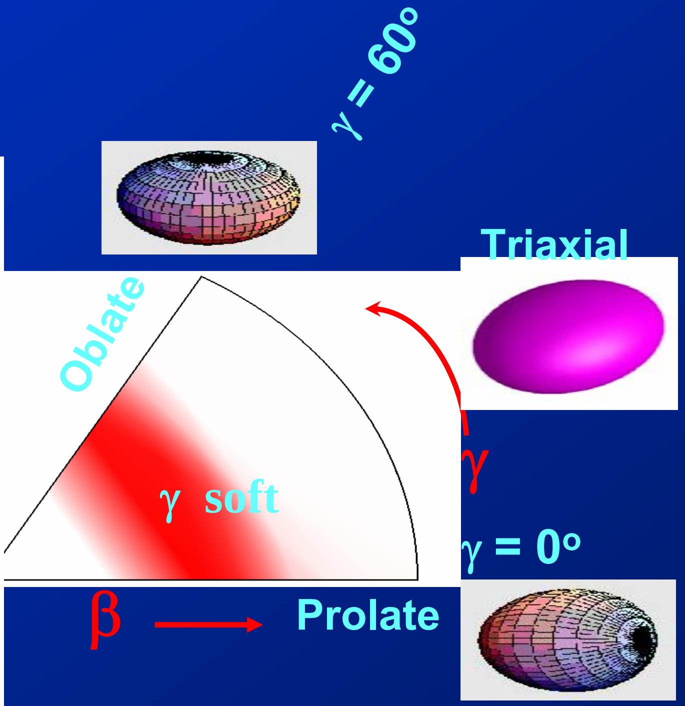
S. Frauendorf
NPA677, 115 (2000).

Very regular band structure ($\Delta I = 1$) with a few valance particles (holes) in high j orbital

Non-axial deformation → γ-soft or rigid triaxial ?



N.V. Zamfir and R.F. Casten
PLB 260, 265 (1991)



Non-axial deformation → triaxiality

Experimental manifestation

- **Signature inversion**

  explained as a manifestation of the drift of the rotation axis in the intrinsic frame when a triaxial nucleus rotates.
  - degree of triaxiality in a deformed basis

  R. Bengtsson et al., Winter meeting on Nucl. Phys. Bromino (1982)

  phase of the staggering of $S(I) = E(I) - E(I-1)$ reverses

  can as well be consistent with an axially symmetric shape

  I. Hamamoto, PLB235, 221 (1990)

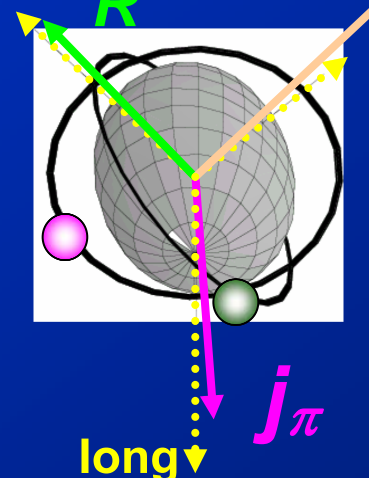
- **Wobbling excitation**

  TSD bands in ^{163,165}Lu

- **Chiral bands**

  based on the specific geometry of three components of the total angular momentum

Nuclear chirality



A Triaxial Nucleus becomes Chiral if it rotates about an axis that lies outside the three planes spanned by the principal axes of it's triaxial ellipsoidal shape.

- Two identical bands
  almost same Energy and Parity
- De-excitation of the partner bands
  in a very similar way

S. Frauendorf, J. Meng, NPA 617, 131 (1997)
S. Frauendorf, Rev. Mod. Phys 73, 463 (2001)

A~130

Odd-Odd ($\pi h_{11/2} \nu h_{11/2}^{-1}$)

^{134}Pr, ^{136}Pm, ^{130}Cs, ^{128}Cs

Odd-A ($\pi(h_{11/2})^2 \nu h_{11/2}^{-1}$)

^{135}Nd

A~105

Odd-Odd ($\pi g_{9/2}^{-1} \nu h_{11/2}$)

^{106}Ag, ^{106}Rh, ^{104}Rh, ^{102}Rh

Odd-A ($\pi g_{9/2}^{-1} \nu(h_{11/2})^2$)

^{107}Ag, ^{105}Rh, ^{103}Rh

A~190

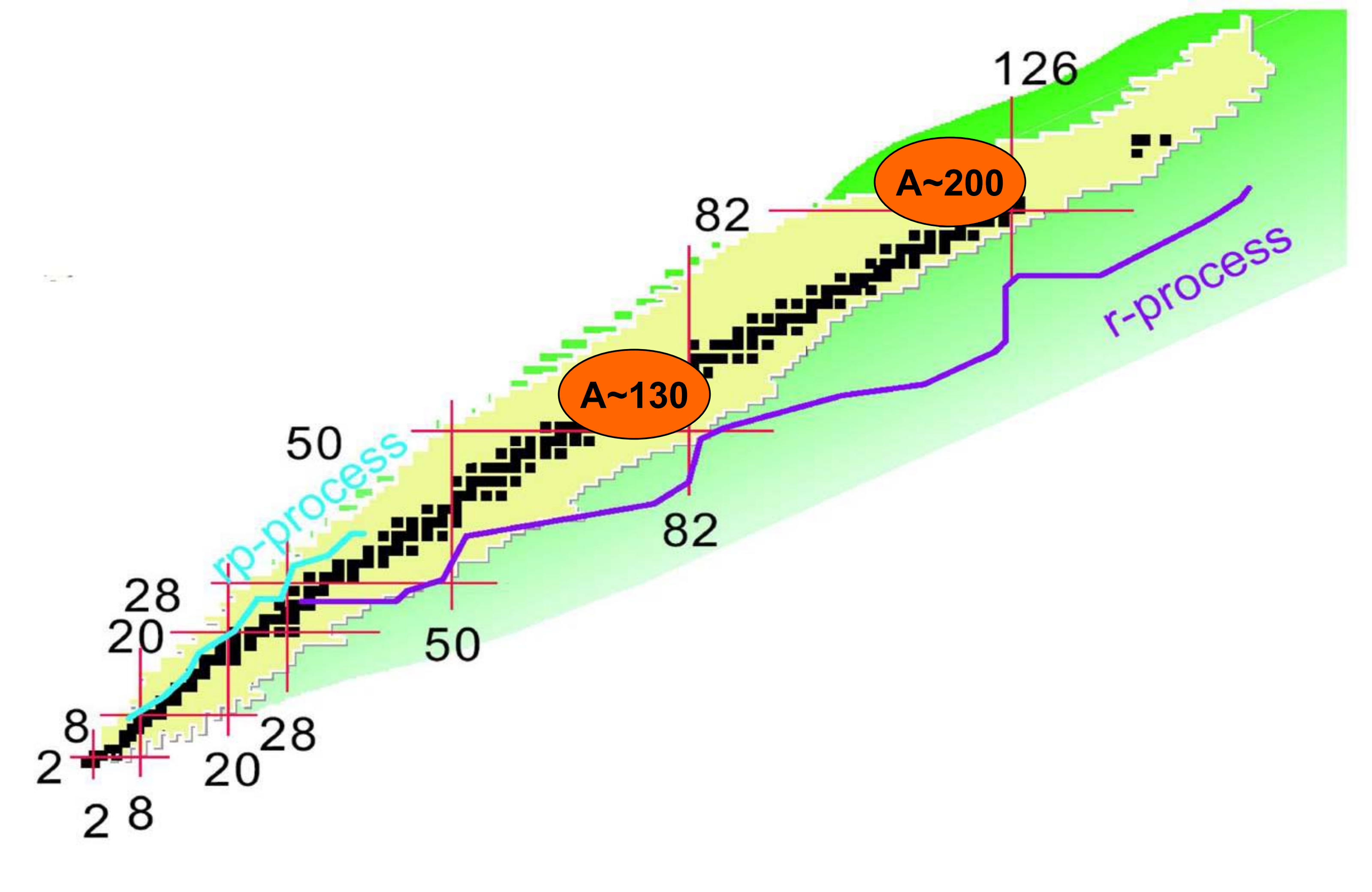
Odd-Odd ($\pi h_{9/2} \nu i_{13/2}$)

^{188}Ir (?)

^{198}Tl

T. Koike, NPA 834, 36c (2010)

Nuclei with few particles or holes around Z/N = 82

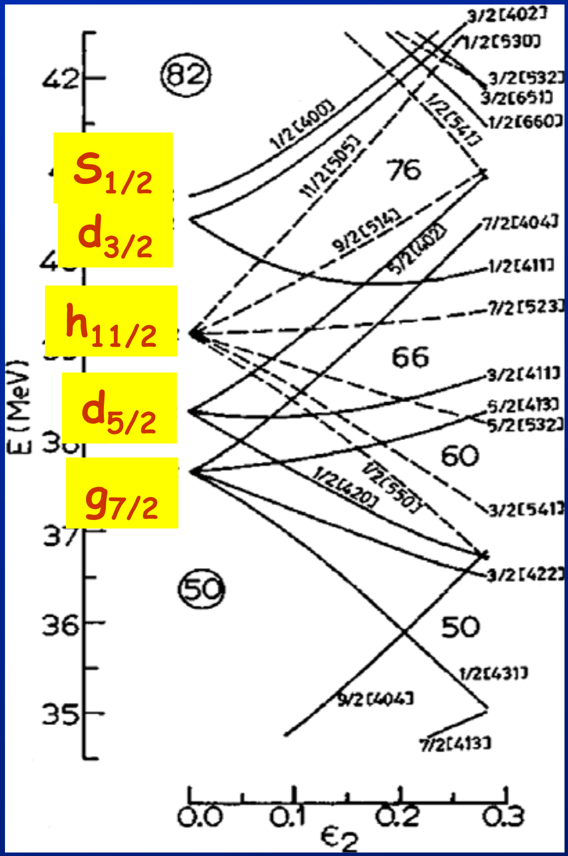


Transitional nuclei in A~130 region

- Multi-quasiparticle excitations with valance protons and neutrons
  - Shape driving effects, γ softness

- Presence of high-j $h_{11/2}$ orbital for both protons and neutrons

- Prolate driving $\pi h_{11/2}$ & Oblate driving $\nu h_{11/2}$
  - Structutre associated with $\pi h_{11/2} \otimes \nu h_{11/2}$ configuration in odd-odd nuclei



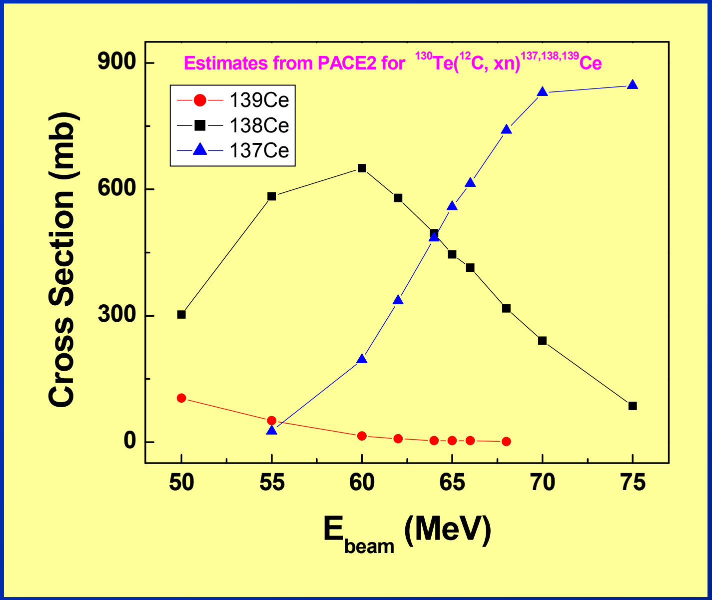
- Magnetic rotation (^{199}Pb, ^{197}Pb, ^{134}Ba, ^{134}Ce, ^{136}Ce, ^{138}Ce …..)
  triaxial bands (^{139}Nd, ^{140}Nd)
  Chiral bands (^{134}Pr, ^{130}Cs, ^{135}Nd)

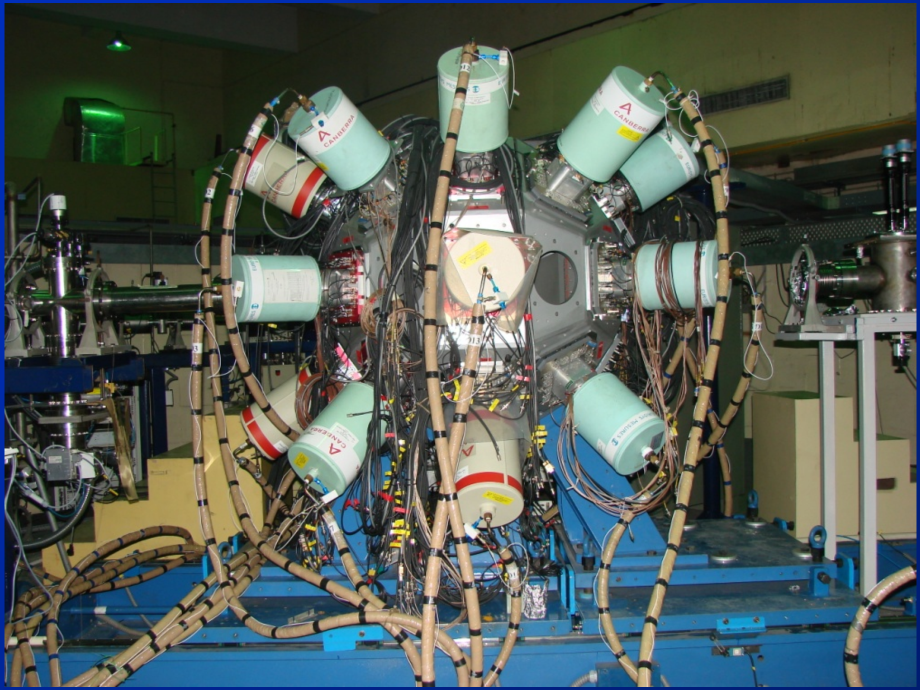
Properties of band structure in ^{138}Ce

$^{130}Te(^{12}C, xn)\ ^{137,138}Ce$

E_{beam}: 63 MeV

0.8 mg/cm² ^{130}Te on
4.8 g/cm² Au backing





18 Clover Ge
Indian National Gamma Array
@ IUAC, New Delhi

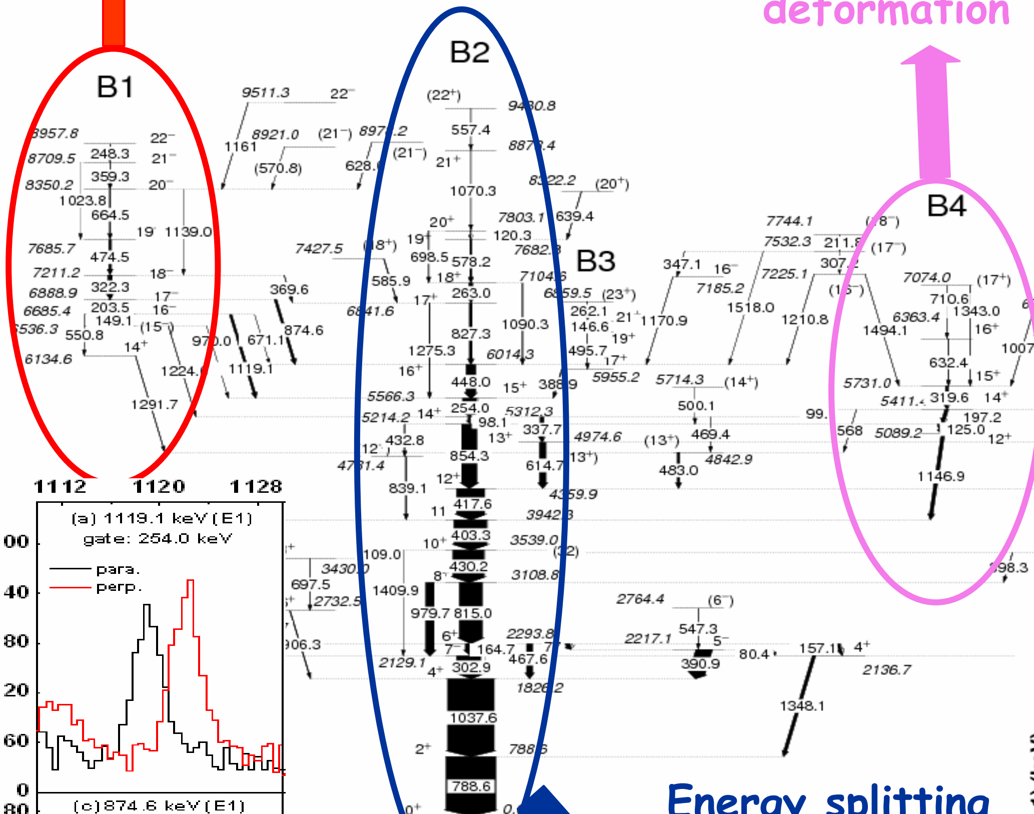
Level structure of ^{138}Ce

Shears band : $(\pi h_{11/2} g_{7/2}) \otimes (\nu h_{11/2}^{-2})$

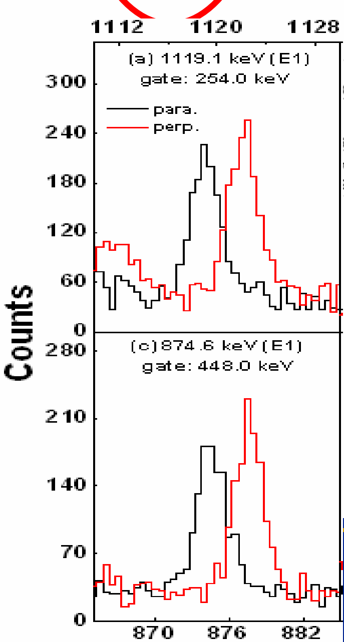
Four quasi particle structure; oblate deformation

^{138}Ce

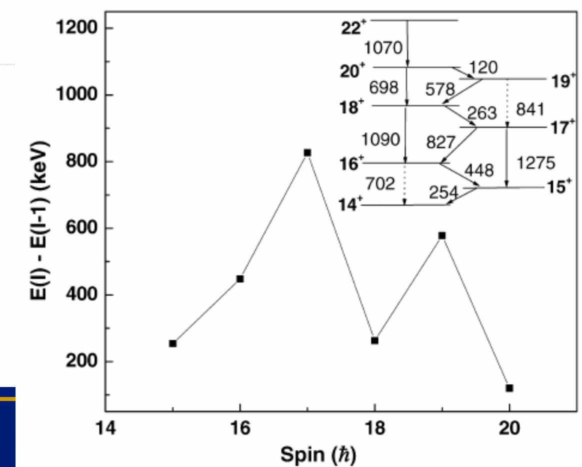
T. Bhattacharjee et al., NPA 825, 16 (2009)



Yrast band



Energy splitting above 14+ →



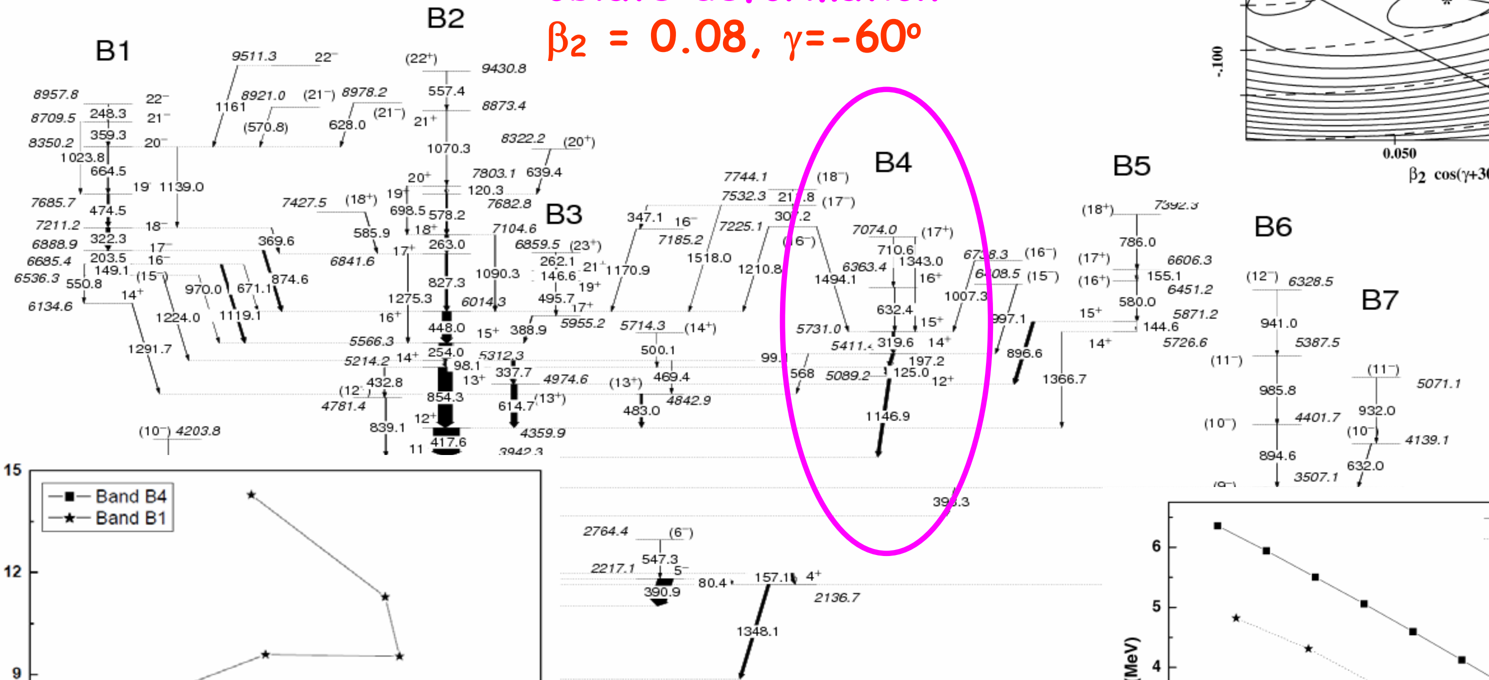
Multi-quasiparticle band in ^{138}Ce

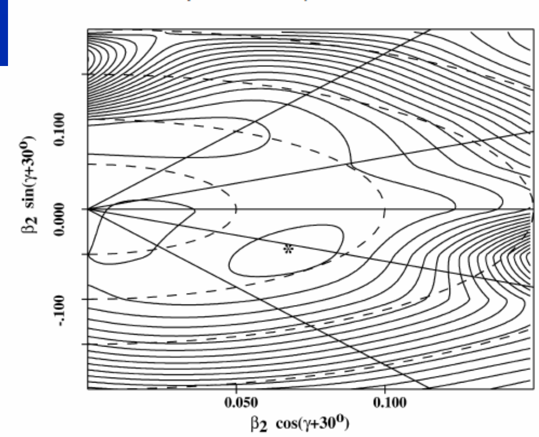
Four quasi particle structure

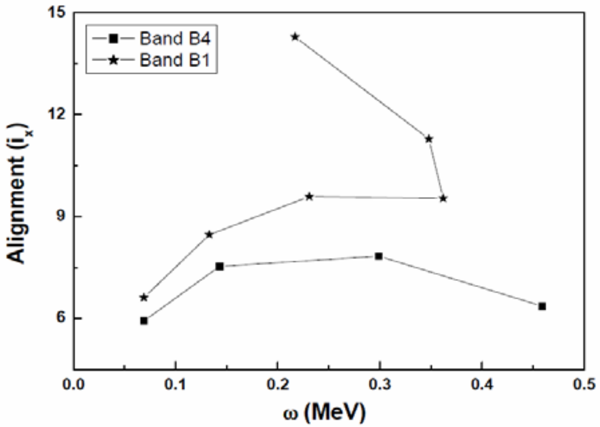
$\pi d_{5/2}\, g_{7/2} \otimes \nu h^{-1}_{11/2}\, \nu d^{-1}_{11/2}$

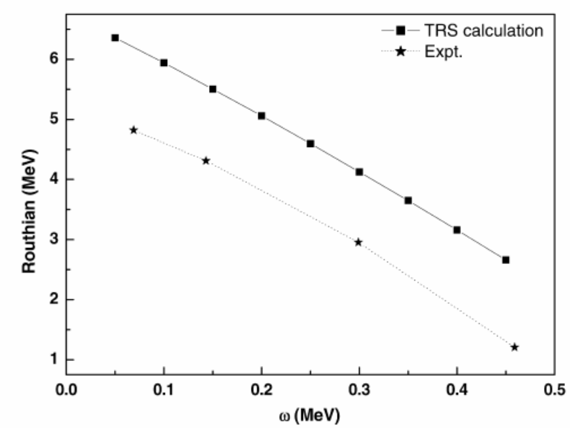
oblate deformation :

β_2 = 0.08, γ=-60°









Heavier rare earth nuclei in A~190-200

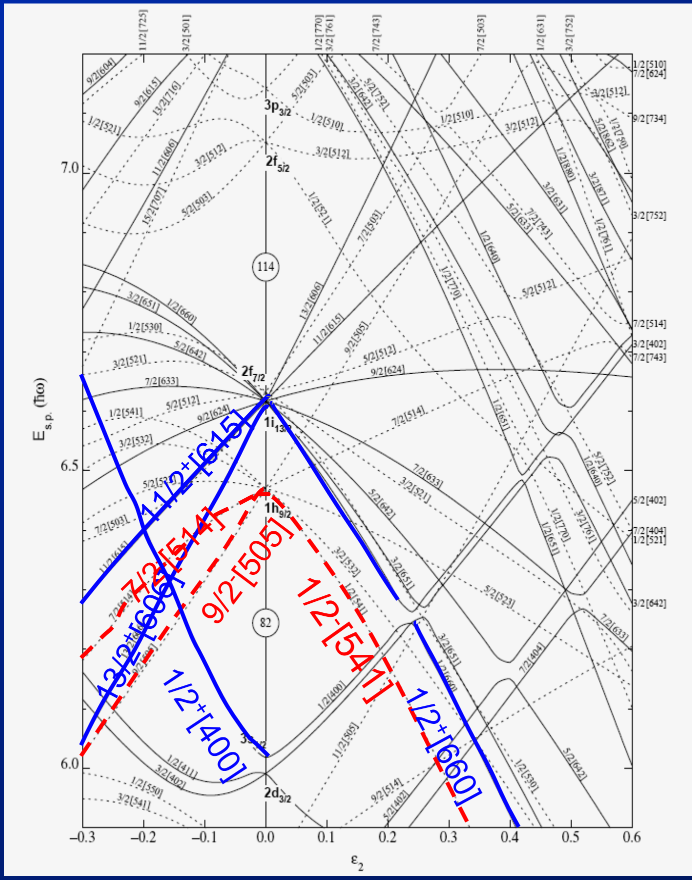
- Role of low-Ω $\pi h_{9/2}$ orbital to generate the band structure
  - similar as the $h_{11/2}$ states for lighter rare-earth nuclei.

- Rotational bands built on the intruder states $i_{13/2}$ at higher spin.

- The ground state of odd-A Tl nuclei are $1/2^+$
  → occupation of the unpaired proton in the $3s_{1/2}$ orbital below the Z = 82.

- $\pi h_{9/2}$ orbital above the Z = 82 shell closure, is accessible by the odd-proton in Tl nuclei for oblate deformation.

- For heavy Tl isotopes, the neutron numbers favor the oblate deformation as they occupy the upper part of the $i_{13/2}$ orbital.

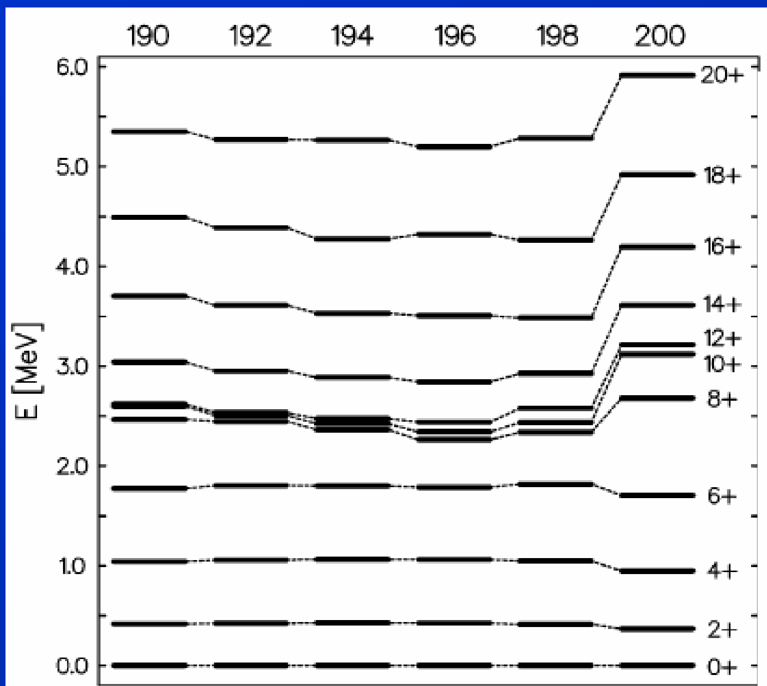


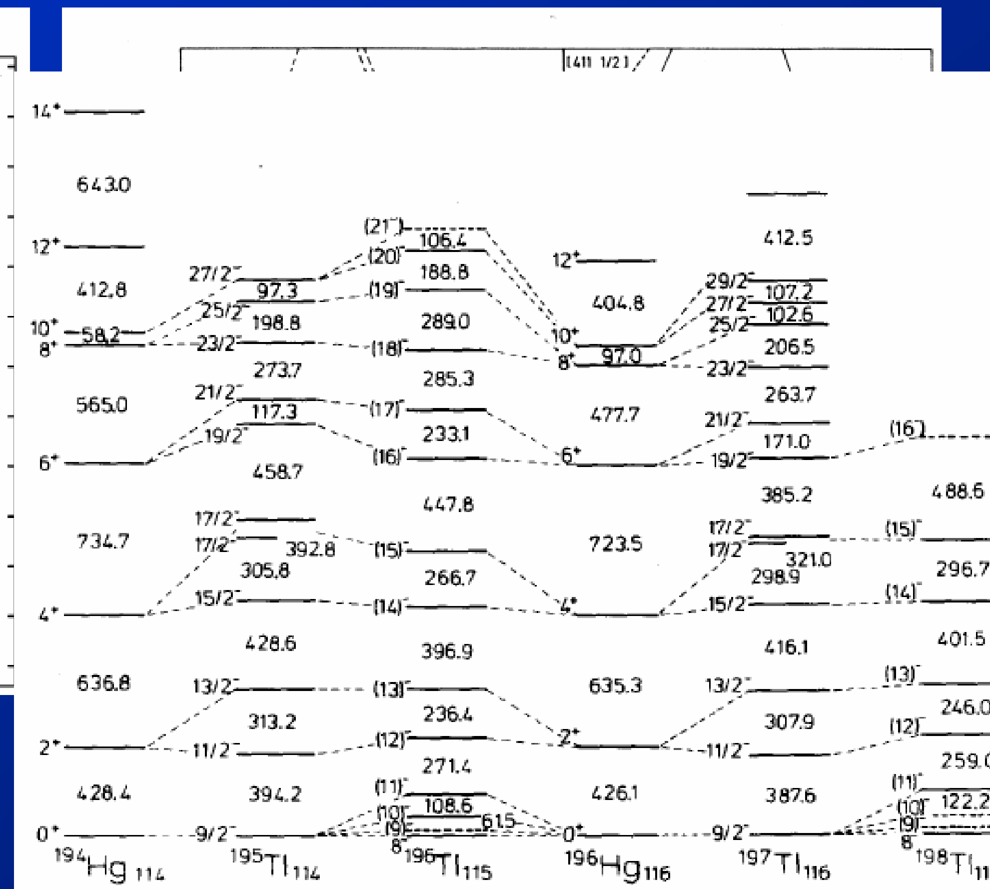
Protons

ANUP ICTS

Core (Hg) systematics

Even Hg isotopes

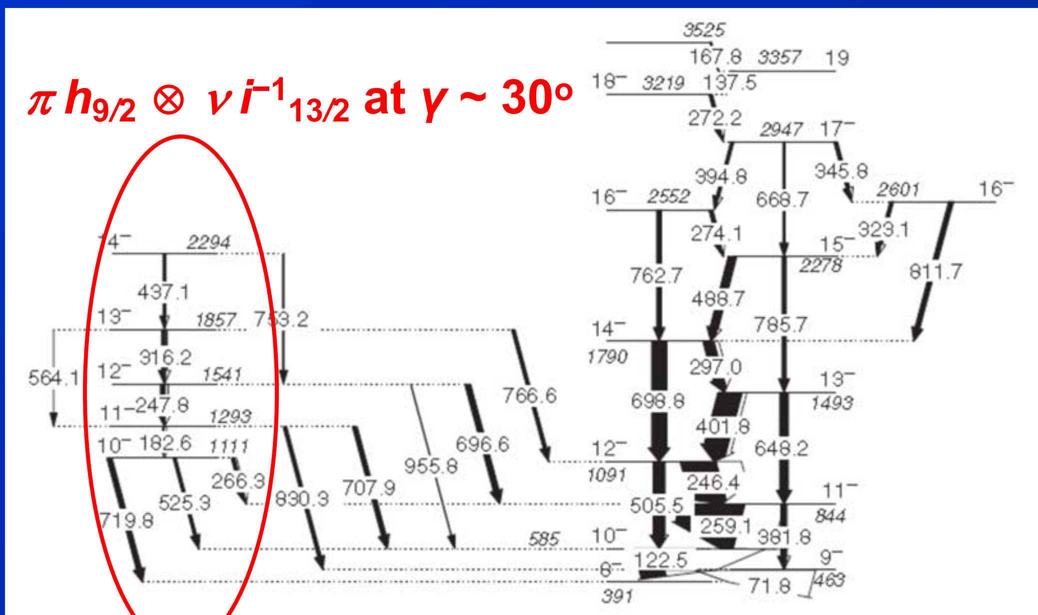


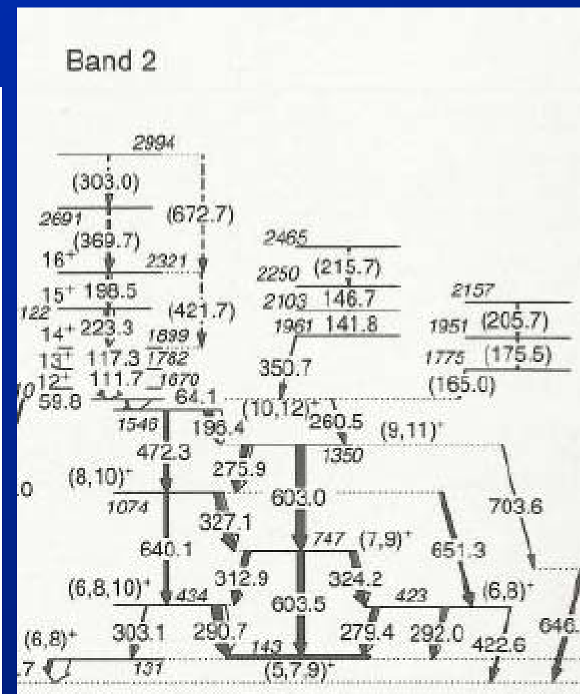


Possible chirality in the doubly-odd ^{198}Tl

E. A. Lawrie *et al.*,
PRC 78, 021305(R) (2008)

$\pi h_{9/2} \otimes \nu i^{-1}_{13/2}$ at $\gamma \sim 30^o$





$\pi h_{9/2} \otimes \nu i^{-1}_{13/2}$
at $\beta \sim$ -0.15

Four quasiparticle structure
$\pi h_{9/2} \otimes \nu i^{-2}_{13/2}\ \nu j$ (j=$p_{3/2}$, $f_{5/2}$, $p_{1/2}$)

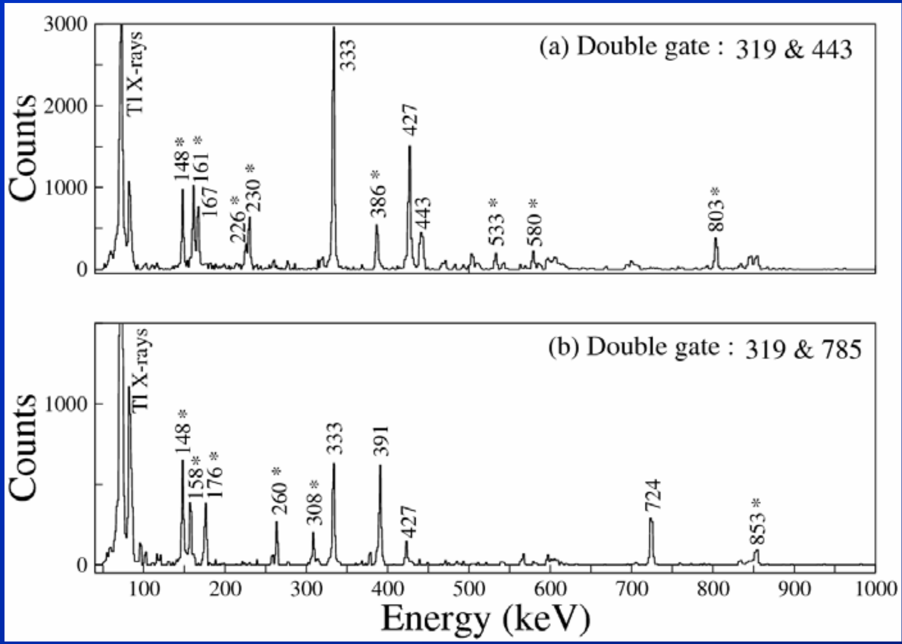
High spin structure of ^{200}Tl, ^{201}Tl

^{198}Pt(^{7}Li, xn) ^{200,201}Tl

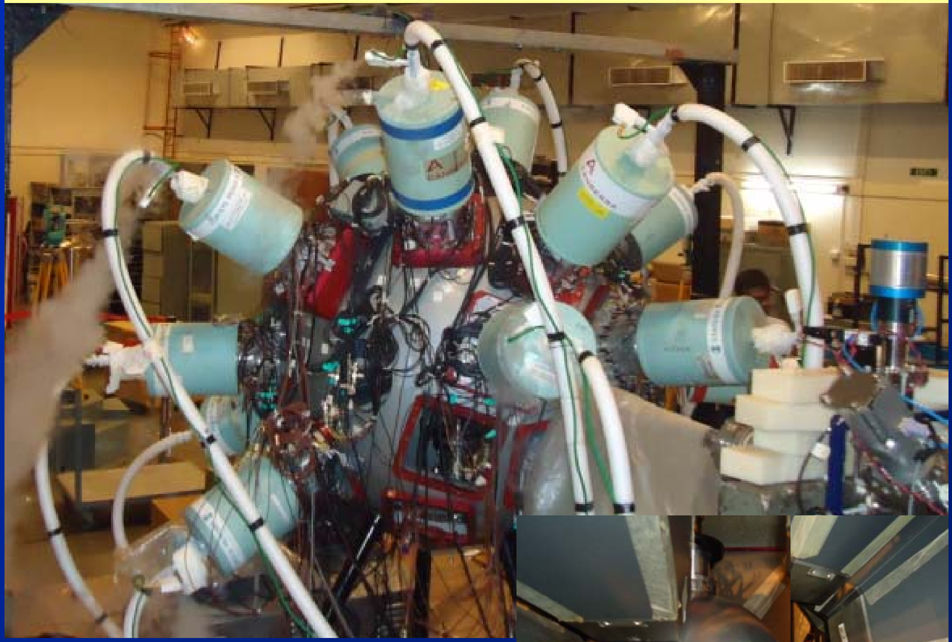
E_{beam}: 45 MeV

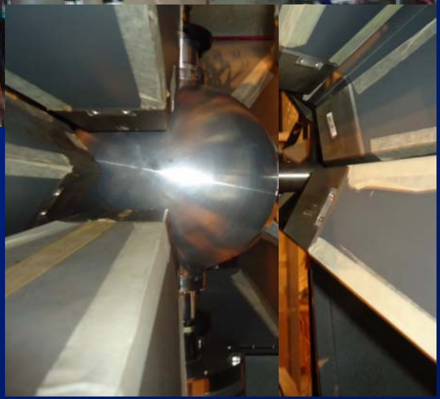
^{198}Pt (alpha, xn) ^{199,201}Hg

From incomplete fusion



15 Clover Ge detectors INGA @TIFR



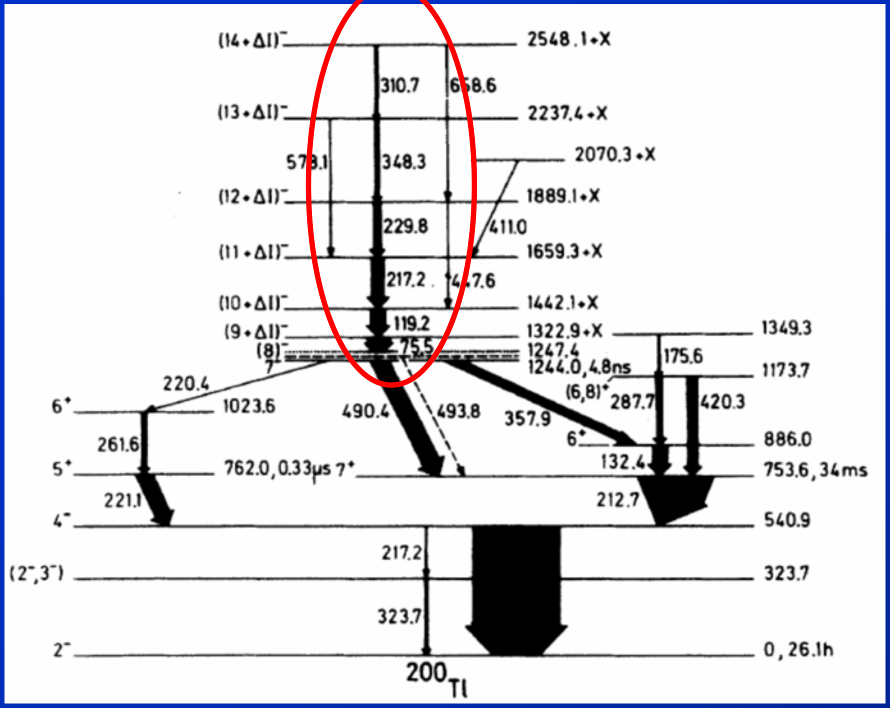


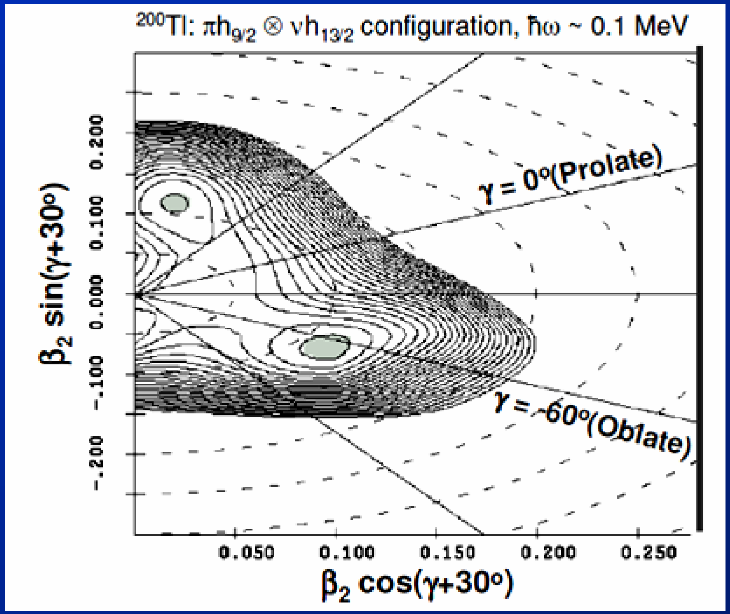
Trigger :

γ-γ at Clover level

Digital DAQ

Band structure of ^{200}Tl





$\pi h_{9/2} \otimes \nu i_{13/2}$

A.J. Kreiner et al
PRC 23, 748 (1981)

Two minima with similar deformation of β_2 = 0.12

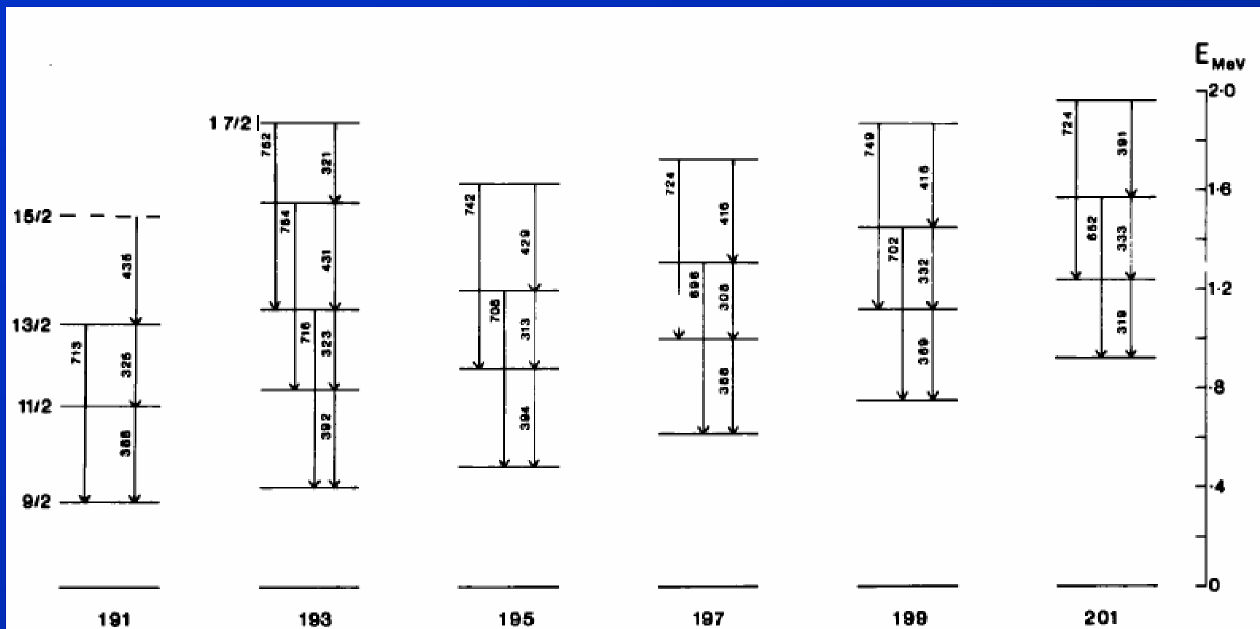
at near oblate shape (γ = -64°)

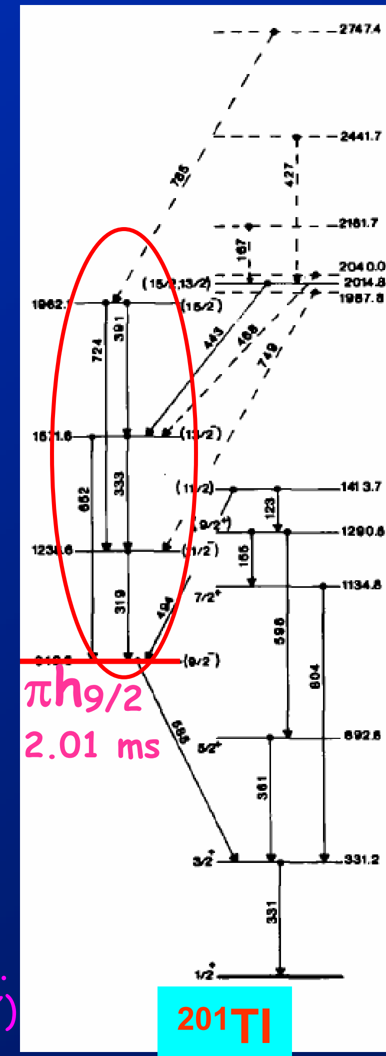
→ an oblate deformation for the yrast band

at triaxial shape (γ = 48°)

→ possibility to observe Chiral structure

^{201}Tl : states above $h_{9/2}$ isomer





M.G. Slocombe et al.
NPA 275, 166 (1977)

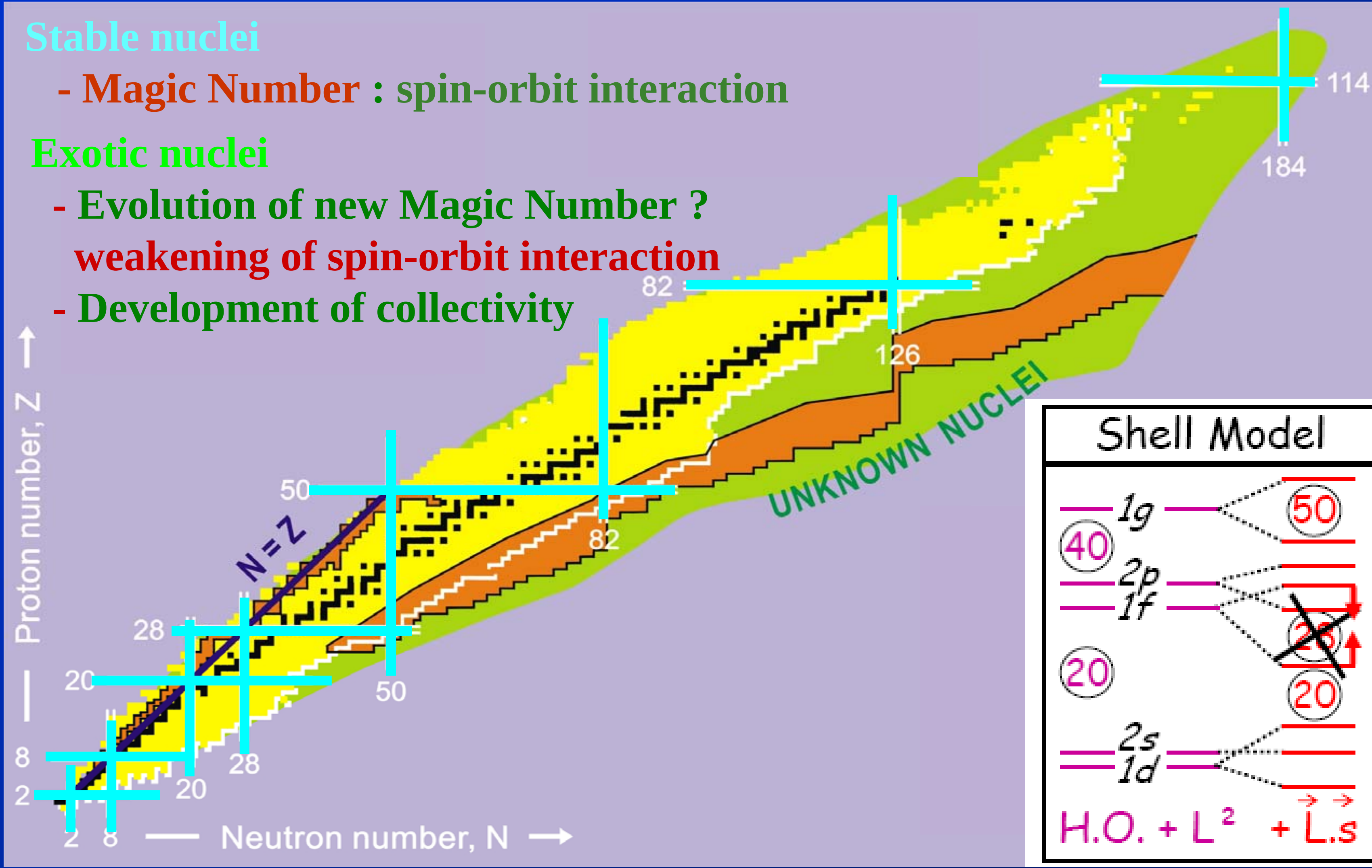
What is happening away from stability ?

Stable nuclei

- **Magic Number : spin-orbit interaction**

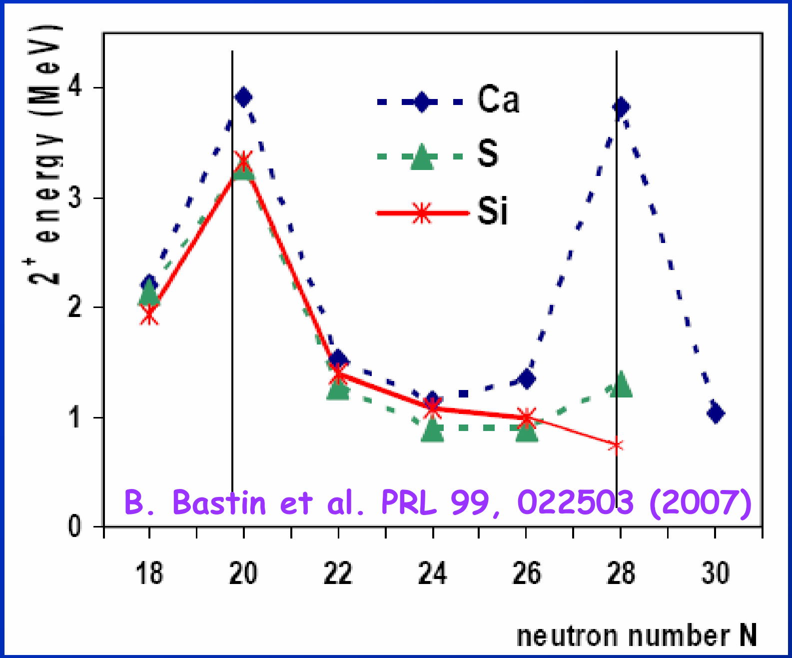
Exotic nuclei

- **Evolution of new Magic Number ?**
  weakening of spin-orbit interaction
- **Development of collectivity**



New region of deformation near N=28

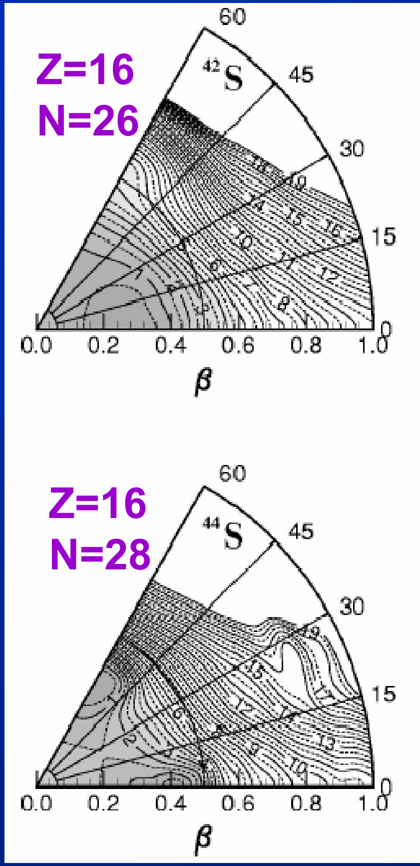
Breakdown of N=28 shell gap at Z=14



→ high collectivity

→ strong deformation ($\beta=0.45$)

→ no magicity



γ-soft

D. Sohler *et al.*
PRC 66, 054302 (2002)

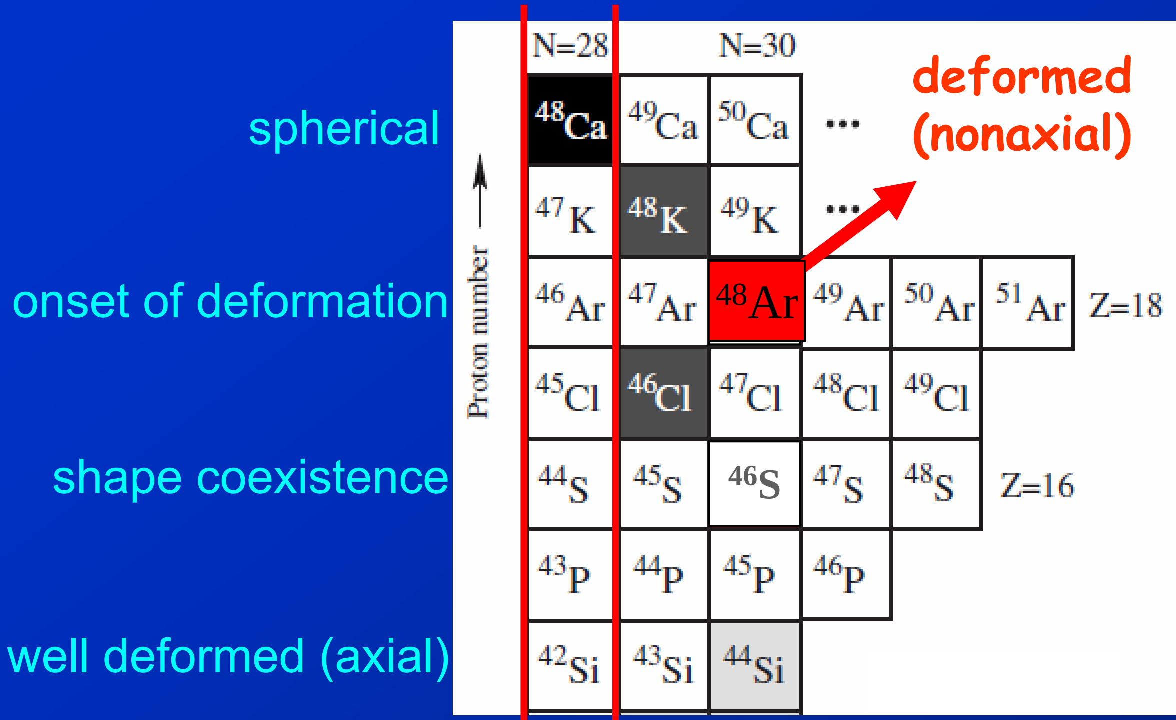
Shape mixing in low energy states

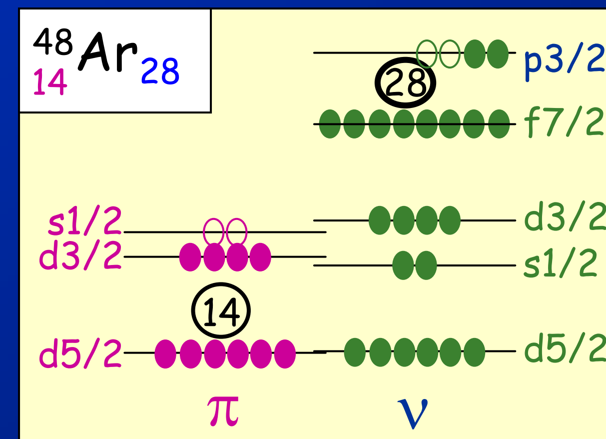
Coexistence of 1p-1h and 2p-2h Configuration

D. Santiago-Gonzalez et al
PRC, 83, 061305(R) (2011)

Erosion of N=28 shell closure at Z=16

Development of collectivity near N=28



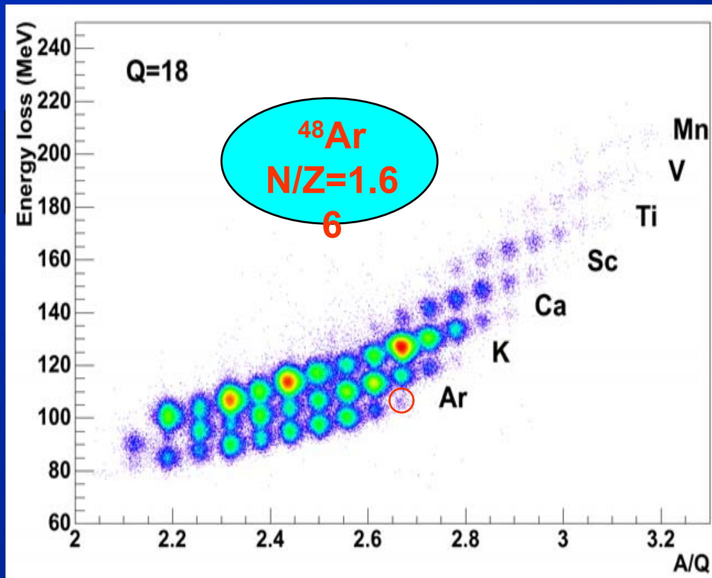


- ✓ Strong presence of N_{ph} excitations from ν$f_{7/2}$ orbital
- ✓ Role of neutron proton correlation on collective motion
- ✓ Strong quadrupole interaction between Protons in sd and neutrons in pf
- ✓ Rapid development of collectivity

Deep inelastic reaction in inverse kinematics @GANIL

^{238}U @ 5.5 MeV/u
(N/Z=1.58)
~ 12% above barrier

^{48}Ca (1 mg/cm^2)
(N/Z=1.4)



11 Nos. segmented Clover detectors
High v/c (~ 14%) of fragments

Accurate Doppler correction is must !!

Determination of Angle event by event

Velocity of fragment (VAMOS Reconstruction)

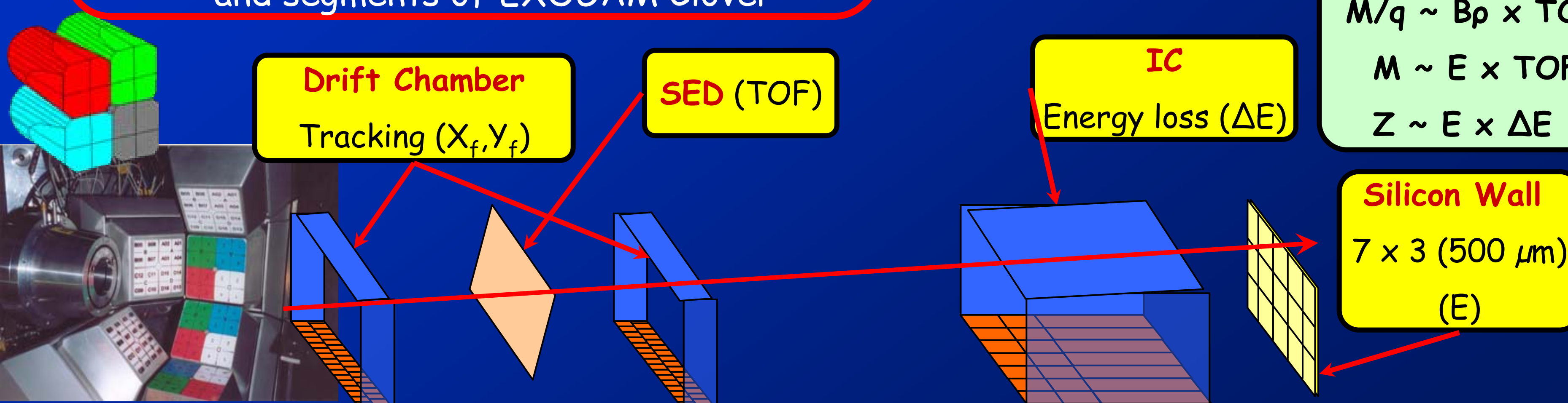
and segments of EXOGAM Clover

Identification

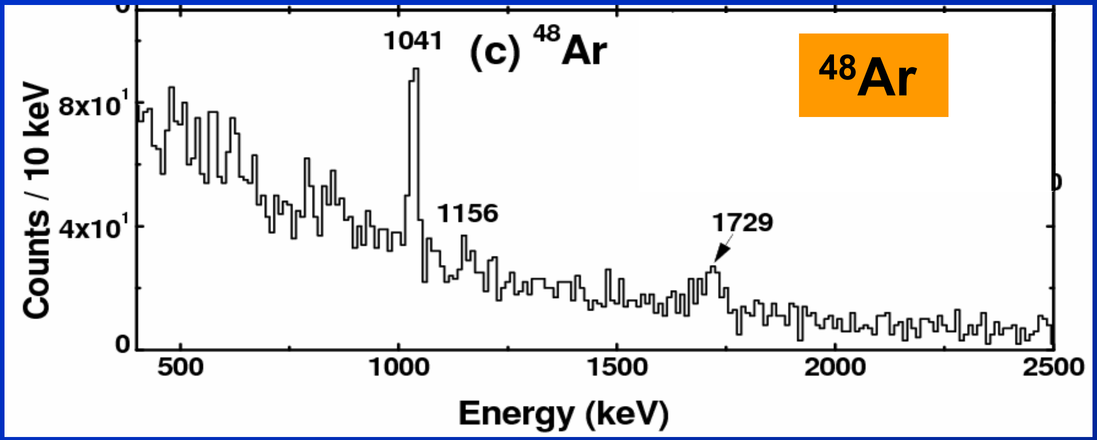
M/q ~ Bρ x TOF

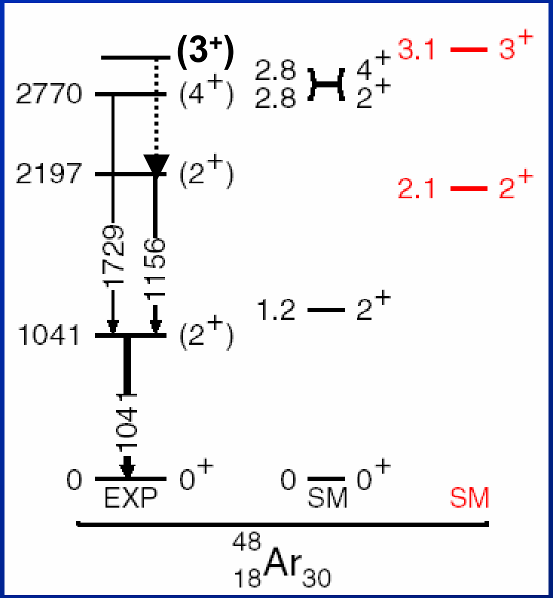
M ~ E x TOF^2

Z ~ E x ΔE



Signature of triaxiality in ^{48}Ar





Signature of triaxiality :

$E(2^+_2)/E(2^+_1) = 2.1$

$E(4^+_1)/E(2^+_1) = 2.6$

Agreement with Davydov and Filipov

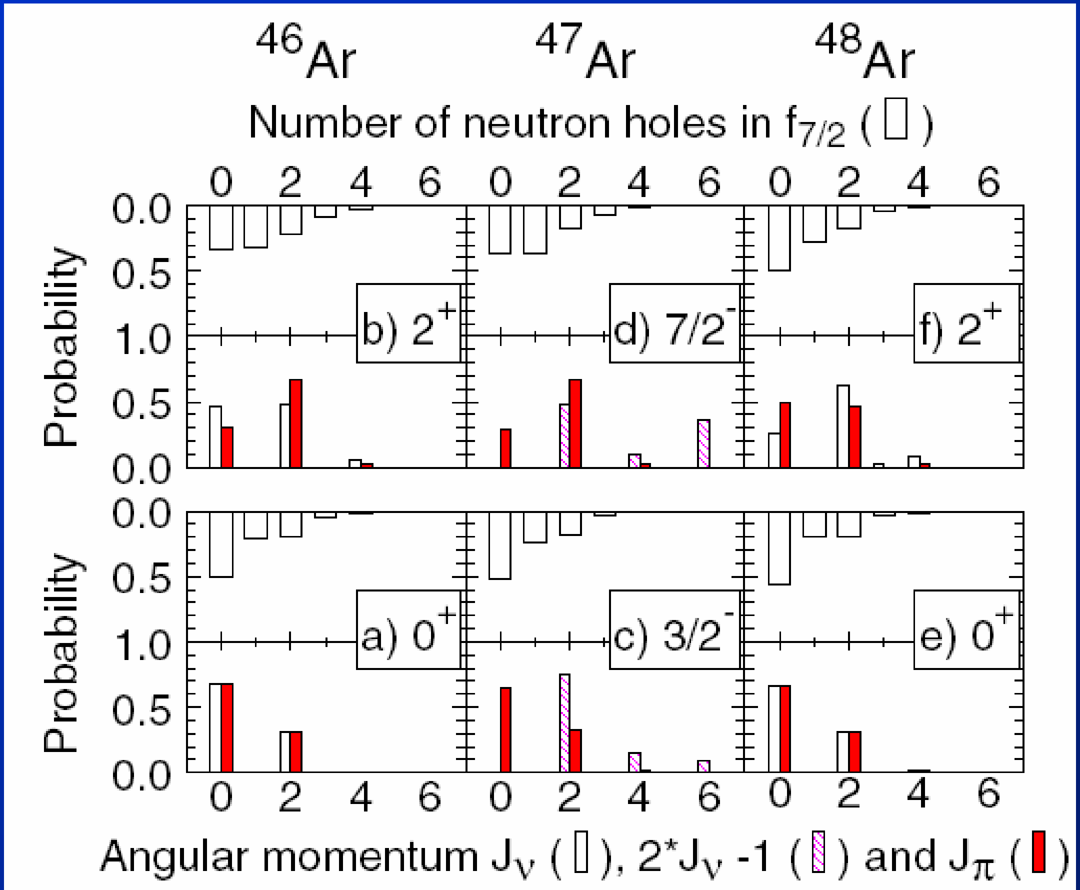
Appearance of a low lying γ-band

Deviation from axial symmetry

$\beta=0.25,\ \gamma=40^o$

S. Bhattacharyya et al., PRL 101, 032501 (2008)

Properties of calculated states



Summary and conclusion

- ✓ Transitional nuclei in A~130 and A~200
- ✓ Role of
  - shape driving intruder orbitals
  - triaxial degrees of freedom
- ✓ Magnetic Rotation and multi-quasiparticle bands in ^{138}Ce
- ✓ High spin spectroscopy of $^{200,201}Tl$
- ✓ Development of collectivity near N=28 for neutron rich nuclei

Collaboration

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