Study of exotic excitations in nuclei near spherical and deformed shell gaps using INGA

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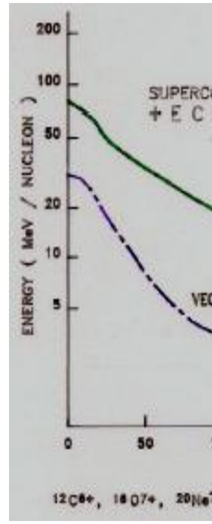
Shapes and Symmetries in Nuclei: from Experiment to Theory (SSNET'18)
CNRS campus ,Gif-sur-Yvette, France. November 5 - 9, 2018

Variable Energy Cyclotron Centre

- Accelerator based experimental research
  nuclear and material science
- Nuclear Data Evaluation
- Experimental high energy physics
- Theoretical nuclear and particle physics

Accelerators at VECC

p, d, α, HI (^{16}O, ^{20}Ne, ^{36}Ar)



K-130 is th
the Nucle

Medical Cyclotron (Cyclone-30)

- 30 MeV proton cyclotron (500 μA)
- 5 beam lines: 3 for isotope production
- Isotopes: ^{18}F, ^{67}Ga, ^{201}Tl,...
- SPECT and PET facilities

Nuclear Data Services

Section Données Nucléaires, AIEA

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E-mails

- Daniel Abriola
- Balraj Singh
- Daniel Cano
- Iris Dillmann
- Alejandro Sonzogni
- Bernd Pfeiffer
- José L. Tain
- Ivan Borzov
- Alan Chen
- Paul Garrett
- Giuseppe Lorusso
- Krzysztof Rykaczewski
- Michael Birch
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All E-mails

- Mail to All

Links

- IAEA Nuclear Data Services
- IAEA Nuclear Data Section
- DDEP Homepage
- Meeting Homepage

New IAEA CRP on Beta-Delayed Neutron Emission Evaluation

Project Officer: Daniel Abriola   Secondary Officer: Paraskevi Demetriou

INFORMATION ON THIS WEB PAGE IS FOR EXCLUSIVE USE BY Beta-delayed neutron meeting PARTICIPANTS. THE DATA FROM THIS WEB PAGE SHOULD NOT BE QUOTED OR USED WITHOUT THE EXPLICIT CONSENT OF THE CONTRIBUTING AUTHOR.

We are pleased to announce that a new Coordinated Research Project on a "Reference Database for Beta-Delayed Neutron Emission" has been approved by the IAEA.

CRP Objective

The overall CRP Objective is to enhance Member States' (MS) knowledge and calculational capabilities in the fields of nuclear energy, safeguards, used fuel and waste management and nuclear sciences by creating a Reference Database for Beta-Delayed Neutron Emission that contains both a compilation of existing data and recommended data, which will be made readily available to the user community. The project is due to start in 2013 and is envisioned to have a length of 5 years.

Specific Research Objectives

- Compile the existing beta-delayed neutron data, in particular half-lives, neutron emission probabilities and neutron spectra for individual precursors
- Produce a priority list for evaluations and new measurements
- Define and document the evaluation methodology and the "Standards" for delayed neutron emission in different mass regions
- Produce tools to extrapolate results to unknown nuclei by use of theoretical models or systematic trends
- Create a reference database of evaluated data for beta-delayed neutron emission
- Re-evaluate the beta-delayed neutron reactor constants in suitable group format for energy applications and include in database

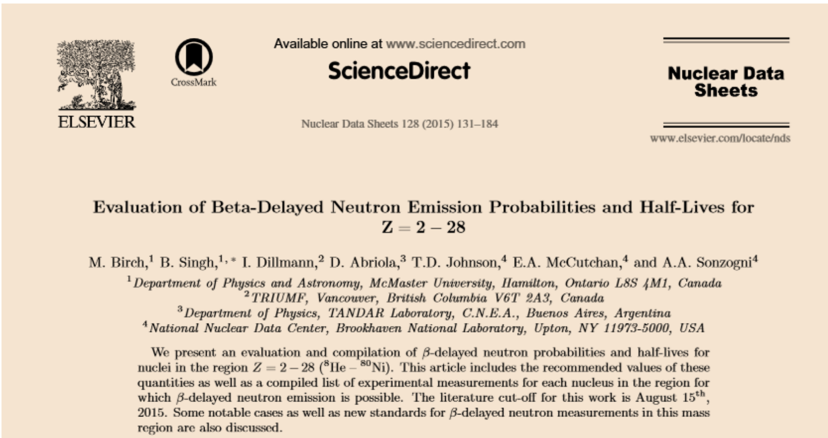
Expected Research Outputs

- Reference Database of beta-delayed neutron emission
- Re-evaluation of group reactor constants for beta-delayed neutron emission of fissile actinides actinides
- Technical document describing the evaluation methodology and the new database

Meet Work

Compilation and Evaluation of βDN data

Nuclei with Z < 28 (^{8}He - ^{80}Ni)



Available online at www.sciencedirect.com
ScienceDirect
Nuclear Data Sheets
Nuclear Data Sheets 128 (2015) 131–184
www.elsevier.com/locate/nds

Evaluation of Beta-Delayed Neutron Emission Probabilities and Half-Lives for Z = 2 − 28

M. Birch,[1] B. Singh,[1,*] I. Dillmann,[2] D. Abriola,[3] T.D. Johnson,[4] E.A. McCutchan,[4] and A.A. Sonzogni[4]
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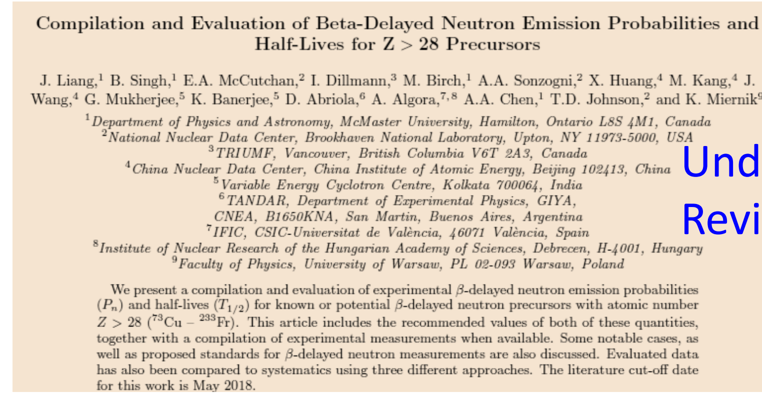
[3] Department of Physics, TANDAR Laboratory, C.N.E.A., Buenos Aires, Argentina
[4] National Nuclear Data Center, Brookhaven National Laboratory, Upton, NY 11973-5000, USA

We present an evaluation and compilation of β-delayed neutron probabilities and half-lives for nuclei in the region $Z = 2-28$ (^{8}He – ^{80}Ni). This article includes the recommended values of these quantities as well as a compiled list of experimental measurements for each nucleus in the region for which β-delayed neutron emission is possible. The literature cut-off for this work is August 15th, 2015. Some notable cases as well as new standards for β-delayed neutron measurements in this mass region are also discussed.

- Compilation and Evaluation
- Measured values of P_n and $T_{1/2}$
- For known or potential β-delayed neutron precursors

  $Q_{\beta^-} - Sn > 0$
- Recommended values of both P_n and $T_{1/2}$
- Comparison of Evaluated data with the systematics using three different approaches

Nuclei with Z > 28 (^{73}Cu - ^{233}Fr)



Compilation and Evaluation of Beta-Delayed Neutron Emission Probabilities and Half-Lives for Z > 28 Precursors

J. Liang,[1] B. Singh,[1] E.A. McCutchan,[2] I. Dillmann,[3] M. Birch,[1] A.A. Sonzogni,[2] X. Huang,[4] M. Kang,[4] J. Wang,[4] G. Mukherjee,[5] K. Banerjee,[5] D. Abriola,[6] A. Algora,[7,8] A.A. Chen,[1] T.D. Johnson,[2] and K. Miernik[9]
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We present a compilation and evaluation of experimental β-delayed neutron emission probabilities (P_n) and half-lives ($T_{1/2}$) for known or potential β-delayed neutron precursors with atomic number $Z > 28$ (^{73}Cu – ^{233}Fr). This article includes the recommended values of both of these quantities, together with a compilation of experimental measurements when available. Some notable cases, as well as proposed standards for β-delayed neutron measurements are also discussed. Evaluated data has also been compared to systematics using three different approaches. The literature cut-off date for this work is May 2018.

Under Review

Kratz-Herrmann Formula (KHF) Systematic

$$P_n \sim a \left(\frac{Q_{\beta n}}{Q_\beta - C} \right)^b$$

C = 0, even-even
= 13/ √A odd-A
= 26/√A odd-odd

McCutchan systematic

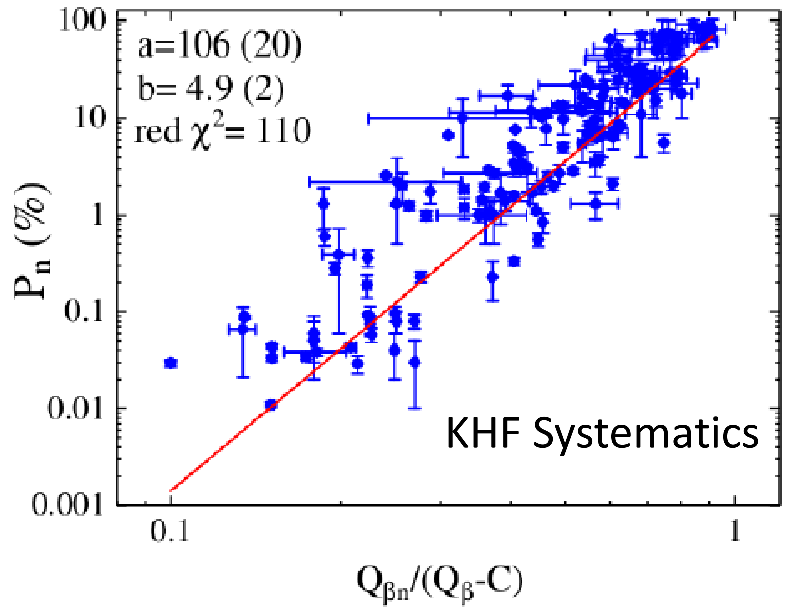
$$\frac{P_{1n}}{T_{1/2}} \sim c\, Q_{\beta n}^d$$

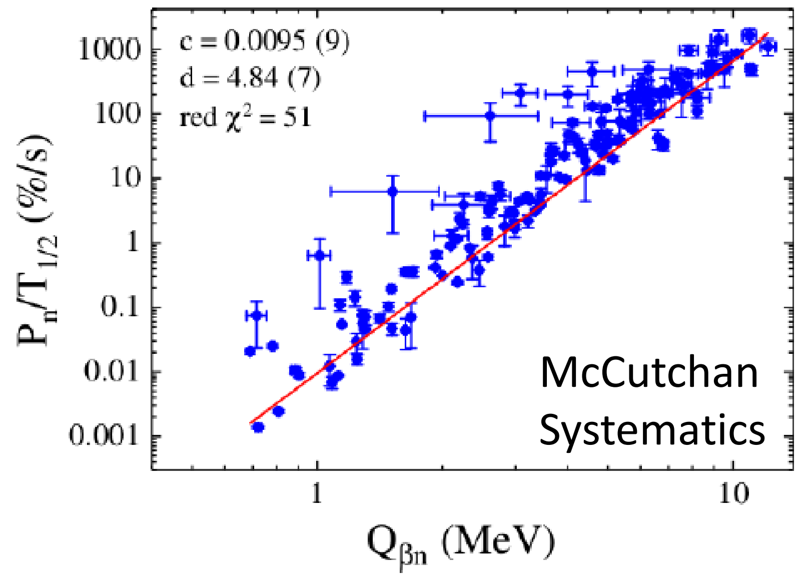
Outliers: ^{79}Zn, ^{86}Ge, ^{94}Br, ^{92}Rb, ^{102}Rb, ^{97}Sr, ^{105}Y, $^{109-110}$Nb, ^{129}In, ^{139}Sb, ^{142}I, and ^{150}Cs

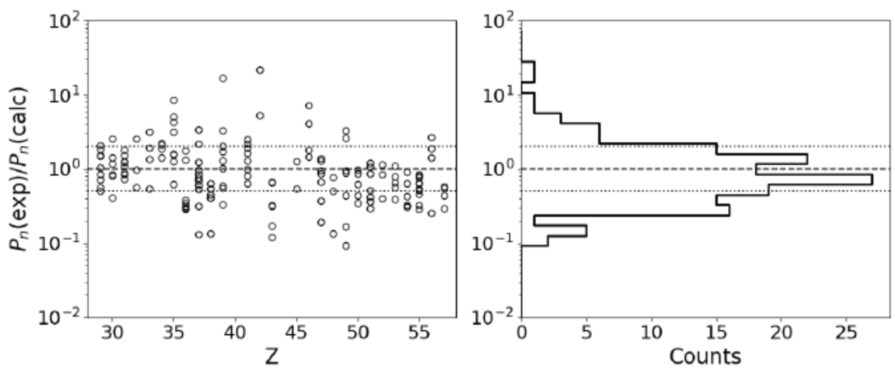
Systematics based on the Effective Density (EDM) Model

$$S_\beta(E) \;\propto\; \rho(E) = \frac{\exp(a_d\sqrt{E})}{E^{2/3}}$$

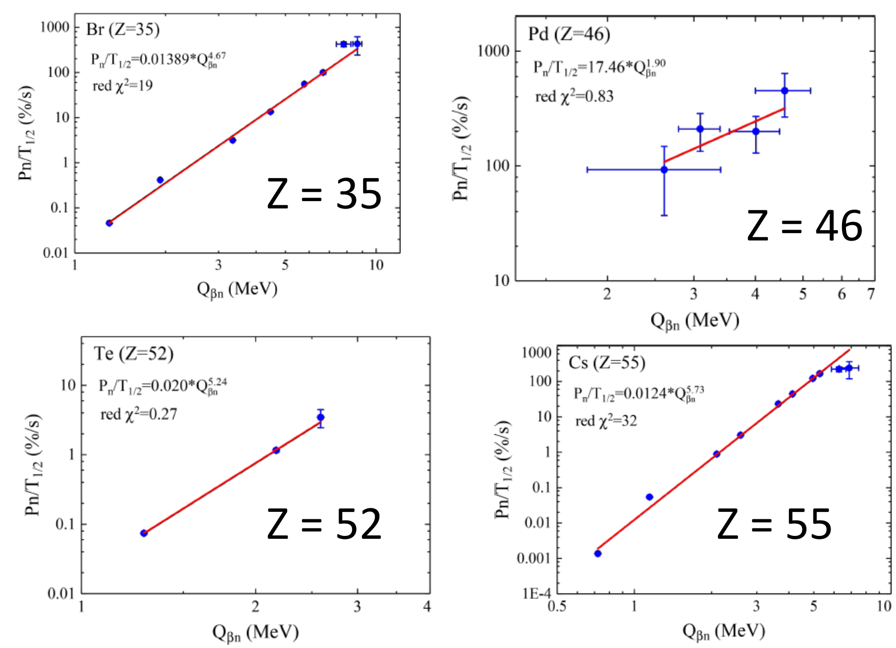
Comparison of Pn values with the systematics







EDM Systematics

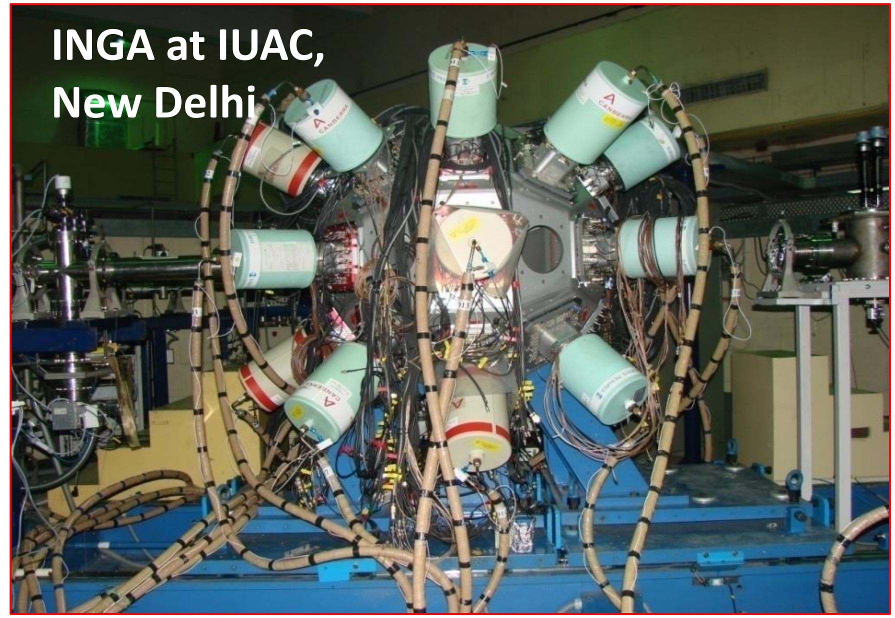


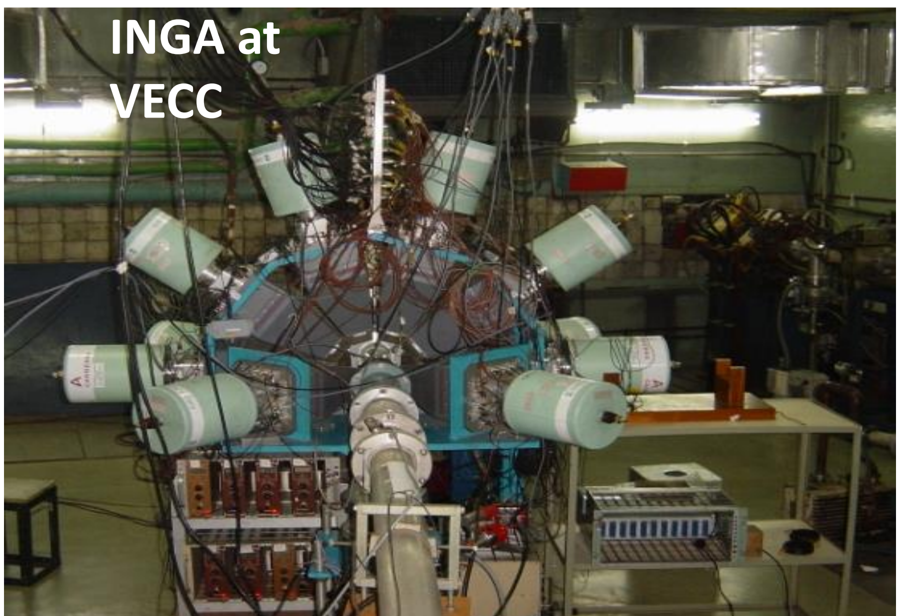
Facilities for High-resolution γ-ray Spectrometers at VECC

VENUS: **VE**CC array for **NU**clear **S**pectroscopy

INGA: **I**ndian **N**ational **G**amma **A**rray


VENUS at VECC,
Kolkata


INGA at IUAC,
New Delhi

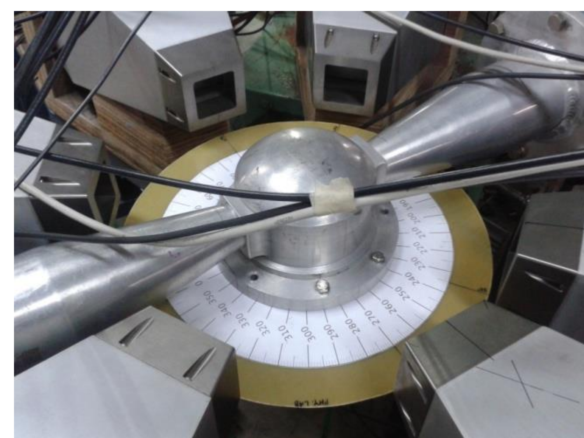

INGA at
VECC


INGA at
TIFR

VENUS: VECC array for NUclear Spectroscopy

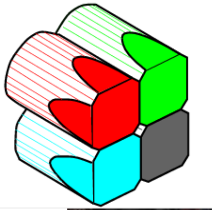
Clover HPGe Detectors

- 6 CS Clover HPGe
- Horizontal plane configuration
- Flexible angles
- Can be used for both online and offline experiments
- VME based data acquisition system
- A few experiments have been performed.

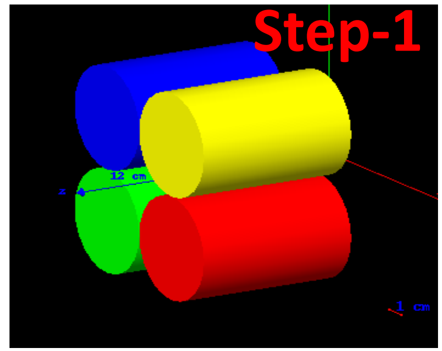


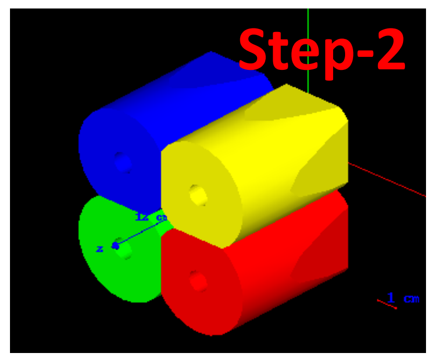
Geant 4 simulation of the VENUS

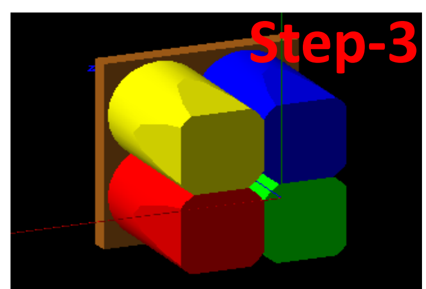
VENUS: VECC array for NUclear Spectroscopy: 6 CS clover HPGe detectors

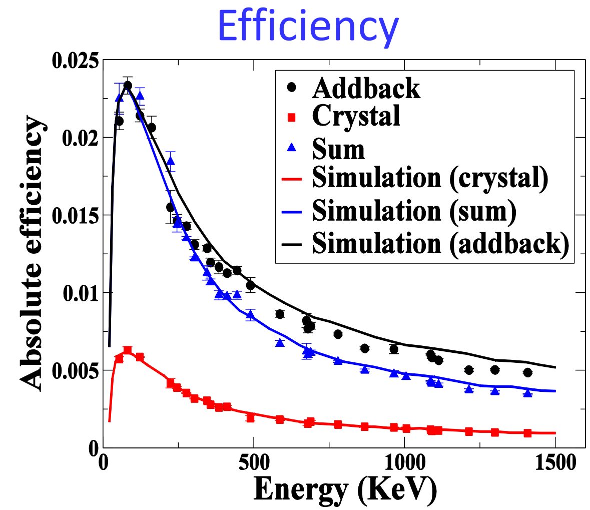


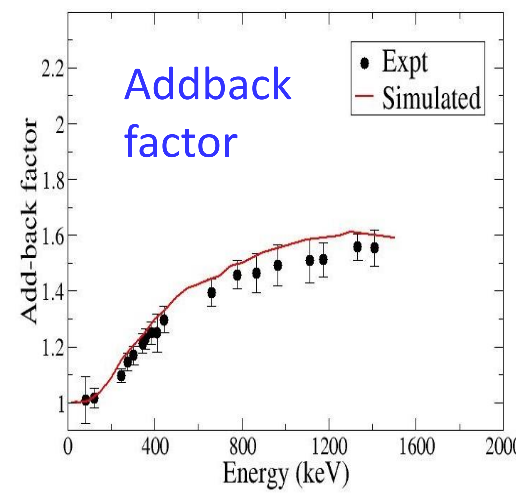
Single Clover HPGe detector



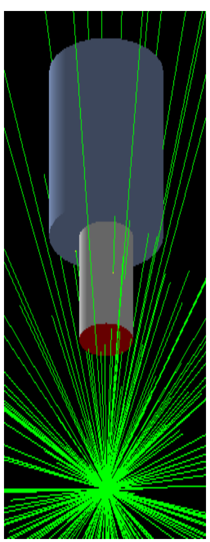


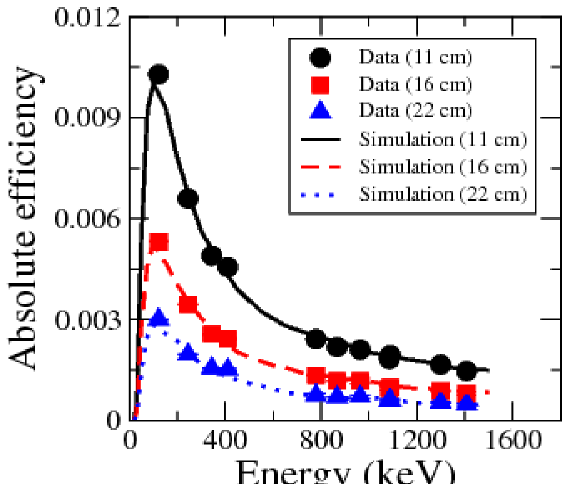






Single crystal HPGe





Md. A. Asgar et al., DAE Symp Nucl Phys. (2016)

PHYSICAL REVIEW C 98, 044311 (2018)

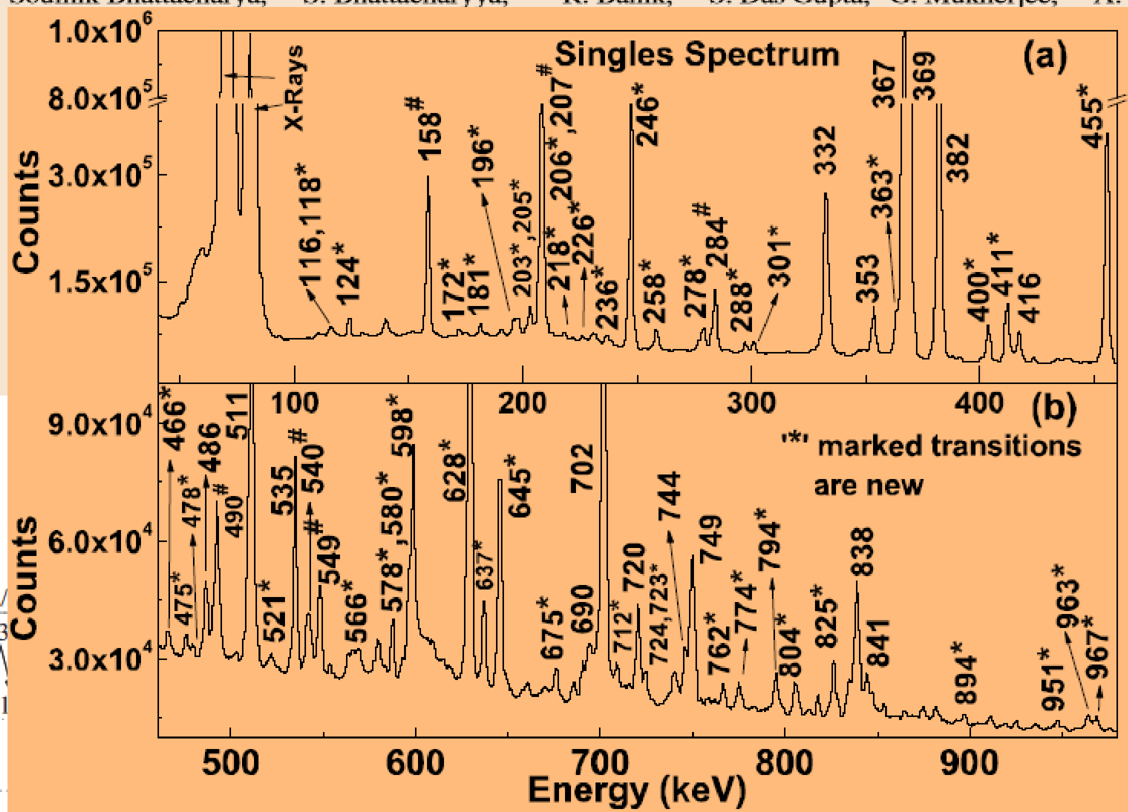
First Paper on on-line measurement with VENUS

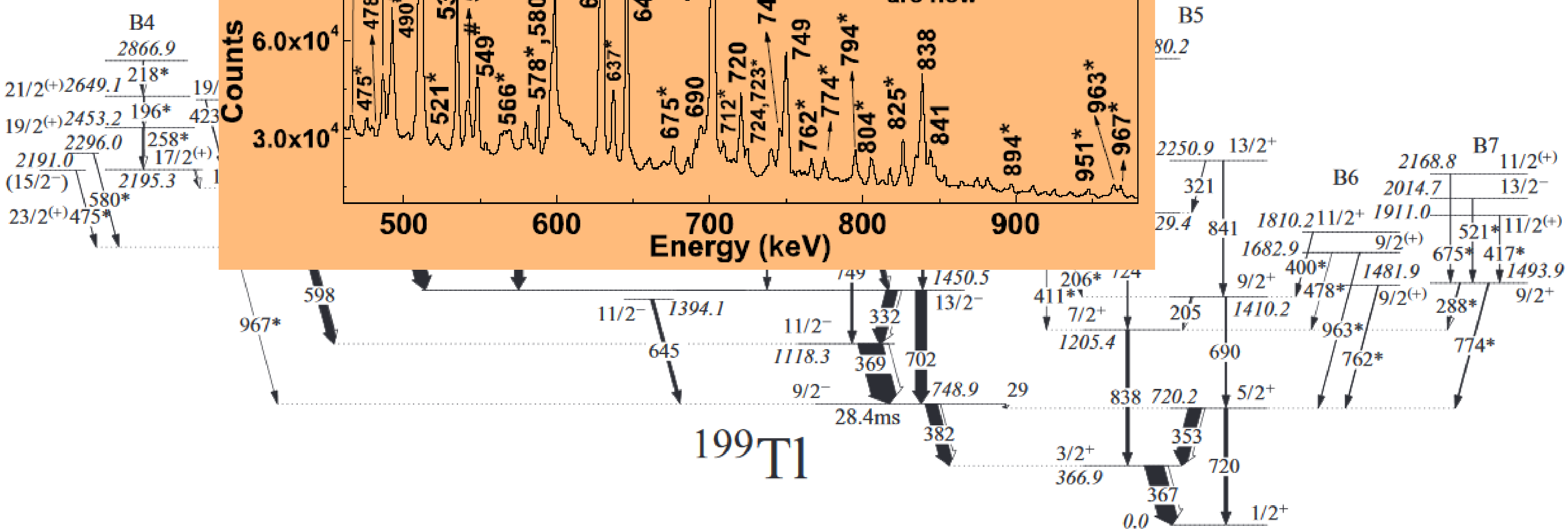
Yrast and non-yrast spectroscopy of ^{199}Tl using α-induced reactions

Soumik Bhattacharya,[1,2] S. Bhattacharyya,[1,2,*] R. Banik,[1,2] S. Das Gupta,[3] G. Mukherjee,[1,2] A. Dhal,[1] S. S. Alam,[1,2]
...asish Mondal,[1,2]
...Banerjee[1]
...4, India

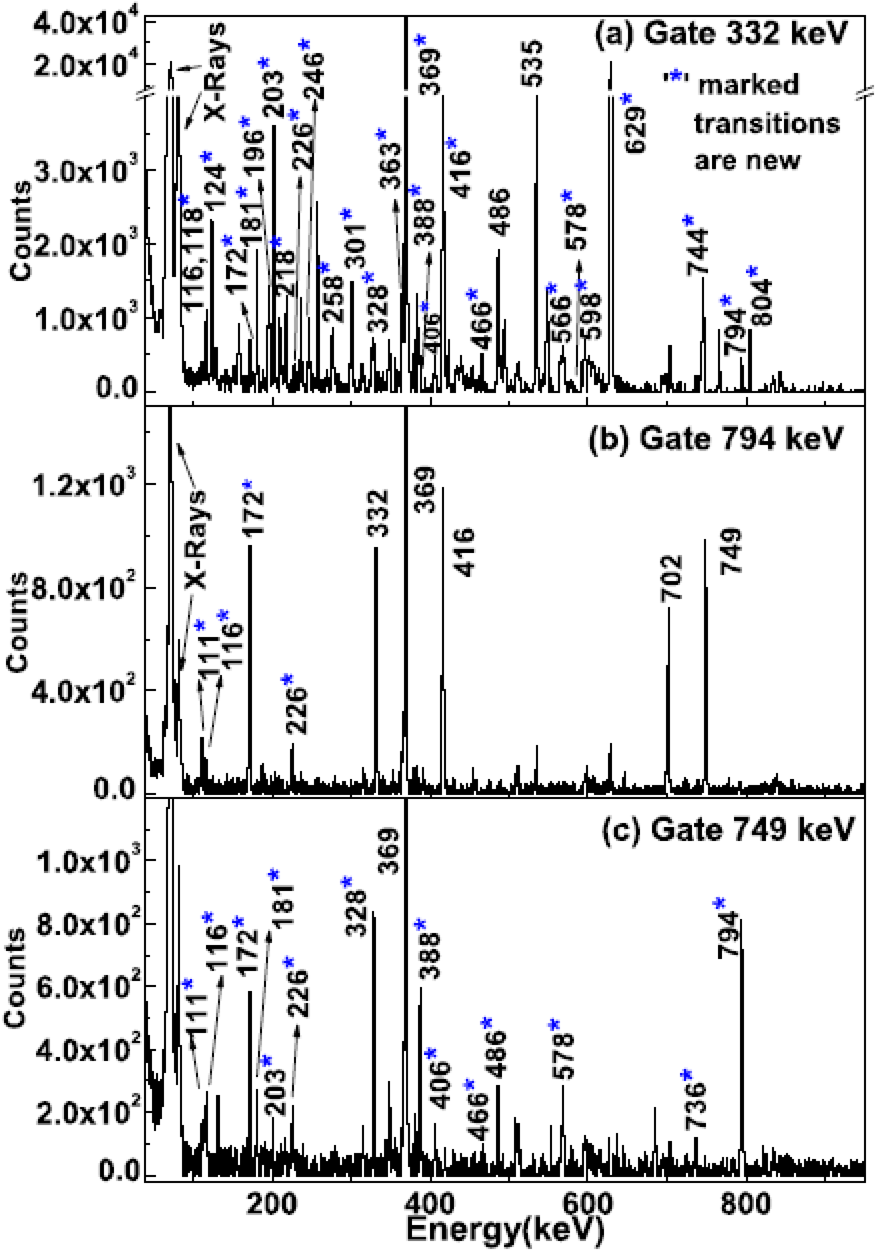
...ober 2018)

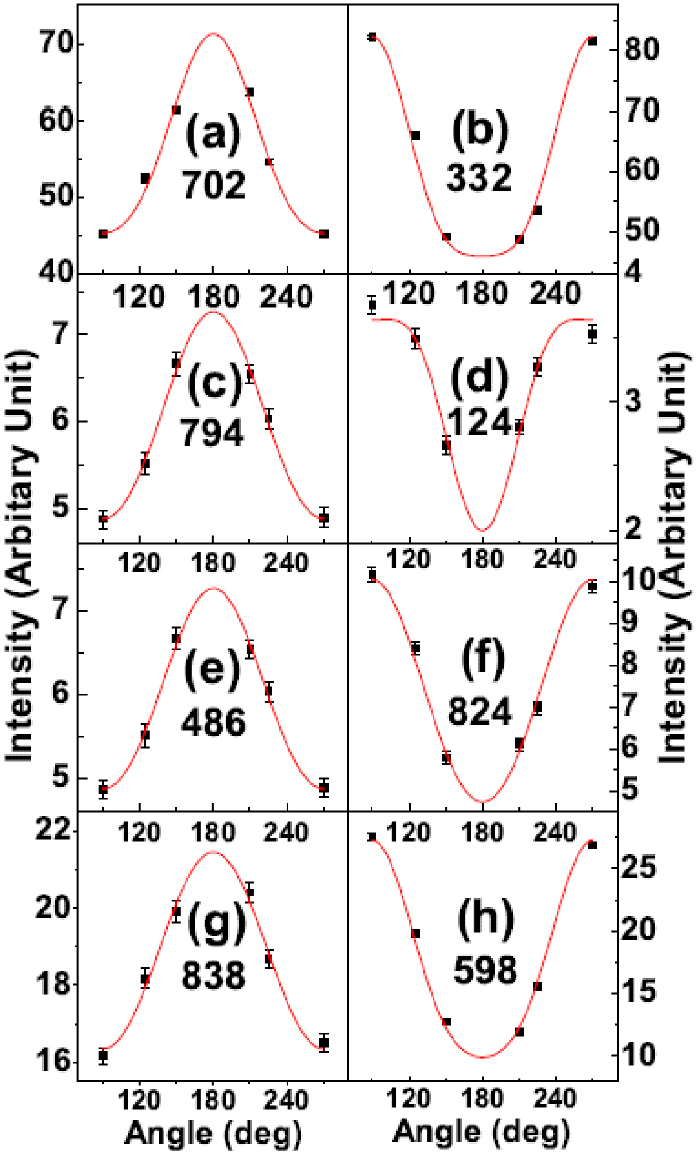
...n evaporation
...y for NUclear
...significantly



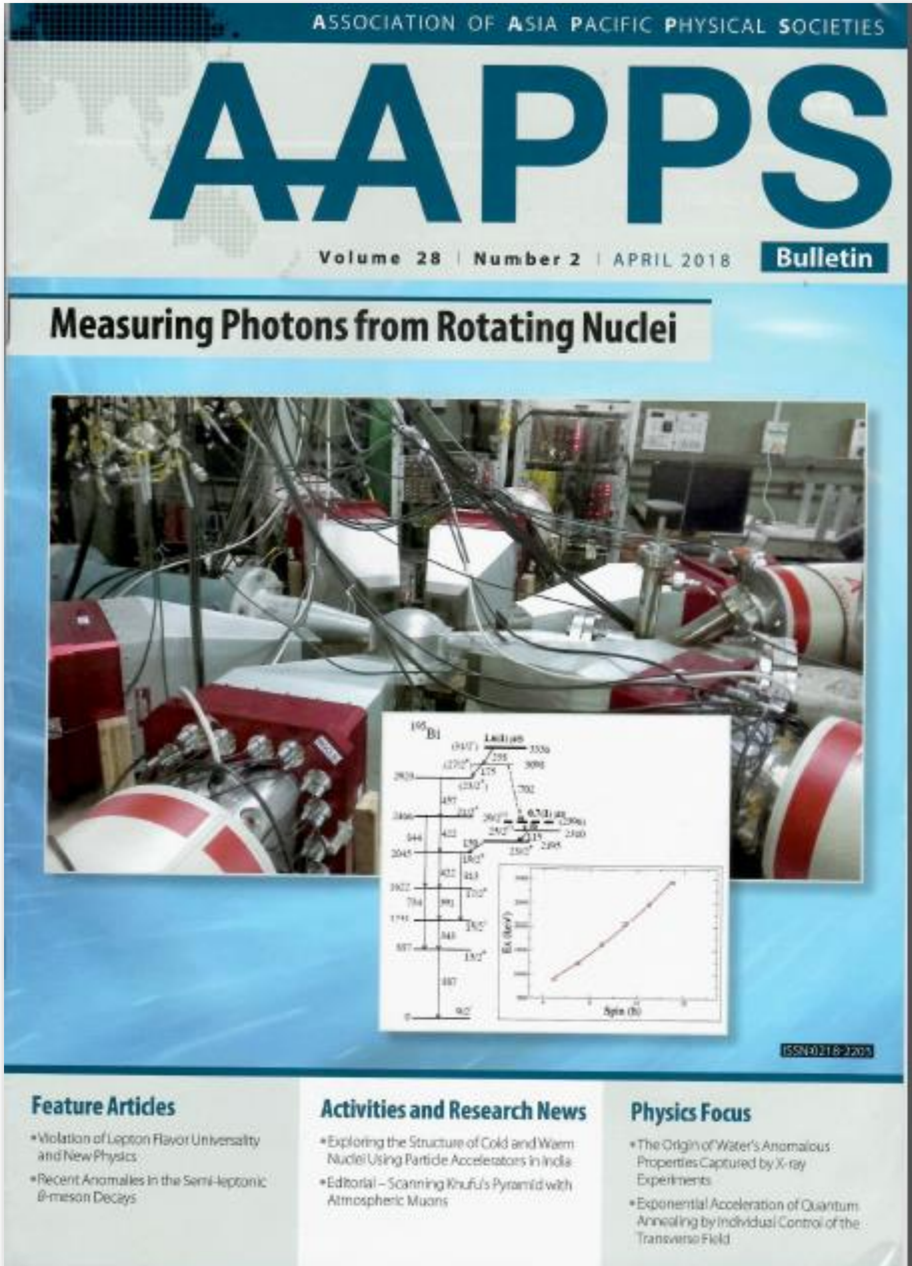


Gated Spectra and Angular distribution in ^{199}Tl from VENUS data





Soumik Bhattacharya et al. PRC 96, 044311 (2018)



VENUS appears in the cover page of Association of Asia Pacific Physical Society Bulletin.

Vol. 28 | Number 2 | APRIL 2018 Issue

INGA: Indian National Gamma Array

❖ An array of Clover HPGe detectors pooled from different institutions in India

❖ Moves between three accelerator Centres in India:

- TIFR, Mumbai
- IUAC, New Delhi
- VECC, Kolkata

❖ Upto 24 clovers (experiments performed with maximum of 22 clovers)

❖ More than 150 publications in peer reviewed journals and more than 50 Ph.Ds completed.

At present the INGA detectors are at VECC, Kolkata and IUAC, New Delhi.

INGA setup @ VECC (2017-18)

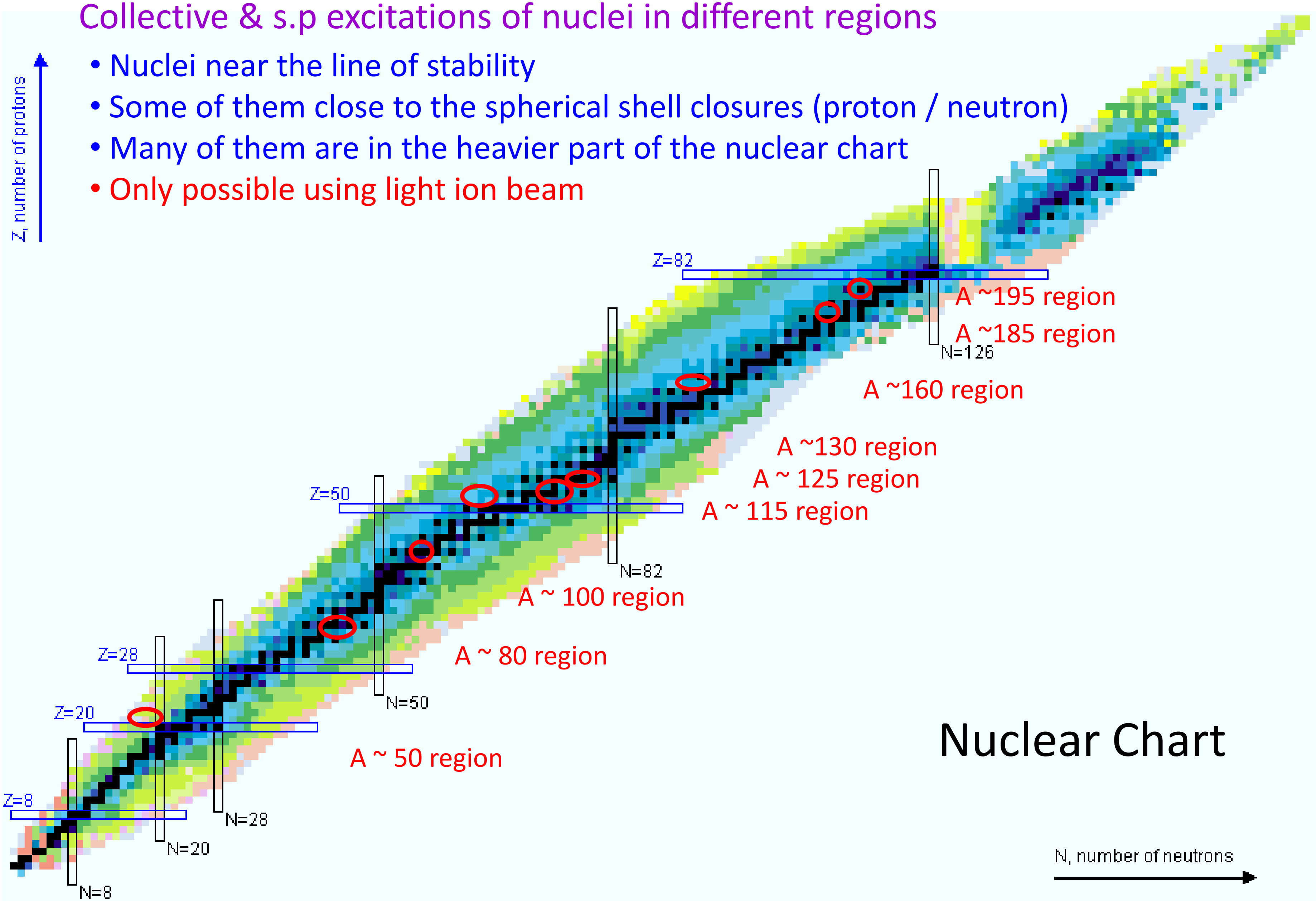
- 8 CS-Clovers (up to)
- 2 LEPS (up to)
- Digital Data Acquisition
- Fusion evaporation reaction using α beam

Support of a strong team of students to work together !

Nuclei studied in the INGA@VECC 2017-18 Campaign

Collective & s.p excitations of nuclei in different regions

- Nuclei near the line of stability
- Some of them close to the spherical shell closures (proton / neutron)
- Many of them are in the heavier part of the nuclear chart
- Only possible using light ion beam

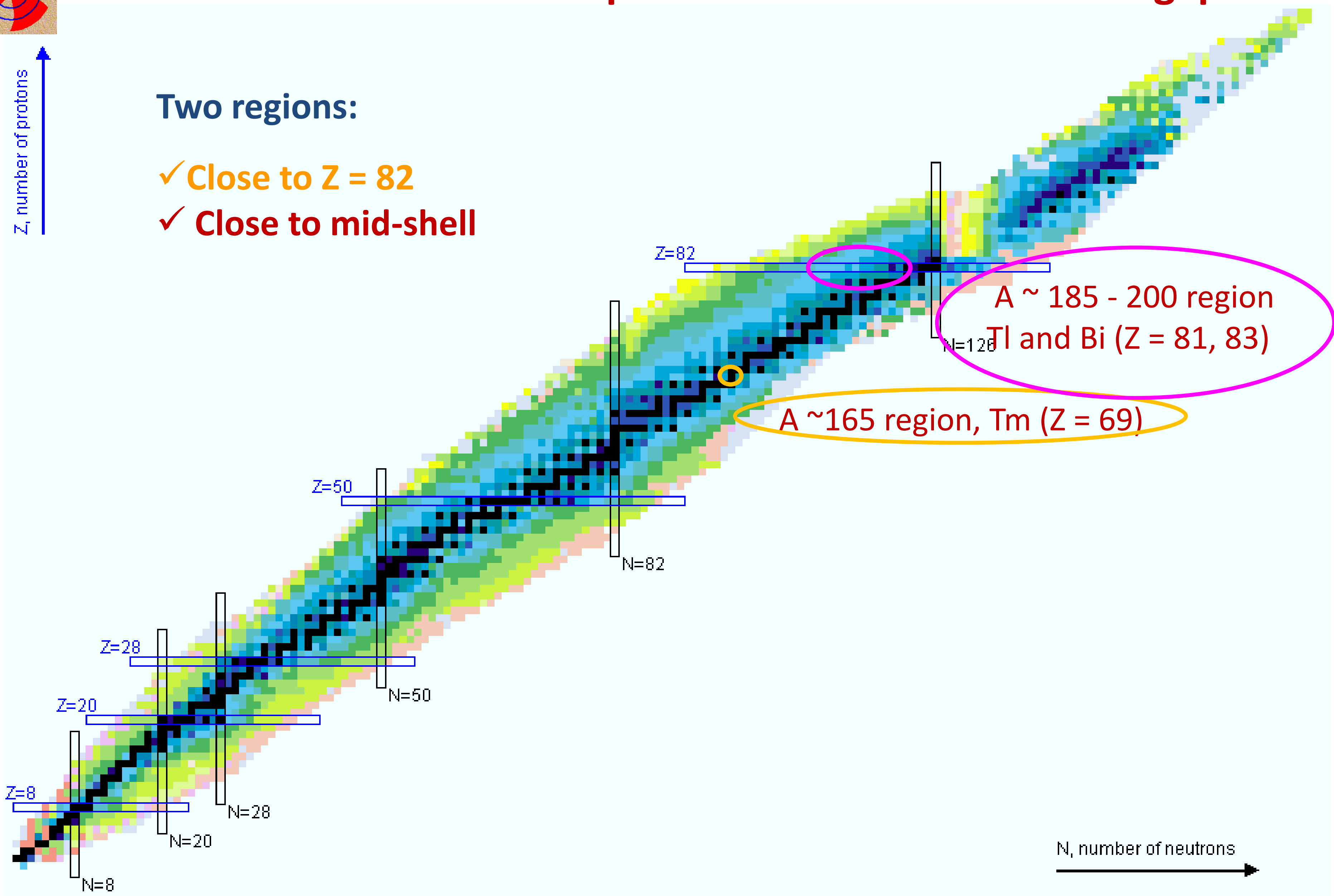


Nuclear Excitations near spherical and Deformed Shell gaps

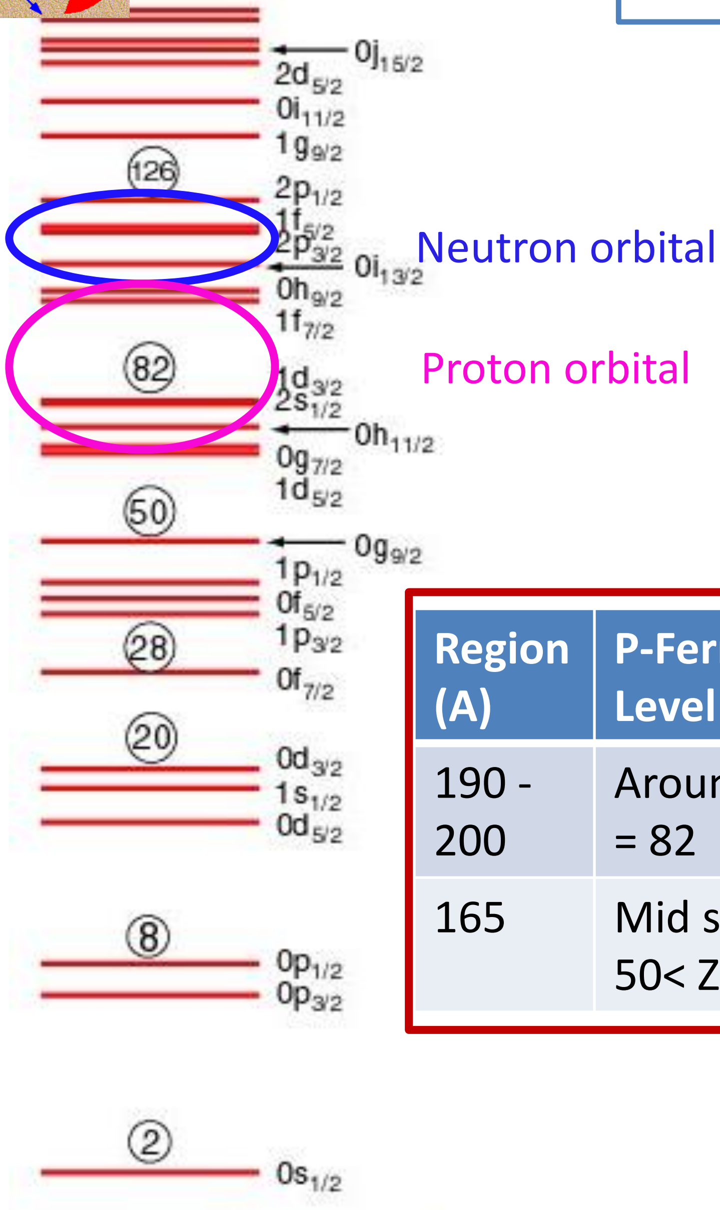
Two regions:

✓ Close to Z = 82

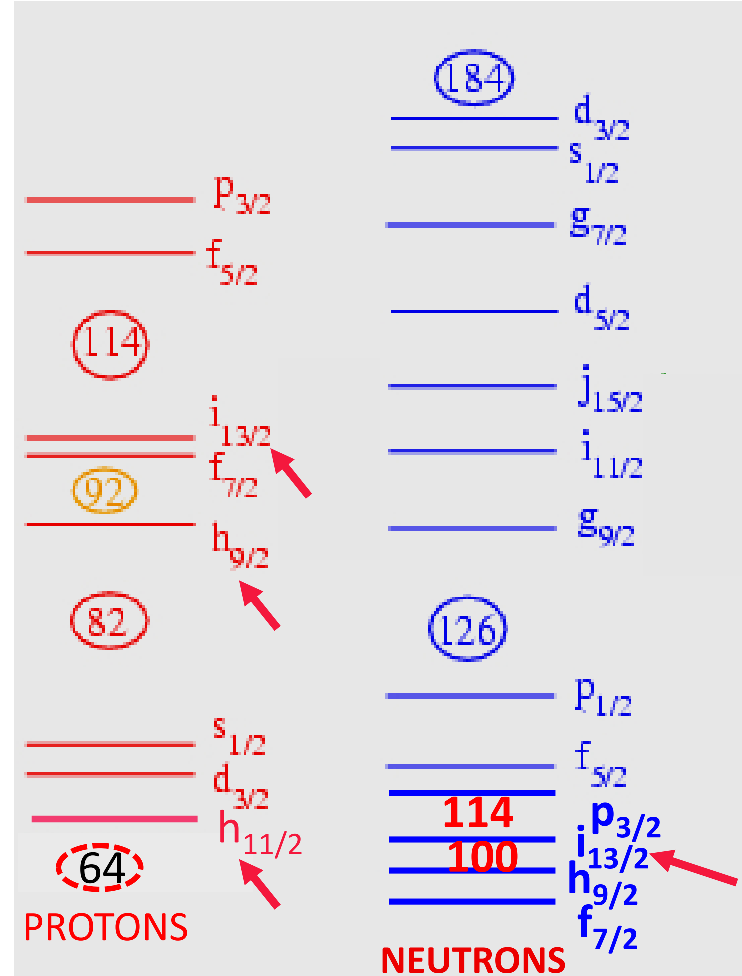
✓ Close to mid-shell



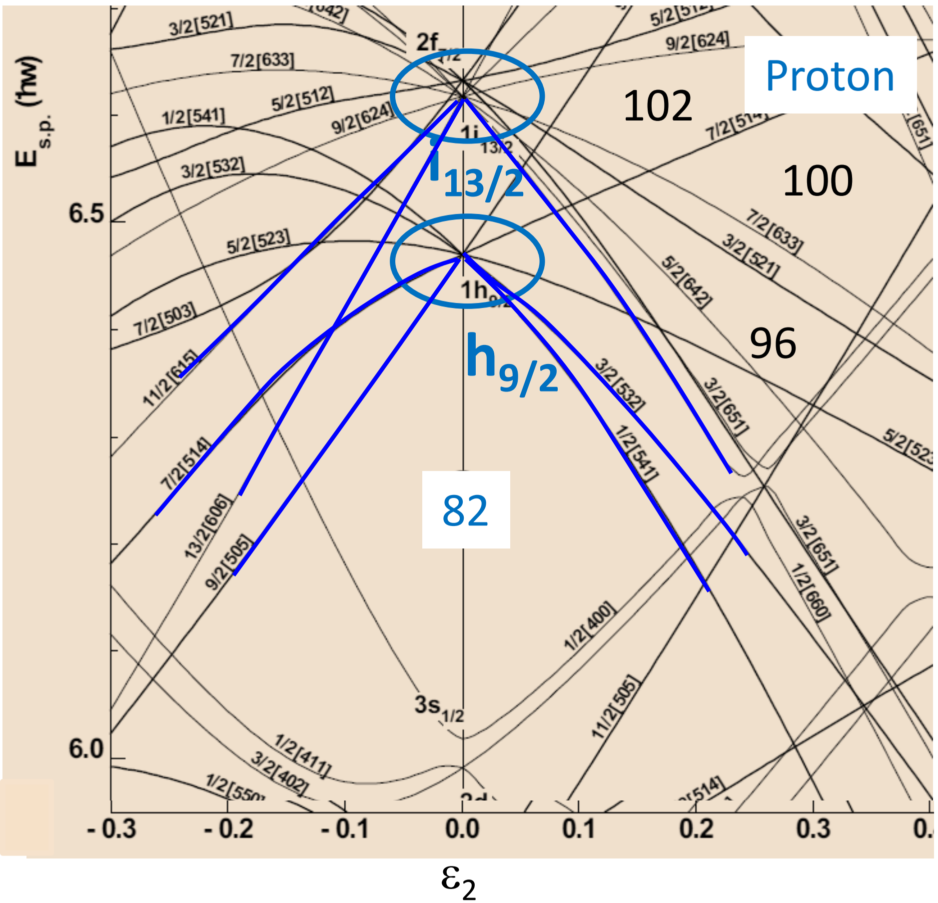
Shell model nucleonic states

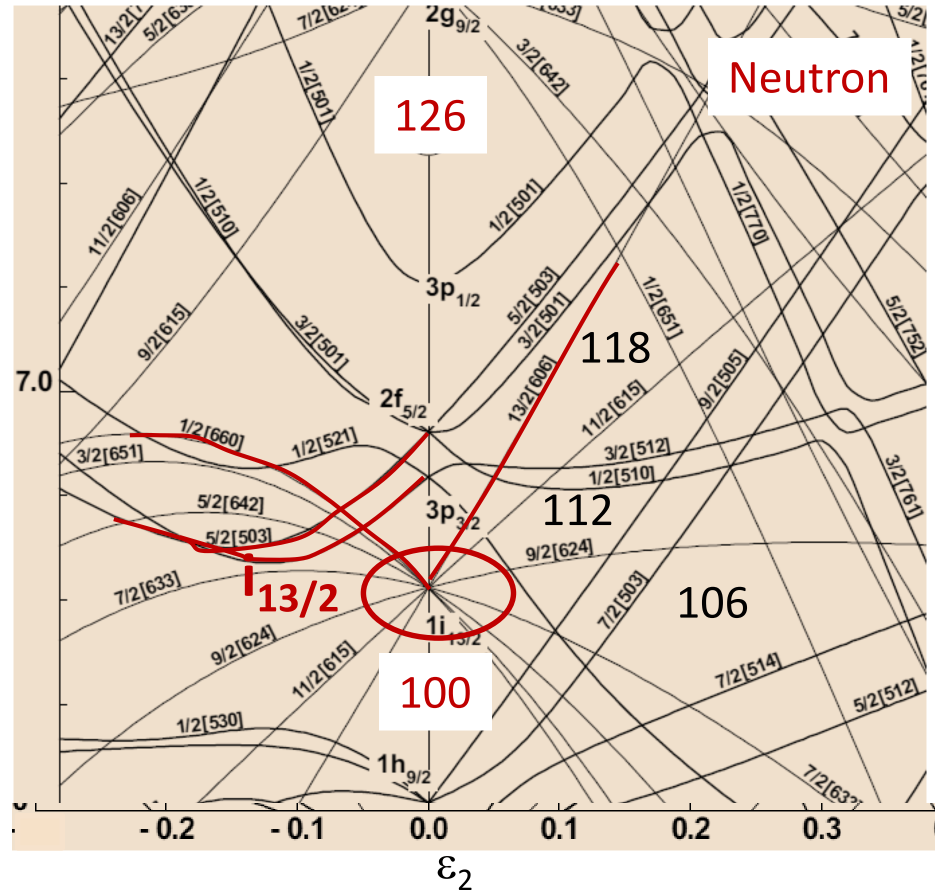


Region (A)	P-Fermi Level	N-Fermi Level
190 - 200	Around Z = 82	Below N = 126
165	Mid shell 50< Z <82	Mid shell 82< N <126



Deformation driving Intruder Orbitals





More particle (hole) excited to in high-j orbitals generate deformed shape

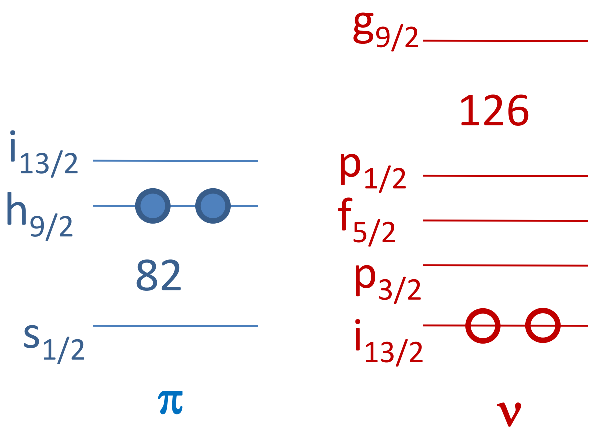
Effect of shells and shell gaps

Two aspects :

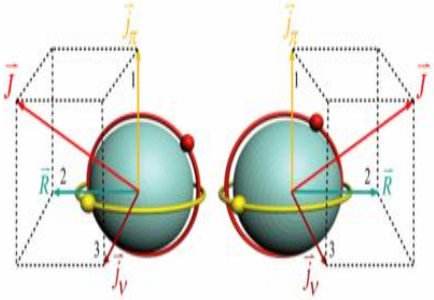
- ❑ **Stability of nuclei near the shell gaps**
- ❑ **Intruder levels**

Several effects

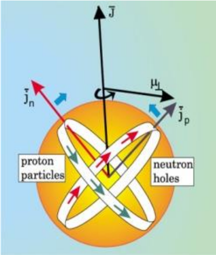
- ➢ **Different modes of excitations**
- ➢ **Shape evolution with spin and iso-spin**
- ➢ **Nature of Particle alignment in rotational nucleus**



Particle-hole excitations in high-j orbitals



Chirality

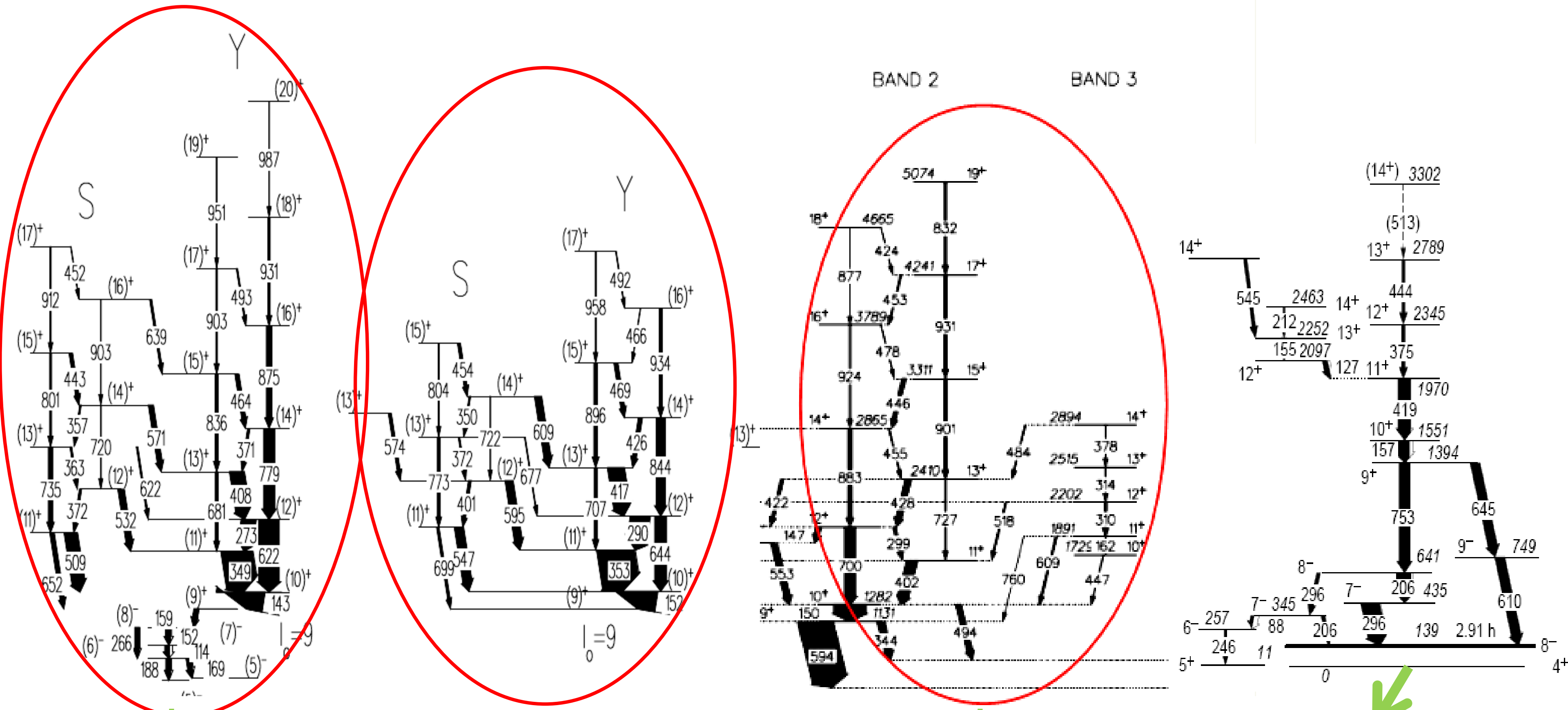


Magnetic Rotation

Similar situation in A ~ 130 nuclei

$\pi h_{11/2} \otimes \nu h_{11/2}$ bands in odd-odd Cs (Z = 55) isotopes

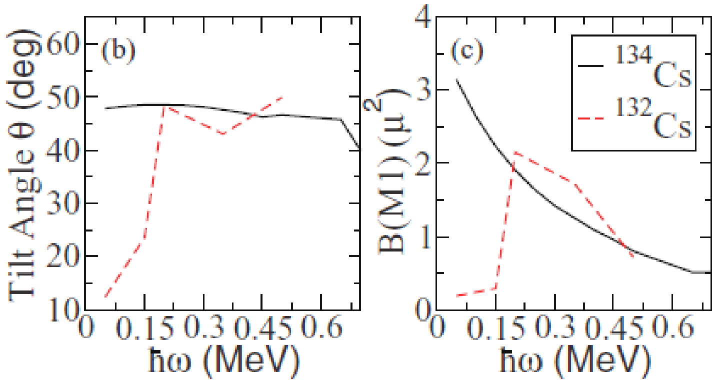
^{128}Cs (N = 73) ^{130}Cs (N = 75) ^{132}Cs (N = 77) ^{134}Cs (N = 79)



A different band structure in ^{134}Cs ➔ MR band

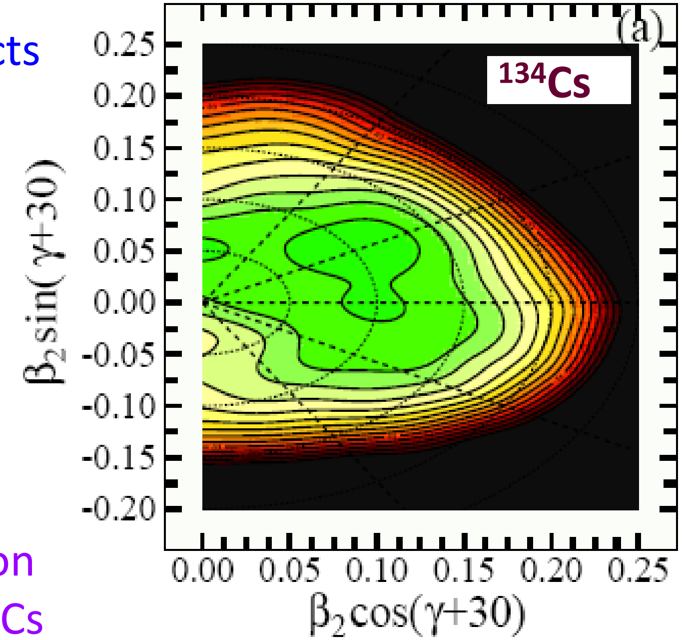
Chiral doublet bands

Theoretical Calculations and shape change in Cs isotopes

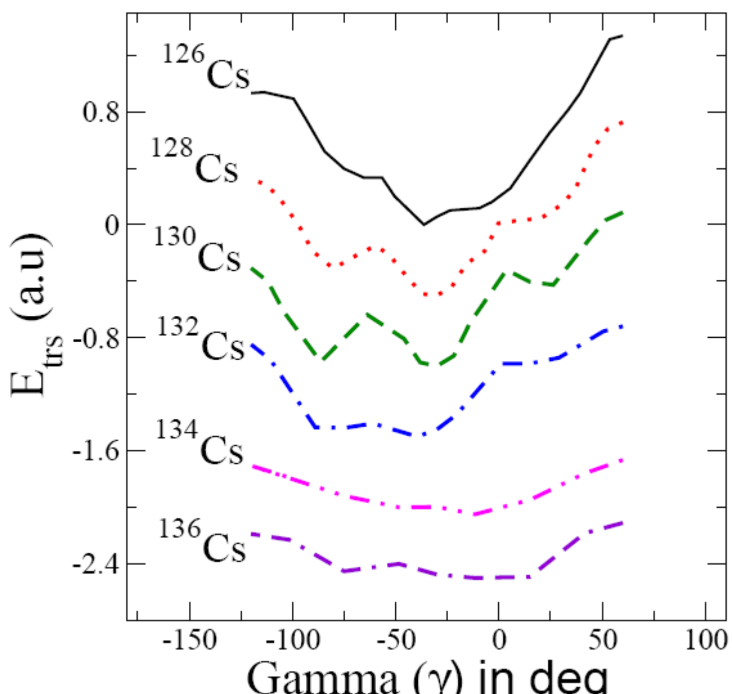


TAC Calculations predicts different behavior for ^{132}Cs and ^{134}Cs.

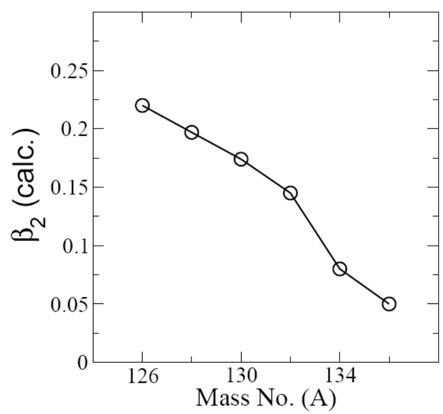
TRS Calculations show difference in potential energy minima.

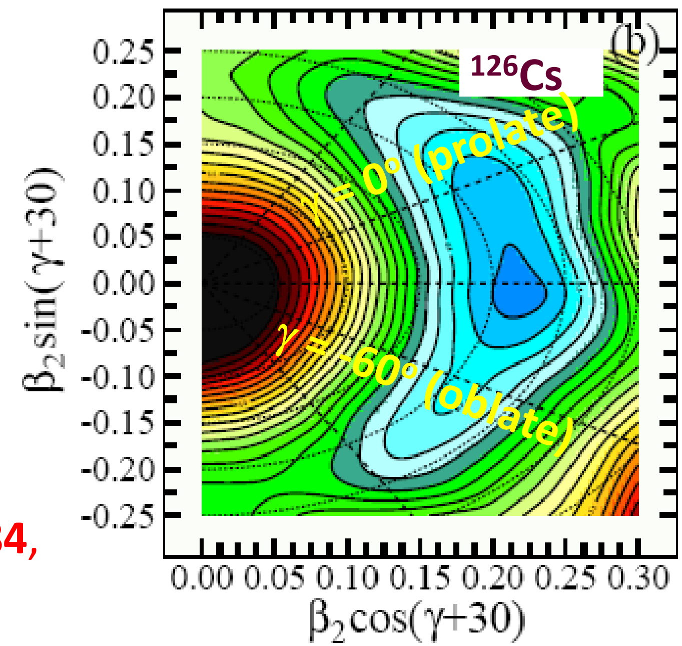


Increase in γ-softness with increasing mass No. (A) in Cs isotopes



Decrease in deformation β_2 with increasing A in Cs isotopes





H. Pai, GM et al. PRC **84**, 041301(R) (2011)

Experiment and data analysis

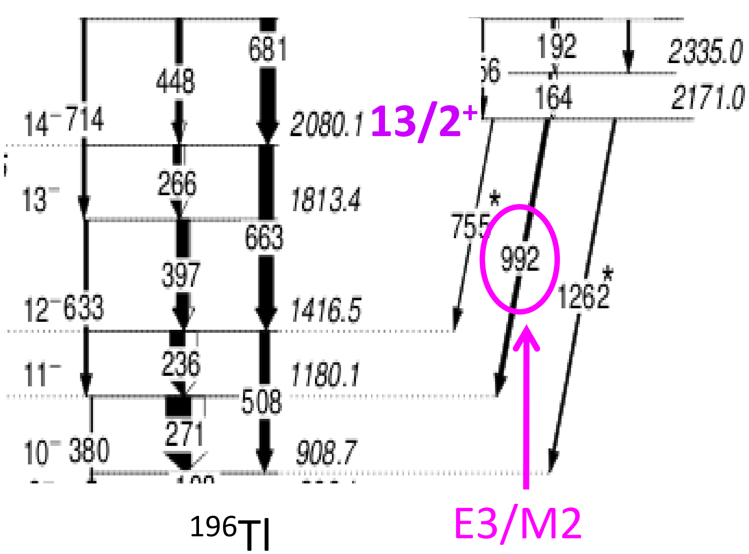
- Experiments were performed at VECC, TIFR, IUAC
- Fusion evaporation and inelastic excitations
- INGA and VENUS array
- Coincidence relation: γ–γ matrix, γ–γ–γ cube
- Spin, Parity: Angular distribution, DCO Ratio, Polarization (Δ_{IPDCO} and P) and their combination

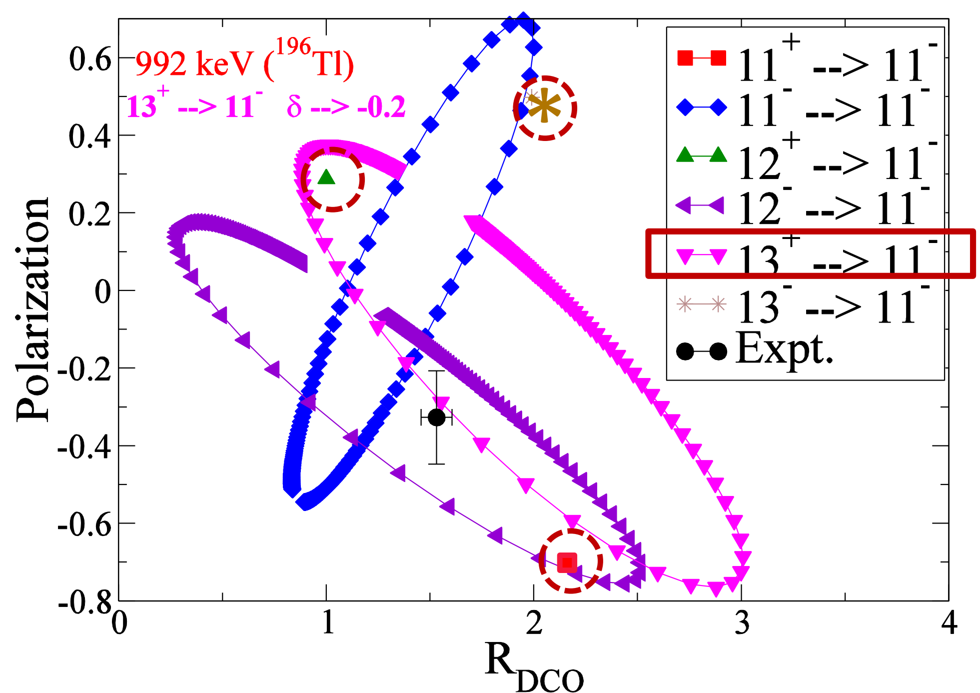
$$R_{\mathrm{DCO}} = \frac{I_{\gamma_1} \text{ at } \theta_1, \text{ gated by } \gamma_2 \text{ at } \theta_2}{I_{\gamma_1} \text{ at } \theta_2 \text{ gated by } \gamma_2 \text{ at } \theta_1}$$

$$\Delta_{IPDCO} = \frac{a(E_\gamma)N_\perp - N_\parallel}{a(E_\gamma)N_\perp + N_\parallel}$$

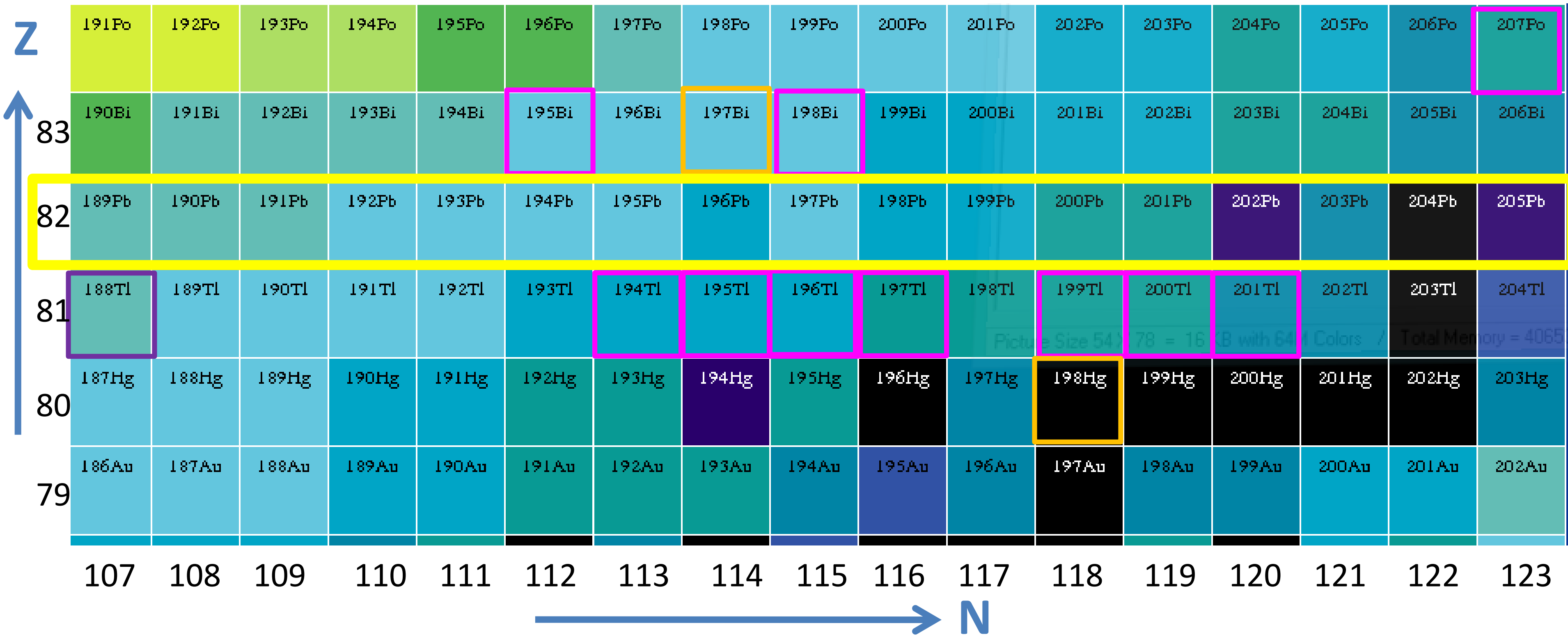
Polarization (P) = Δ_{IPDCO}/Q

Q → polarization sensitivity





Nuclei around Z = 82



^{198}Hg (Z = 80)

Several isotopes of Tl (Z = 81)

3 isotopes of Bi (Z = 83)

Few isotopes of Po (Z = 84) and At (Z = 85)

Major findings in nuclei around Z = 82

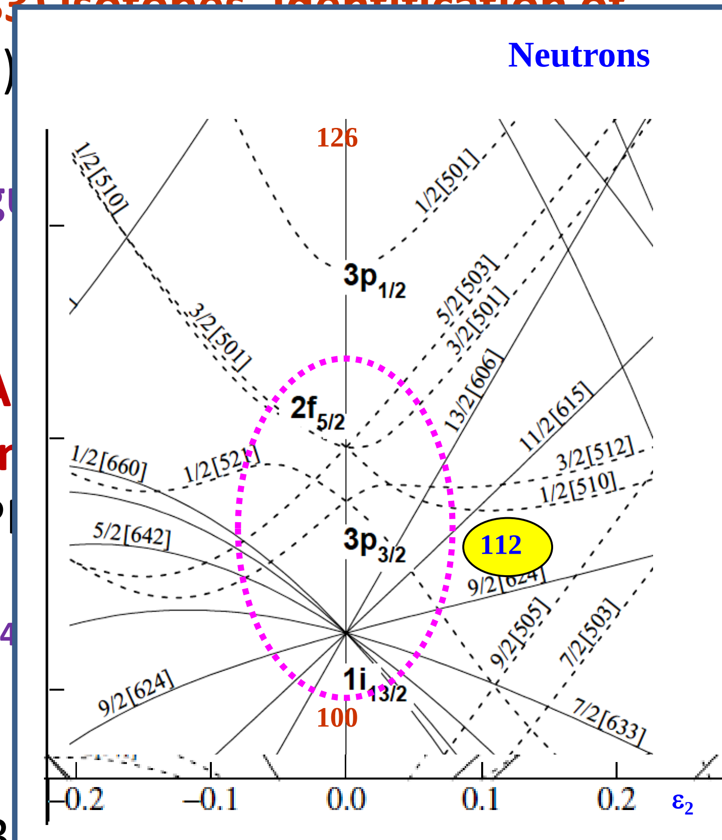
❖ **Onset of deformation at N = 112 for Bi (Z = 83) isotones. Identification of high spin isomer in ^{195}Bi.** [PRC**85**, 064317 (2012)

❖ **Several MR bands with large multi-qp config**
^{198}Bi [PRC90, 064314 (2014)]

❖ **Systematic study of the $\pi h_{9/2}$ bands in odd-A**
the persistence of rotational band (deformation
N = 120. [PRC**88**, 044328 (2013); ibid. 064302; P

❖ **Identification of band crossing in odd-odd ^{194}**
(2012), PRC**95**, 014301 (2017)]

❖ **Evidence of MR band in ^{194}Tl** [PRC**85**, 064313



❖ **Evidence for Multiple Chiral Doublet (MχD) bands in odd-A ^{195}Tl** [PLB**782** (2018) 768]

Physics Letters B 782 (2018) 768–772

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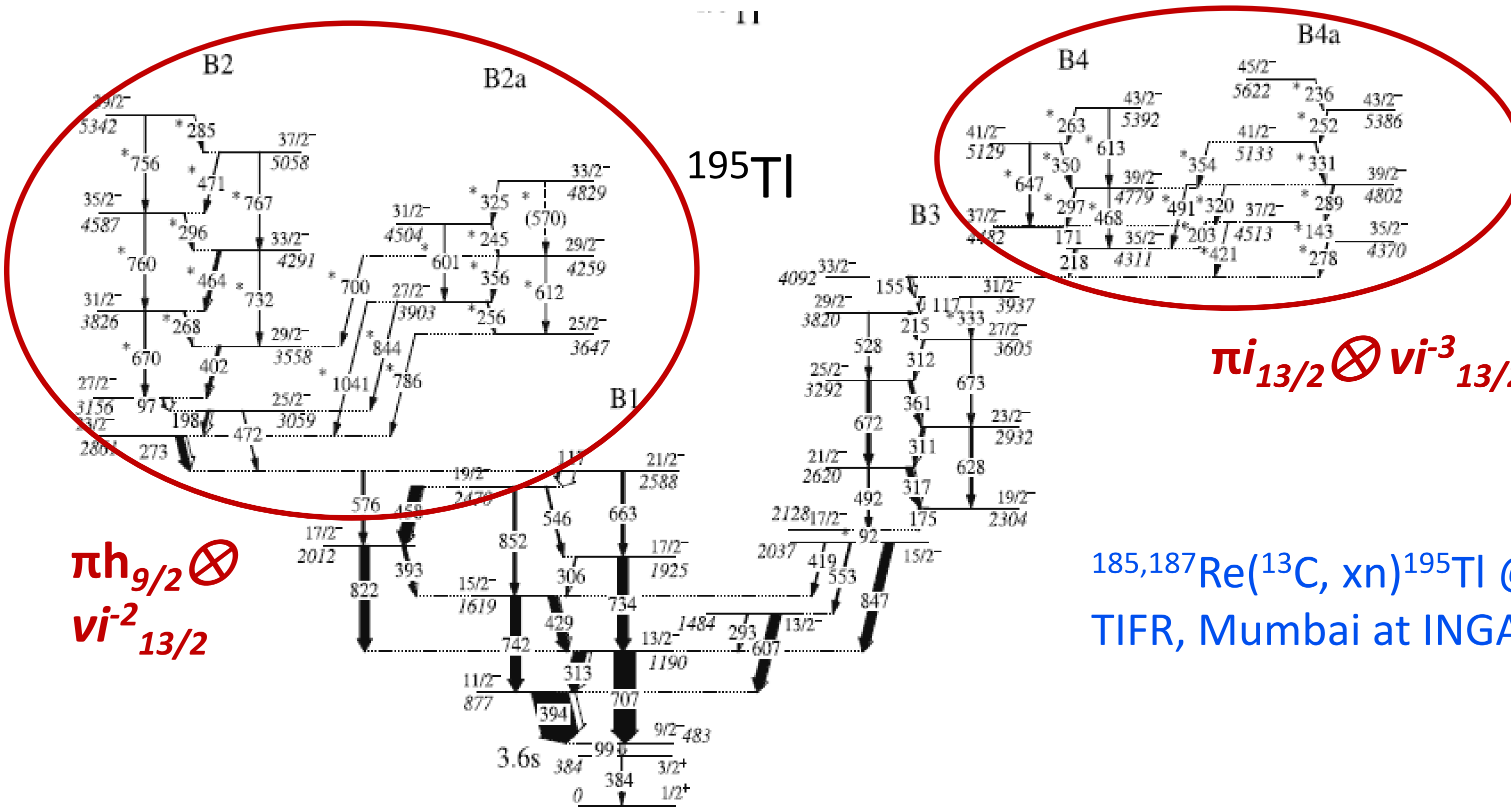
Observation of multiple doubly degenerate bands in ^{195}Tl

T. Roy [a,b], G. Mukherjee [a,b,*], Md.A. Asgar [a,b], S. Bhattacharyya [a,b], Soumik Bhattacharya [a,b], C. Bhattacharya [a,b], S. Bhattacharya [a,1], T.K. Ghosh [a,b], K. Banerjee [a,b,c], Samir Kundu [a,b], T.K. Rana [a], P. Roy [a,b], R. Pandey [a,b], J. Meena [a], A. Dhal [a], R. Palit [d], S. Saha [d], J. Sethi [d], Shital Thakur [d], B.S. Naidu [d], S.V. Jadav [d], R. Dhonti [d], H. Pai [e], A. Goswami [e]



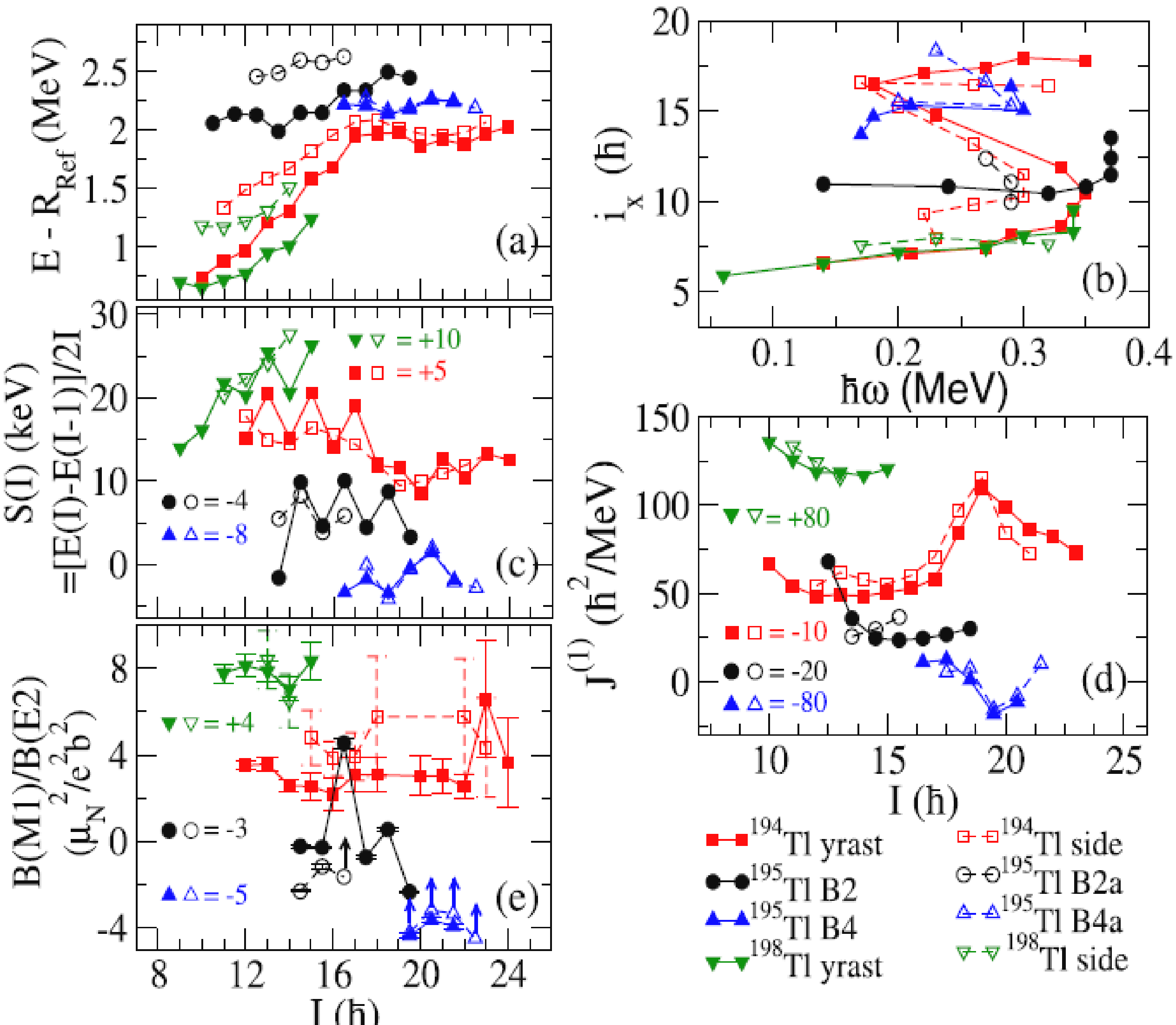
$\pi i_{13/2} \otimes \nu i^{-3}_{13/2} (p_{3/2} f_{5/2})^{-1}$

$\pi h_{9/2} \otimes \nu i^{-2}_{13/2}$

^{185,187}Re(^{13}C, xn)^{195}Tl @ 75 MeV

TIFR, Mumbai at INGA with 15 Clovers

Comparison of the Bands B2-B2a and B4-B4a with other Chiral partner bands



- **First observation of MχD in A = 190 region.**
- **First observation of doublet bands with configuration involving as large as 5 quasi-particles.**
- **ΔE_{av} ~25 keV (Δe_{max} = 59 keV) for B4-B4a represents one of the best degenerate bands.**

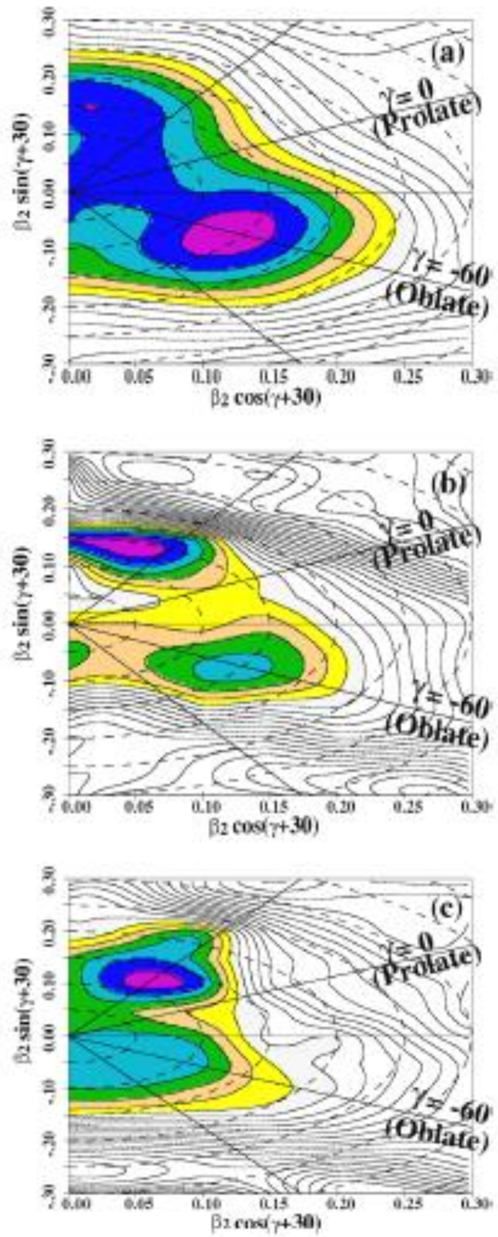
T. Roy et al., Phys. Lett. B 782 (2018) 768

Total Routhian Surface (TRS) Calculations: Shape of ^{195}Tl For different configuration

1-qp

3-qp

5-qp



The Oblate shape for 1-qp configuration changes to a triaxial shape with $\gamma \sim +39^o$ for 3-qp configuration.

For 5-qp configuration, a stable triaxial minimum with $\gamma \sim +31^o$ appears.

More number of neutrons in $i_{13/2}$ orbital gives stable triaxiality.

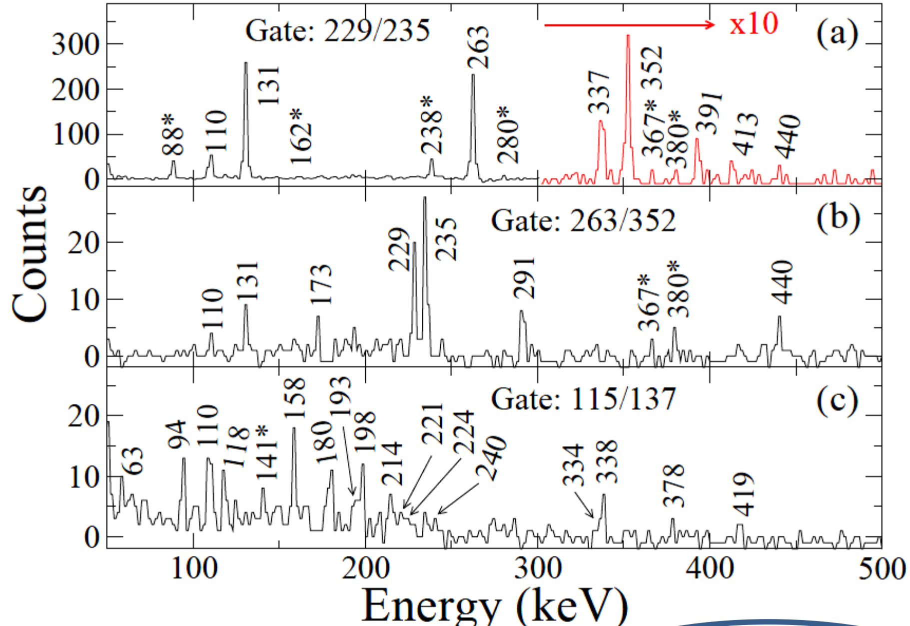
The proton particle in $h_{9/2}$ and neutron holes in $i_{13/2}$ coupled with the triaxial core provides the chiral geometry in ^{195}Tl.

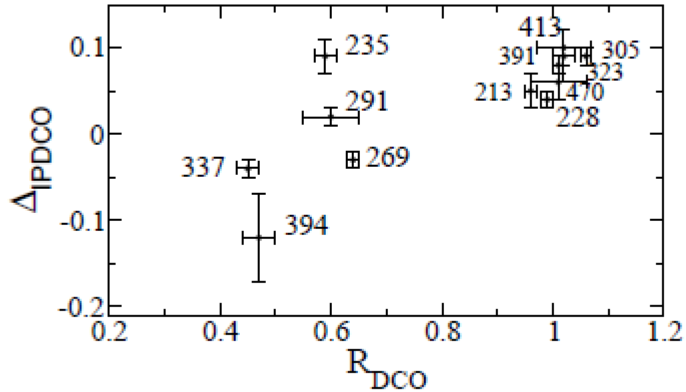
T. Roy et al., Phys. Lett. B 782 (2018) 768

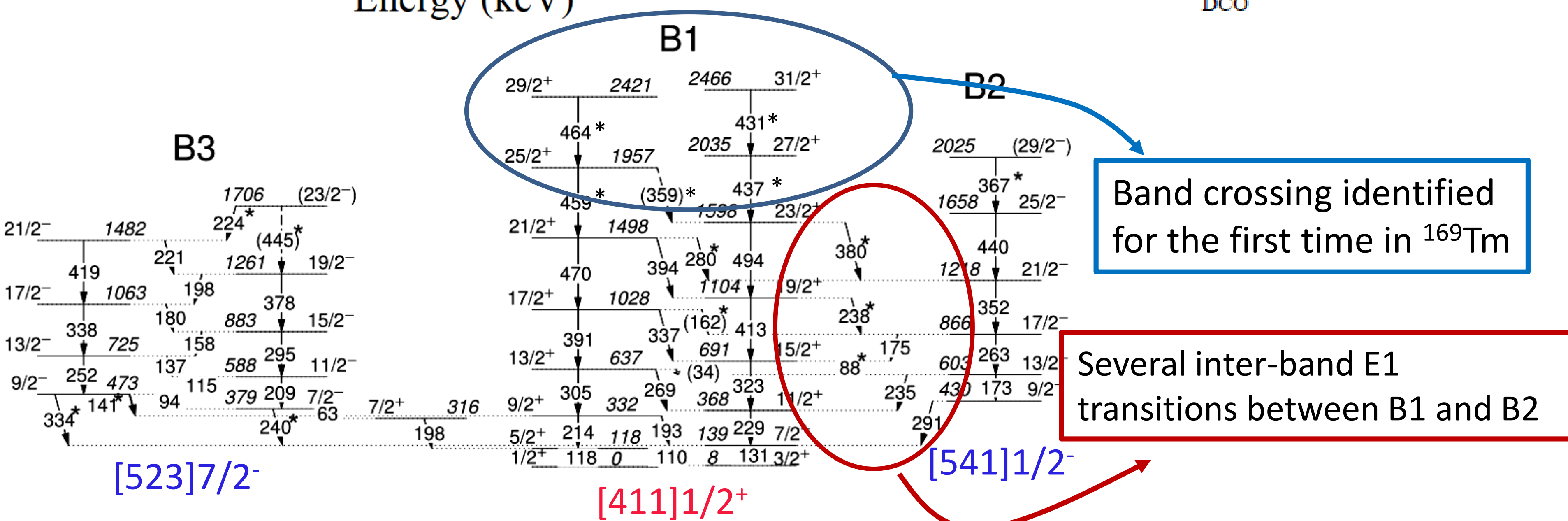
Inelastic Excitation of ^{169}Tm

^{169}Tm(^{32}S, ^{32}S')^{169}Tm*

@164 MeV at TIFR, Mumbai
using 19 clovers (INGA)

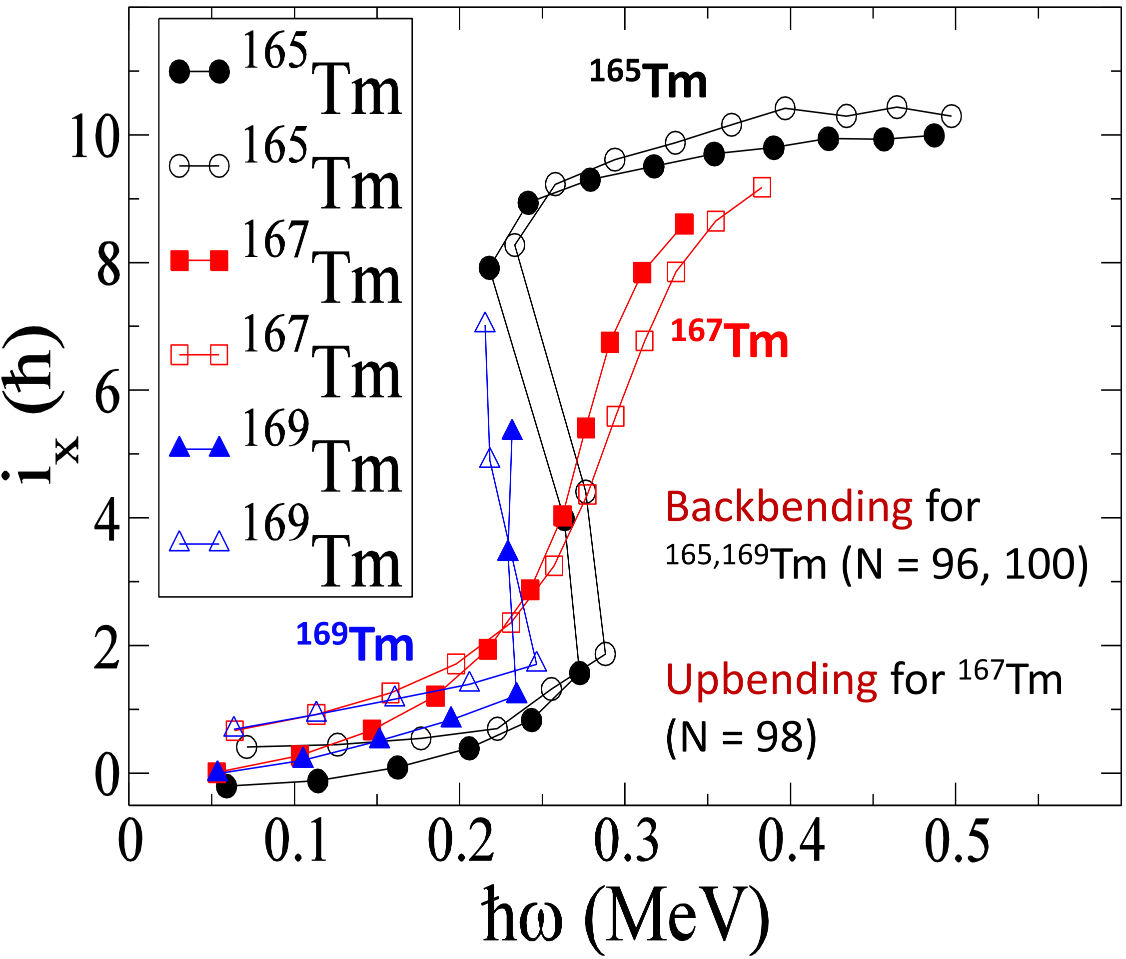


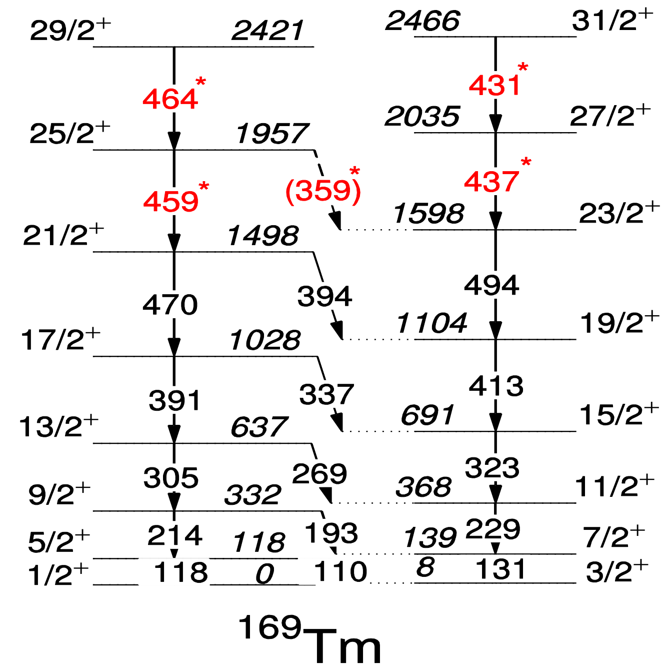




Band crossing in Tm isotopes

Md. A. Asgar, T.Roy, GM, et al. , PRC 95, 031304(R) (2017)

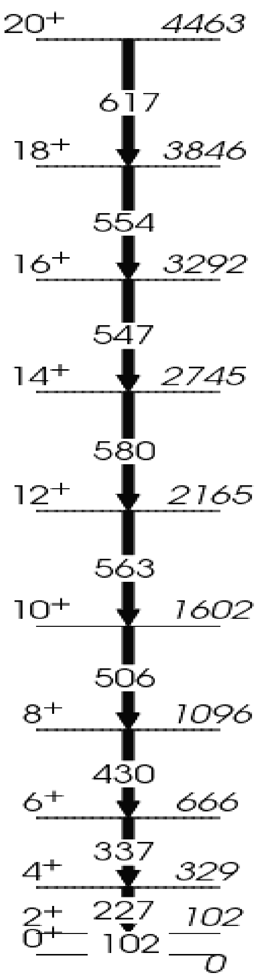


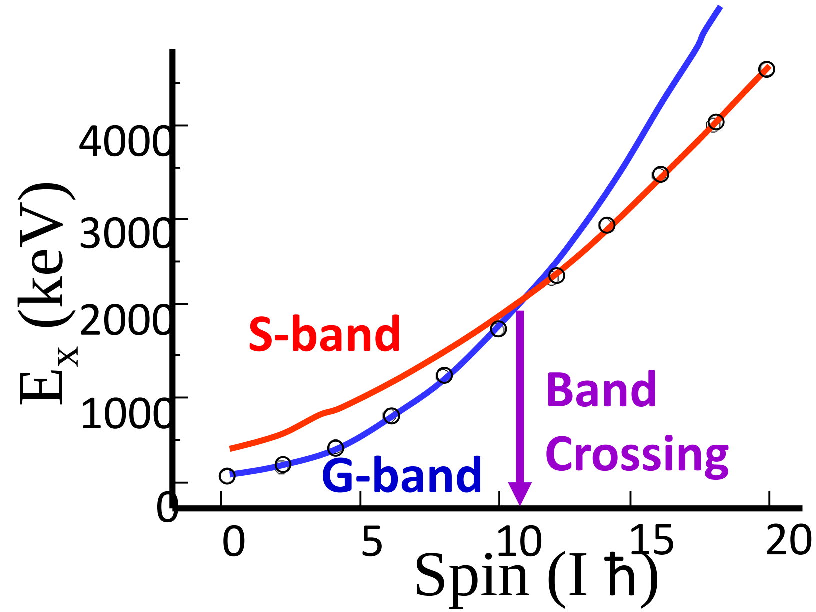


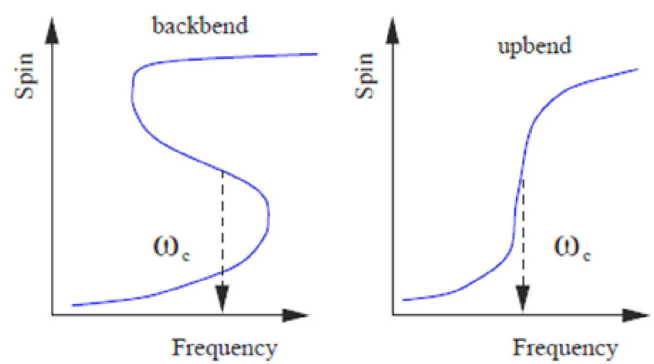
The alignment in ^{169}Tm has been found to be Back-bending in nature similar to ^{165}Tm but in contrast to its immediate neighbour ^{167}Tm.

This suggests that the interaction strength between g-band and s-band in ^{167}Tm is different (higher) than that in ^{165}Tm and ^{169}Tm.

Band Crossing in a Deformed (Midshell) nucleus







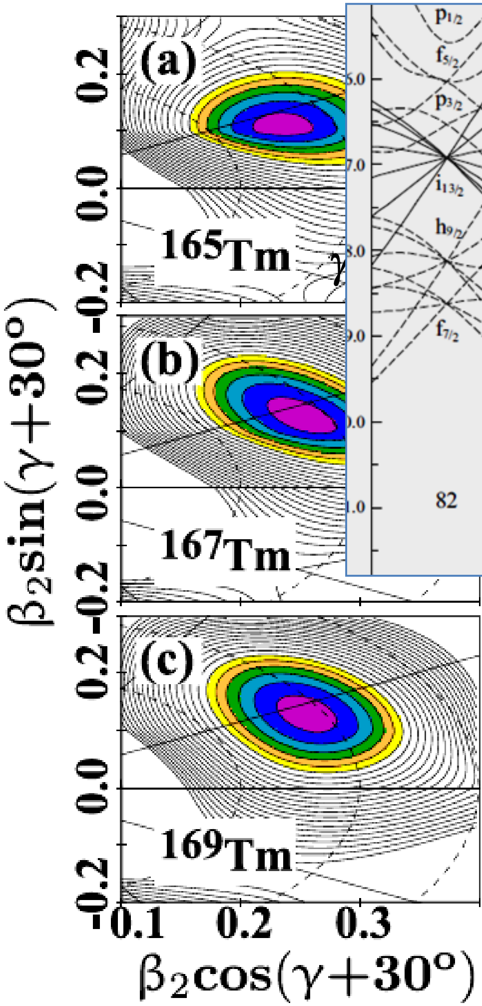
Stronger interaction

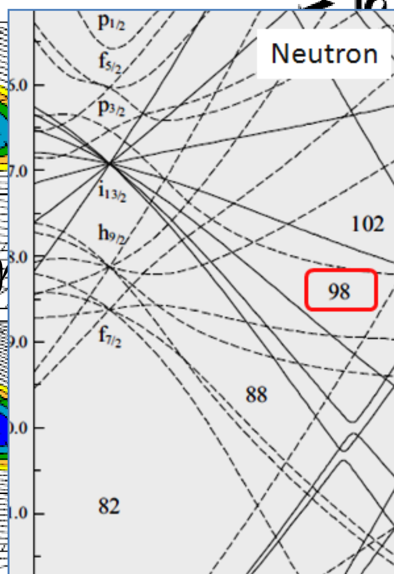
Weaker interaction

Cranked Shell Model Calculation

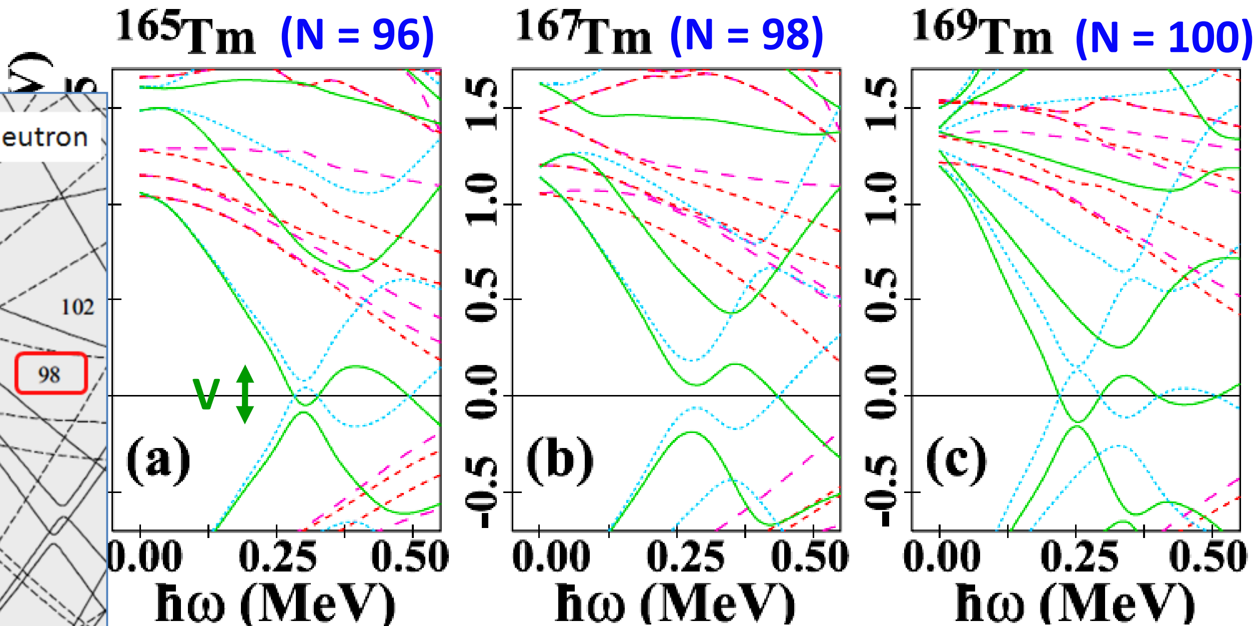
Theoretical calculations in the cranking formalism has been performed with Woods-Saxon potential and BCS pairing. **Md. A. Asgar et al. , PRC, 95, 031304(R) (2017)**

TRS : Very similar ground state shape for the Tm isotopes





Single particle Routhians for neutrons



N = 98 isotope show larger interaction strength at the band crossing ➔ forward bending

Larger V between 1-qp and 3-qp bands for N = 98 deformed shell gap

A	ω_c(exp) (MeV)	ω_c(cal) (MeV)	V (keV)
165	0.29	0.30	20
167	~ 0.27	0.28	125
169	0.24	0.25	10

Recent Evidence for N = 98 deformed shell gap

PHYSICAL REVIEW LETTERS **120**, 182502 (2018)

Masses and β-Decay Spectroscopy of Neutron-Rich Odd-Odd ^{160,162}Eu Nuclei: Evidence for a Subshell Gap with Large Deformation at $N = 98$

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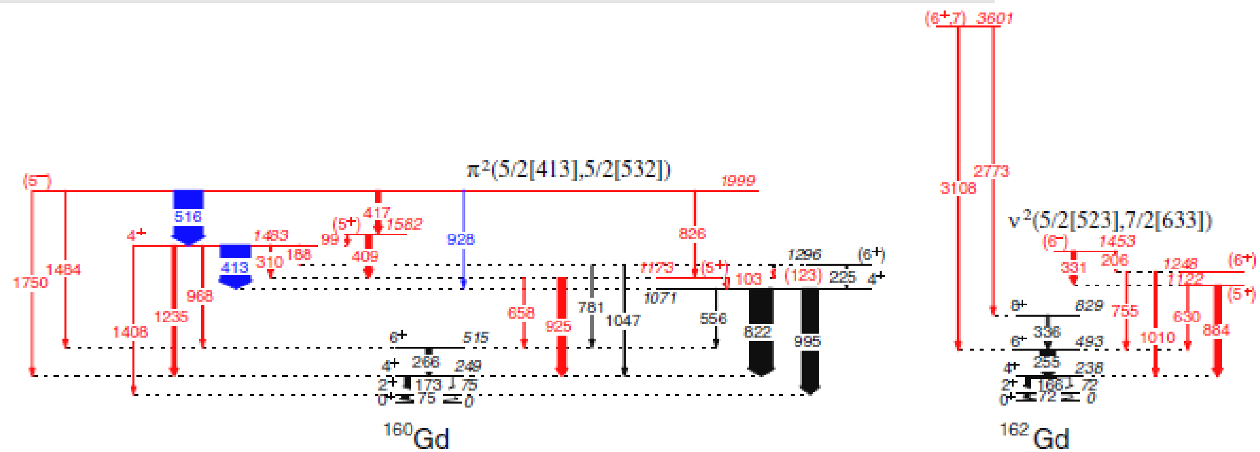
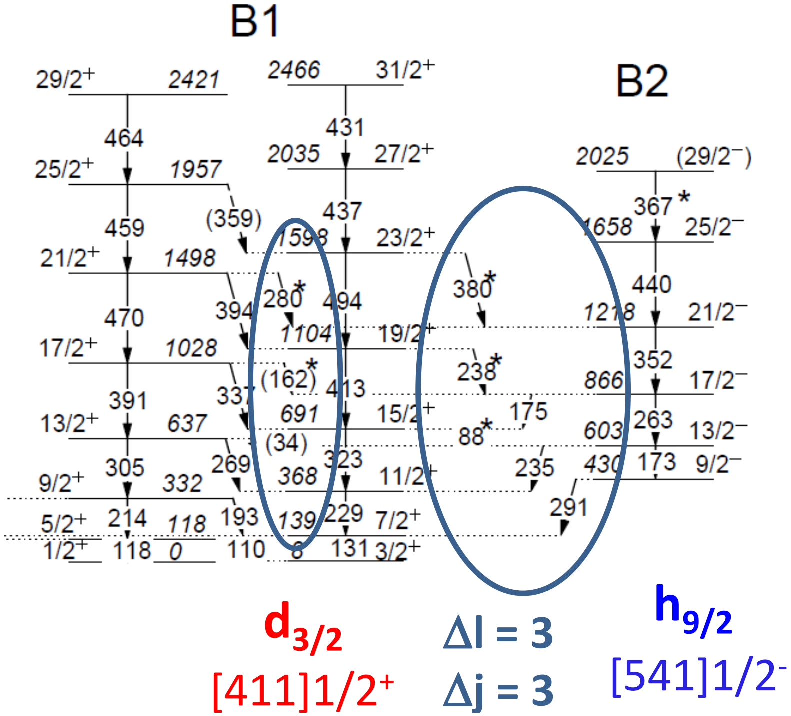
The structure of deformed neutron-rich nuclei in the rare-earth region is of significant interest for both the astrophysics and nuclear structure fields. At present, a complete explanation for the observed peak in the elemental abundances at $A \sim 160$ eludes astrophysicists, and models depend on accurate quantities, such as masses, lifetimes, and branching ratios of deformed neutron-rich nuclei in this region. Unusual nuclear structure effects are also observed, such as the unexpectedly low energies of the first 2^+ levels in some even-even nuclei at $N = 98$. In order to address these issues, mass and β-decay spectroscopy measurements of the $^{160}Eu_{97}$ and $^{162}Eu_{99}$ nuclei were performed at the Californium Rare Isotope Breeder Upgrade radioactive beam facility at Argonne National Laboratory. Evidence for a gap in the single-particle neutron energies at $N = 98$ and for large deformation ($\beta_2 \sim 0.3$) is discussed in relation to the unusual

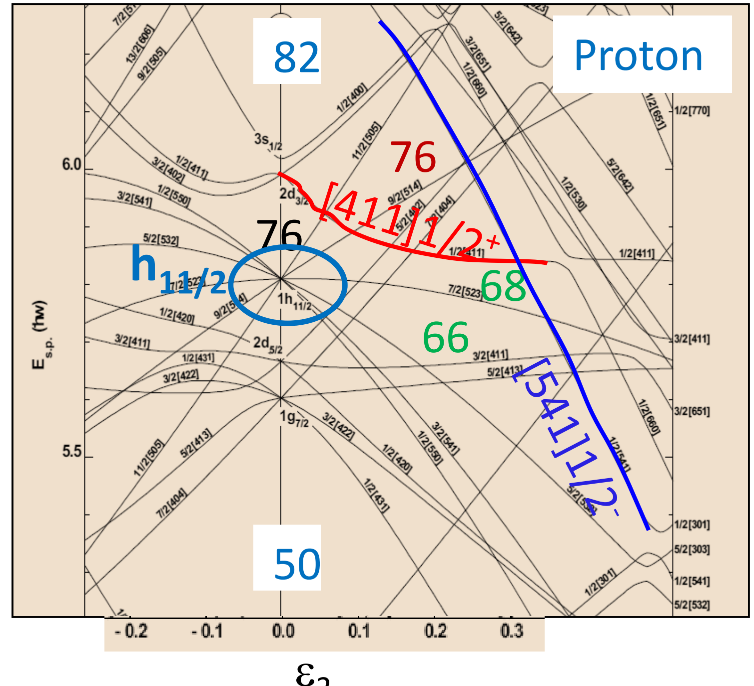
In order to explain the 2+ energies of the neutron rich even-even nuclei around Z = 64 mid-shell nuclei, the **energy gap at N = 98 at β_2 ~ 0.25** needed to be increased.

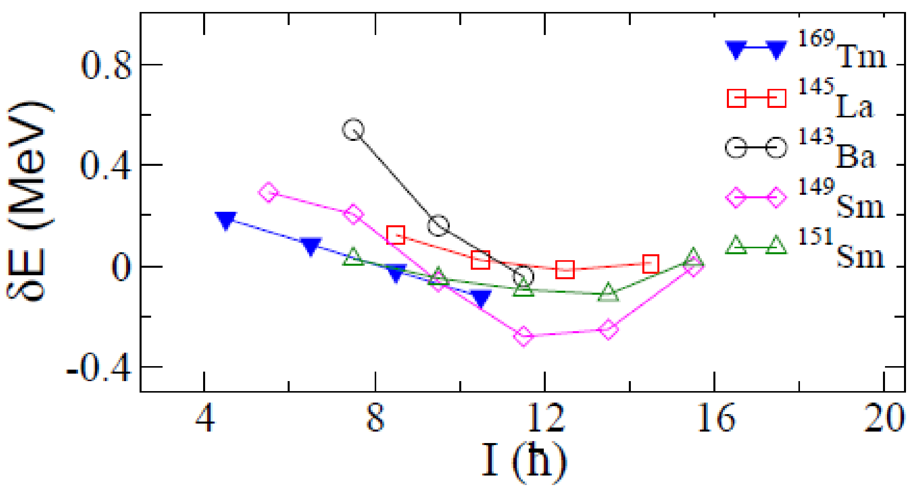
This also explains the decay properties of ^{162}Eu (N = 99) compared to ^{160}Eu (N = 97)



E1 transitions : indication of Octupole Correlation in ^{169}Tm ?







$$\delta E = E(I^-) - \frac{(I+1)E(I-1)^+ - IE(I+1)^+}{2I+1}$$

$$\frac{B(E1)}{B(E2)} = 0.771 \frac{I_\gamma(E1)}{I_\gamma(E2)} \frac{E_\gamma^5(E2)}{E_\gamma^3(E1)} (10^{-6} fm^{-2})$$

~ 0.2 – 2.0 for A = 140-150 (N ~ 88)

$\pi d_{5/2} - h_{11/2}$ $\nu f_{7/2} - i_{13/2}$

~ 0.12 – 0.44 for ^{169}Tm (N = 100)

$\pi d_{3/2} - h_{9/2}$

Contribution from protons only in ^{169}Tm !!

^{157}Tm (N = 88) would be interesting

Summary

- INGA (at VECC, TIFR and IUAC) and VENUS (VECC) setup play important roles for γ-ray spectroscopic studies in India.
- Structural changes observed both with neutron number and angular momentum for the nuclei near the shell gaps.
- Different aspect of structural phenomena have been revealed in nuclei near Z = 82 shell closure including chiral doublet bands and first observation of MχD in A = 190 region.
- Difference in the band crossing phenomena in Tm isotopes are understood from the deformed shell gap at N = 98.
- Is there octupole correlation in ^{169}Tm ?

Thank You