Effects of high j proton and neutron orbitals in nuclear structure (A~180-200)

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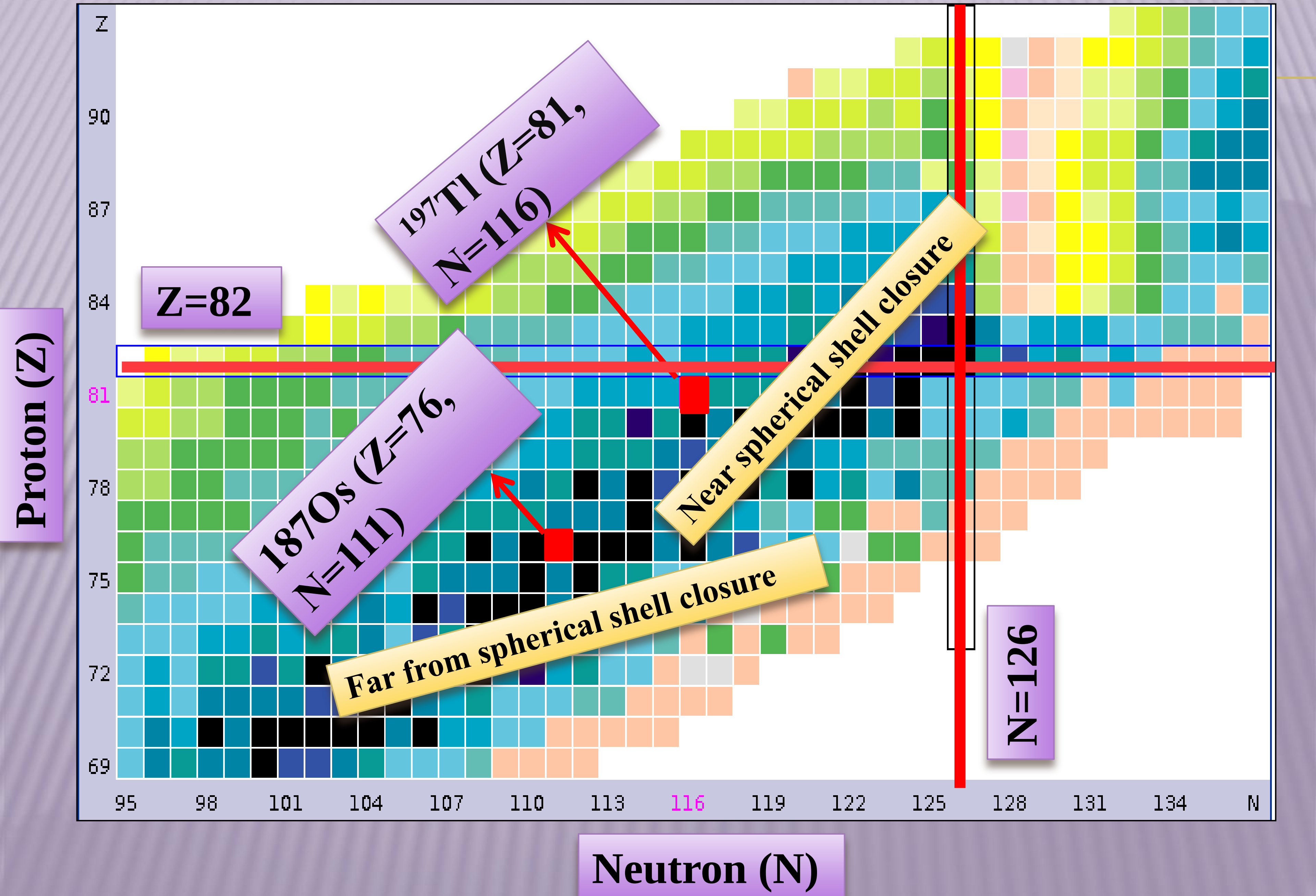
Outline

- Introduction
- Motivation to study the nuclei in mass A~180-200 region
- VENUS and INGA setup at VECC
- Results on ^{197}Tl
- Preliminary results on ^{187}Os
- Summary

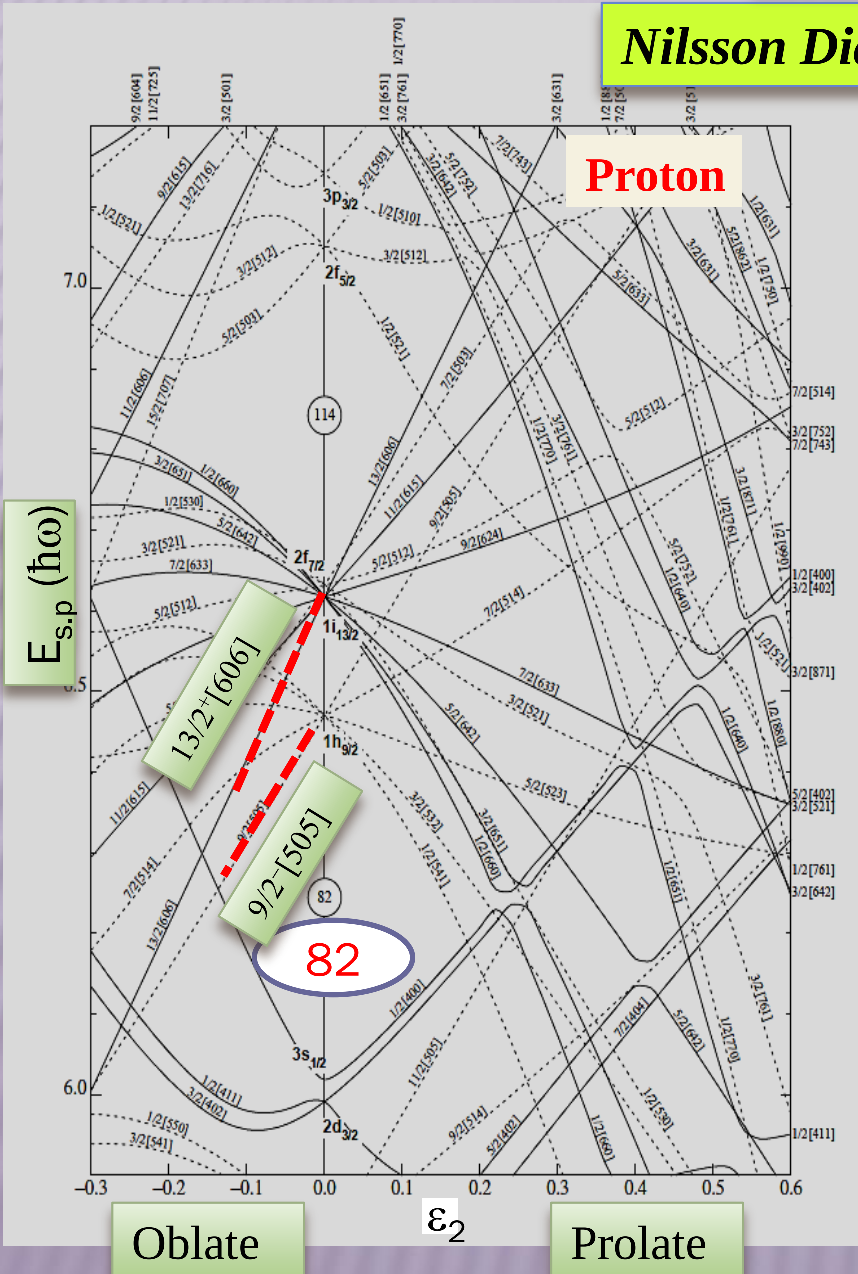
Introduction

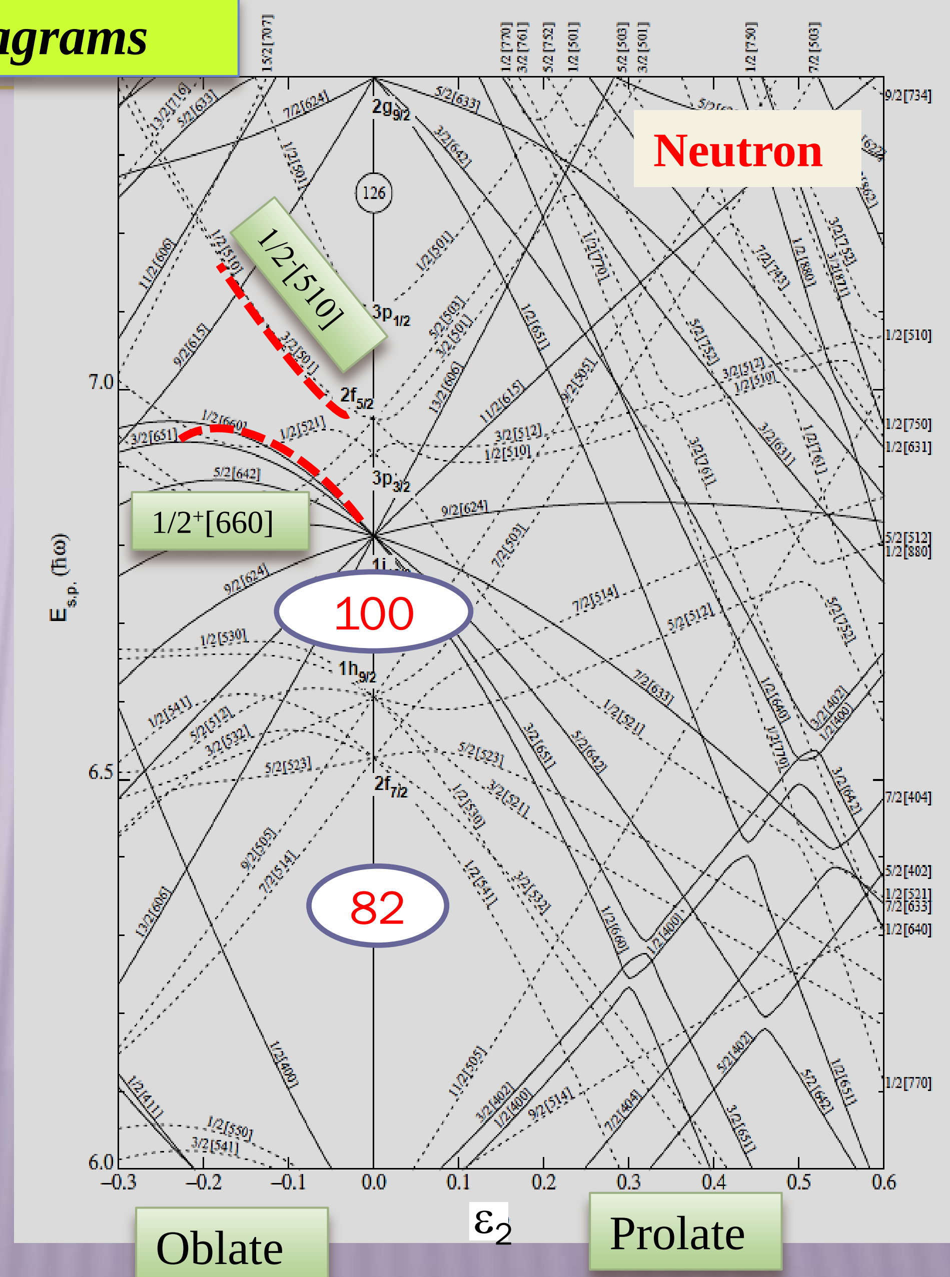
- Nucleus is a complex many body quantum system composed of protons and neutrons.
- Nucleus can be excited to higher energies and angular momenta by the excitation of a few nucleons (s.p excitation) or collective excitation (all/many nucleons involved).
- In odd A nuclei, the last unpaired nucleon goes into different single particle orbitals, based on that configuration, nucleus shows various novel excitation.
- Systematically neutron deficient Tl isotopes like **^{194}Tl, ^{195}Tl, ^{196}Tl, ^{197}Tl, ^{199}Tl, ^{200}Tl, ^{201}Tl** nuclei have been studied by our group.
- In my Ph.D, The nuclear structure of **^{197}Tl** and **^{187}Os** nuclei were studied.


Z
90
87
84
81
78
75
72
69
95
98
101
104
107
110
113
116
119
122
125
128
131
134
N
Z=82
¹⁹⁷Tl (Z=81, N=116)
187Os (Z=76, N=111)
Near spherical shell closure
Far from spherical shell closure
N=126
Proton (Z)
Neutron (N)

^{197}Tl

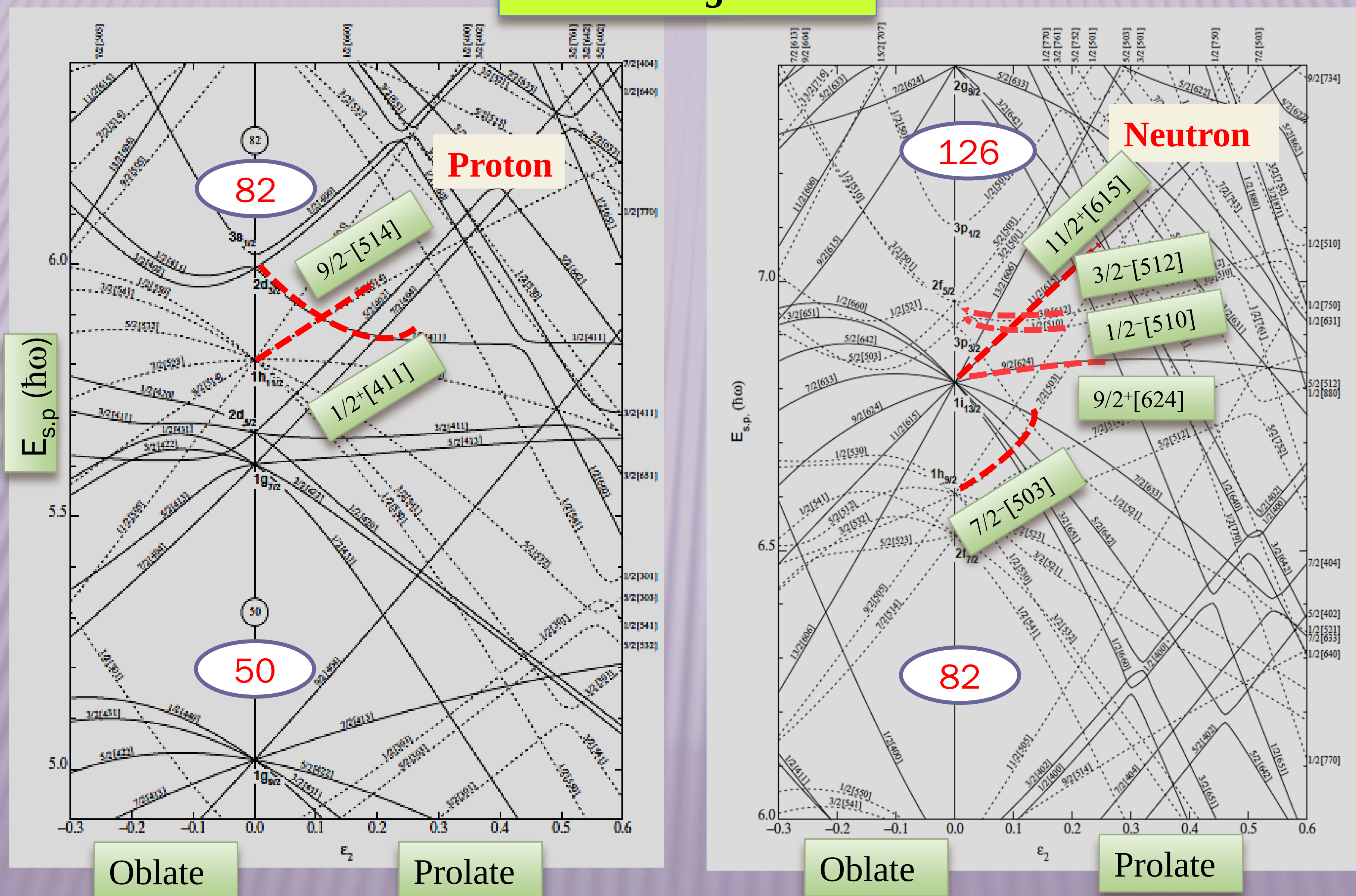
Nilsson Diagrams





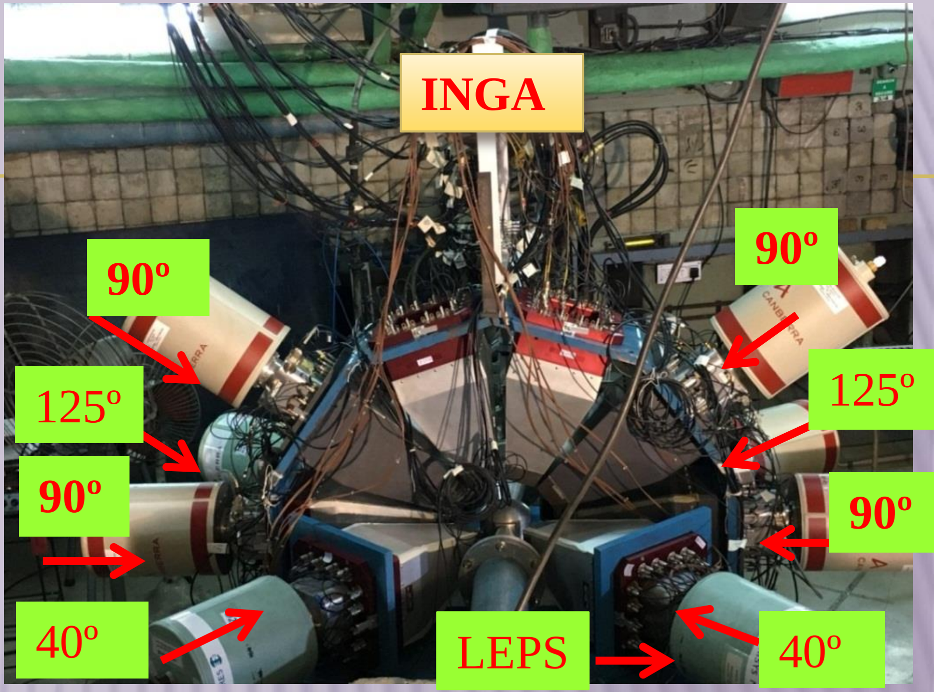
^{187}Os

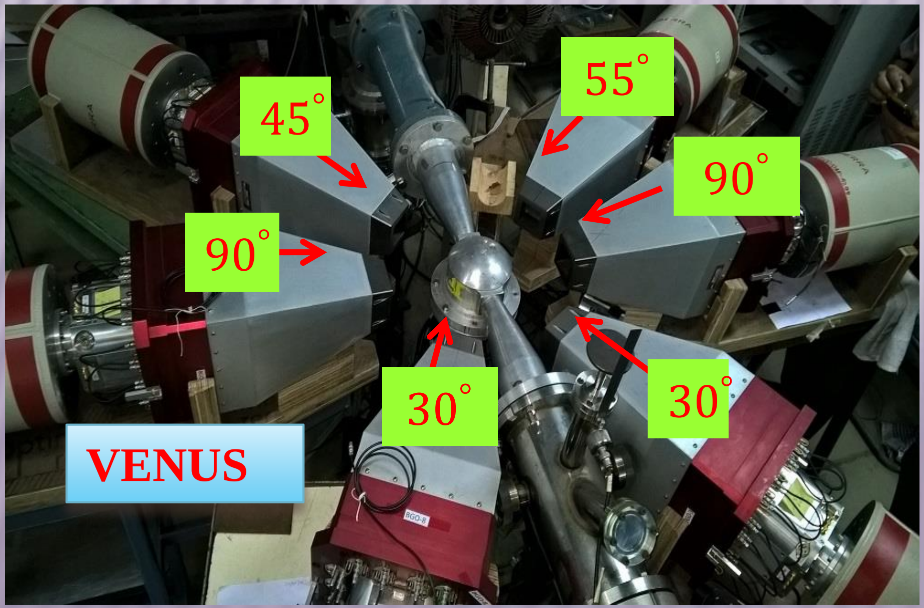
Nilsson Diagrams



VENUS and INGA setup at VECC

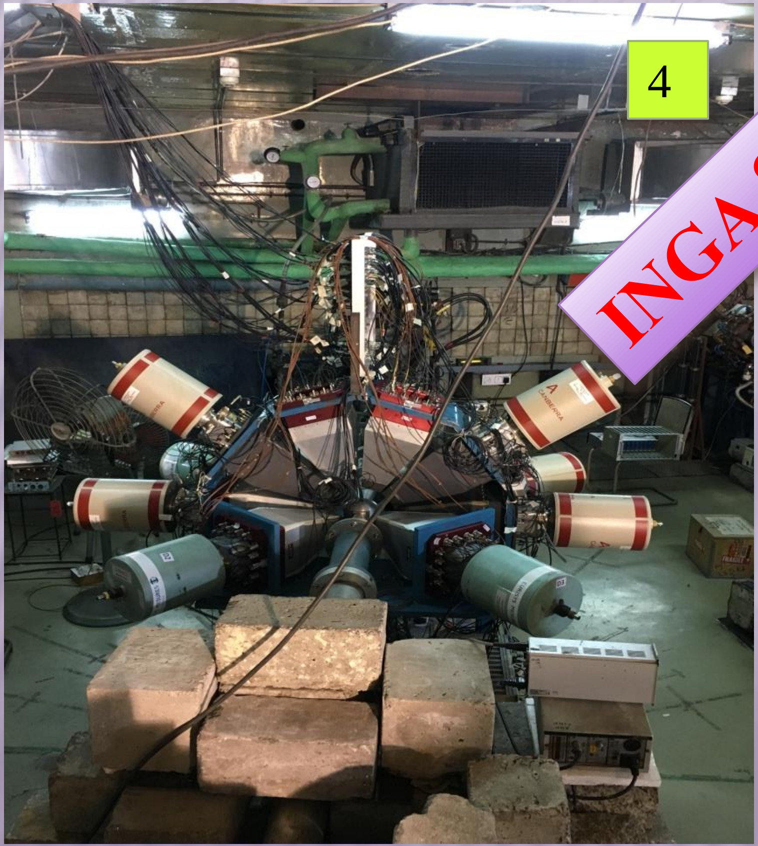
- VEcc NUclear Spectroscopy array (VENUS) contains of six Compton suppressed clover detectors.
- The absolute efficiency of the array is 1.0% at 1 MeV.



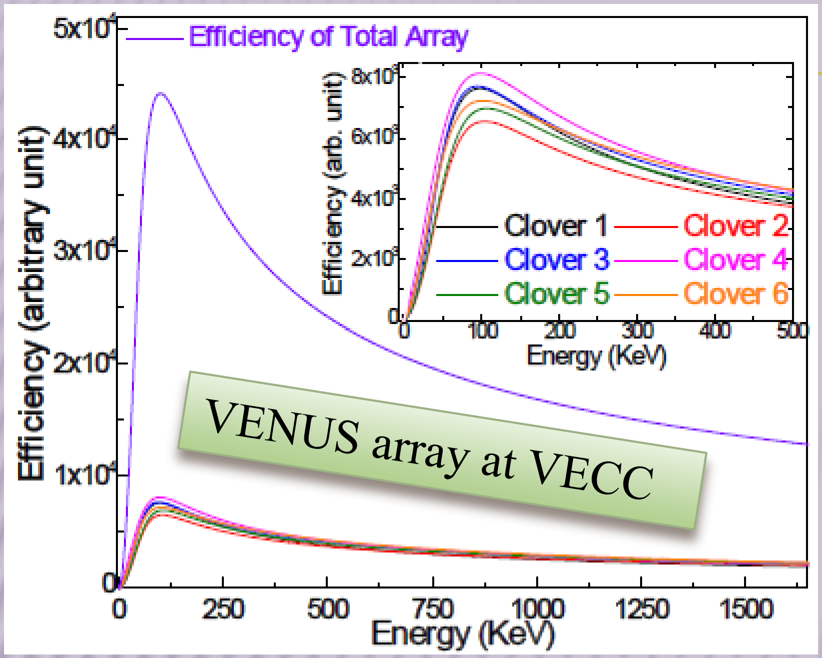


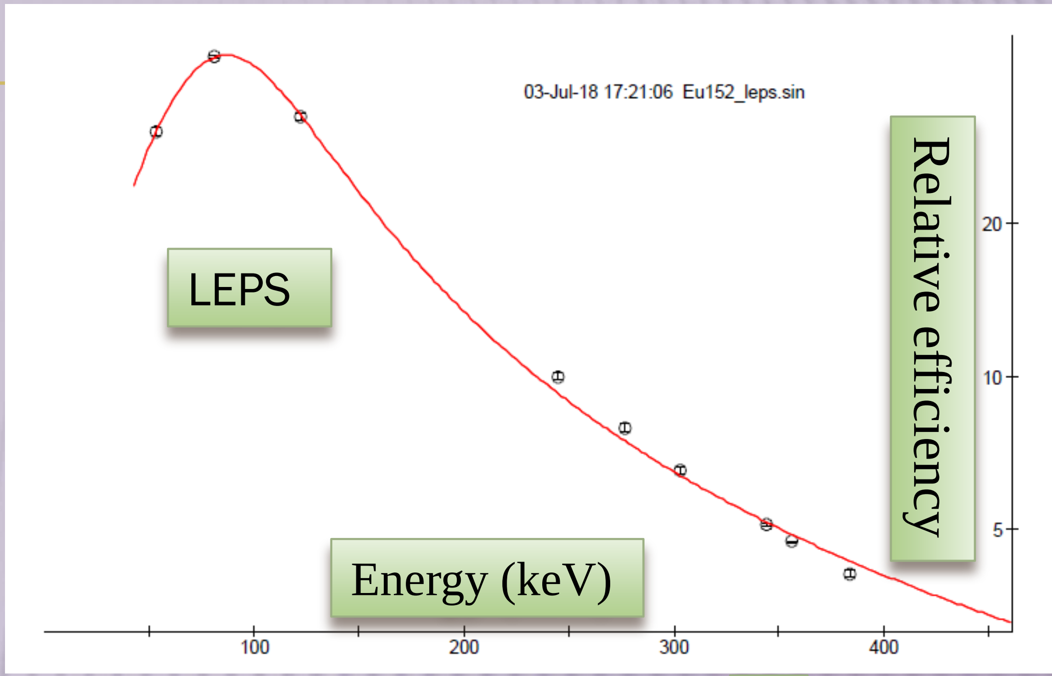
- Indian National Gamma Array (INGA) at VECC contains seven Compton suppressed clover detectors and one LEPS detector.
- The absolute efficiency of a detector in addback mode is 0.17%. for 1 MeV gamma rays.

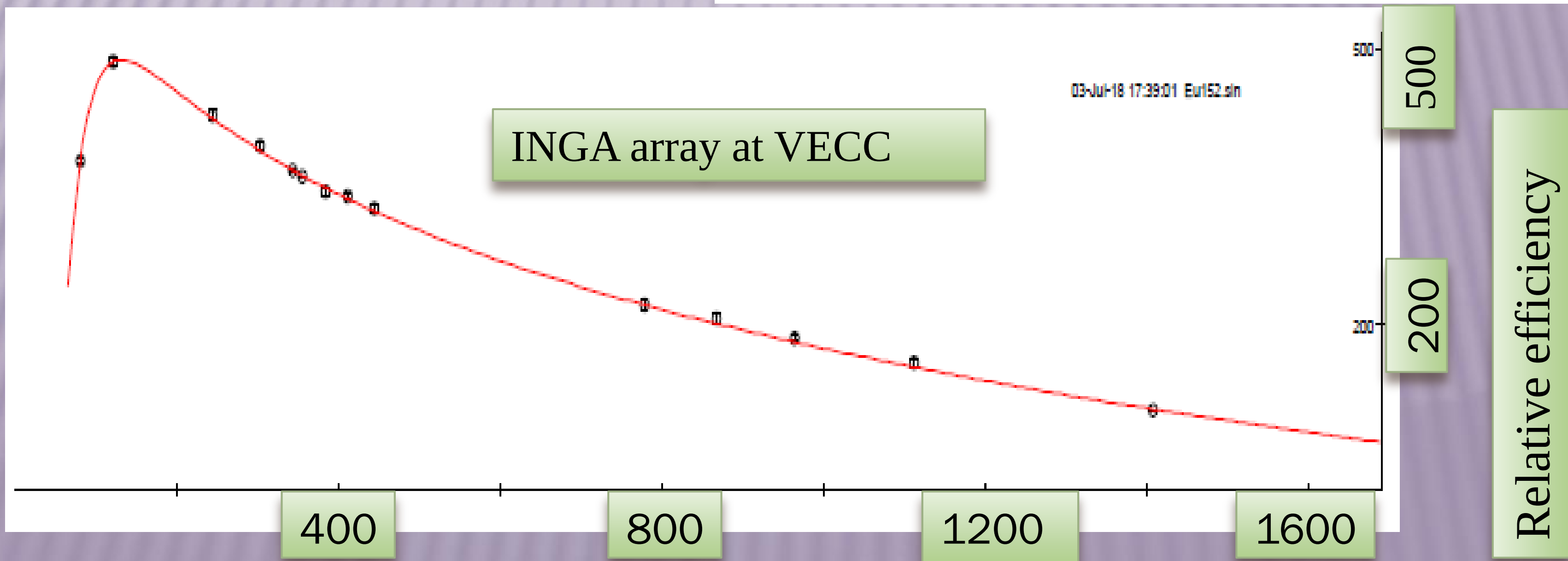
INGA Setup at VECC



Efficiency of VENUS and INGA array

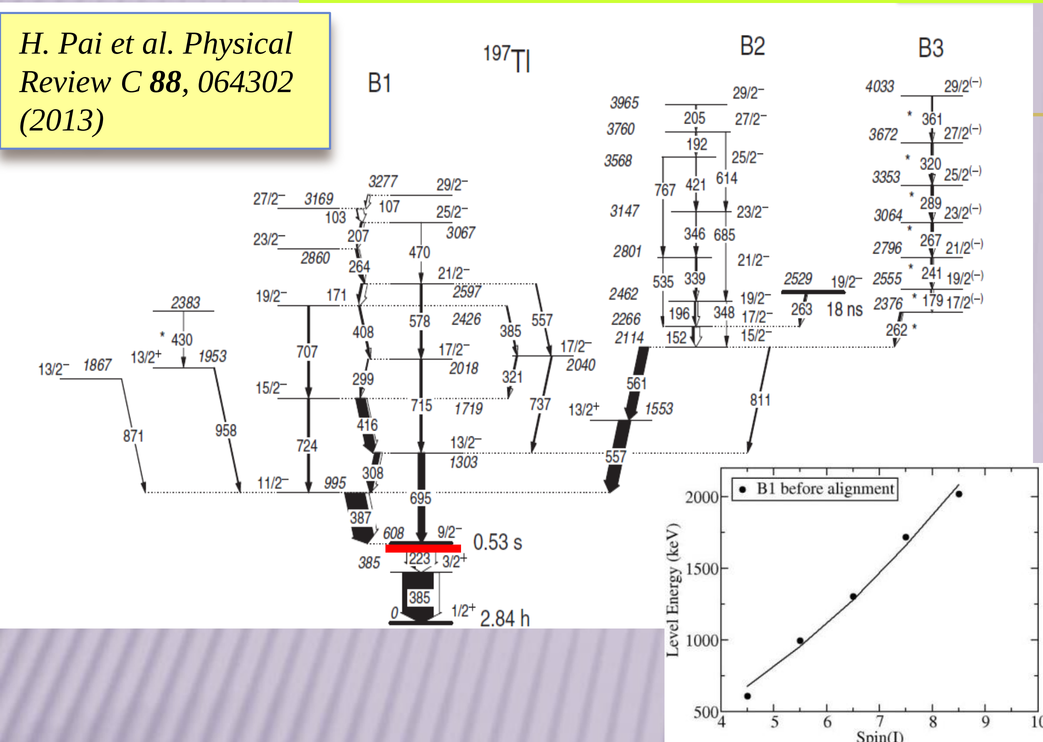






Existing information on ^{197}Tl (Z = 81)

H. Pai et al. Physical Review C ***88****, 064302 (2013)*



Exp.-1

- [^{197}Au(^{4}He, 4n)^{197}Tl] at 51 MeV
- One Ge(Li) with C. S. and a small (11%) planar Ge detectors.

R. M. Lieder et al. Nucl. Phys. A ***299*** *(1978) 255-284*

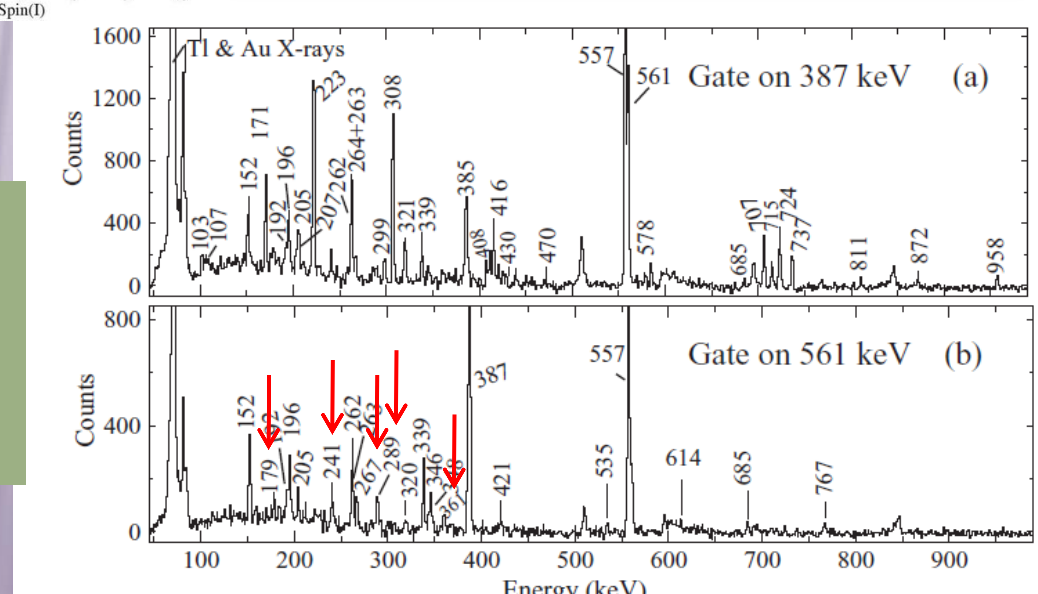
Exp.-2

- [^{197}Au(^{4}He, 4n)^{197}Tl] at 48 MeV
- One HPGe and one CLOVER detector.

H. Pai et al. Physical Review C ***88****, 064302 (2013)*

Issues remain to be solved

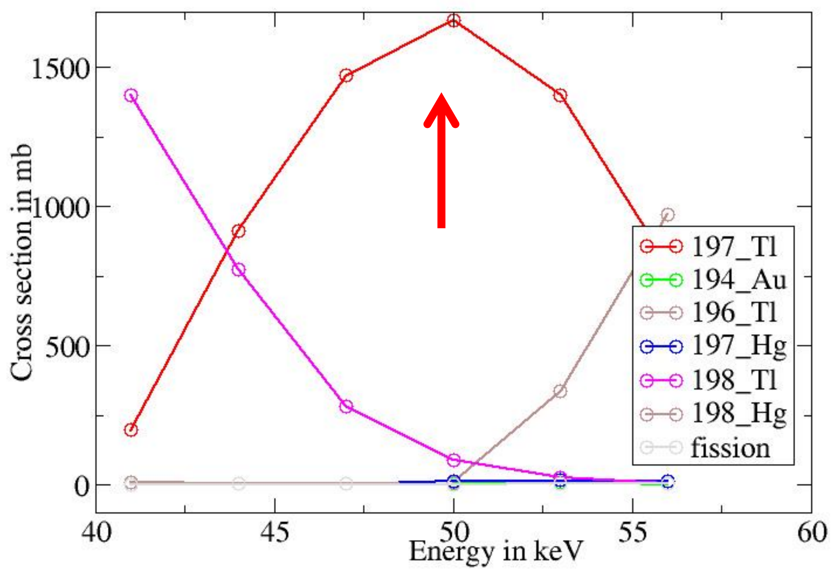
- Effect of unpaired neutron in $i_{13/2}$
- Spin and Parity of the band B2
- Coincidence relation in band B3
- Position of intruder $\pi i_{13/2}$ state



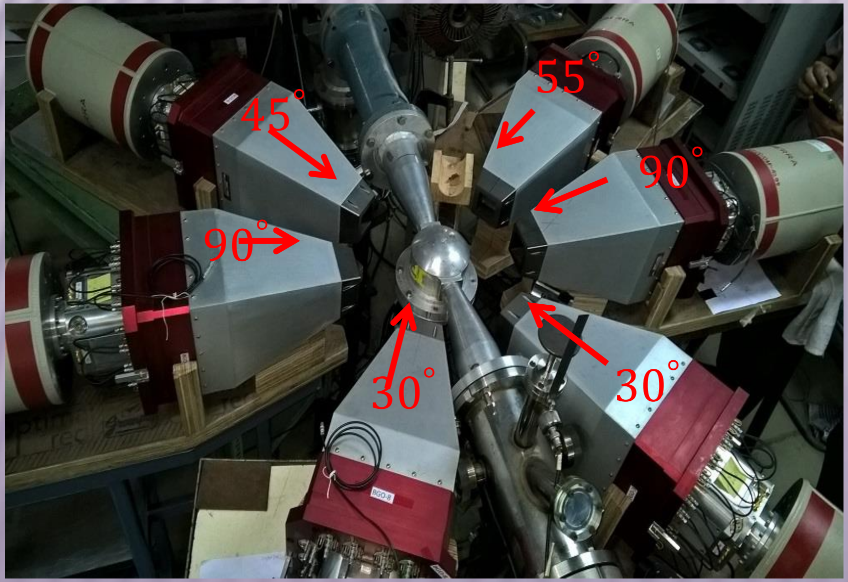
New investigation on ^{197}Tl

A new experiment has been performed at VECC to address the unsolved issues

- Reaction:- **[$^{197}Au(^4He, 4n)^{197}Tl$] at 50 MeV**
- Beam:-^4He
- Target:-^{197}Au of thickness 5mg/cm^2
- Detector:-**VENUS** array of Six Compton suppressed Clover detectors.



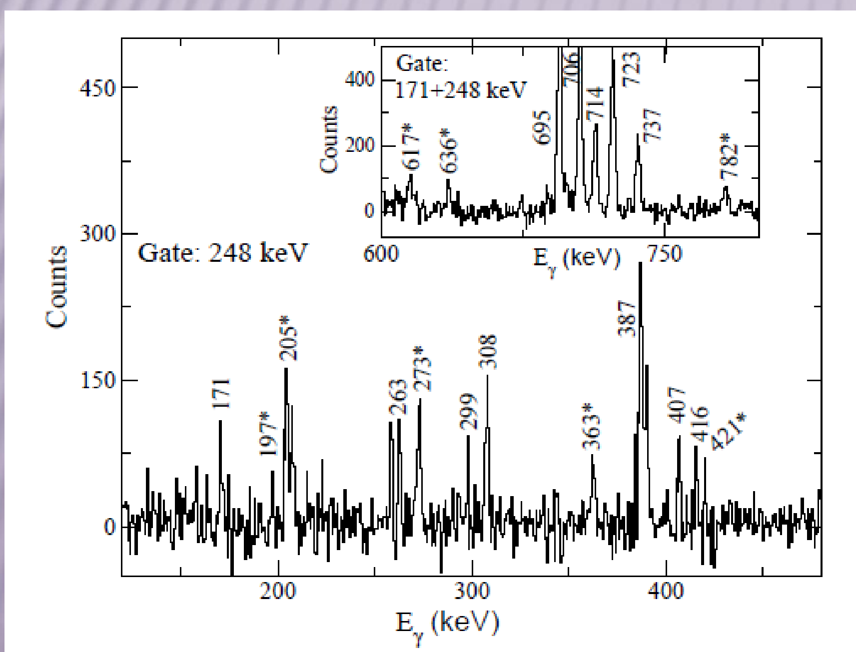
The excitation function of ^4He + ^{197}Au reaction as calculated from PACE-IV

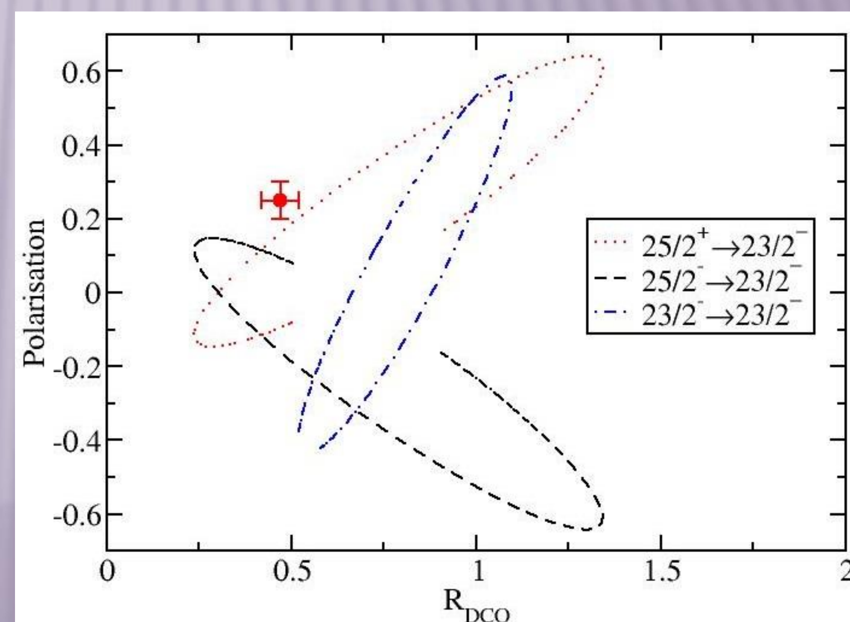


- Various γ-γ matrices were constructed to build the level scheme.
- The multipolarity and the type of the gamma rays assigned using DCO, IPDCO and angular distribution measurement.

Newly observed band B in ^{197}Tl

- A new level scheme has been proposed with placement of several new γ lines.
- A new band structure (band B) has been identified on top of the 2858-keV, $23/2^-$ state.
- J^π of the band head has been assigned from the R_{DCO} and P measurement of the 248-keV transition (found to be E1).
- All the γ rays are confirmed in the single gate of 248 keV.





Comparison between two possible configurations for Band B

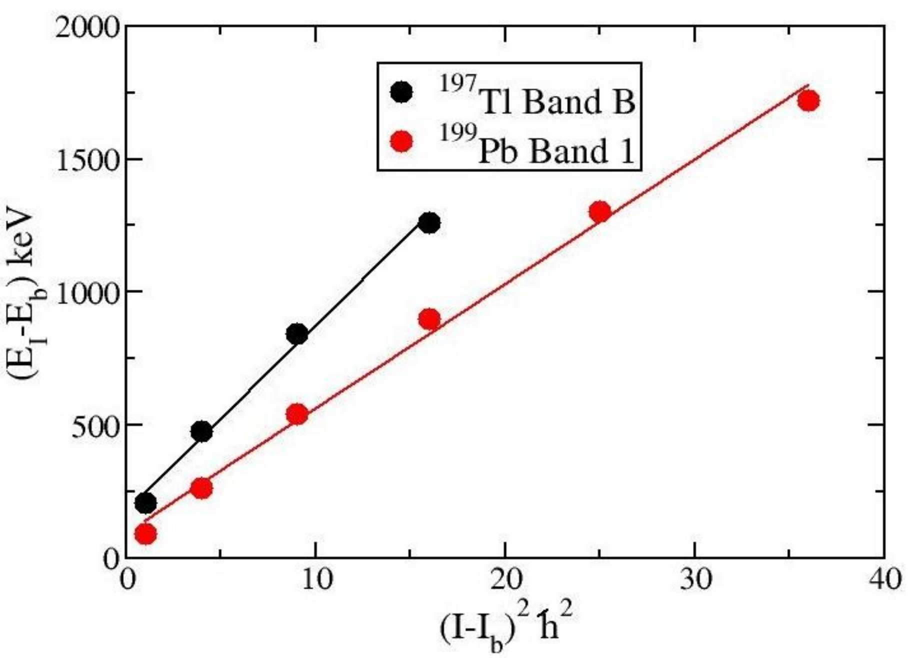
	Experimental Observation (band B)	Configuration 1	Configuration 2
Config.		$\pi h_{11/2}^{-1} \otimes \nu i_{13/2}^{-1}\ \nu(p_{3/2},f_{5/2})^{-1}$	$\pi i_{13/2}^{+1} \otimes (\nu i_{13/2})^{-2}$
Excitation energy	3106 keV	3522 keV (estimated)	3062 keV (estimated)
g factor	0.49(2) (form B(M1)/B(E2) ratio)	0.34	0.44
Nature of band	Strongly Coupled / MR	Decoupled (Proton hole in low Ω orbital)	Strongly Coupled (Proton particle in high Ω orbital)
		Observed in odd-A Au isotopes	Observed in odd-A Bi after neutron alignment

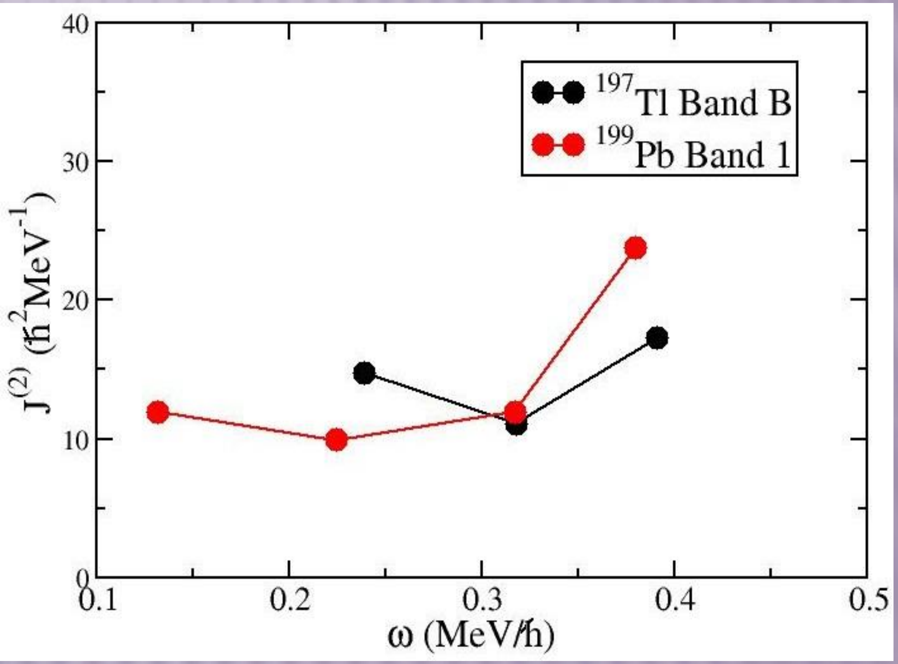
Adopted Configuration : $\pi i_{13/2}^{+1} \otimes (\nu i_{13/2})^{-2}$: 1-particle ⊗ 2-hole

➔ MR Band ?

Nature of band B

- E_I-E_b vs $(I-I_b)^2$ of band B in ^{197}Tl compared with already established MR band in ^{199}Pb.
- Band1 in ^{199}Pb reported as a magnetic rotational band of configuration $\pi h_{9/2}^{+1} \pi i_{13/2}^{+1} \otimes \nu i_{13/2}^{-1}$.
- The typical values of dynamic moment of inertia for a MR band in this mass region are **10-30** $\hbar^2/MeV^{-1}$





- Band B with $\pi i_{13/2}^{+1} \otimes (\nu i_{13/2})^{-2}$ configuration might be a MR band

- According to Macchiavelli et al. the neutron and proton angular momentum coupled to generate spin I and interacting via $V_2 P_2 \cos(\theta)$.
- The excitation energy with respect to band head energy vs shears angle has been plotted and fitted by equation-

$$V\big(I(\theta)\big) = E_I - E_b = \left(\frac{3}{2}\right) V_2 \cos(\theta_I)^2$$

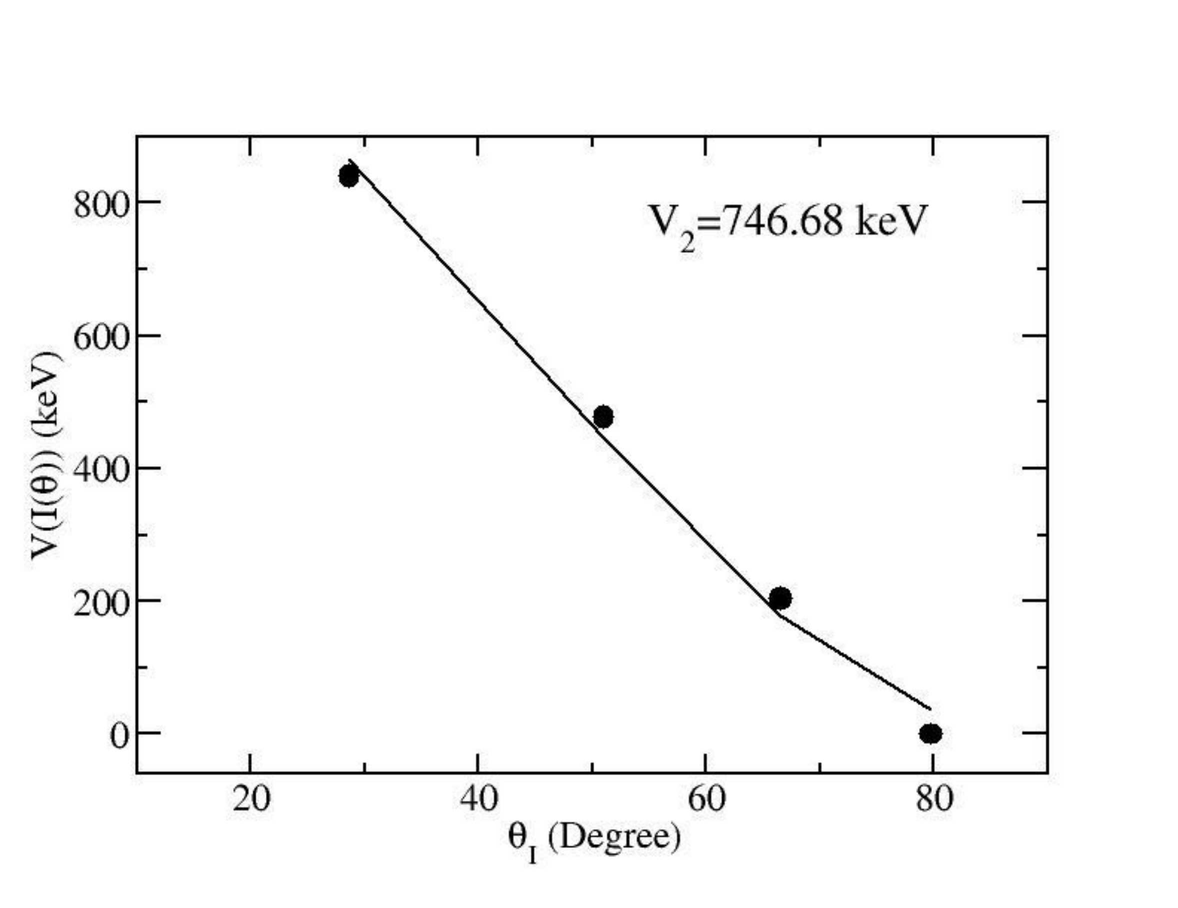
- **$V_2^{1p\text{-}2h}$ =746.68 keV**

(for 2 particle-hole pairs)

➔ Av. (per p-h pair)

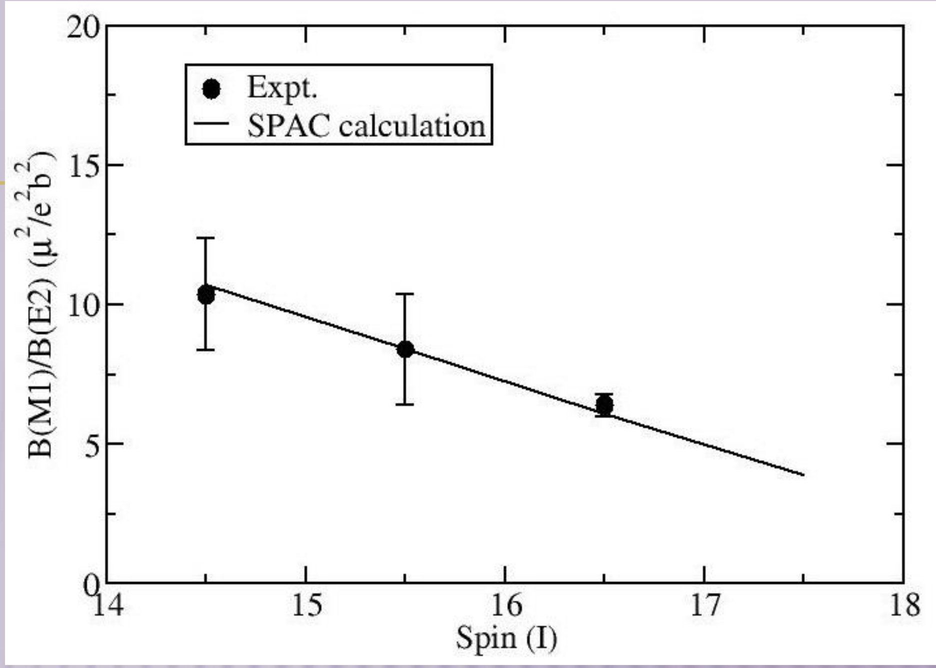
$V_2^{1p\text{-}1h}$ =373.34 keV

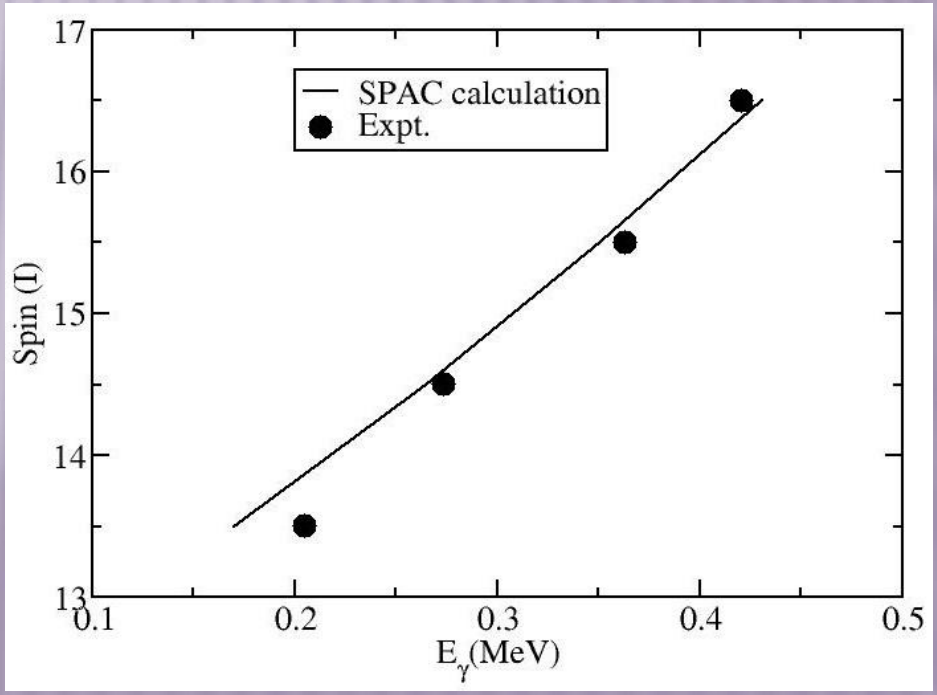
- This compares well with the typical value of Av. 1p-1h interaction strength in Pb region is **$V_2^{1p\text{-}1h} \sim$ 300 keV**



SPAC Calculation

- SPAC (Shears with principle axis crancking) calculation was done for band B.
- The calculated B(M1(/B(E2) ratio and gamma energy with spin compared with the experimentally measured values.



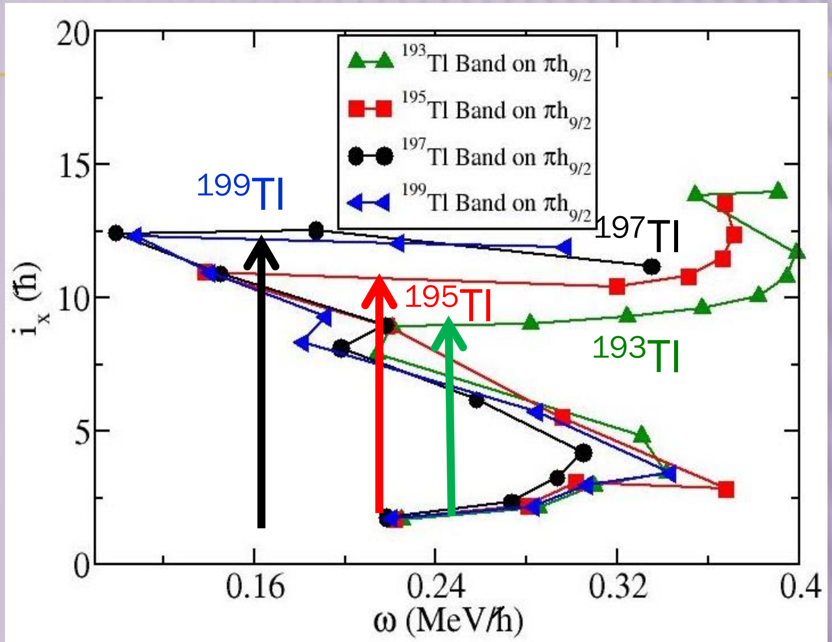


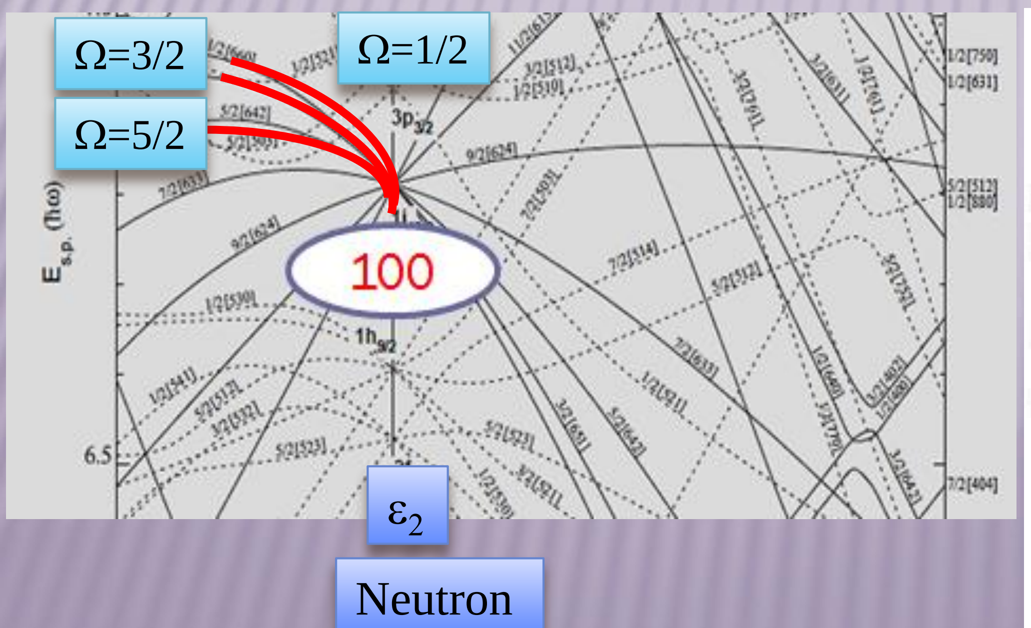
- Values of input parameters used for SPAC calculations are:-

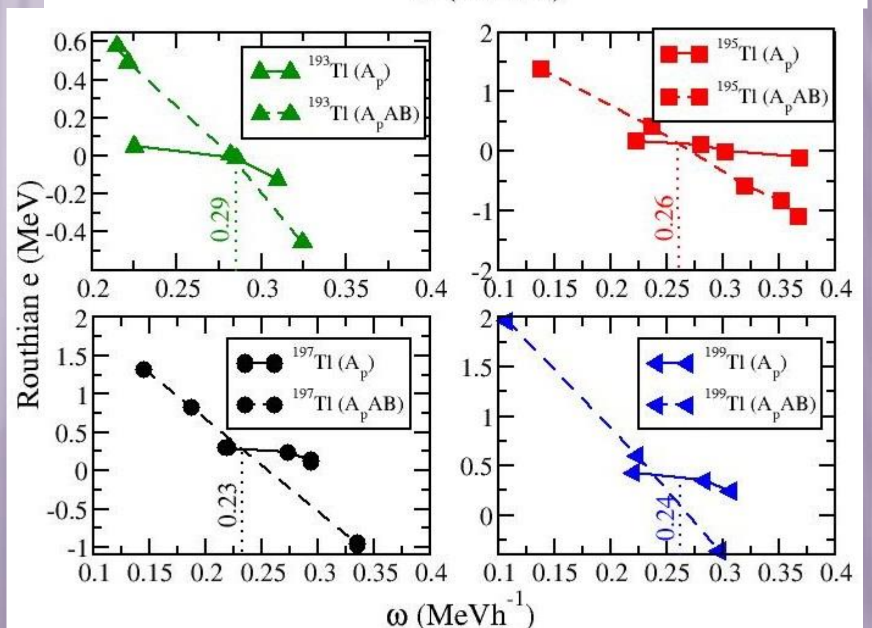
V_2 =1.05MeV
J_π=5.5$\hbar$
J_ν=10$\hbar$
Core Moment of inertia=5.5 $\hbar^2$/Mev

Observation of Neutron alignment in the band based on $\pi h_{9/2}$

- Neutron pair alignments in $h_{9/2}$ band in Tl nuclei are compared.
- Gain in alignment increases with neutron number until ^{197}Tl and saturates afterwards.
- The crossing frequencies (ω_c) are obtained from the experimental Routhians.
- ω_c decreases with the increase in neutron number up to ^{197}Tl.

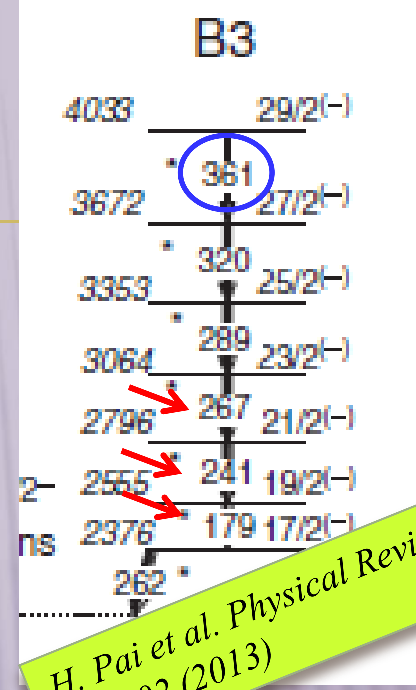




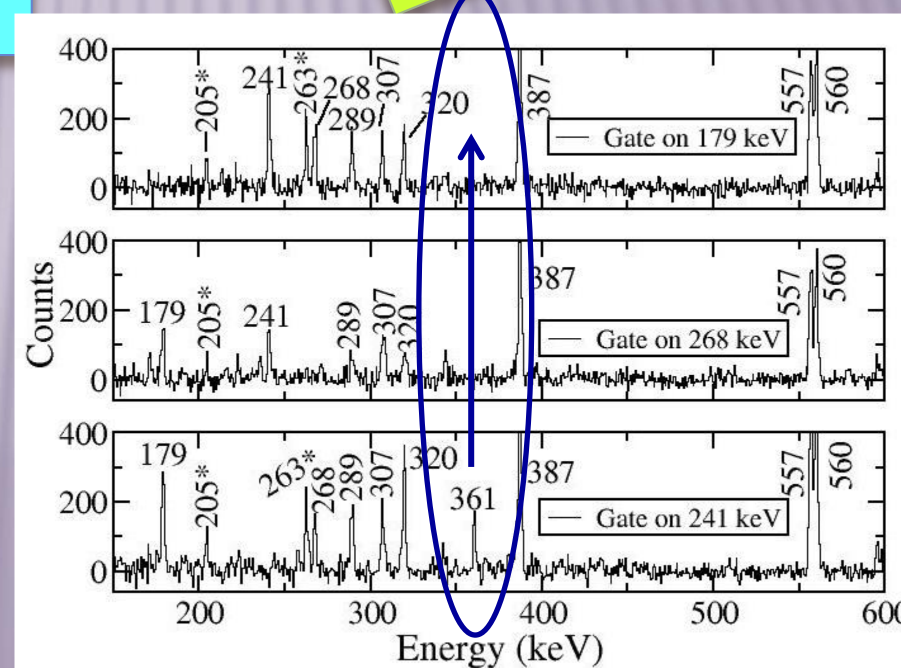


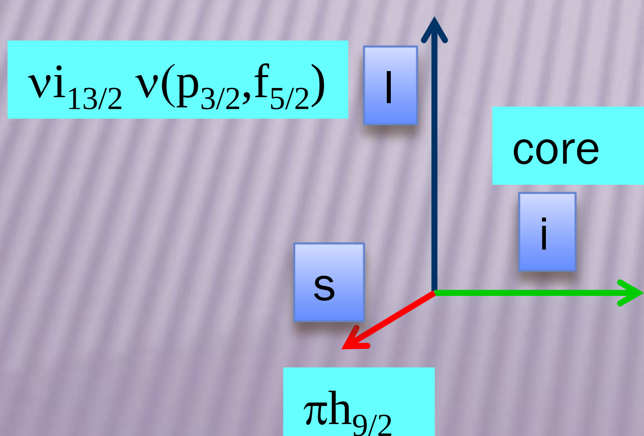
Modification and discussions on band B3

- The gated spectrum shown below shows that the band B3 needs modification.
- Band B3 has been modified and extended using coincidence relation and intensity argument.
- The assigned configuration for band B3 is $\pi h_{9/2} \otimes \nu i_{13/2}\ \nu(p_{3/2}, f_{5/2})$.



H. Pai et al. Physical Review C **88**, 064302 (2013)

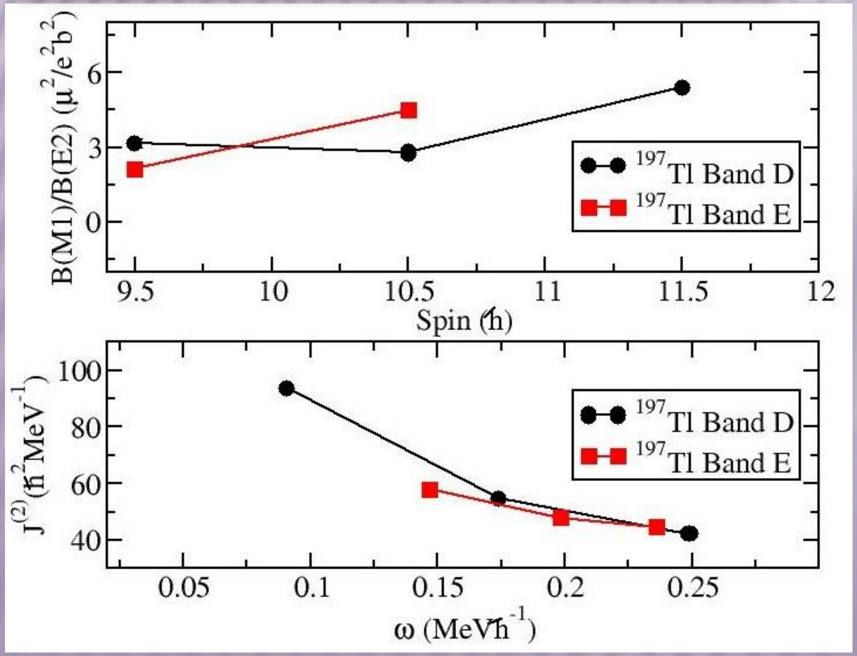


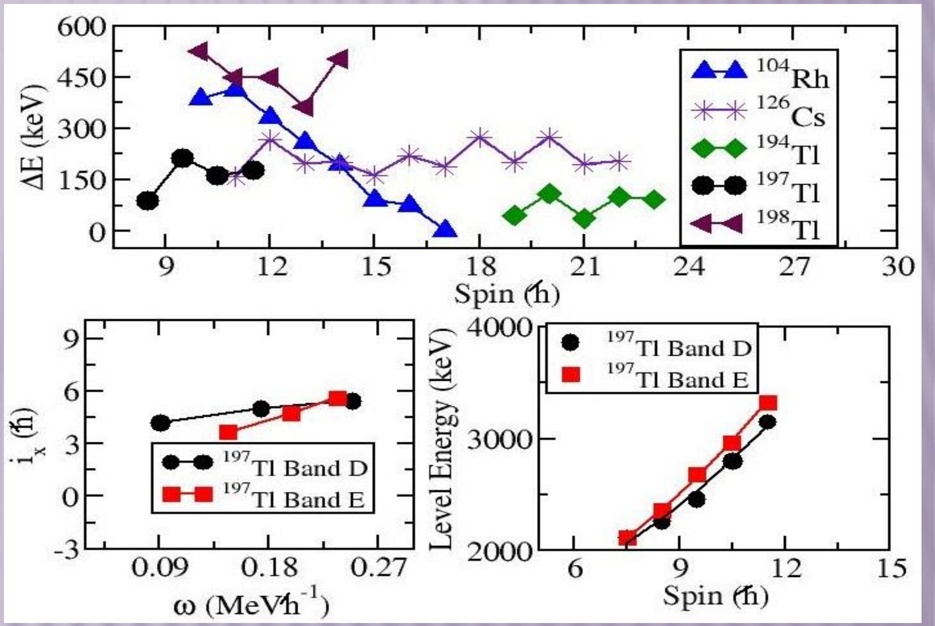


Indication of chirality in ^{197}Tl

- The modified band B3 possibly a chiral partner band of previously observed band B2 by H. Pai et. al.
- The connecting transitions between the bands were not found. It may be due to low statistics.

- Conf.=$\pi h_{9/2} \otimes \nu i_{13/2} \otimes \nu(p_{3/2}, f_{5/2})$
- High $\Omega = \pi h_{9/2}$
- Low $\Omega = \nu i_{13/2} \otimes \nu(p_{3/2}, f_{5/2})$



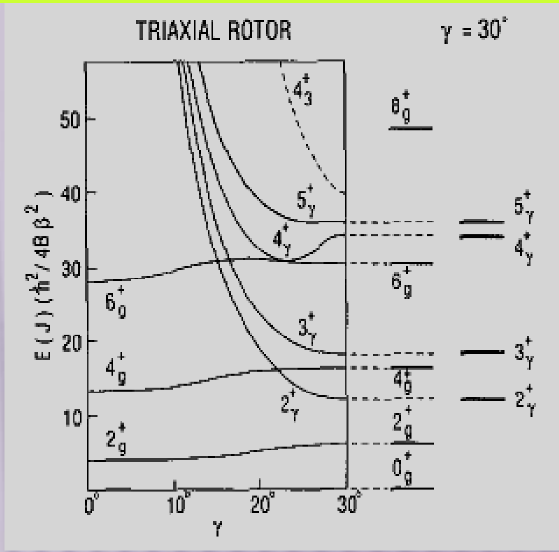


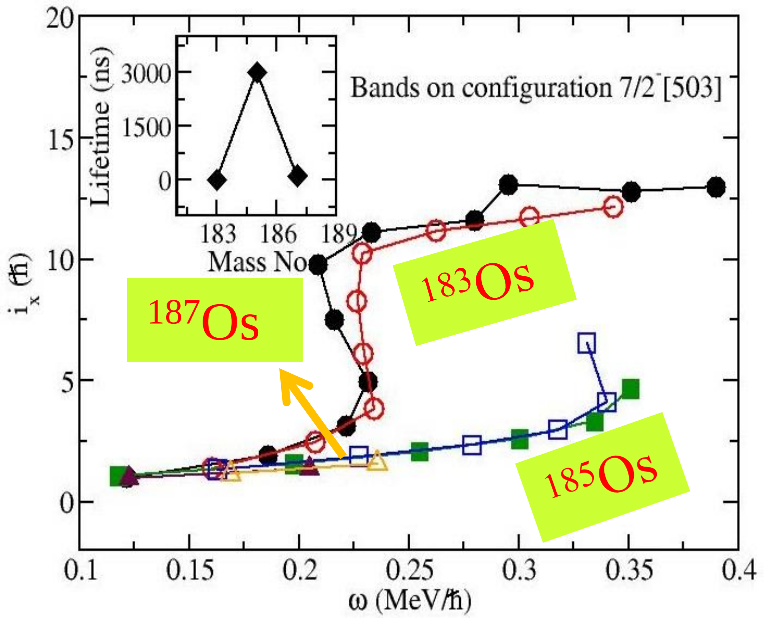
Study of the excited states in ^{187}Os

Motivation

1. Os (Z = 76) nuclei lie in the region of nuclei with gamma-soft and triaxial shapes.
2. The triaxiality in a nucleus manifested by different modes of excitation like gamma band, doubly degenerate band structure, Wobbling band etc.
3. The neighboring even-even core nucleus ^{186}Os has a gamma band and has been interpreted with a significant gamma deformation.
4. It would be interesting to study the effect of unpaired neutron on triaxial core.
5. For the 7/2$^-$[503] band, a much delayed crossing has been observed in ^{185}Os (N=109) compared to ^{183}Os (N=107). Data on ^{187}Os (N=111) is limited below the band crossing.

A S Davydov et al. Nucl. Phys. ***8*** *(1958) 237*

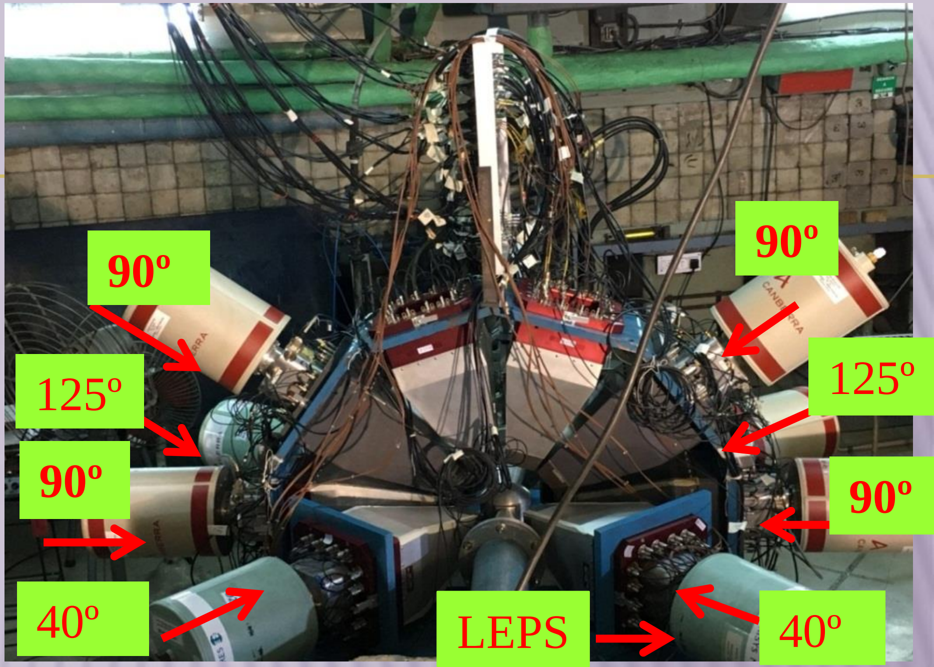


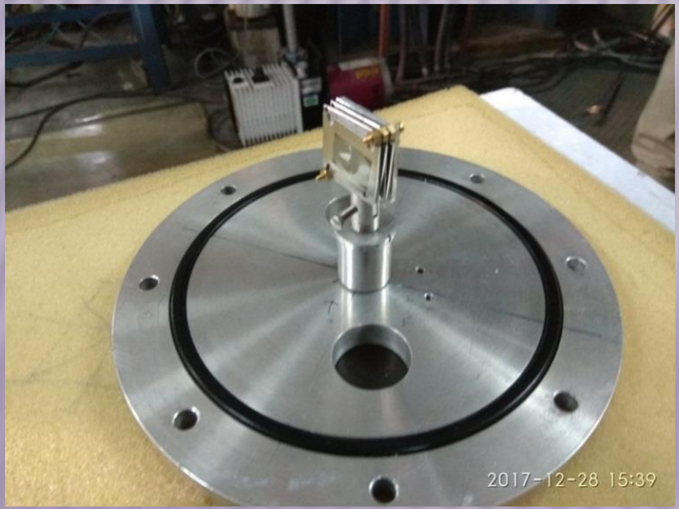


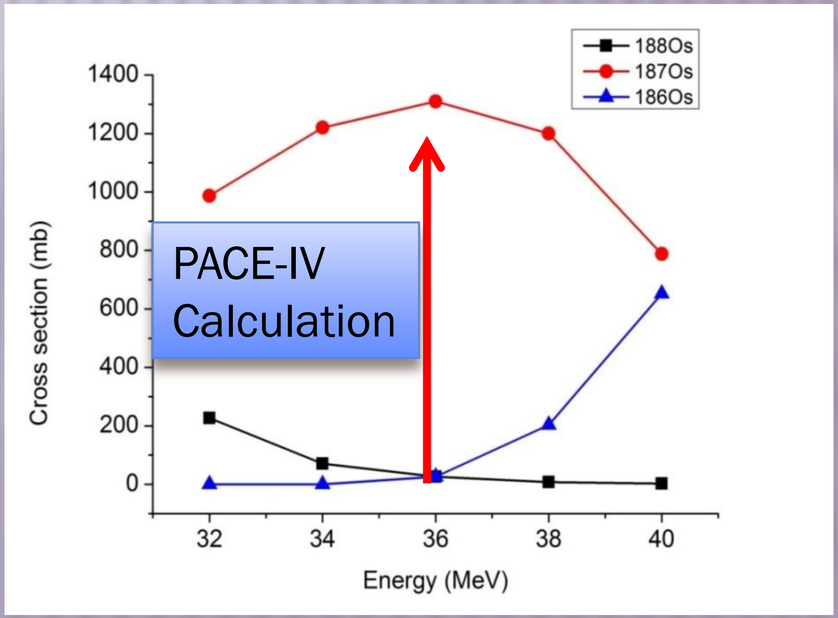
One Experiment has been performed at VECC using the INGA setup to study the excited states in ^{187}Os.

Experimental Setup

- Reaction:- **[$^{186}W(^{4}He, 3n)^{187}Os$] at 36 MeV**
- Beam:-^{4}He
- Target:- 300μg/cm^2 thick ^{186}W on 20μg/cm^2 C backing. Three stacked targets were used (with 2.5 mm gap).
- Detector:-**INGA** array with Seven CS-Clovers and a LEPS detector.
- Acquisition:- PIXIE -16 digitizer.

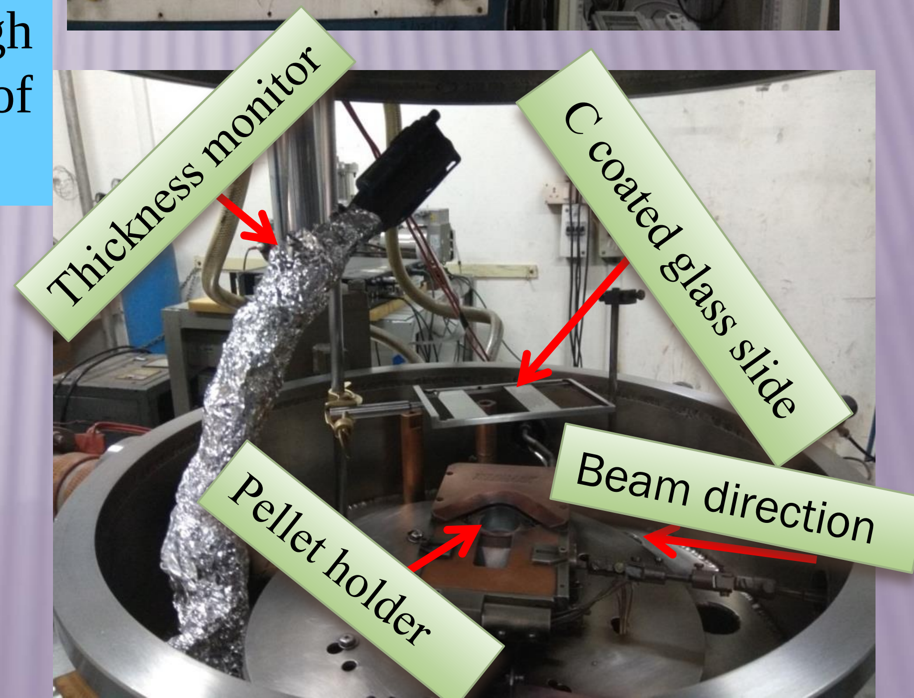






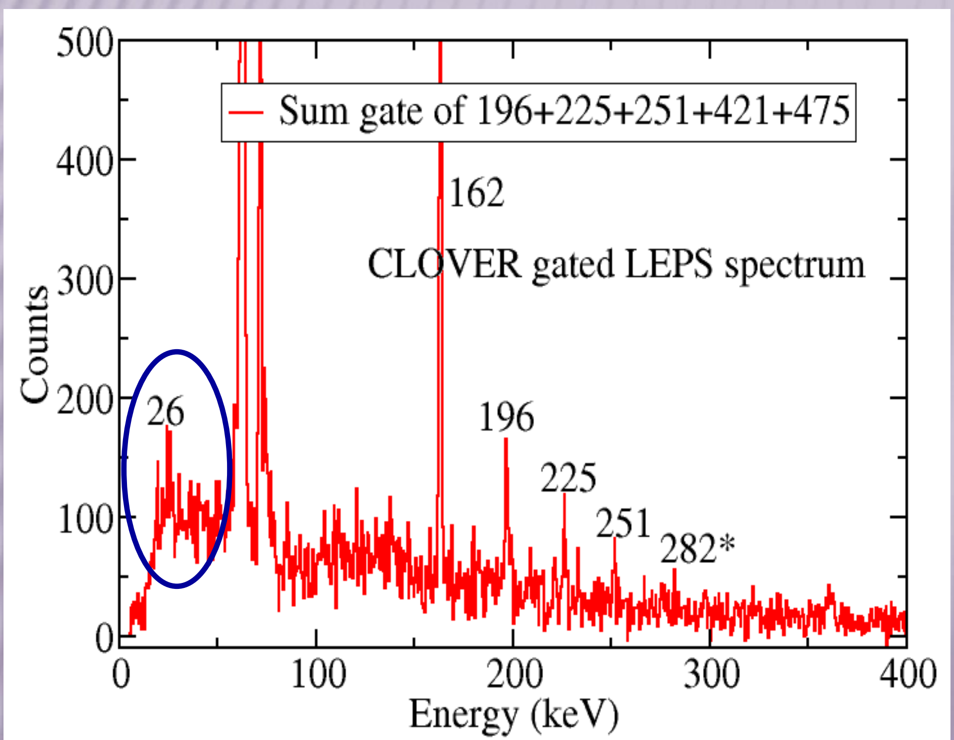
Target Preparation

- Enriched ^{186}W targets were used.
- Preparation of thick (1-2 mg/cm^2) ^{186}W target from its metal powder is quite challenging due to high melting point (3422ºC).
- 300μg/cm^2 thick ^{186}W target on 20μg/cm^2 C backing has been made by using electron gun evaporation technique in ultra-high vacuum environment with the help of target lab in IUAC, New Delhi.

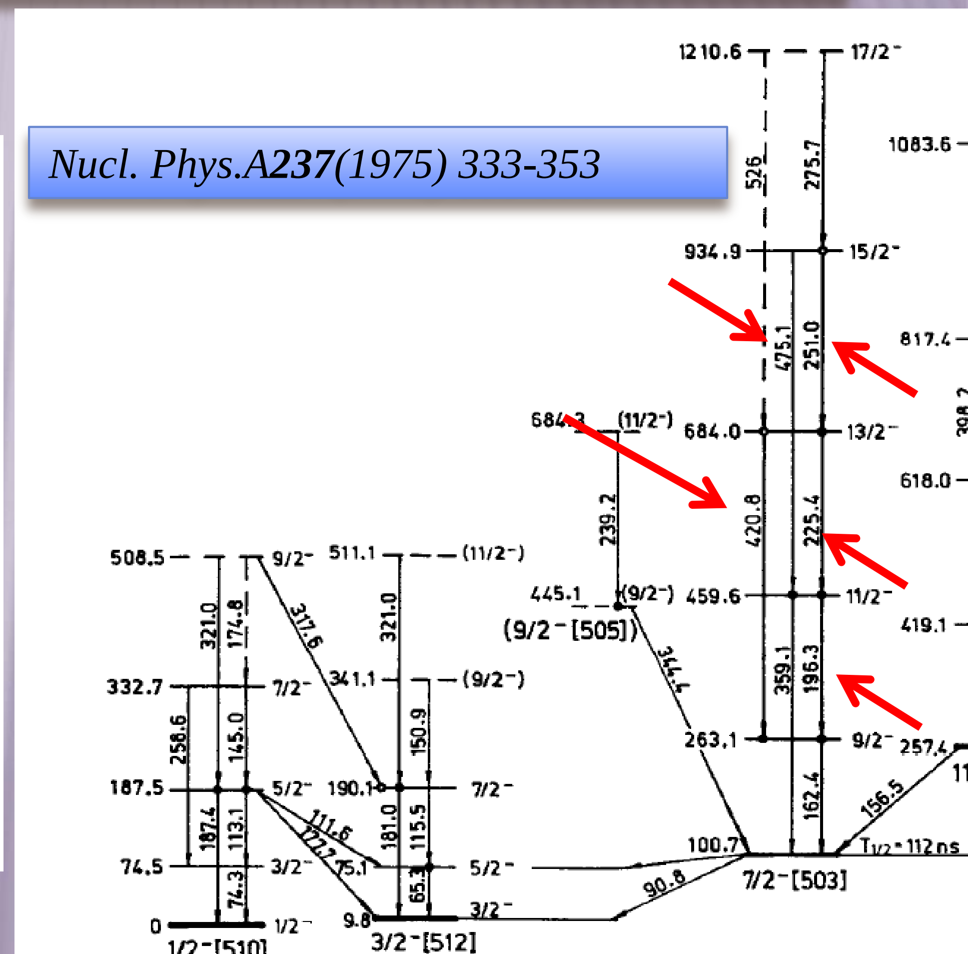


Preliminary results on ^{187}Os

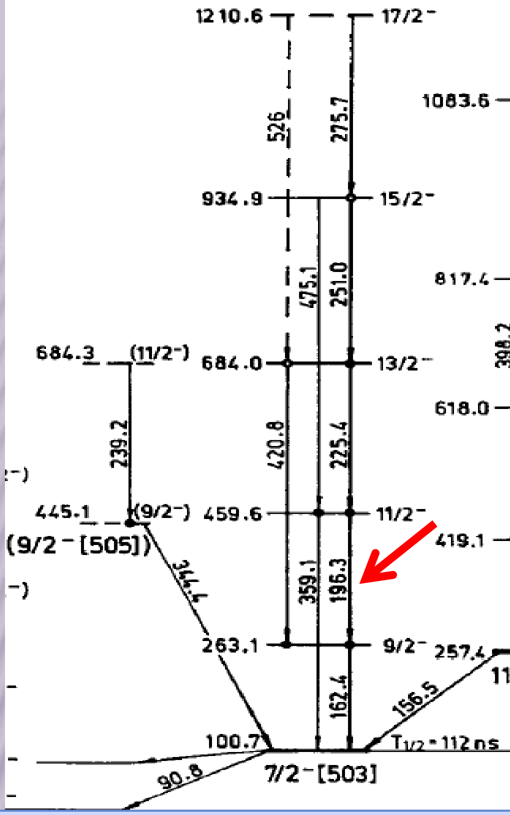
- In the preliminary analysis, we have seen that all the bands extended well after the band crossing and several new band structures have been based on different nucleonic orbitals.
- Low energy 26 keV transition has been confirmed in the sum gated spectrum of 196+225+251+421+475 keV transitions.



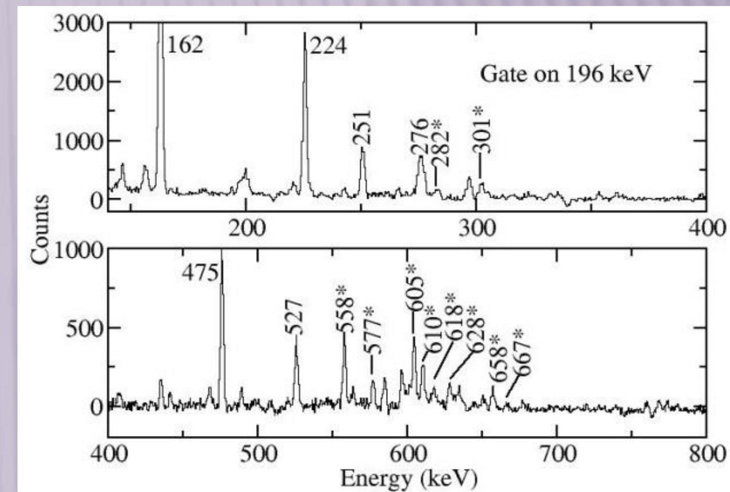
*Nucl. Phys.A**237**(1975) 333-353*



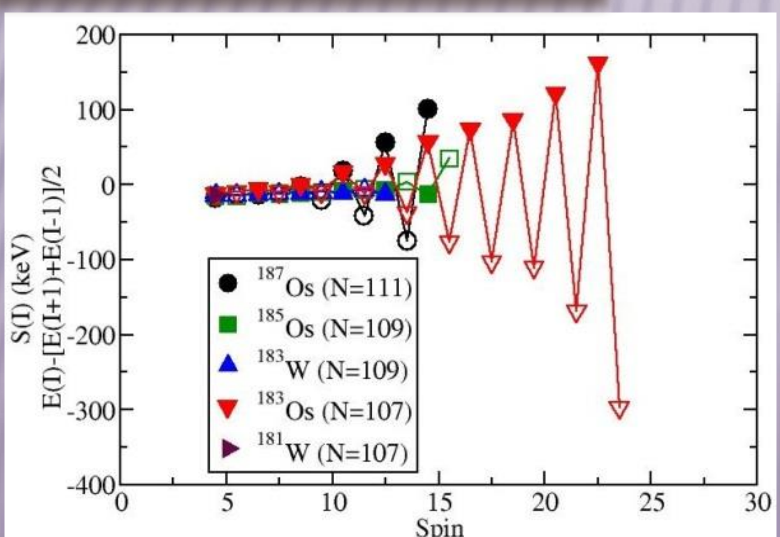
Band based on $\nu h_{9/2}$ in ^{187}Os

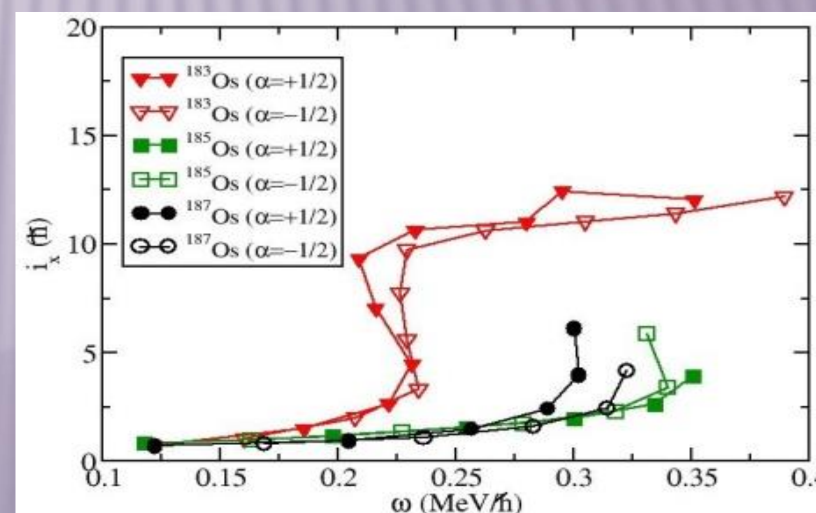


- Band on $\nu h_{9/2}$ extended beyond after band crossing.
- The delay in crossing frequency explained by N=110 deformed shell gap.
- Anomalous staggering can be explained by gamma softness or prolate to oblate shape transition.



*Nucl. Phys.A**237**(1975) 333-353*





Summary

- In ^{197}Tl, the existing level scheme is well extended and few things of the level scheme have been modified.
- A new band B has been found in ^{197}Tl which was interpreted as MR band.
- The band B3 in ^{197}Tl is modified and this can be a possible chiral partner of band B2.
- In ^{187}Os, several new band structures has been observed and all the existing bands extended after first band crossing.
- The detail analysis is in progress.

Thank you