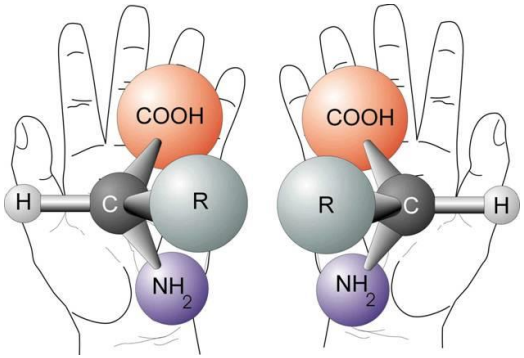
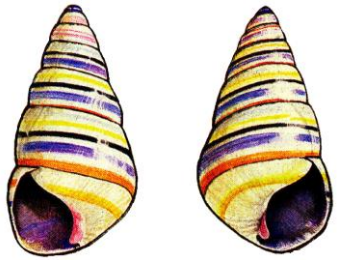
# Chiral symmetry in the Tl isotopes




**Elena A Lawrie**
iThemba LABS, South Africa

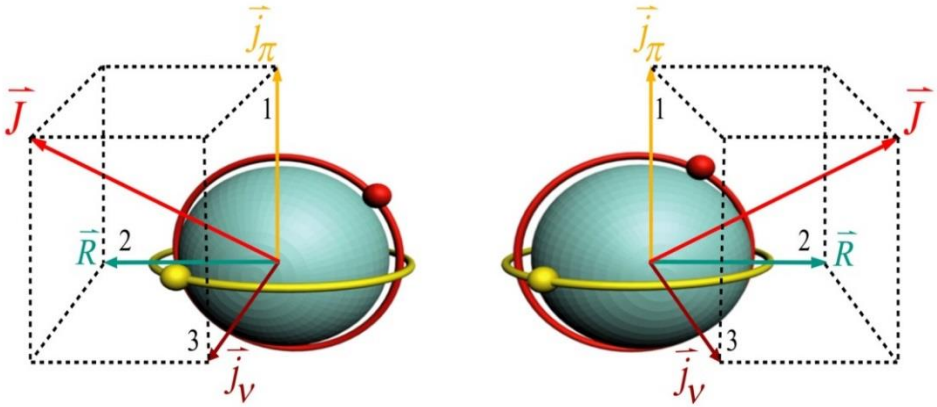


**Left-** **Right-**

P.L. Masiteng, J. Ndayishimye, O. Shirinda, A.A. Pasternak[#], J.J. Lawrie, J.L. Easton, R.A. Bark, S.P. Bvumbi, B.G. Carlsson, T.R.S. Dinoko, P. Jones, R. Lindsay, F. Komati, J. Kau, N.Y. Kheswa, E.O. Lieder, R. Lieder, T.E. Madiba, P. Maine, S.M. Maliage, I. Matamba, S.N.T. Mayola, S.M. Mullins, S.H.T. Murray, K.P. Mutshena, D. Negi, S.S. Ntshangase, J.N. Orce, P. Papka, I. Ragnarsson, T.M. Ramashidzha, D.G. Roux, J.F. Sharpey-Schafer, S. Stankiewicz, P.A. Vymers, M. Wiedeking, S.M. Wyngaardt

# Chiral symmetry in nuclei

*forms in angular momentum space,*
*by the angular momenta of the odd proton, odd neutron*
*and the rotation of the nucleus*




**a chiral system can be identified by the observation of a pair of degenerate rotational bands**

**→ in excitation energies**

**→ alignments, moments of inertia**

**→ B(M1) and B(E2) reduced transition probabilities**



**S. Frauendorf and J. Meng, Nucl. Phys. A 617 (1997) 131**

**Experimental data on chiral systems:**

→ A = 80

→ A=100

→ A=130

→ A=190

Looking for almost identical chiral pair.

Several experiments were performed at iThemba LABS South Africa on the Tl isotopes

**Experimental studies in the 190 mass region - the Tl isotopes**

angular momenta geometry –

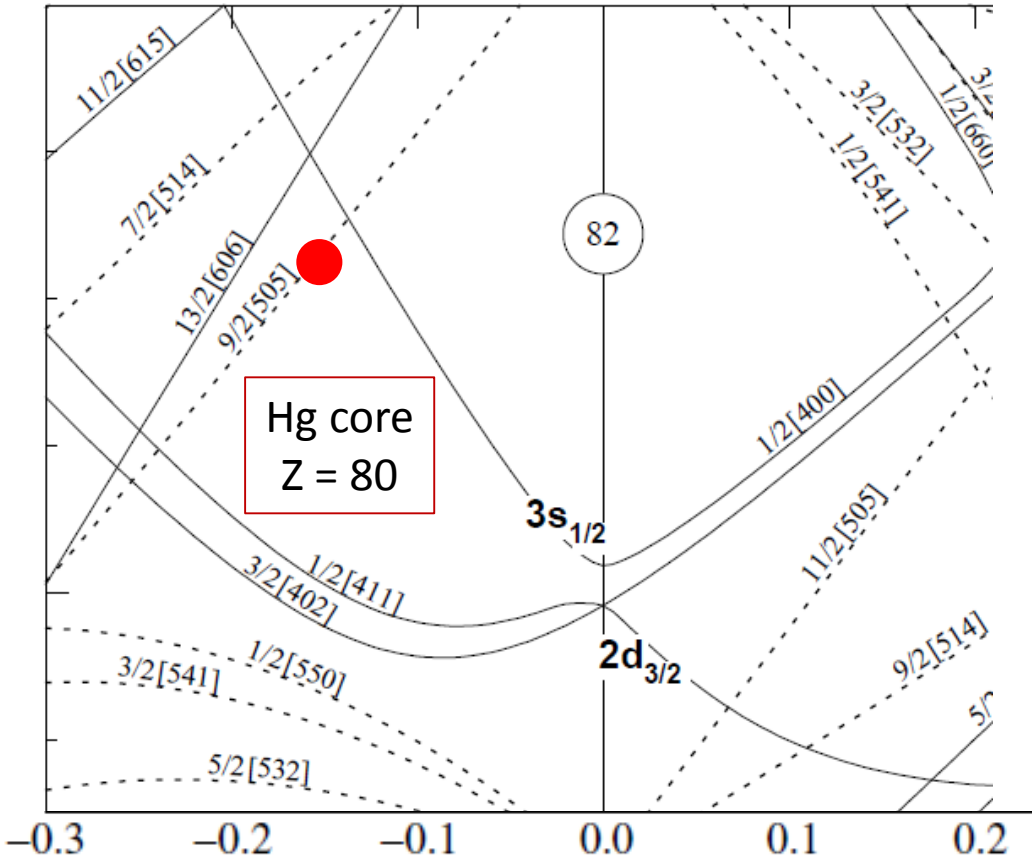
- ✓ $h_{9/2}$ proton at the bottom of the $h_{9/2}$ shell
  particle nature, $j_p$ along the short nuclear axis
- ✓ $i_{13/2}$ neutrons at the upper part of the $i_{13/2}$ shell
  hole nature, $j_n$ along the long axis
- ✓ triaxial shape (moderate quadrupole deformation ~0.15; triaxiality ~40)
  collective rotation along the intermediate axis

# Nucleon orbitals near the Fermi surface of the Tl isotopes with A ~ 192 - 198

Proton configurations
→ Z = 81
→ Hg core + 1 proton
→ quadrupole deformation ~ 0.15

Configuration
→ $\pi s_{1/2}$
→ $\pi h_{9/2}$ , $\Omega = 9/2$
**proton at the bottom of the $h_{9/2}$ shell,**
i.e. particle nature

Odd Tl isotopes:
-> near ground state – $\pi s_{1/2}$
-> higher spins - $\pi h_{9/2}$

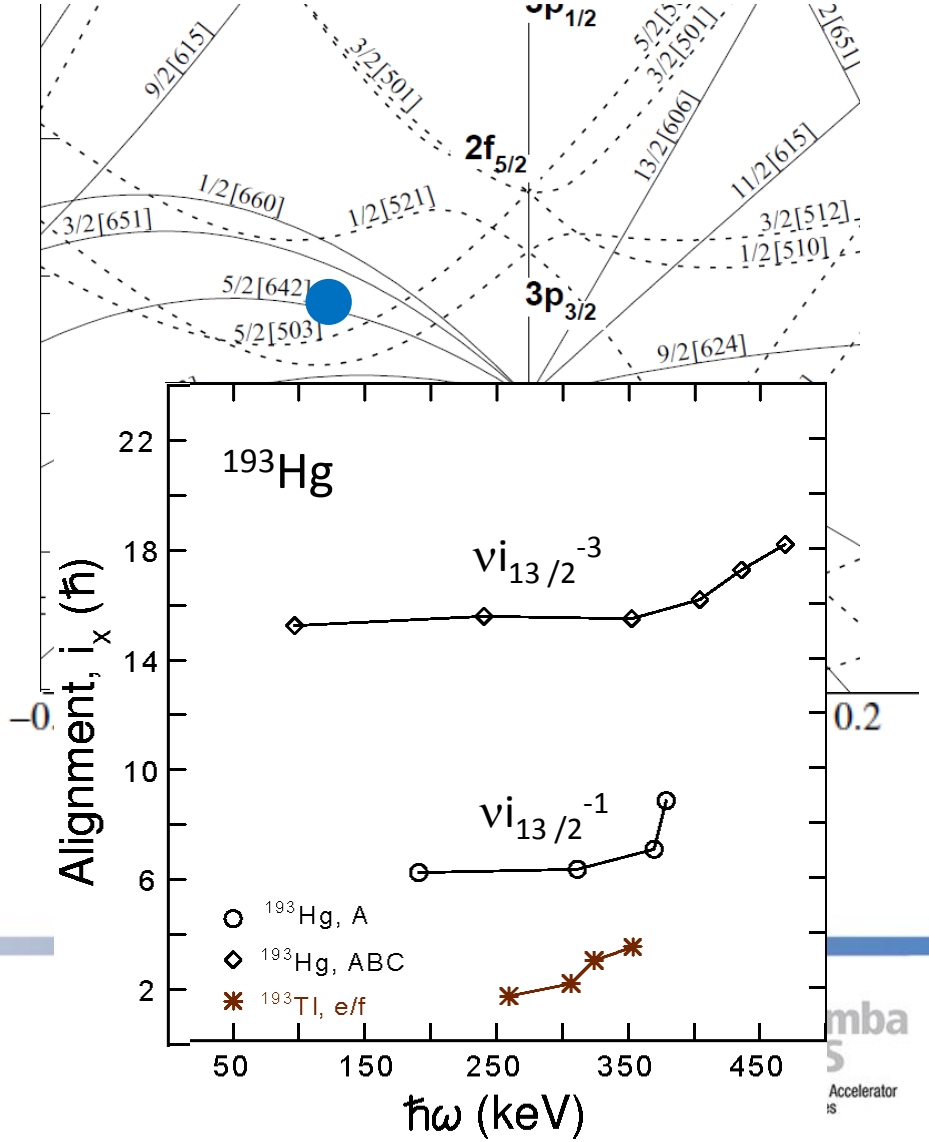


# Nucleon orbitals near the Fermi surface of the Tl isotopes with A ~ 194

Neutron configurations
→ N = 113
→ quadrupole deformation ~ 0.15

Configuration
→ $\nu i_{13/2}$, $\nu j$ -> j = $p_{3/2}$, $f_{5/2}$
→ $\nu i_{13/2}$, Ω = 5/2, but aligns with i=13/2
Neutron near the bottom of the $i_{13/2}$ shell, i.e. hole nature

Odd $^{193}$Hg (N=113):
-> $\nu i_{13/2}$, i ≈ 6 ħ
-> $\nu i_{13/2}^3$, i ≈ 16 ħ
-> $\nu i_{13/2}^2 \nu j$



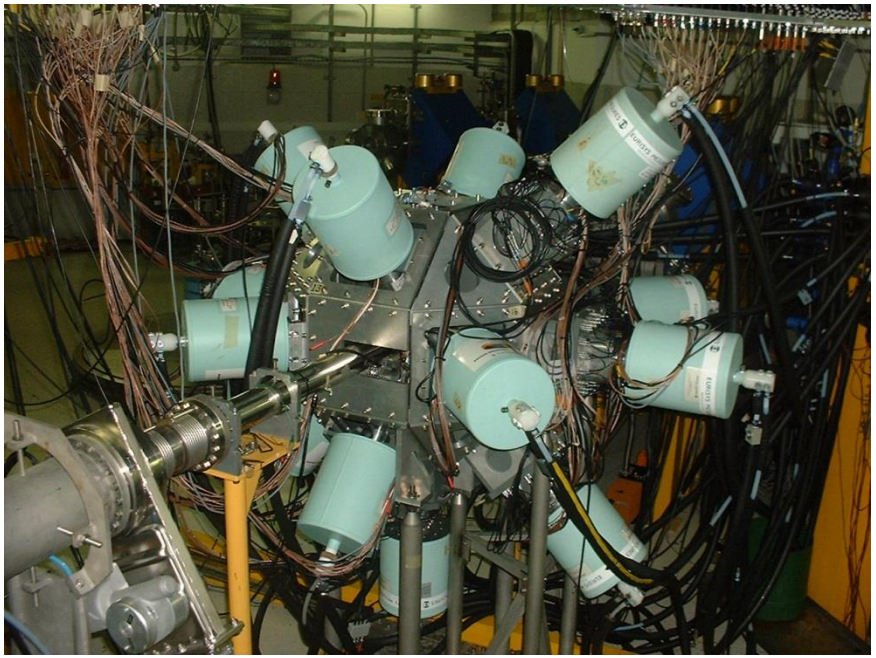
# Studying the Tl isotopes:
## $^{198}$Tl

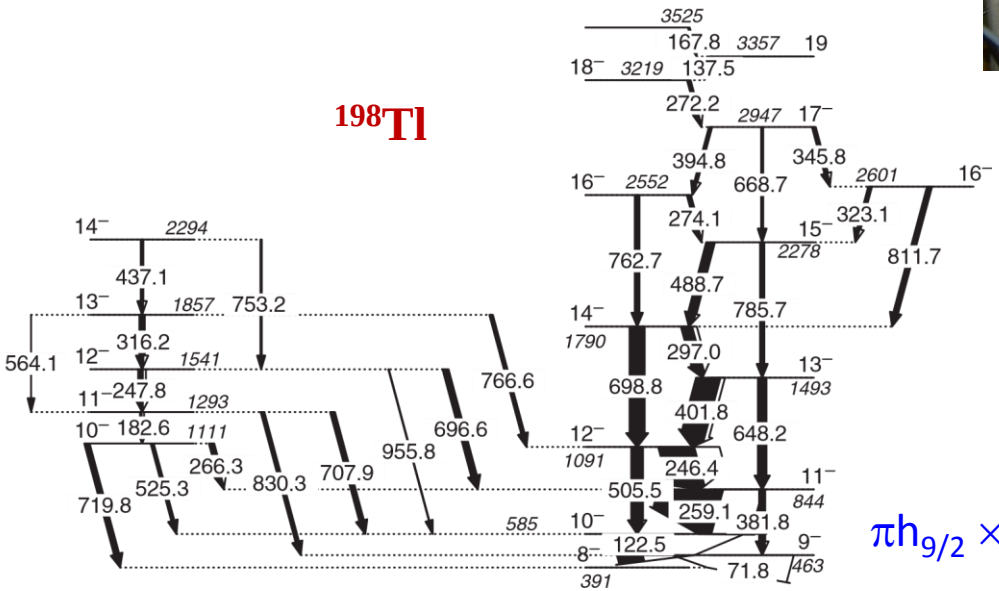
**AFRODITE array at iThemba LABS, South Africa**

9 HpGe clover detectors (7 cm x ∅5 cm),
Compton suppressed with BGO shields
efficiency of 1.8% at 1.3 MeV

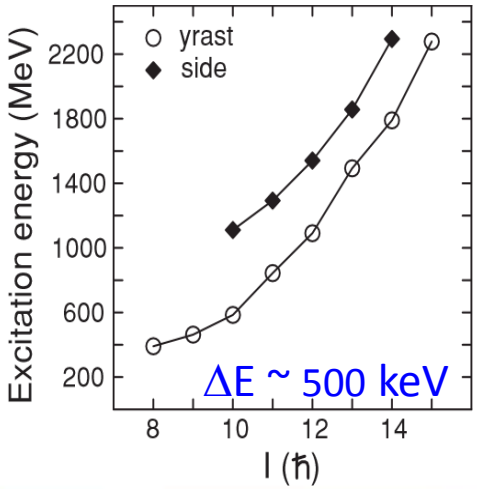
8 HpGe LEPS detectors ( 1 cm x ∅ 6 cm)

$^{197}$Au(α,3n)$^{198}$Tl at beam energy of 40 MeV



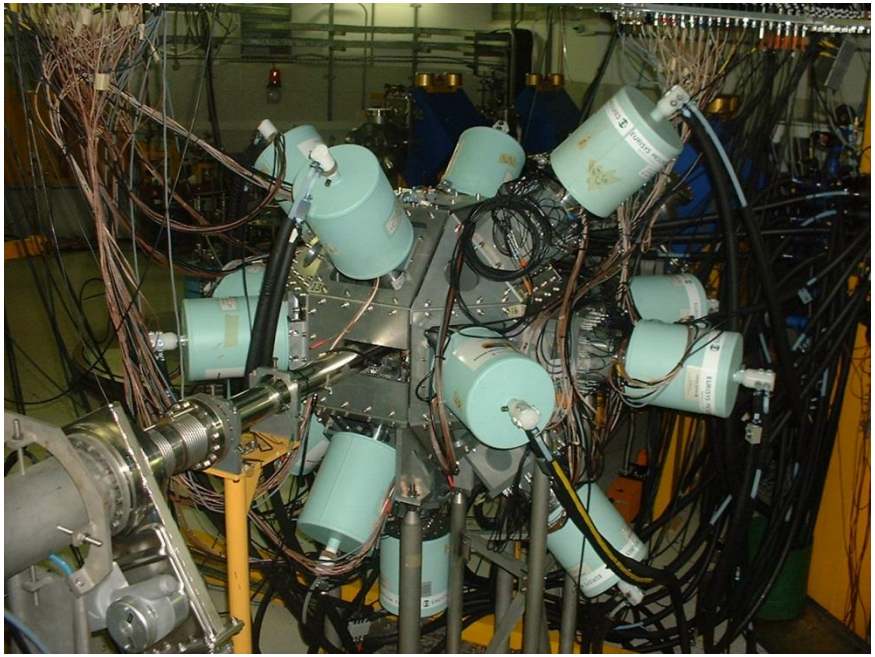



$\pi h_{9/2} \times \nu i_{13/2}^{-1}$




E.A. Lawrie et al, Phys. Rev. C 28, 021305(R) (2008)

# Studying the Tl isotopes:
# $^{194}$Tl



**AFRODITE array at iThemba LABS, South Africa**

9 HpGe clover detectors (7 cm x ∅5 cm),
Compton suppressed with BGO shields
efficiency of 1.8% at 1.3 MeV

8 HpGe LEPS detectors ( 1 cm x ∅ 6 cm)

$^{181}$Ta($^{18}$O,5n)$^{194}$Tl at energy E($^{18}$O)=92 MeV

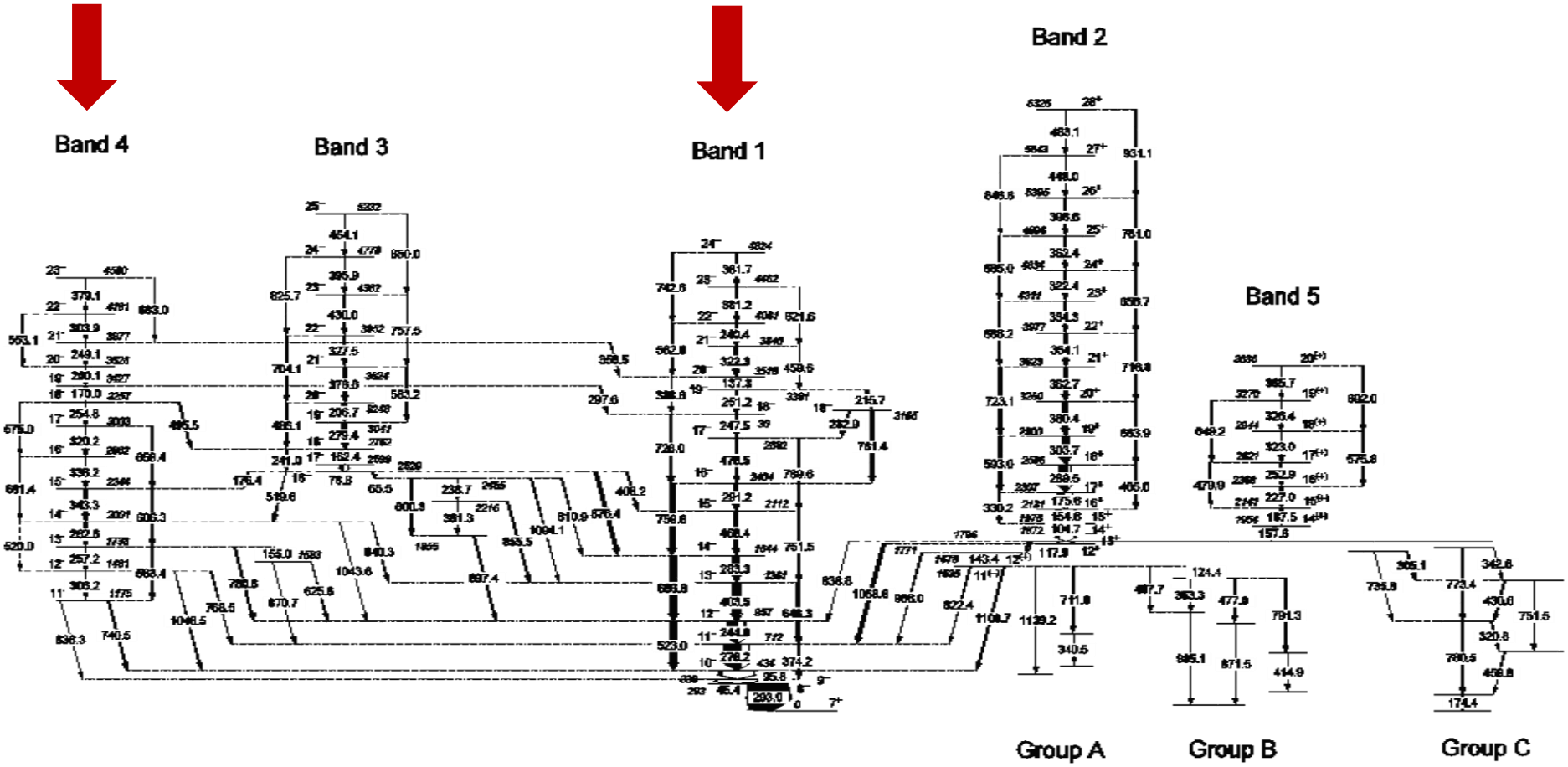
**Target:** $^{181}$Ta foil of 1mg/cm$^2$

Beam time → 2 weekends

Data analysis: gamma-gamma matrices, angular distribution ratio analysis, linear polarization analysis, gamma-ray intensities.

# Level scheme of $^{194}$Tl

## extended with more than 100 new transitions





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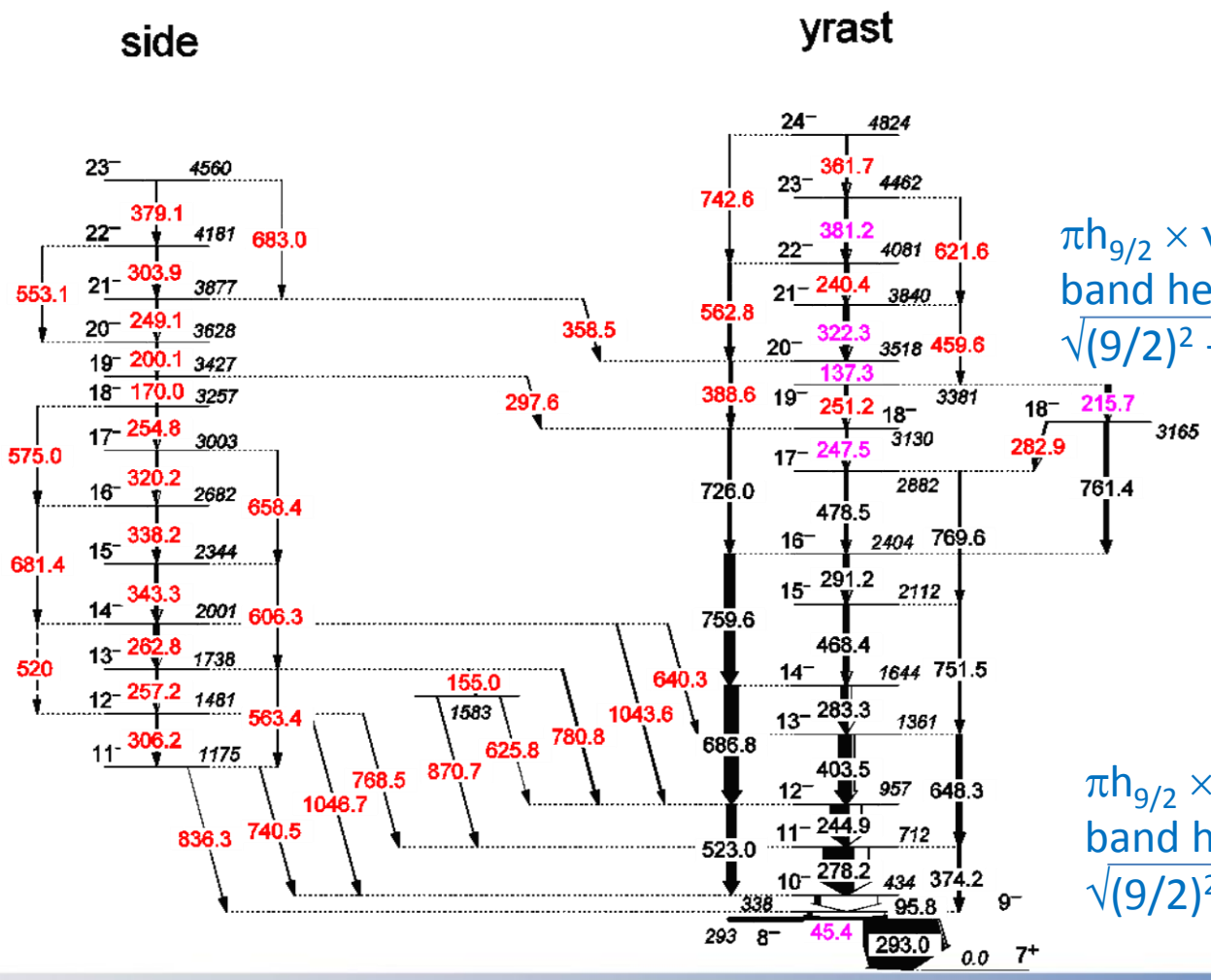
P.L. Masiteng, PhD Thesis
P.L. Masiteng et al, Eur. Phys. J. A 50 (2014) 119

NRF National Research Foundation
iThemba LABS Laboratory for Accelerator Based Sciences

# Chiral pair in $^{194}$Tl

→ the only pair that is observed across backband region

→ excellent near-degeneracy above the band crossings

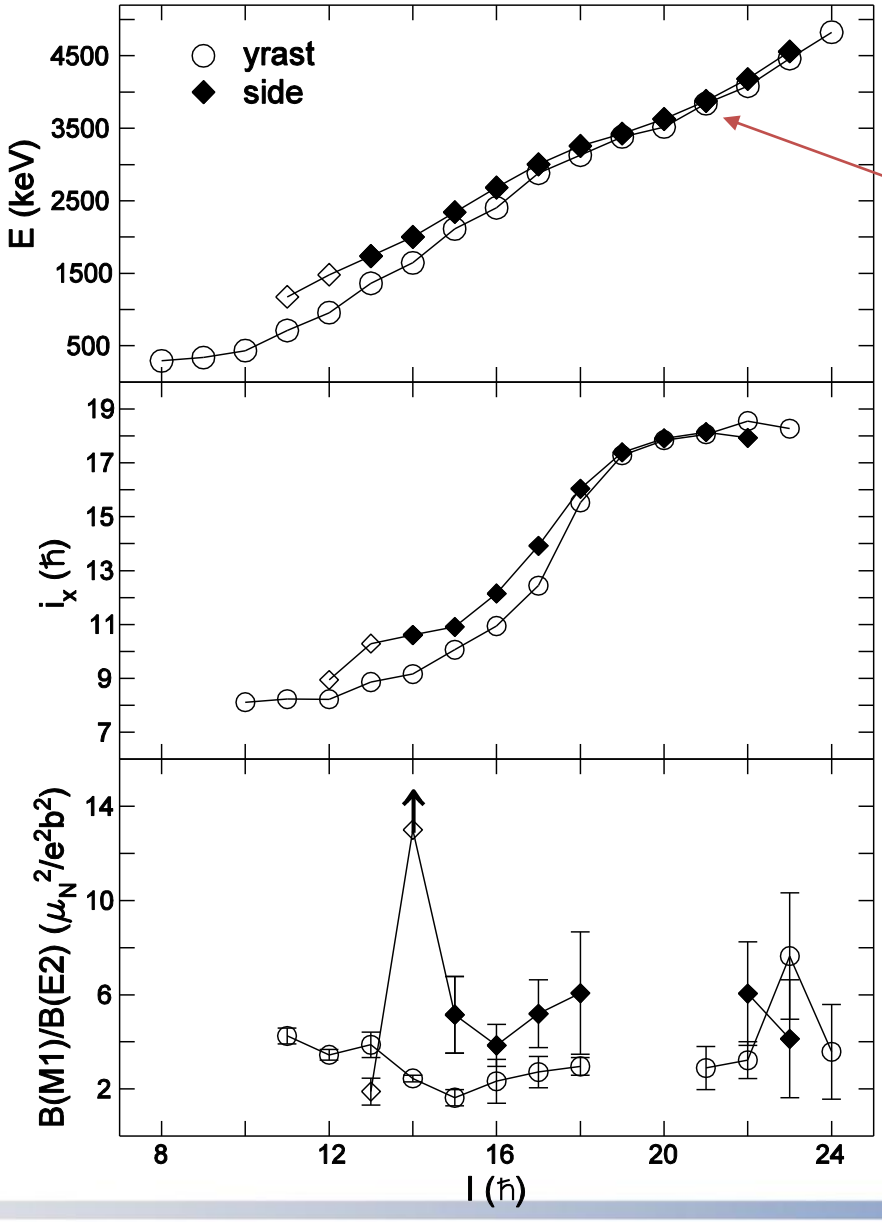



$\pi h_{9/2} \times \nu i_{13/2}^{-3}$

$\pi h_{9/2} \times \nu i_{13/2}^{-1}$

$\pi h_{9/2} \times \nu i_{13/2}^{-3}$
band head $\approx 18^-$
$\sqrt{(9/2)^2 + (33/2)^2} \approx 18$

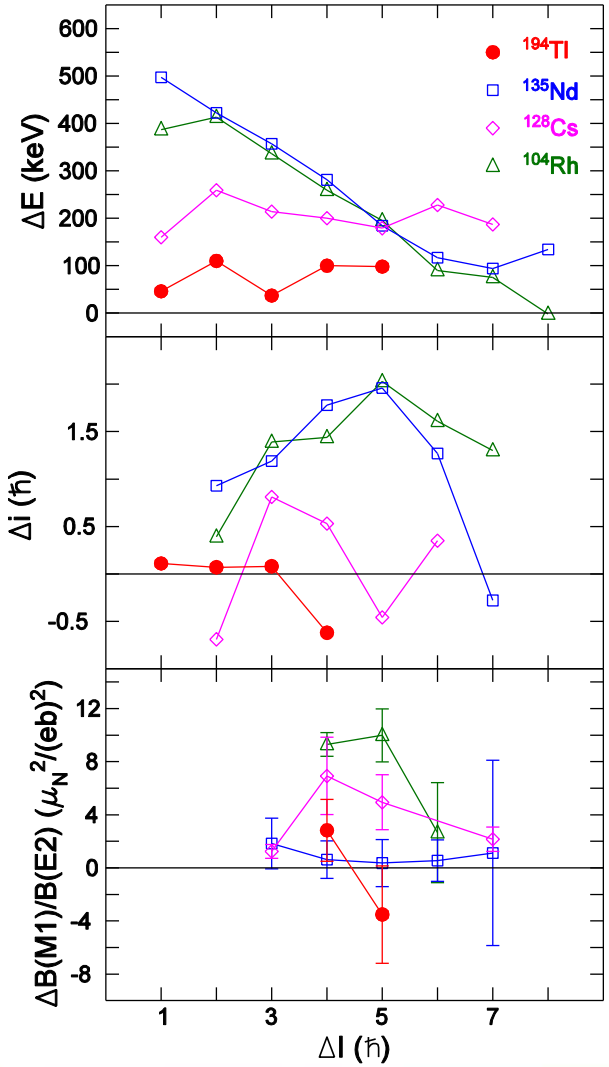
$\pi h_{9/2} \times \nu i_{13/2}^{-1}$
band head $8^-$
$\sqrt{(9/2)^2 + (13/2)^2} \approx 8$




$\Delta E < 110$ keV

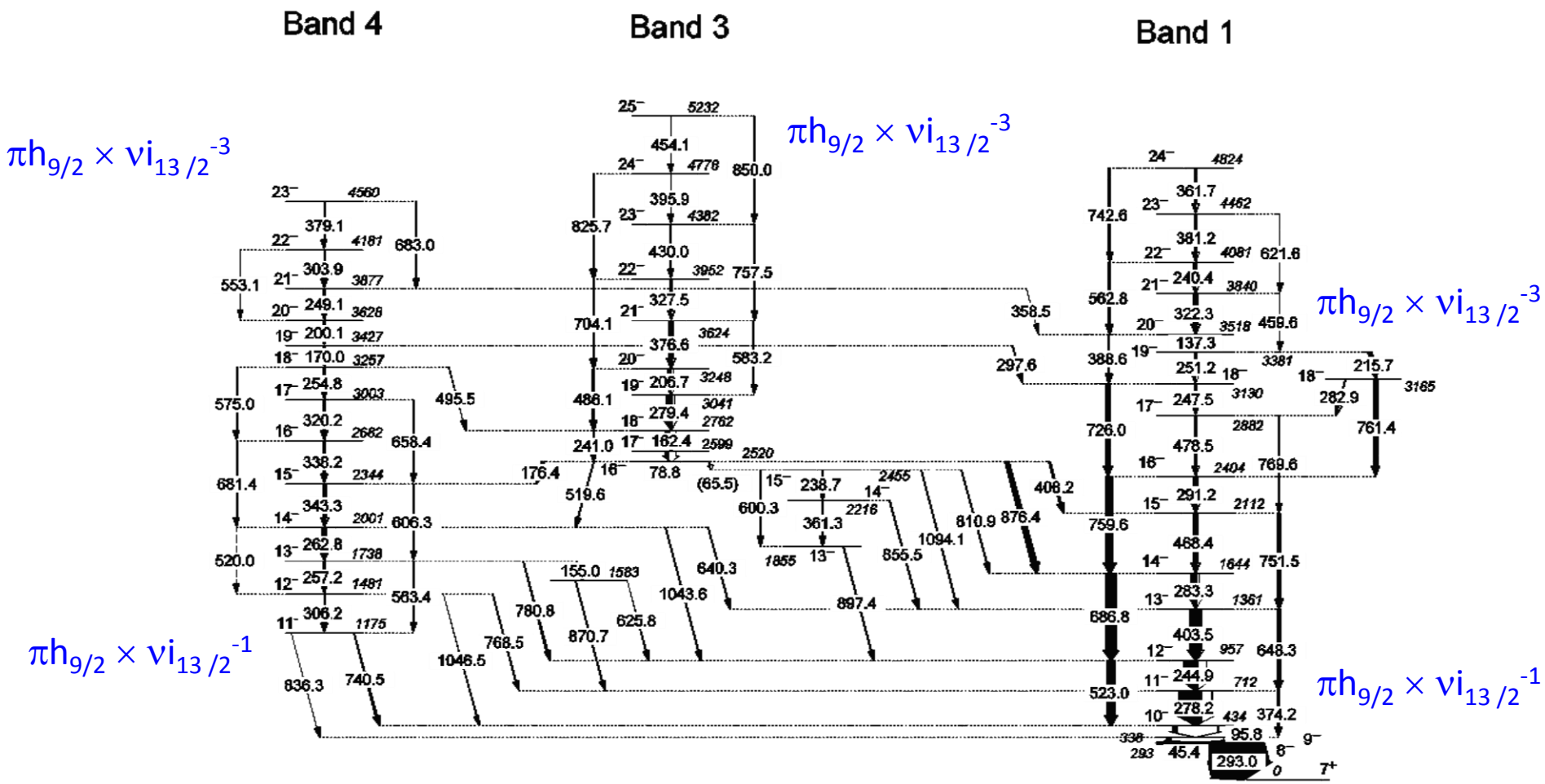
$\Delta E_{min} = 37$ keV

# Near-degeneracy in the 4-qp pair in $^{194}$Tl compared with other chiral pairs




The 4-qp chiral pair in $^{194}$Tl - the pair perhaps best near-degeneracy to date?

# The negative parity bands in $^{194}$Tl





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P.L. Masiteng, PhD Thesis
P.L. Masiteng et al, Eur. Phys. J. A 50 (2014) 119

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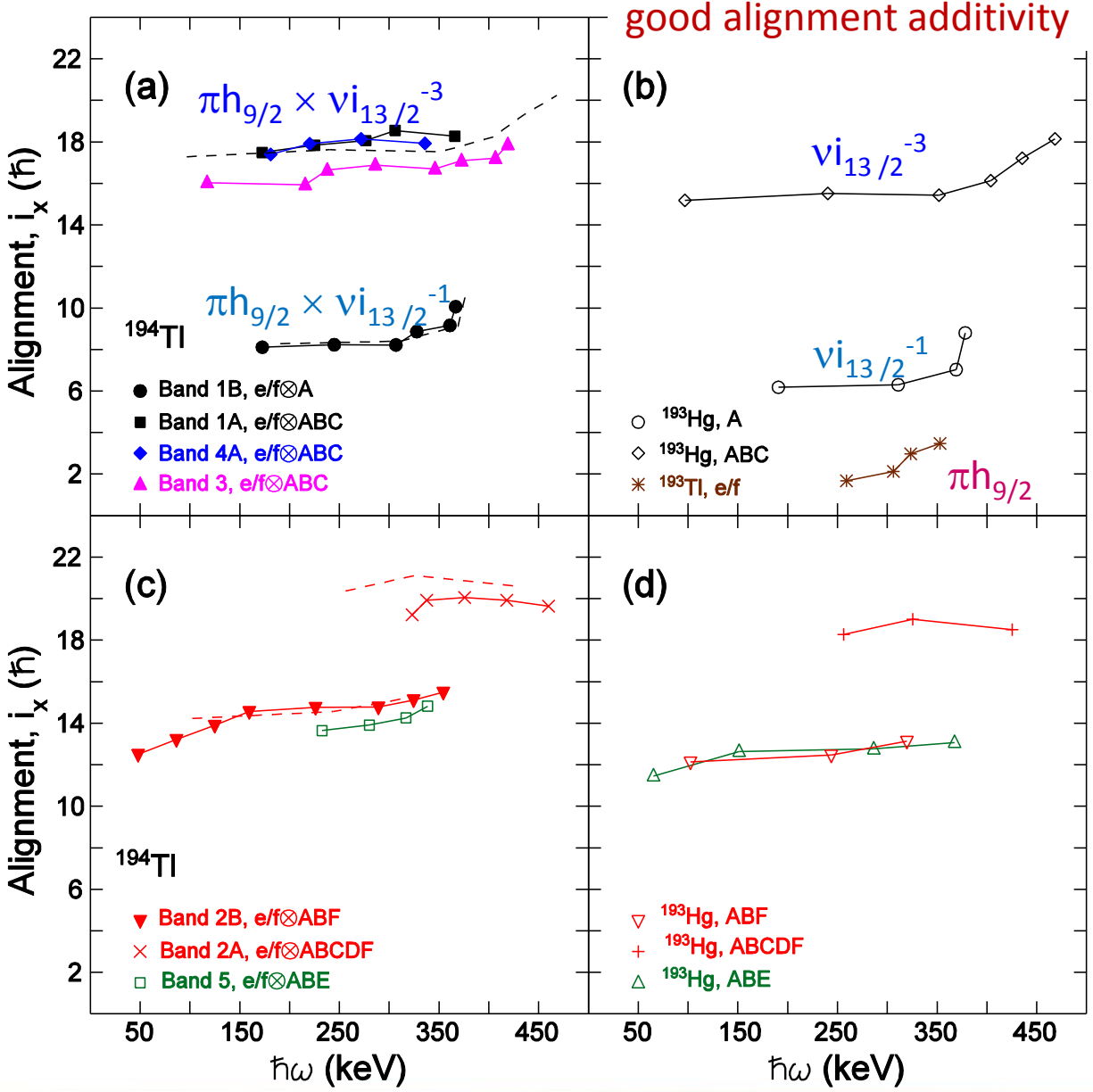
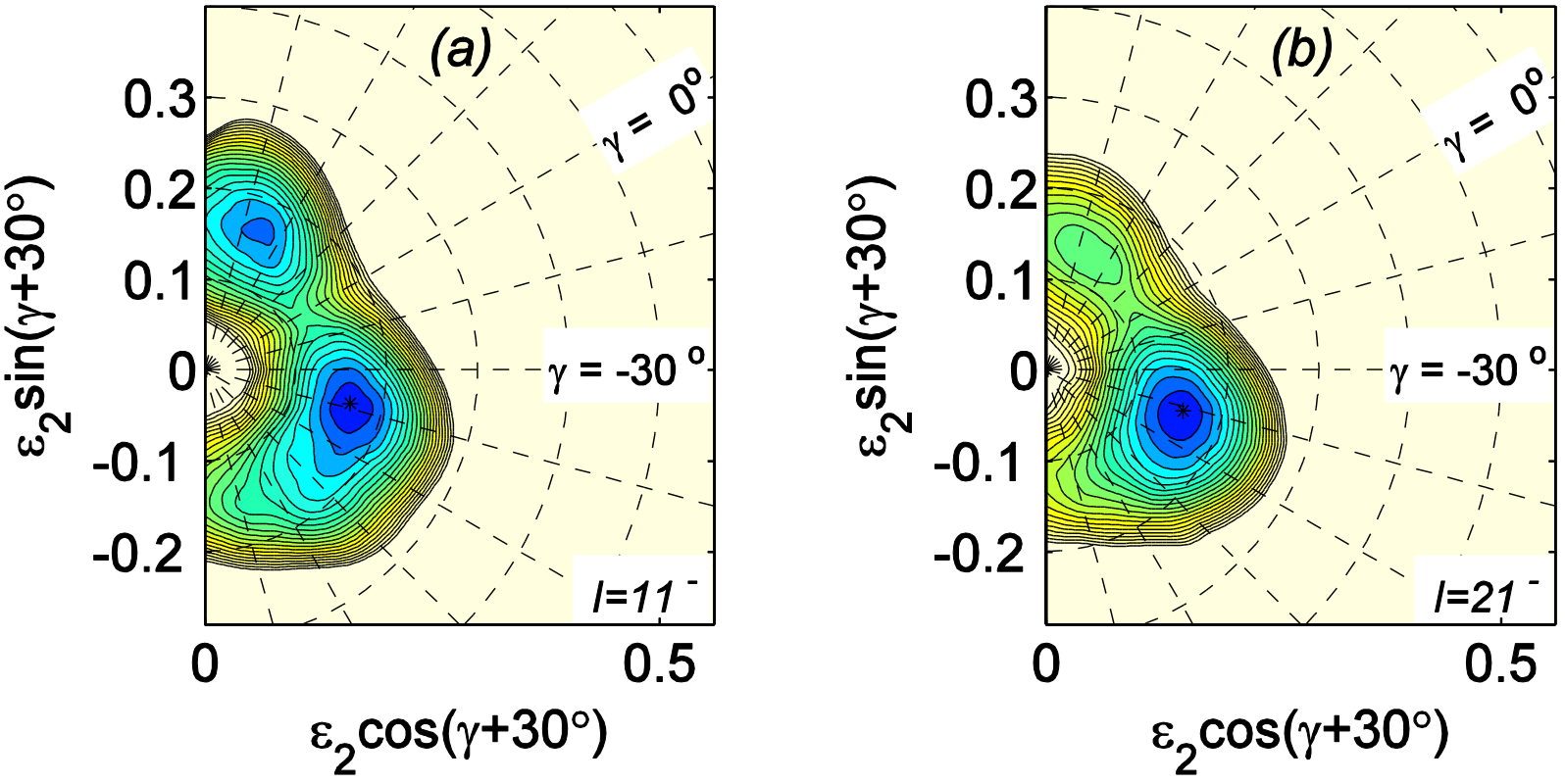
Configuration
of the third negative parity band
→ large alignment ~ 16,
need $\nu i_{13/2}^{-3}$
→ negative parity,
need $\pi h_{9/2}$




→ Two chiral partner bands
with $\pi h_{9/2} \times \nu i_{13/2}^{-3}$
→ third competing band
$\pi h_{9/2} \times \nu i_{13/2}^{-3}$ with
lower alignments (~ 2ħ)
lower excitation energy

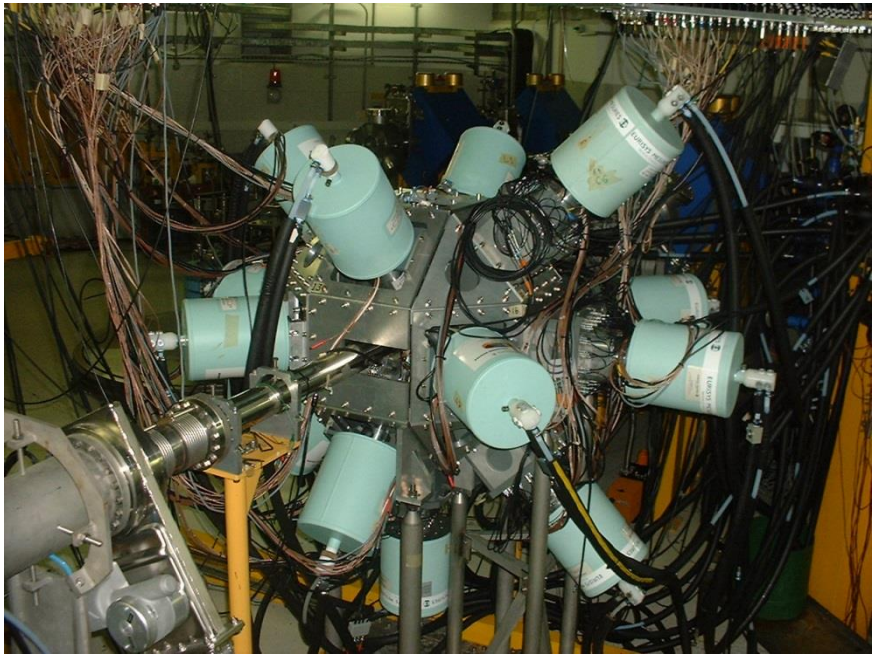
# Nuclear shape for the $\pi h_{9/2} \times \nu i_{13/2}^{-n}$ configuration in $^{194}$Tl
## Cranked Nilsson-Strutinsky calculations




Deformation with $\varepsilon_2 = 0.15$, $\gamma = -40^0 \div -45^0$

rotation predominantly around the intermediate axis → supports chiral symmetry

# Studying the Tl isotopes: $^{194}$Tl DSAM lifetimes



**AFRODITE array at iThemba LABS, South Africa**

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Compton suppressed with BGO shields
efficiency of 1.8% at 1.3 MeV

8 HpGe LEPS detectors ( 1 cm x ∅ 6 cm)

$^{181}$Ta($^{18}$O,5n)$^{194}$Tl at energy E($^{18}$O)=92 MeV

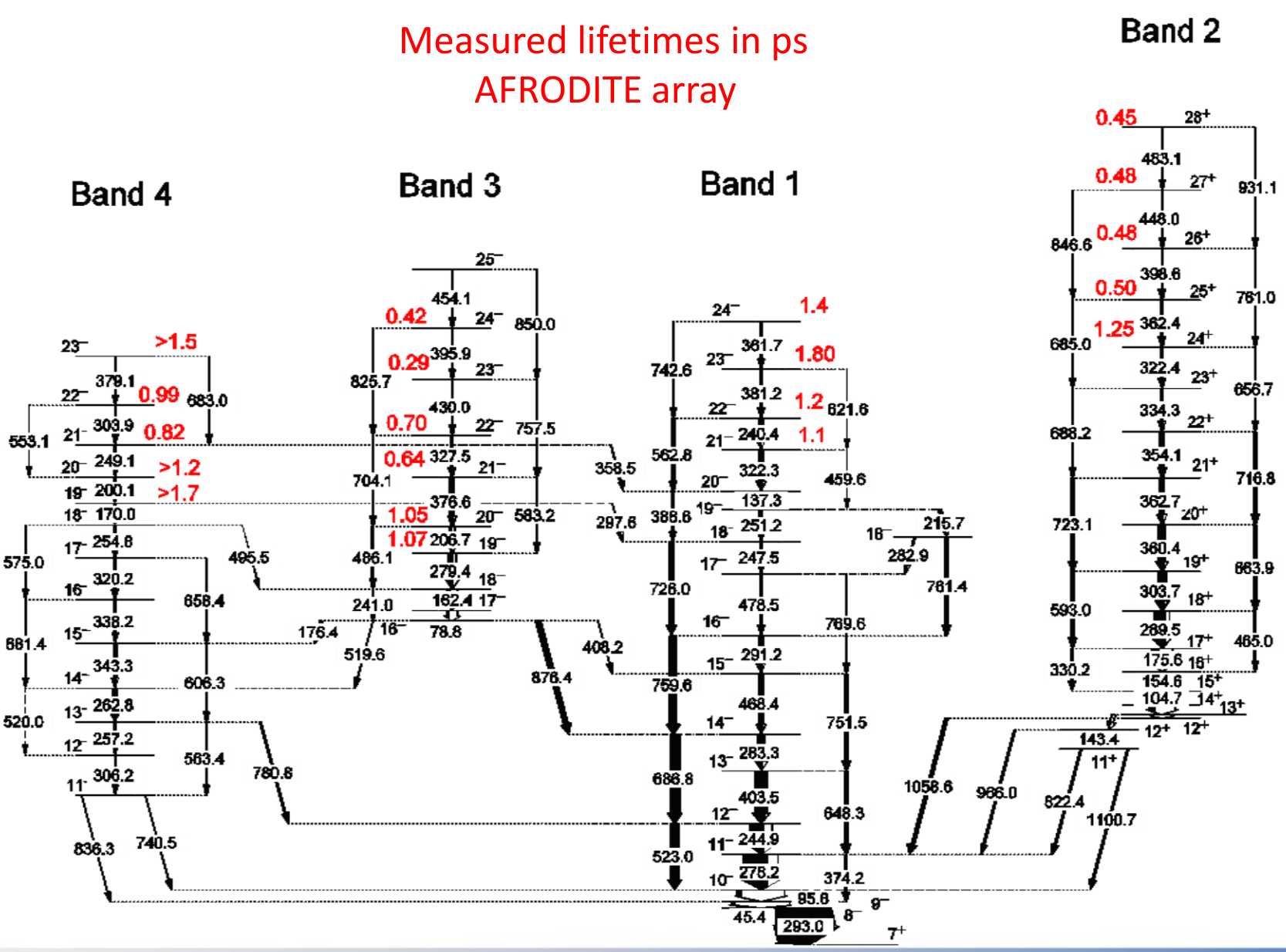
**Target:** $^{181}$Ta foil of 1mg/cm$^{2,}$ onto thick backing of Bi, initial recoil velocity of v/c ~ 0.9 %

Beam time → 3 weekends for experiment A and B respectively

DSAM analysis – using the programs COMPA, GAMMA and SHAPE
(analysis led by Prof. A. Pasternak)
Monte-Carlo methods to simulate the entry states in $^{194}$Tl and the decay (statistical decay, superdeformed bands, stretched M1 bands, known discrete levels)

The lifetimes are extracted step by step starting with the highest-energy level of a band.

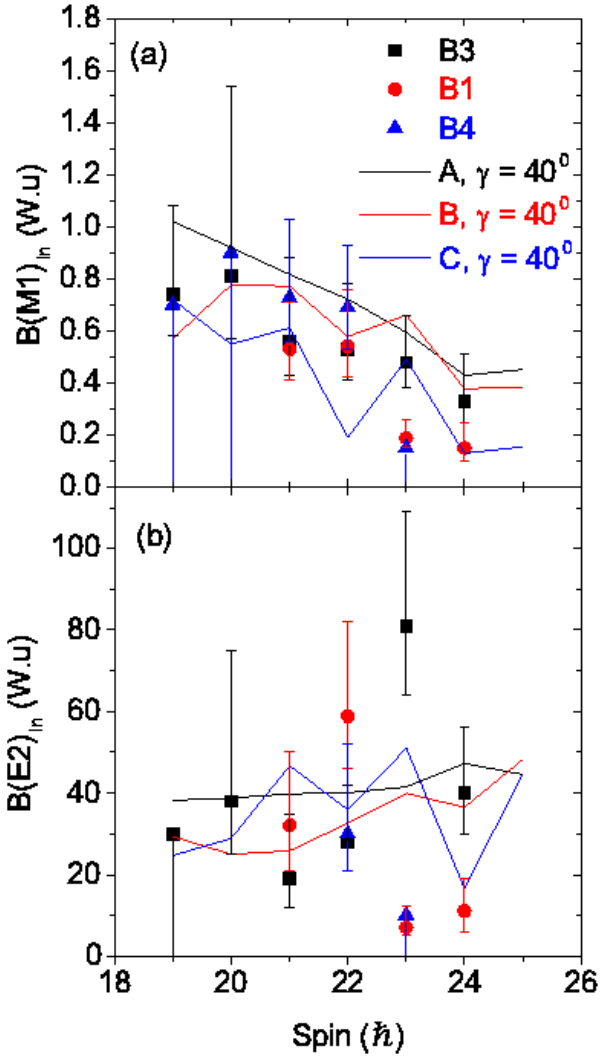
# Measured lifetimes in ps
# AFRODITE array

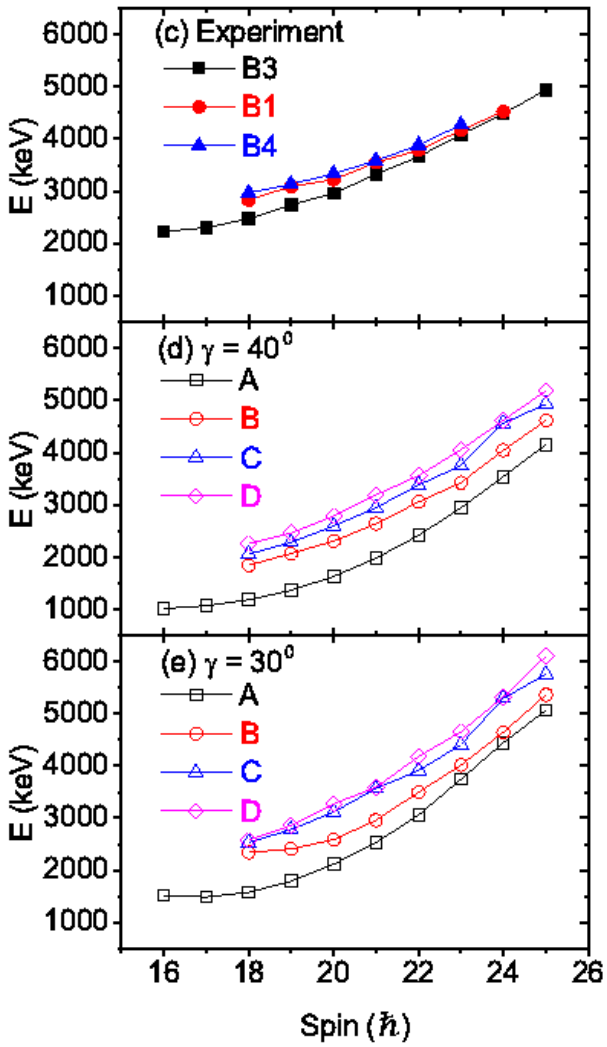


# Multi-particle Rotor Model calculations for the $\pi h_{9/2} \times \nu i_{13/2}^{-3}$ bands

Exp:
Chiral pair
B1 and B4

Third band
B3




(C,D) yrare chiral pair

(A,B) yrast chiral pair

## Multi-particle Rotor Model of Carlsson and Ragnarsson

→ to establish the properties of multiple chiral systems

→ to understand the nature of the three negative parity bands

**single particles** -> Nilsson potential with standard parameters

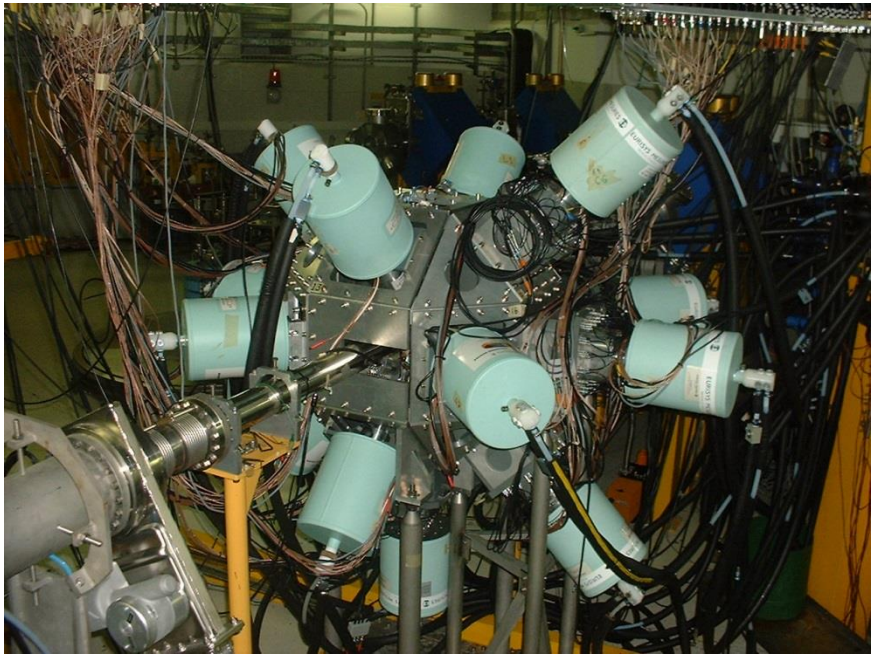
-> $\pi h_{9/2} \times \nu i_{13/2}^{-3}$ configuration is described as 1 proton in the $h_{9/2}$ shell and 11 neutrons in the $i_{13/2}$ shell

**core** -> deformation $\varepsilon_2 = 0.15$ and $\gamma = 40^0$;

-> irrotational moment of inertia

**g-factors** -> $g_R = 0.3$; $g_s = 0.7\ g_{s,free}$

# Studying $^{193}$Tl



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9 HpGe clover detectors (7 cm x ∅5 cm),
Compton suppressed with BGO shields
efficiency of 1.8% at 1.3 MeV

$^{181}$Ta($^{18}$O,6n)$^{193}$Tl at energy E($^{18}$O)=105 MeV

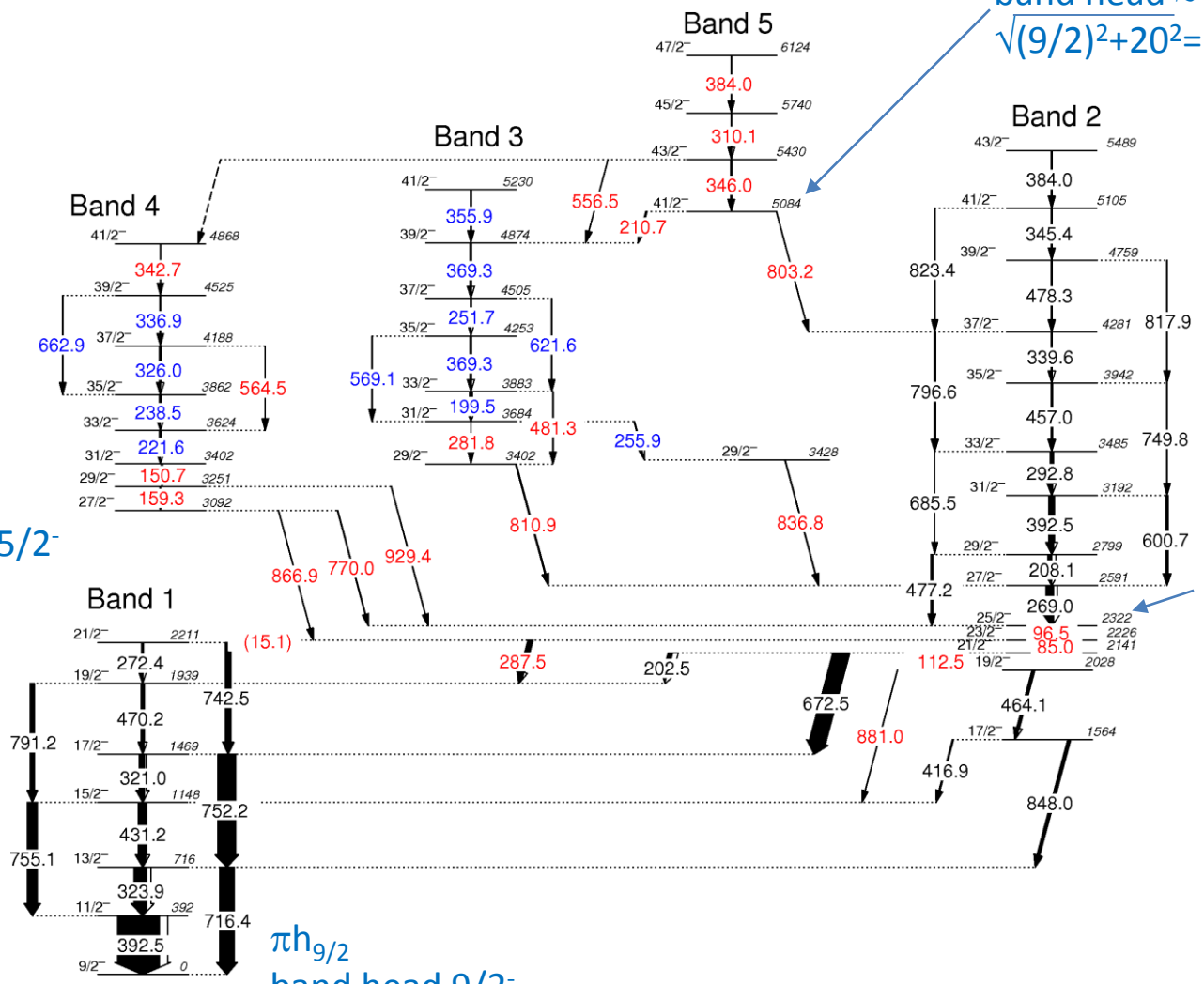
**Target:** $^{181}$Ta foil of 1mg/cm$^2$

Beam time → 2 weekends

Data: Experiment A → 6 x $10^9$ events in the gamma-gamma matrix

Angular distribution ratios → spins of the excited states
Linear polarization → parities of the excited states

# Partial level scheme of $^{193}$Tl




$\pi h_{9/2} \times \nu i_{13/2}^{-4}$
band head $\approx 41/2^-$
$\sqrt{(9/2)^2+20^2}=20.5$

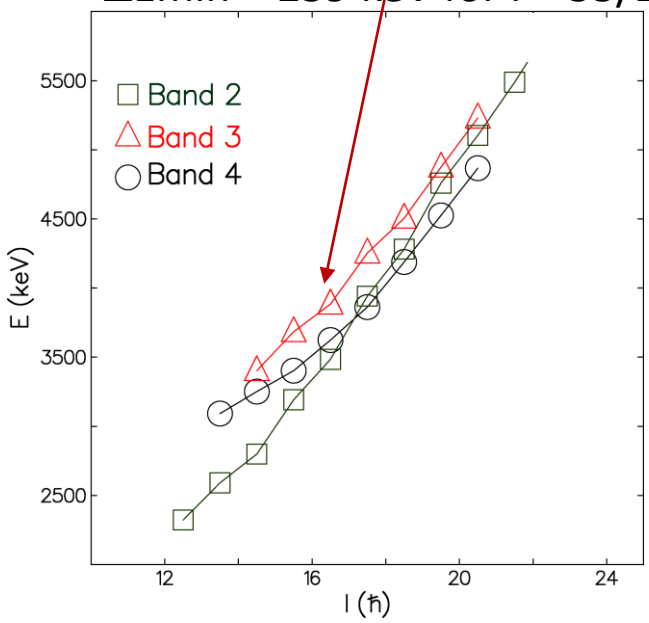
$\pi h_{9/2} \times \nu i_{13/2}^{-2}$
band head $\approx 25/2^-$

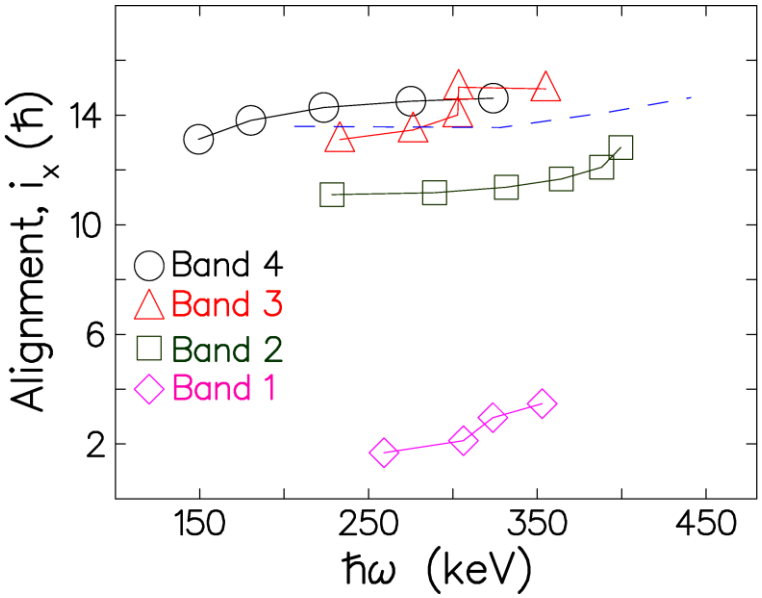
$\pi h_{9/2} \times \nu i_{13/2}^{-2}$
band head $\approx 25/2^-$
$\sqrt{(9/2)^2+12^2}\approx 12.5$

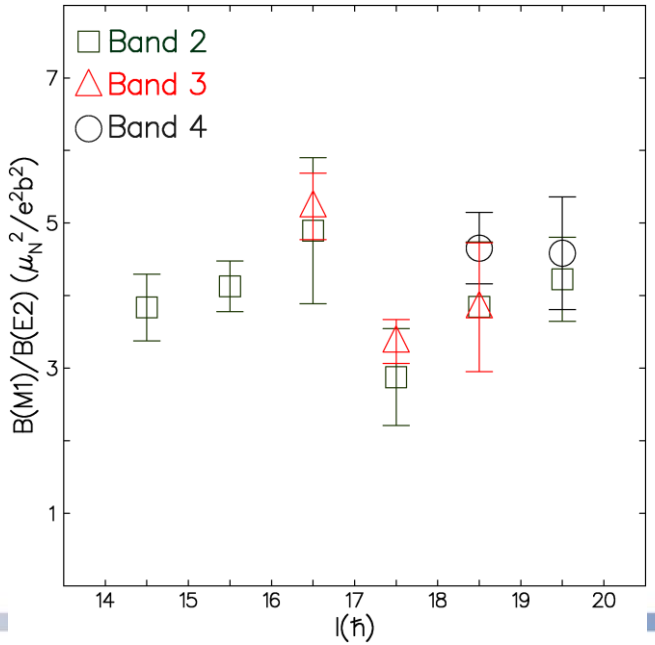
$\pi h_{9/2}$
band head $9/2^-$

ΔE(B3-B4) = 159 - 391 keV

ΔEmin = 259 keV for I = 33/2



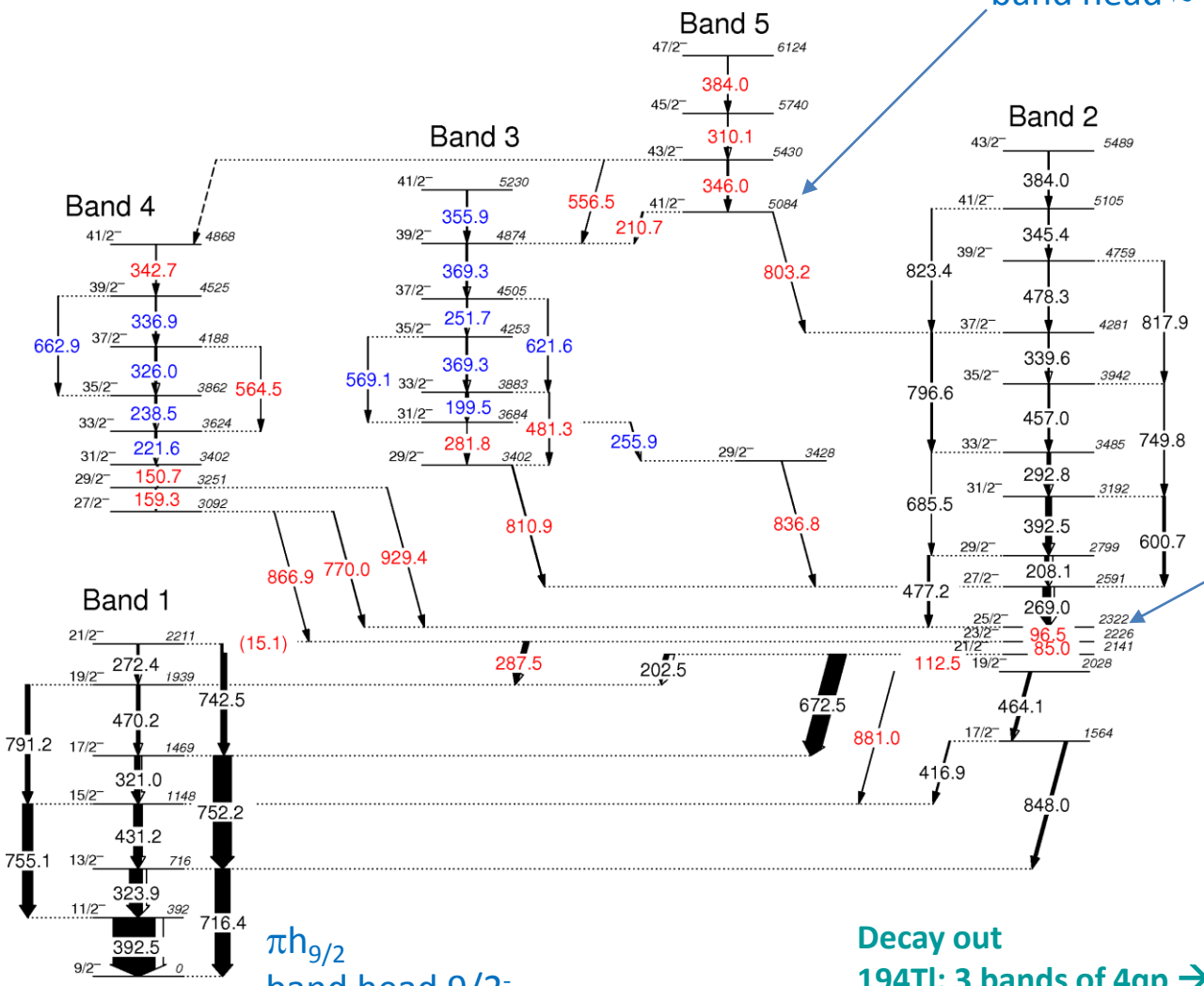

B(M1)/B(E2)

→ similar

# Partial level scheme of $^{193}$Tl

$\pi h_{9/2} \times \nu i_{13/2}^{-4}$
band head $\approx 41/2^-$

New unconnected band




$\pi h_{9/2} \times \nu i_{13/2}^{-2}$
band head $\approx 25/2^-$

$\pi h_{9/2}$
band head $9/2^-$

**Decay out**
**194Tl: 3 bands of 4qp → 3 bands of 2 qp**
**193Tl: 3 bands of 3qp → 1 band of 1 qp**

# Summary

- ➢ Tl isotopes are an interesting region for chiral symmetry studies
- ✓ excellent near-degeneracy in 4qp pair of bands ($^{194}$Tl)
- ✓ chirality extends from 2qp to 4qp configurations ($^{194}$Tl)
- ✓ possibly two chiral systems built on the same configuration ($^{193,194}$Tl)
- ✓ Decay out of 4qp → 2qp and 3qp → 1qp bands – strong support for chirality interpretation

- ➢ **way forward:**
- ✓ study other neighbours, $^{195}$Tl experiment is in progress
- ✓ better statistics, triple gamma-coincidence

5 new clovers are on order to increase the efficiency of the AFRODITE array

Thank you for your attention!