Investigation of octupole excitations in ^{207}Tl using $\gamma\gamma$ angular correlations at the ISOLDE Decay Station

Tom Berry

University of Surrey

t.berry@surrey.ac.uk

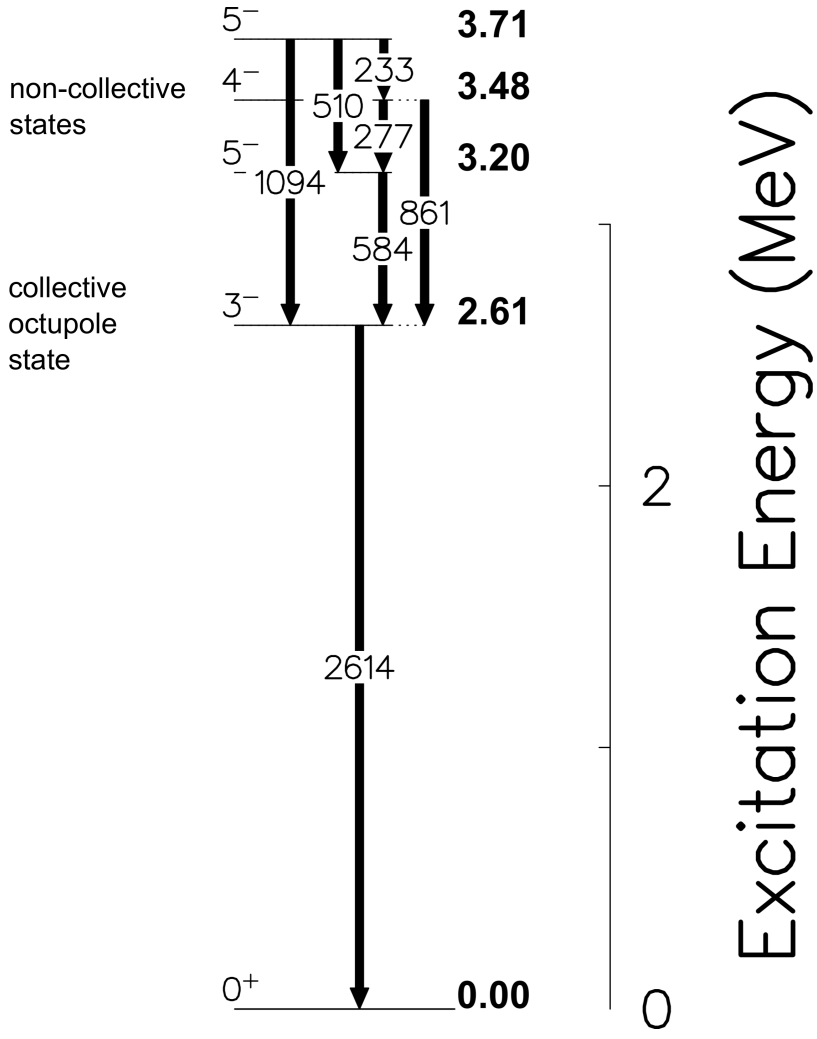
December 5, 2017

Overview

1. Background
   - The octupole excitation in ^{208}Pb
   - The relevance of ^{207}Tl
2. The IS588 experiments
3. Analysis
   - Level scheme
   - Angular correlations
   - Spin-parities
   - Comparison with calculations
4. Summary

The ^{208}Pb region

- Lowest excited state in stable doubly-magic ^{208}Pb is 2.6 MeV collective octupole (3^-) vibration
- This excitation is also observed in several neighbouring nuclei
- Collective excitation near closed shell means we can study interplay of single-particle and collective phenomena

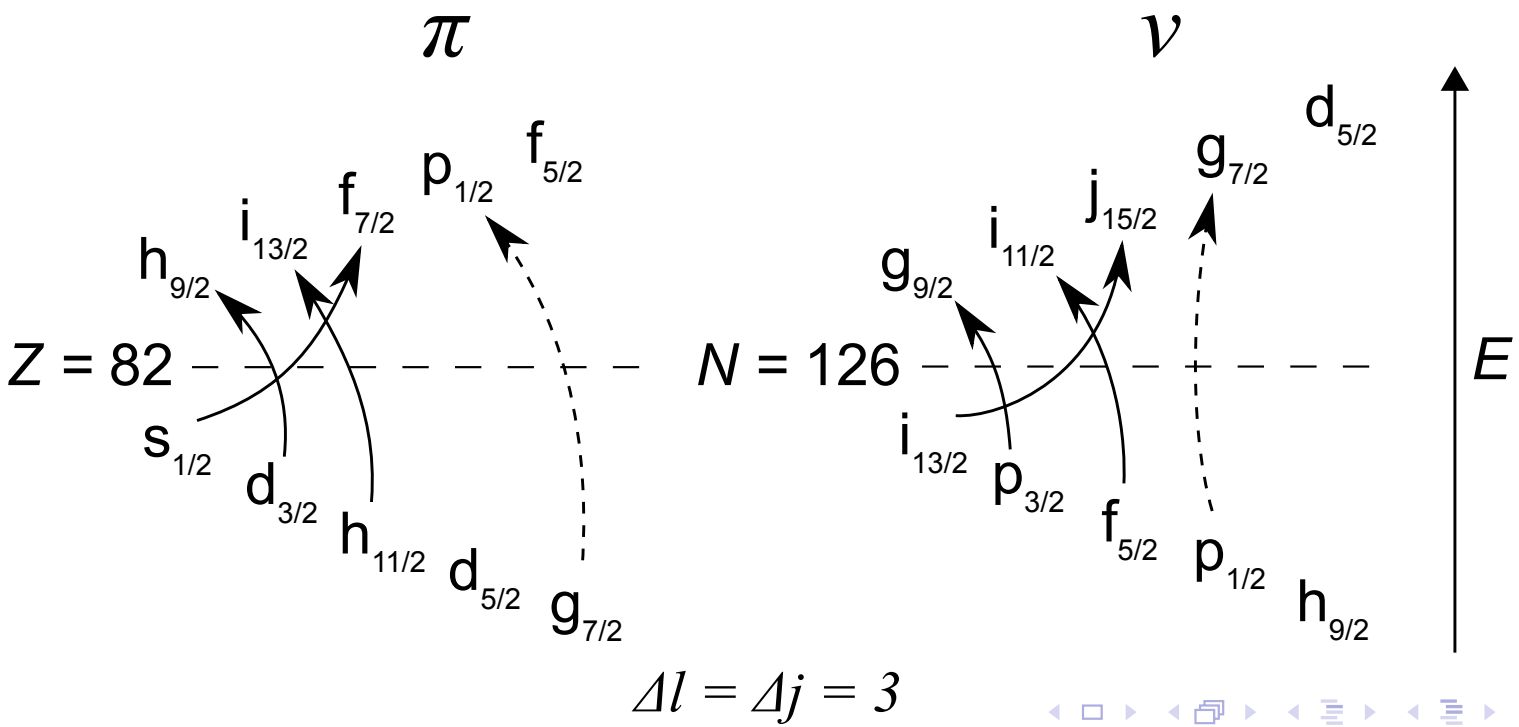


The 3^- excitation

Appears to exist as the result of the presence of many 3^- excitations between single-particle states across the proton and neutron shell gaps.

Approximate wavefunction from shell model calculations

$$|3^-\rangle \propto 0.12|\pi d_{3/2}^{-1} h_{9/2}\rangle + 0.11|\pi s_{1/2}^{-1} f_{7/2}\rangle + 0.05|\pi h_{11/2}^{-1} i_{13/2}\rangle + 0.15|\nu p_{3/2}^{-1} g_{9/2}\rangle + 0.09|\nu f_{5/2}^{-1} i_{11/2}\rangle + 0.07|\nu i_{13/2}^{-1} j_{15/2}\rangle$$

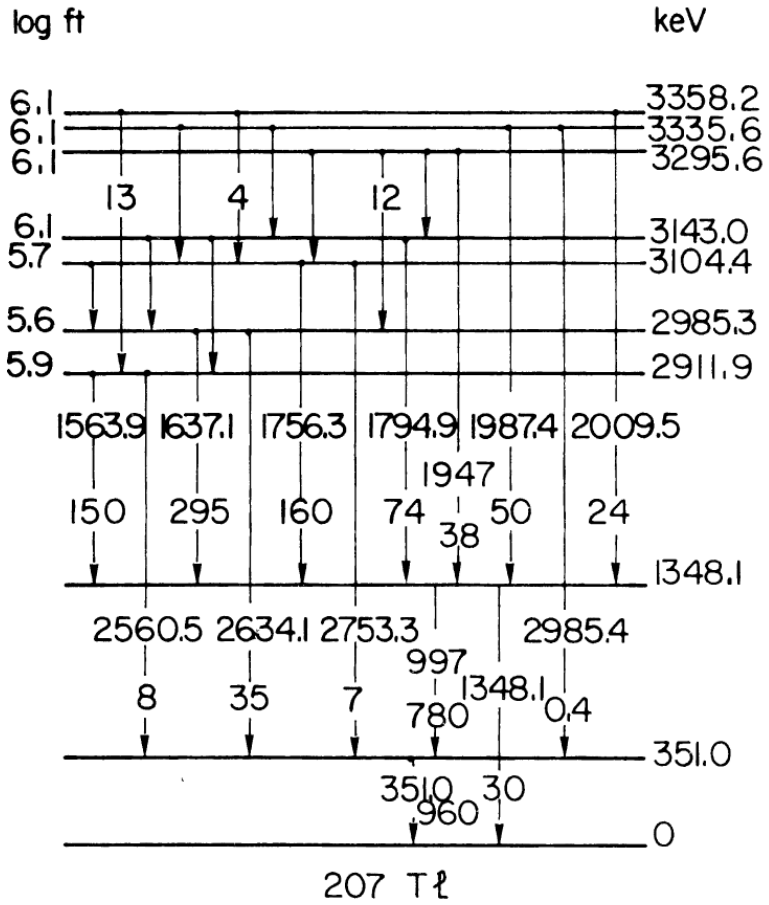


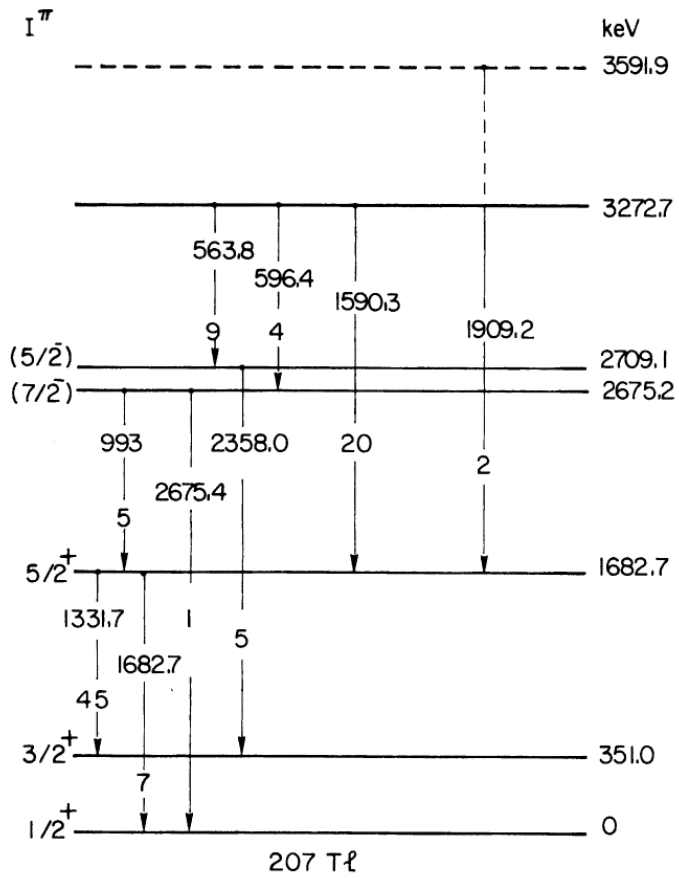
Knowledge of ^{207}Tl

- Single proton hole plus ^{208}Pb core
- Previous experiments predominantly probed single particle and yrast states
- We want to focus on proton-hole + octupole energy range (2 to 5 MeV), populating collective states

States in ^{207}Tl

Scheme from only previous β-decay experiment:

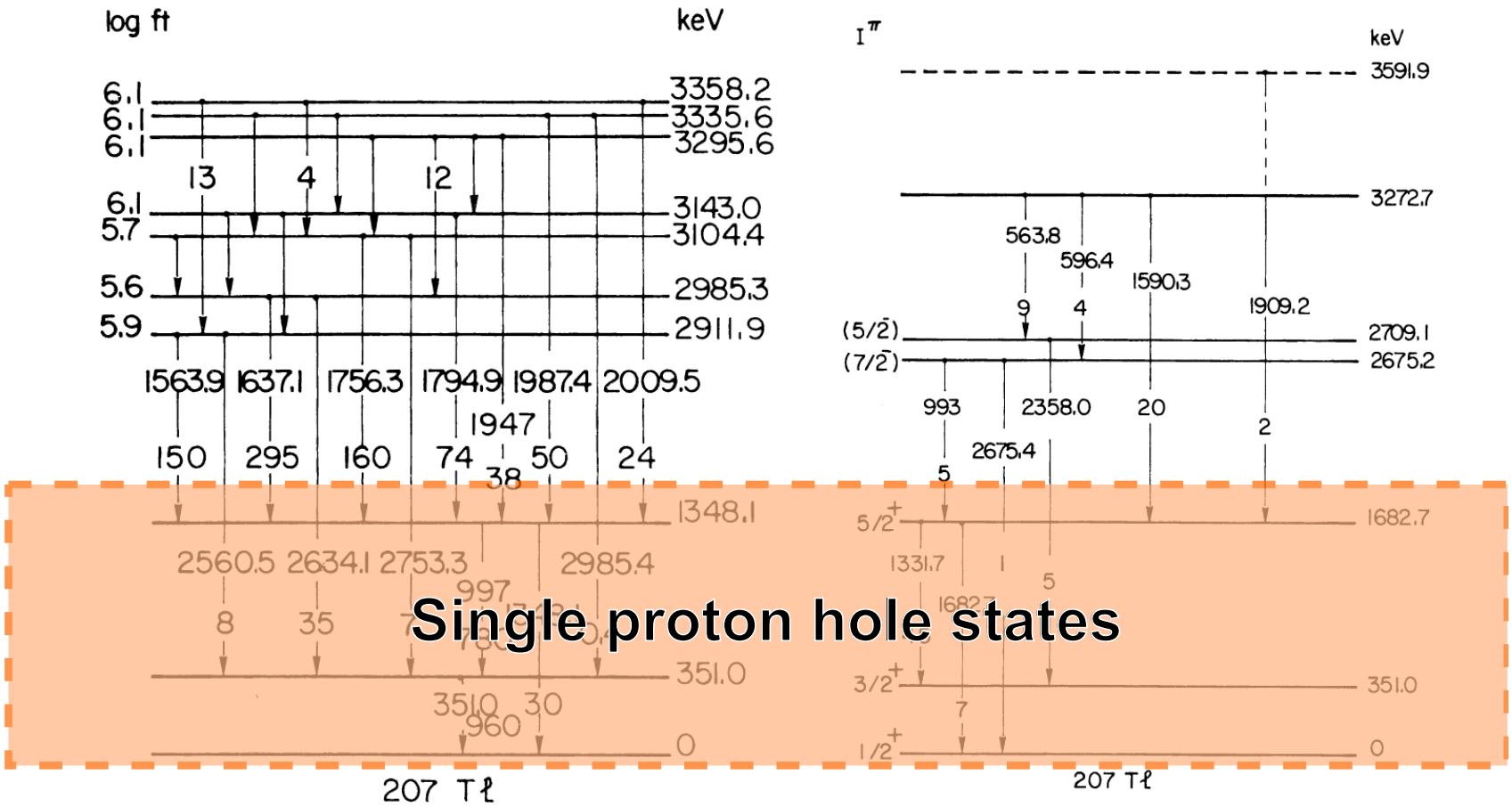




B. Jonson, CERN-81-09, 640 (1981)

States in ^{207}Tl

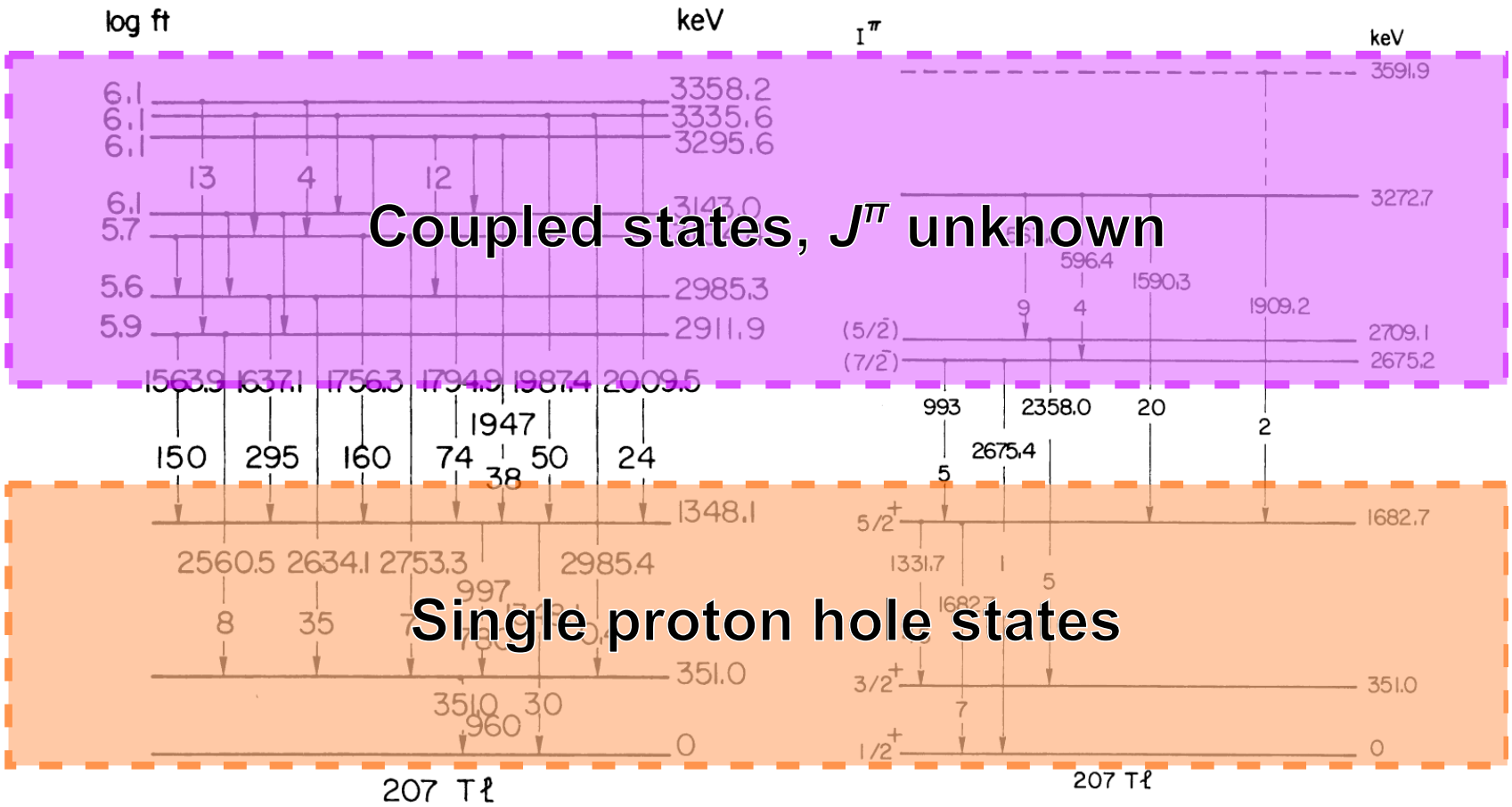
Scheme from only previous β-decay experiment:



B. Jonson, CERN-81-09, 640 (1981)

States in ^{207}Tl

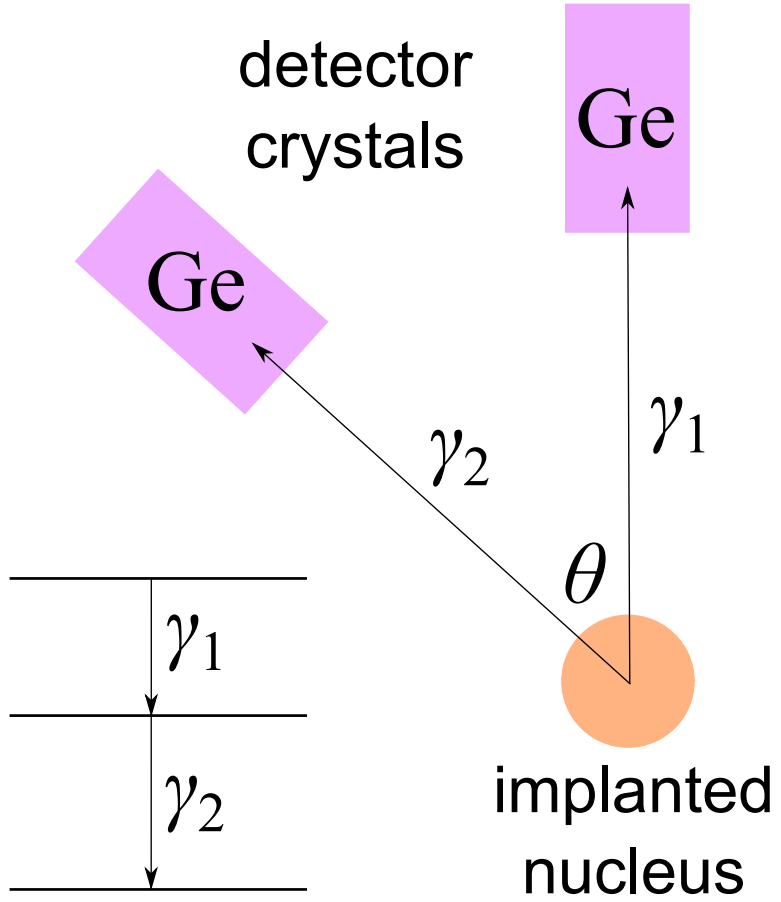
Scheme from only previous β-decay experiment:



B. Jonson, CERN-81-09, 640 (1981)

Angular correlations at the ISOLDE Decay Station

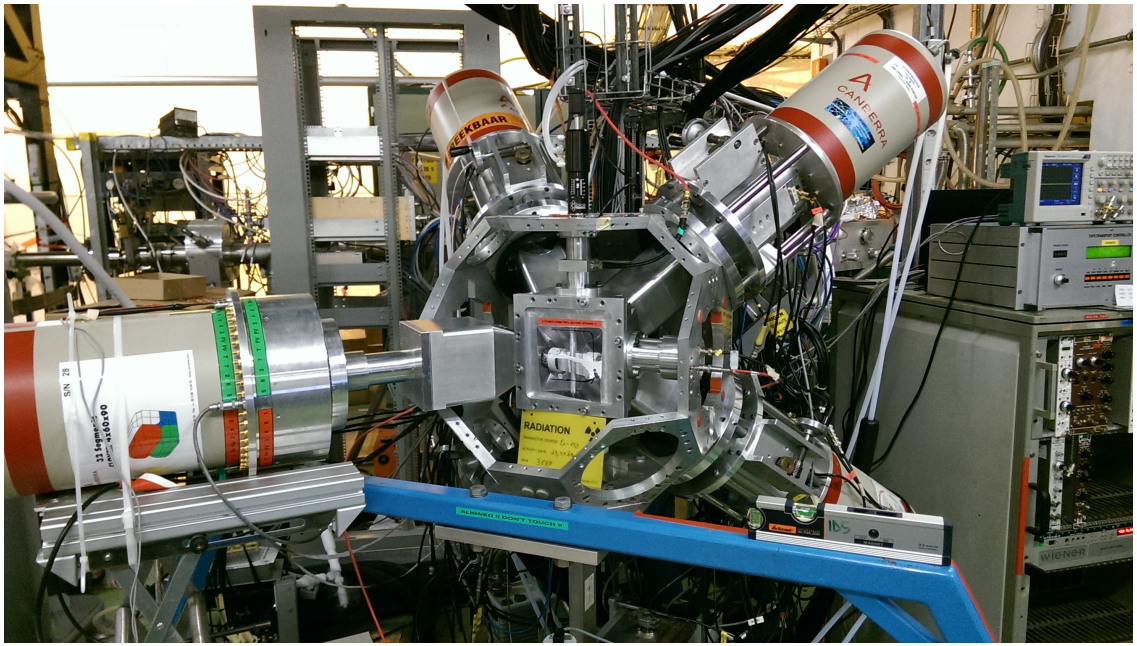
- Angular correlations are a powerful method of spin-parity deduction
- Gate on γ_1 and measure angular intensity distribution $W(\theta)$ of coincident γ_2
- Distribution tells us about spins and multipolarities
- Not previously performed at IDS



$$W(\theta) = 1 + A_2 Q_2 P_2(\cos\theta) + A_4 Q_4 P_4(\cos\theta)$$

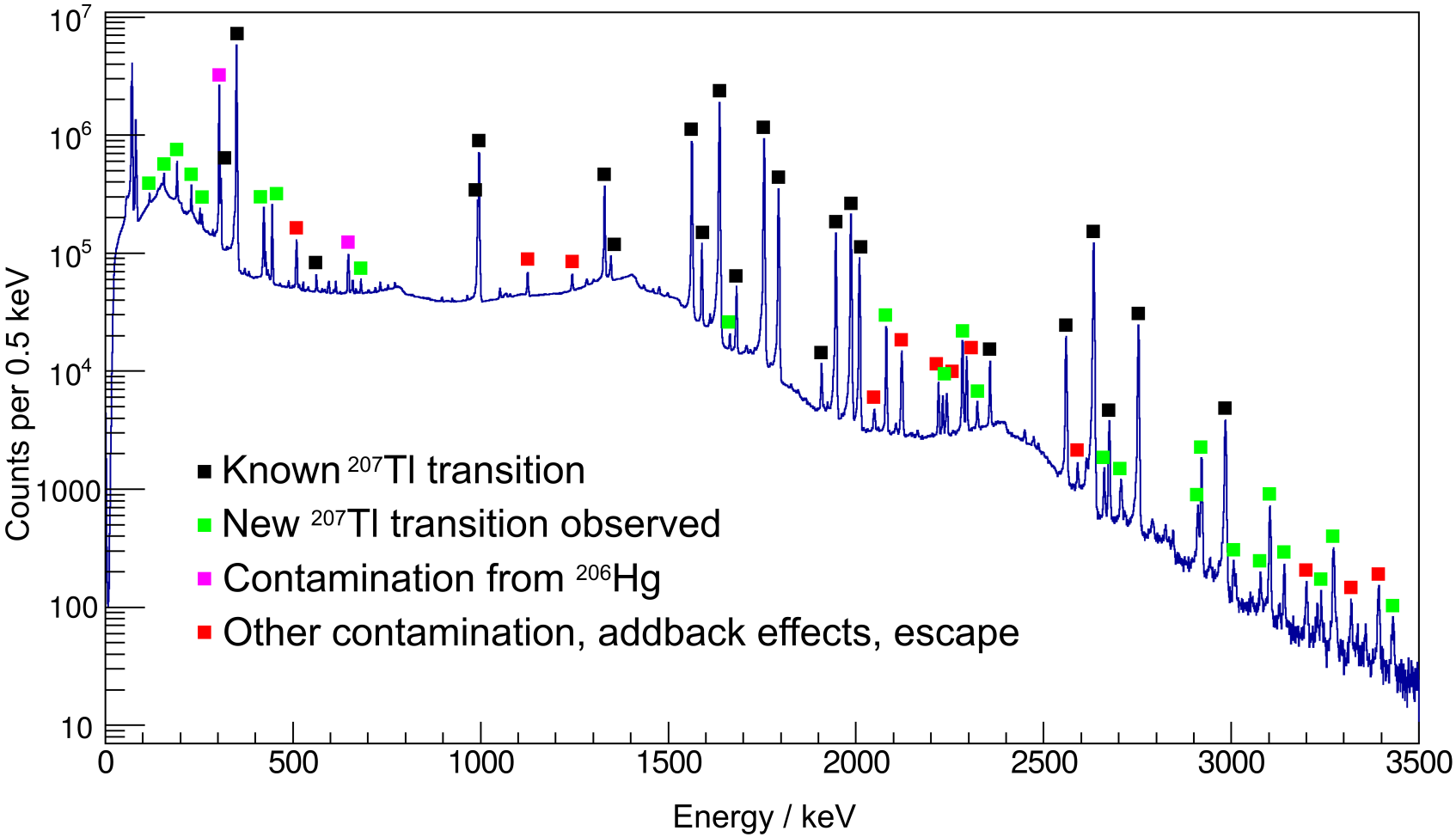
Experiment - IS588 at IDS

- Took place at ISOLDE Decay Station (IDS) in September 2014 and July 2016
- Production of ^{207}Hg from molten lead target... β^- decay takes place on tape at IDS
- Observed $\beta\gamma$ decay using HPGe clovers and plastic scintillators



Analysis - level scheme for ^{207}Tl

9 new levels and 73 new transitions established

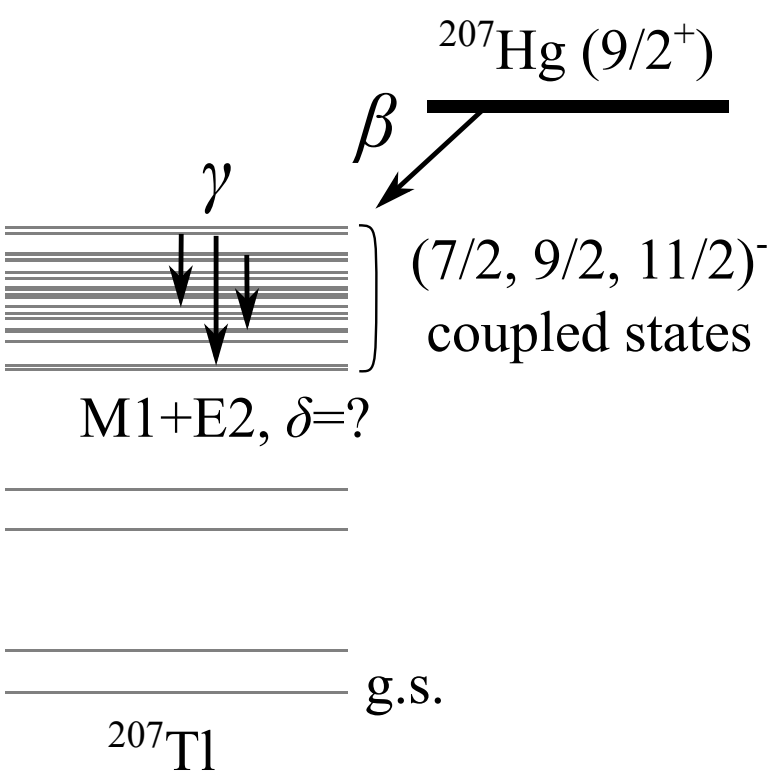


Angular correlations - analysis

$$W(\theta) = 1 + A_2 Q_2 P_2(\cos\theta) + A_4 Q_4 P_4(\cos\theta)$$

- Correlations calculated between individual crystals, rather than whole four-crystal clovers, to increase number of angles and improve granularity for precision
- Solid angle correction coefficients (Q_2, Q_4) calculated
- Known $\gamma\gamma$ coincidences from ^{152}Eu source run used to verify method
- Small number of high-statistics coincidences in ^{207}Tl exhibit clear trends which have been used to support spin-parity assignments

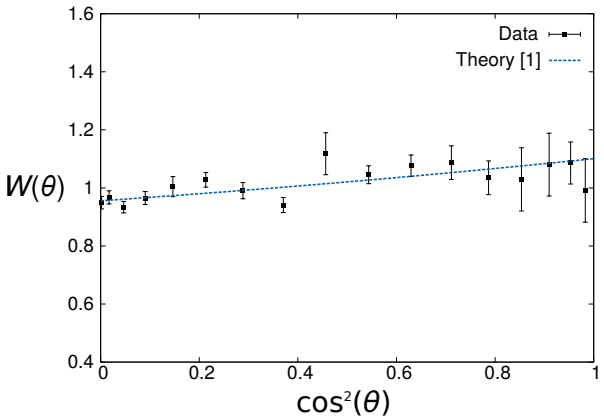
Angular correlations - analysis



- Lack of knowledge of δ means that correlation trends for majority of transitions aren't constrained, limiting possible conclusions.
- An improvement would be a reliable method of deriving mixing ratios e.g. conversion electron detector for low-energy transitions.

Angular correlations - testing with ^{152}Eu coincidences

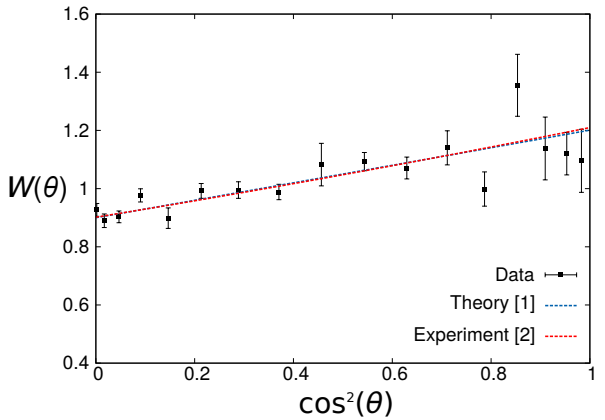
We observe good agreement between our data and expected correlations (theoretical and previous experimental).



244 keV 122 keV

^{152}Sm: $4^+ \longrightarrow 2^+ \longrightarrow 0^+$

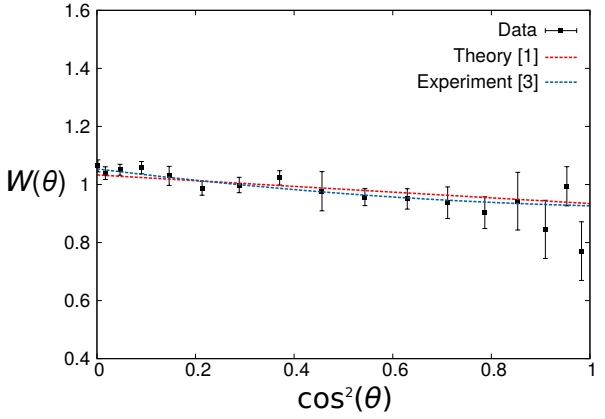
Expected [1]: A_2=0.10 A_4=0.01
Observed: A_2=0.10(3) A_4=-0.02(3)



1408 keV 122 keV

^{152}Sm: $3^- \longrightarrow 2^+ \longrightarrow 0^+$

Expected [1]: A_2=0.22 A_4=0.00
Expected [2]: A_2=0.22(1) A_4=0.02(1)
Observed: A_2=0.18(3) A_4=-0.03(4)



779 keV 344 keV

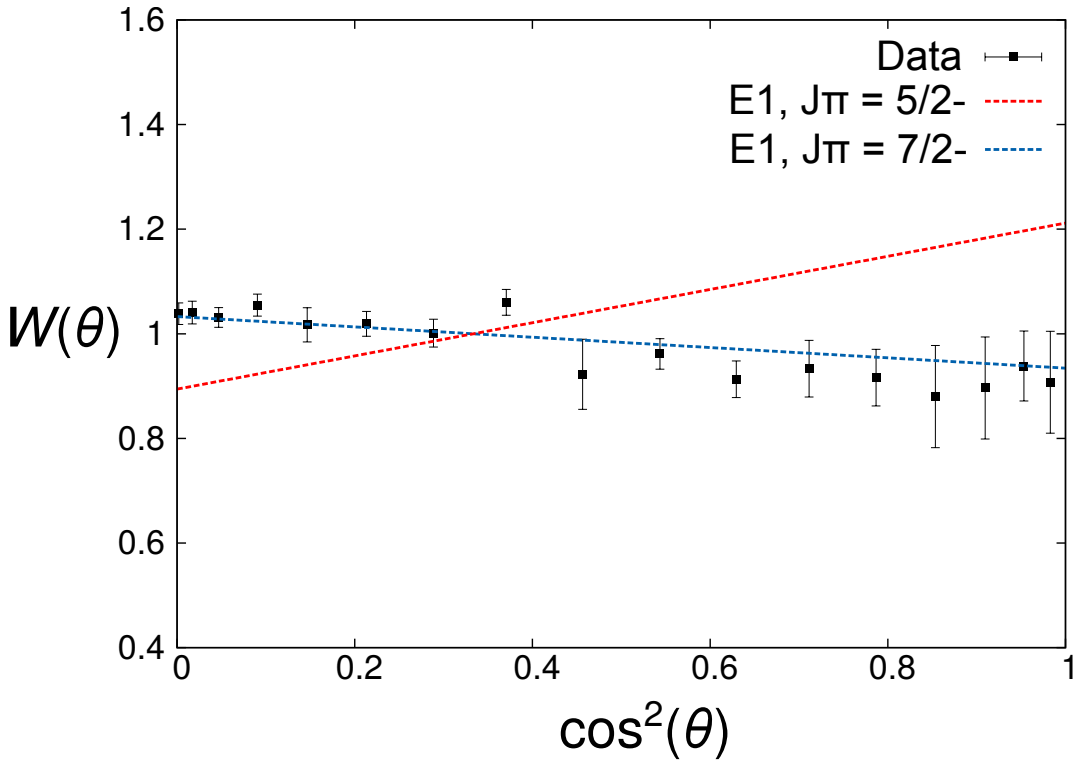
^{152}Gd: $3^- \longrightarrow 2^+ \longrightarrow 0^+$

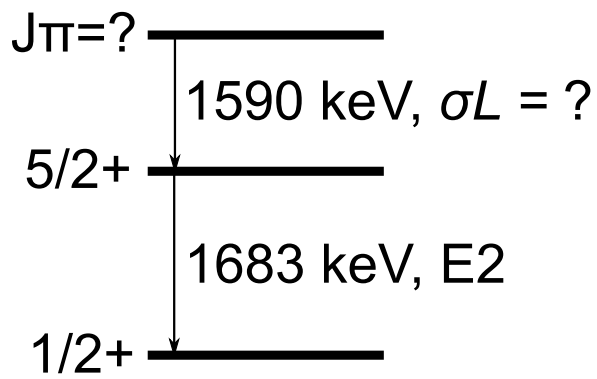
Expected [1]: A_2=-0.071 A_4=0.00
Expected [3]: A_2=-0.10(2) A_4=0.03(3)
Observed: A_2=-0.12(2) A_4=0.01(2)

[1] M. J. Martin, NDS **114**, 1497 (2013).
[2] J. T. Larsen *et al.*, NIM **69**, 229 (1969).
[3] C. A. Kalfas *et al.*, Nucl. Phys. **A169**, 615 (1972).

Angular correlations - results

Mixing has a significant effect on correlations, and so is problematic.
Un-mixed correlations provide more information.
Example: 1590 keV to 1683 keV unmixed coincidence





A_2 (J=5/2) = 0.23
A_2 (J=7/2) = -0.07
A_2 (result) = -0.10(2)

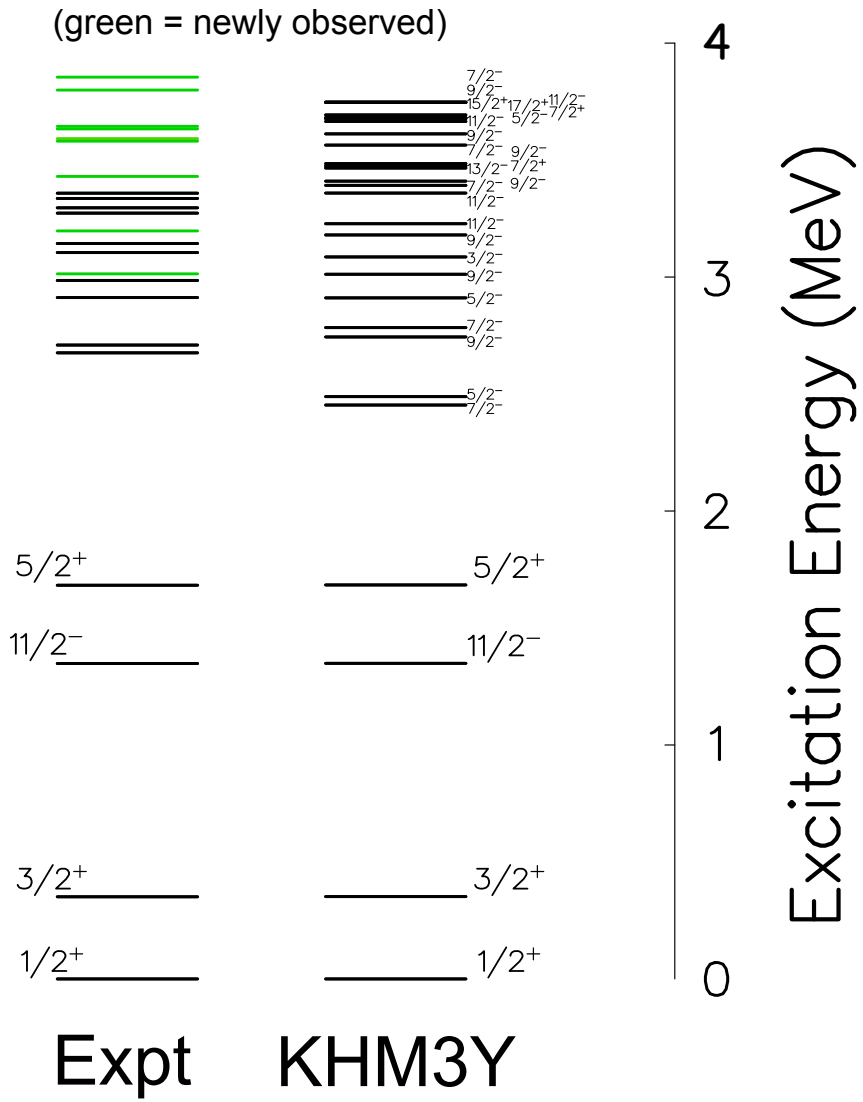
Similar results justify several other 7/2- assignments.

Spin-parity inferences

- The majority of the level spin-parity suggestions have been guided by relative $B(\sigma L)$ transition strengths and log ft values.
- If we make educated assumptions for some transition strengths ($B(E3) = 10$ W.u. or $B(E1) = 1 \times 10^{-4}$ W.u.) then we can calculate strengths for other transitions.
- These results are then supported in places by the angular correlations.

KHM3Y calculation

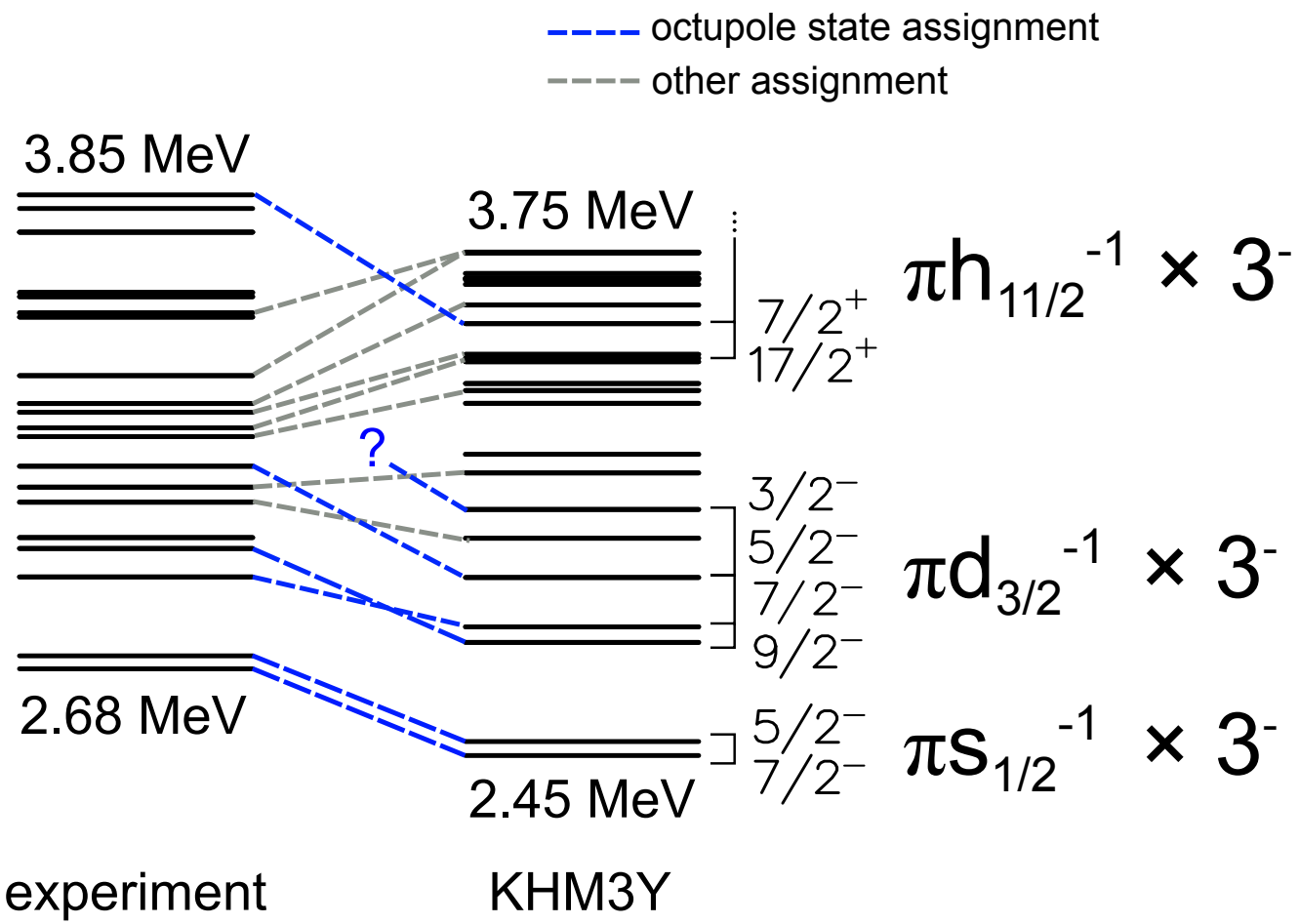
- Shell model KHM3Y calculations performed by Alex Brown
- Takes into account all orbitals expected to contribute significantly to octupole excitation
- Currently achieves the best natural replication of the octupole phonon around ^{208}Pb



B. A. Brown, Phys, Rev. Lett. **85**, 5300 (2000)

Calculations - comparison

Preliminary assignments (2 to 4 MeV):



Summary

- Two experiments producing ^{207}Tl through β-decay of ^{207}Hg took place at the ISOLDE Decay Station.
- A more comprehensive level scheme has been established in this analysis.
- Tentative spin-parity assignments have been made for all levels. Five of the six $s_{1/2}$- and $d_{3/2}$-coupled octupole states have been observed, as well as possibly the $\frac{7}{2}^+$ $h_{11/2}$-coupled state.
- Angular correlations have been successfully employed at IDS for the first time.
- Knowledge of octupole coupling behaviour improves our understanding of the ^{208}Pb octupole phonon.

Acknowledgments

T. A. Berry, Zs. Podolyák, R. J. Carroll, R. Lica, C. Sotty, B. A. Brown, T. Alexander, I. M. Alonso, S. Ansari, M. J. Borge, H. De Witte, C. Fahlander, L. M. Fraile, E. Gamba, W. Gelletly, R.-B. Gerst, A. Gredley, P. Greenlees, L. J. Harkness-Brennan, S. Judge, J. Konki, J. Kurcewicz, I. Kuti, S. Lalkovski, I. Lazarus, M. V. Lund, M. Madurga, C. R. Nita, S.-A. Noe, Z. Patel, J. Phrompao, M. Piersa, V. Pucknell, E. Rapisarda, P. H. Regan, M. Rudigier, C. M. Shand, R. Shearman, S. Stegemann, A. Turturica, V. Vedia, P. Walker, F. Wearing and the IDS Collaboration.

This work has been funded by an STFC Doctoral Training studentship.

Aside - 'node selection rule'

- We observe no β feeding to the $g_{7/2}$ single-particle state, expected to be the only allowed transition. We assign the observation limit $\log ft > 8.9(1)$.
- Follows from Lawson's prediction and Datar *et al.*'s observation of the $\Delta n \neq 1$ selection rule in ^{209}Tl, which destroys an allowed transition.
- This is only the second observation of this effect, and may serve to strengthen the theory explaining this selection rule.