Poster number 46 - A.J. Mitchell (email: Alan.Mitchell@postgrad.manchester.ac.uk)

Evolving high-*j* single-particle energies

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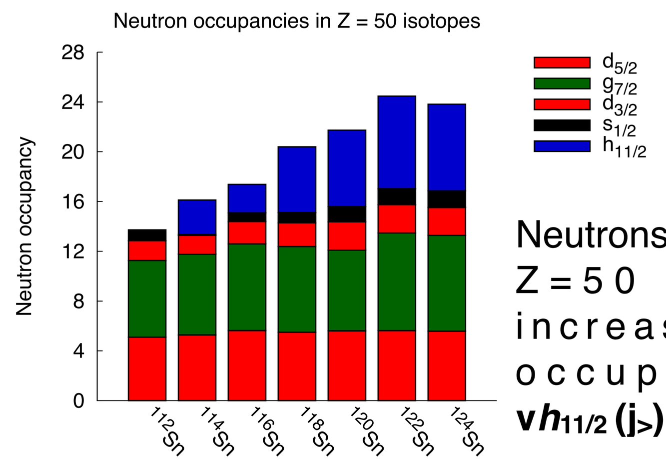
Scientific motivation

★ 2004 study by Schiffer *et al.* [1] investigated the behaviour of the lowest-lying 7/2+ and 11/2- states in *Z*=51 nuclei [1].

★ These were found to possess ~90% of the single-particle strength of the underlying $\pi g_{7/2}$ and $\pi h_{11/2}$ orbitals => strongly single-particle in nature.

★ Systematic separation in energy of ~1 MeV with increasing neutron excess was observed.

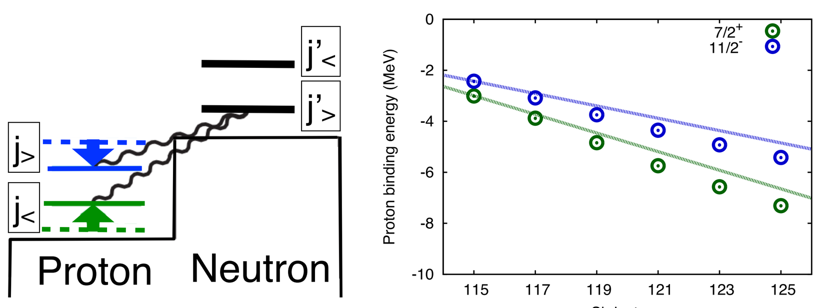


Neutrons in the Z=50 core increasingly occupy the $\nu h_{11/2}$ ($j_>$) orbital.

[1]: J. P. Schiffer *et al.*, PRL **92** 16 (2004).

★ 2005 theoretical study by Otsuka *et al.* [2] => **tensor component of the *NN* interaction** responsible for driving evolution of single-particle orbitals:

$\nu h_{11/2}$ ($j_>$) attractive with $\pi g_{7/2}$ ($j_<$)
$\nu h_{11/2}$ ($j_>$) repulsive with $\pi h_{11/2}$ ($j_>$)



A lack of statistics prevented a detailed analysis of the extent of fragmentation of the single-particle strength.

Our aim was to investigate the smaller fragments of high-*j* strength and gain additional information on the low-*j* states.

[2]: T. Otsuka *et al.*, PRL **95** 232502 (2005).

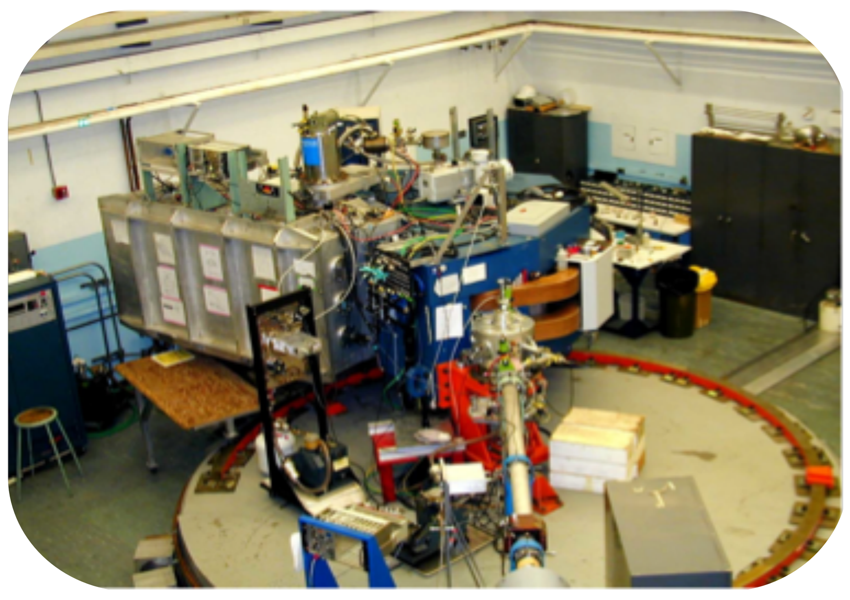
Experimental set up

These experiments were conducted at the A.W. Wright Nuclear Structure Laboratory (WNSL) at Yale University in March 2010.

★ Beams of α particles and ^{3}He nuclei accelerated by the **ESTU tandem Van de Graff accelerator** (right).

★ The beam was tuned to produce a well-defined beam spot less than 2mm diameter.

★ Experimental area shown below.



Experiments were performed on isotopically enriched targets of stable even-even Z=50 isotopes **^{112}Sn – ^{124}Sn.**

For direct reaction studies we require targets with thicknesses ~100-200 μgcm^{-2}:

★ Obtain suitable reaction yields,
★ Limiting resolution effects.

The following measurements were taken for each target:

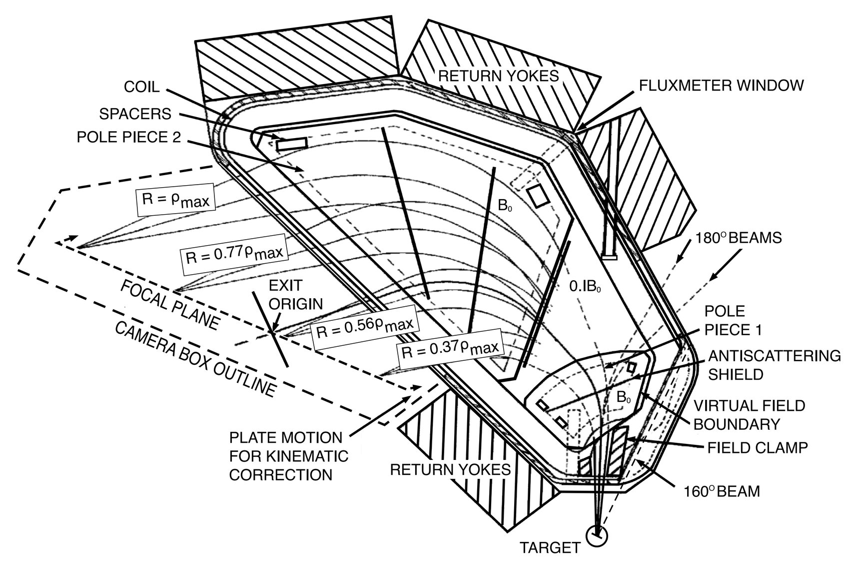
15.0 MeV α particle elastic scattering at 20°
37.5 MeV (α,t) reactions at 6° and 18°
25 MeV (^{3}He,d) reactions at 6° and 15°

Reaction products momentum analysed by the **Enge split-pole spectrometer** (right) and were detected at the focal plane.

The spectrometer rests on a movable platform => allows measurements at different angles.

Detection system of a Position-sensitive Ionisation Drift Chamber (**PIDC**) followed by a **plastic scintillator**.

★ This identifies ejected particles from ***E*, Δ*E*** and **position** measurements.



★ A product of **target thickness and spectrometer aperture size** was determined using elastic scattering measurements.

★ This arrangement is consistent with Rutherford scattering to within 1%.

★ This product is used in subsequent analysis to minimise systematic errors.

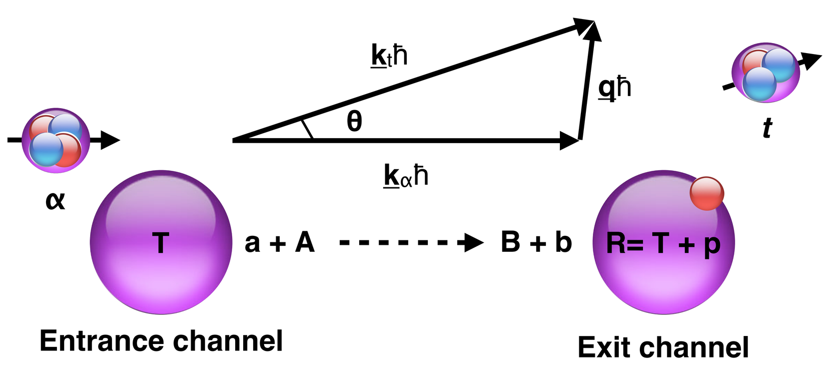
★ The aperture size remained fixed throughout the experiments - can be used to determine nominal values for the thickness of each target.

Transfer reactions

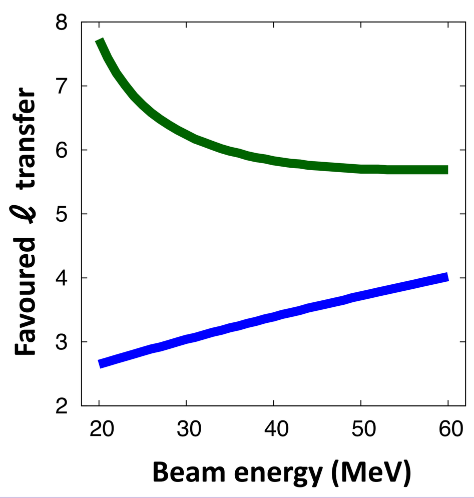
The use of **transfer reactions** to investigate the single-particle structure of the nucleus is well established. As well as observing the degree of fragmentation of single-particle strength caused by residual interactions, it is possible to reconstruct the energy centroids of the single-particle orbitals and observe their trends.

★ Single-step processes.
★ Avoid excitations of the core.
★ Populate low-lying levels similar in structure to the ground state.
★ Reaction amplitudes depend on the overlap of the initial and final states wave functions.

Cross sections of reactions can be modelled by **DWBA calculations** using optical model wave functions to describe the relative motion of the incoming and outgoing channels.



Semi-classically: $\ell = r \times q$



e.g. ^{118}Sn Q-values:
(α,t) -14.705 MeV
(^{3}He,d) -0.384 MeV

(α,t): high-ℓ

(^{3}He,d): low-ℓ

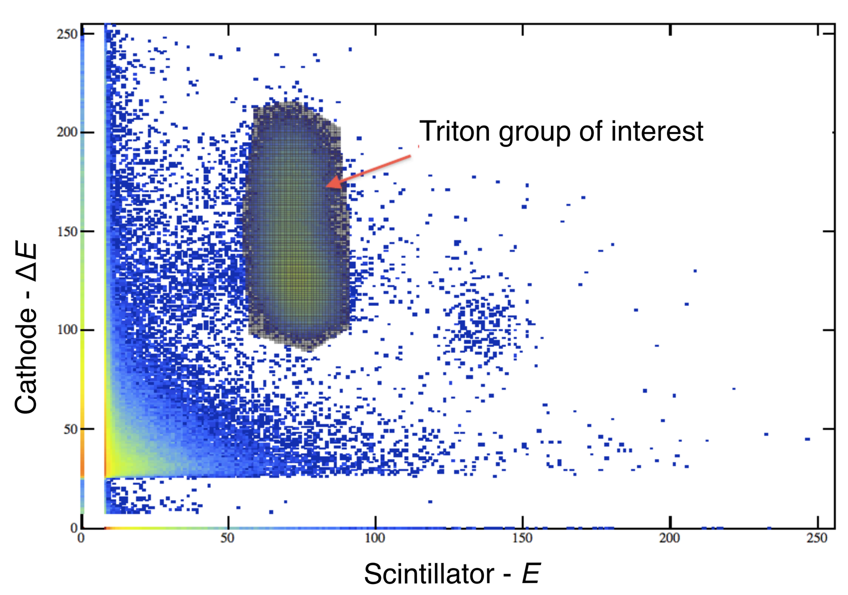
(Calculations performed at θ = 0°)

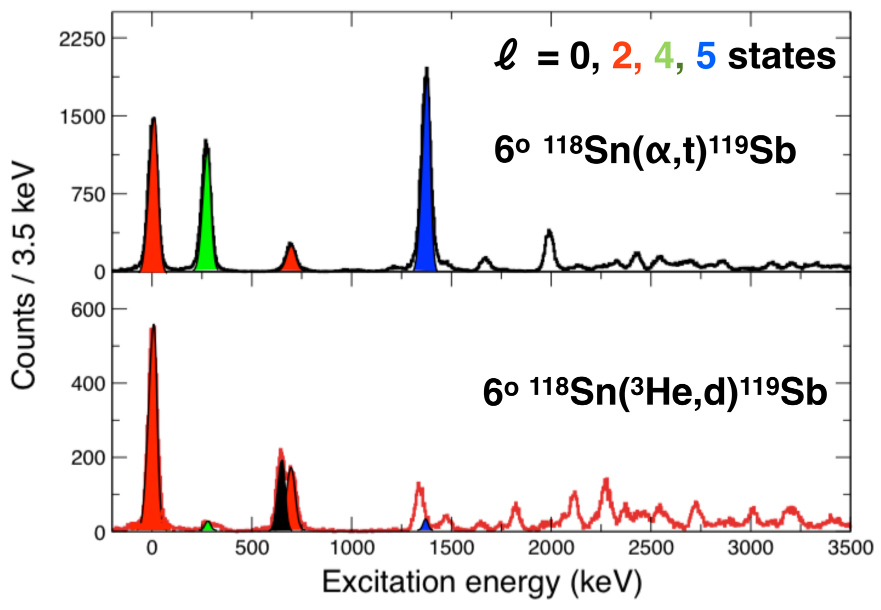
Analysis and results

Particles detected at focal plane:
★ Identified using *E*-Δ*E* signals from scintillator and cathode.
★ Momentum determined from front wire position signals, applying a delay line method.

Typical resolution obtained for the energy calibrated spectra was 40 - 60 keV.

Examples of scintillator-cathode histogram and energy calibrated focal plane spectrum are shown below (target is ^{118}Sn).





★ **Cross sections**: related to reaction yield, the product of target thickness and spectrometer aperture size and the number of beam particles impacting on the target.

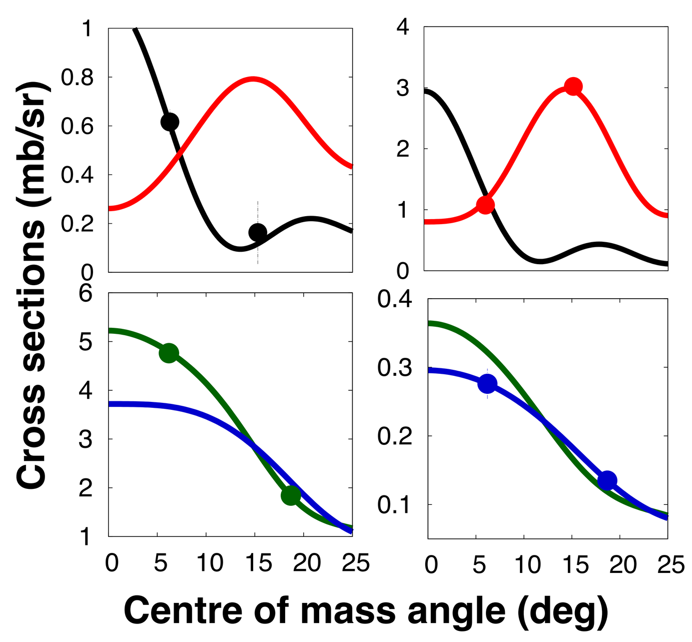
Even-even targets with 0+ ground state => **spin-parity** of states populated in reactions corresponds to degree of ℓ-transfer that takes place.

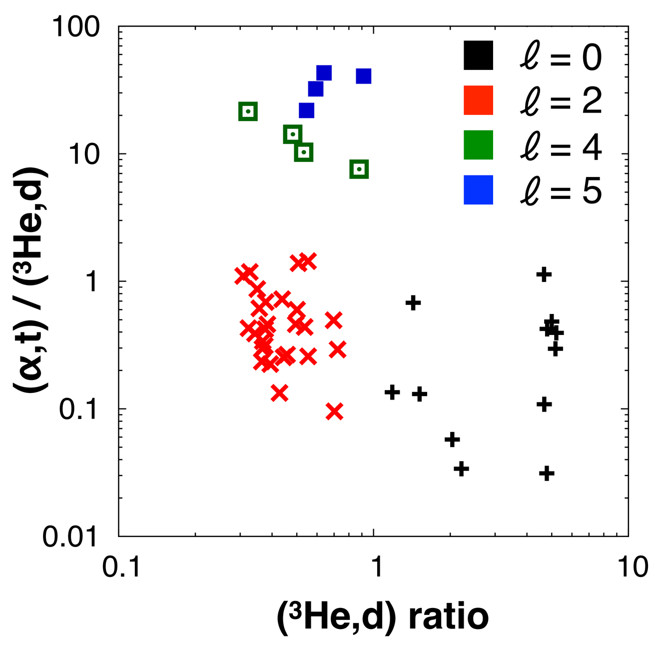
★ **Assigning ℓ values:** experimental cross sections compared to normalised DWBA angular distributions (calculated by Ptolemy).
★ Characteristic shapes used to distinguish between the different values of ℓ transfer.

Some ambiguity arises in weakly populated states:

★ Require ratios of cross sections from **different reactions**.
★ Ratios from one reaction are plotted against ratios from both reactions.
★ These are calibrated using known states to identify the unknown states.

Only by consideration of **all information** can assignments be made!!





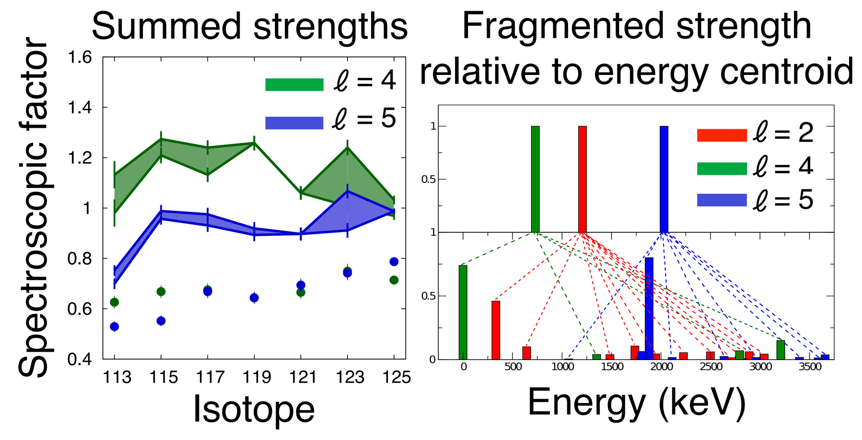
★ **Spectroscopic factor:** gives a measure of overlap between final state and initial state plus one nucleon

$$S_i = \sigma_{EXP} / \sigma_{DWBA}.$$

★ **Macfarlane & French sum rules:** used in summation of spectroscopic factors of individual states.
Single-proton adding to a closed-shell nucleus: S_{max} = 1

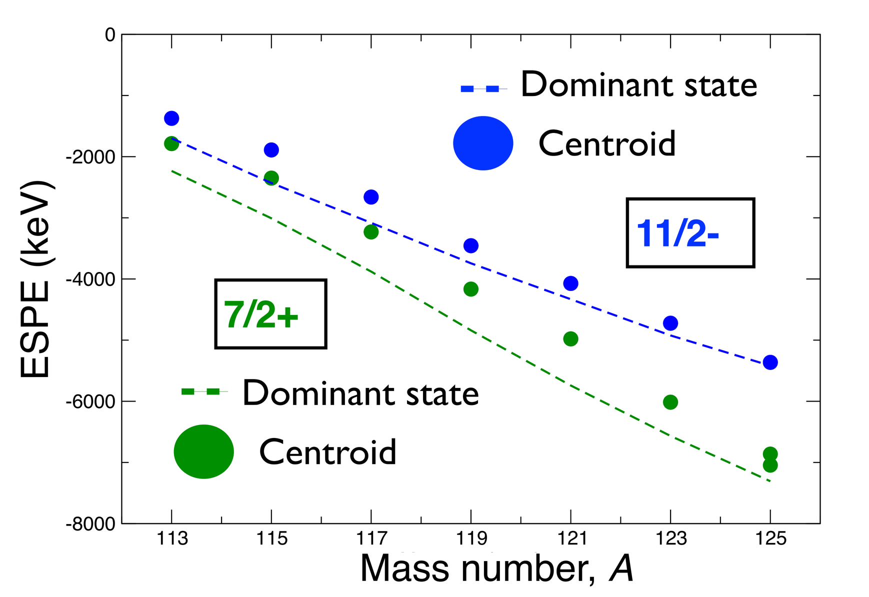
Inadequacies in DWBA calculations require a common normalisation across all orbitals and targets => **relative spectroscopic factors** suitable for comparison.

★ **Summed strengths:** shown with the strength of each dominant state (top right).



★ **Energy centroids:** calculated as weighted sum of individual state energies.

★ Diagram above shows fragmented ℓ = 2, 4 and 5 strength relative to the reconstructed centroids.
★ Highlights the fact that the lowest lying or strongest state alone is not necessarily a good approximation to the underlying orbital energy.



★ **Fragmentation of the $\pi g_{7/2}$ and $\pi h_{11/2}$ shown to be greater than in the previous study [1].**

★ **Binding energies of the centroids lie slightly higher in energy than the dominant states.**

★ **Increased fragmentation does not appear to significantly effect the trends of the single-particle energies.**

Acknowledgements

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