Probing ^{174}Yb and ^{178}Hf Structure With *(p,t)* Reactions

John Santucci

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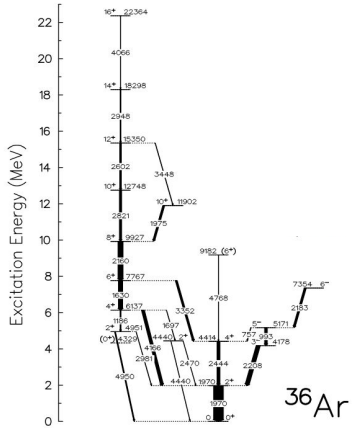
Motivation

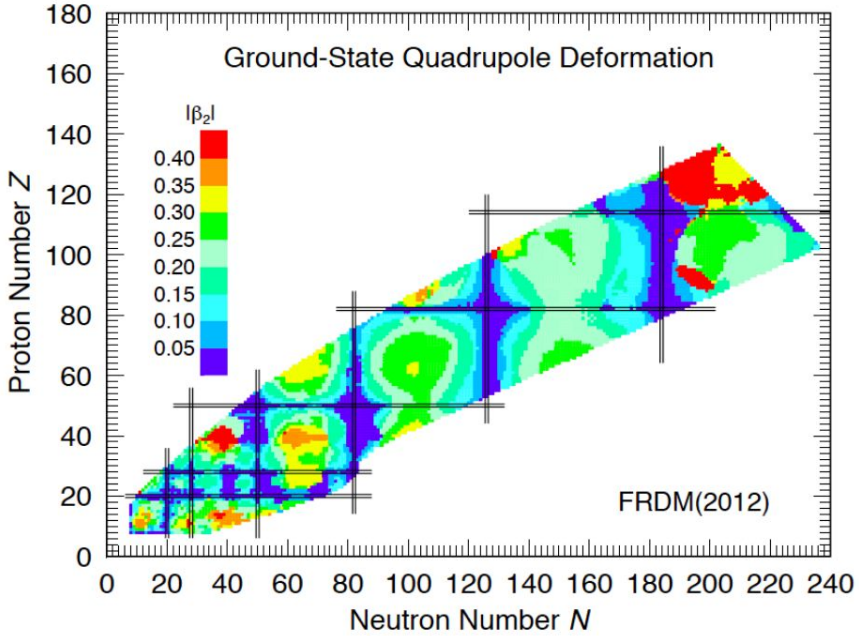
We want to better understand what nuclei look like.

Most nuclei are not spherical.

Existence of rotational bands implies deformation.



[C. E. Svensson, et al. (2000)]



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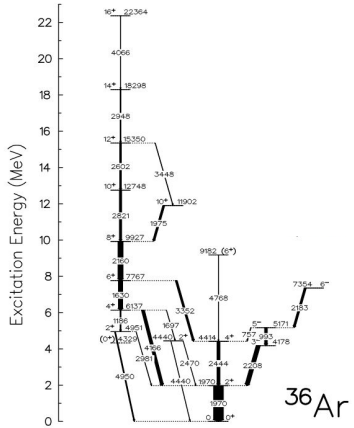

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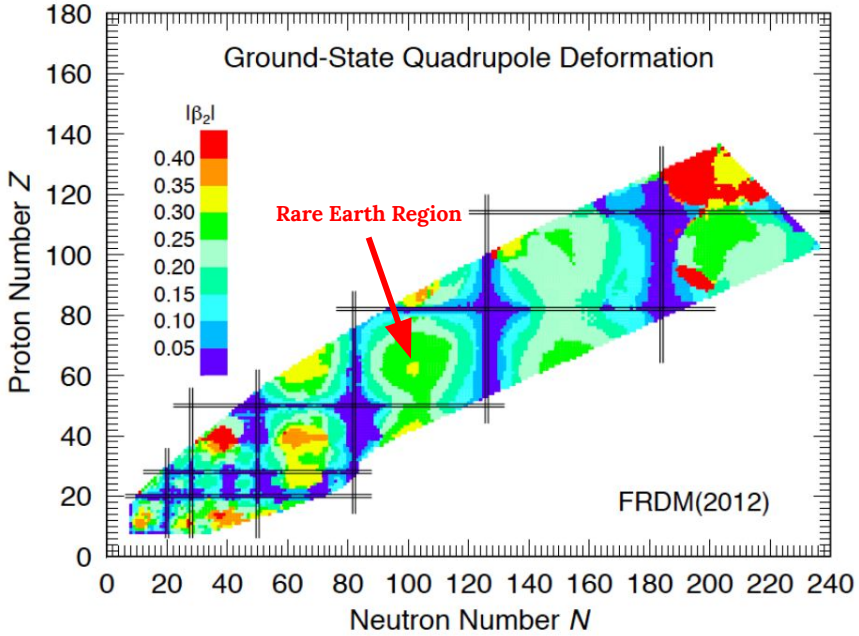

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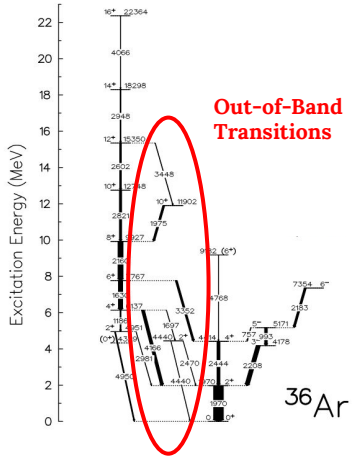

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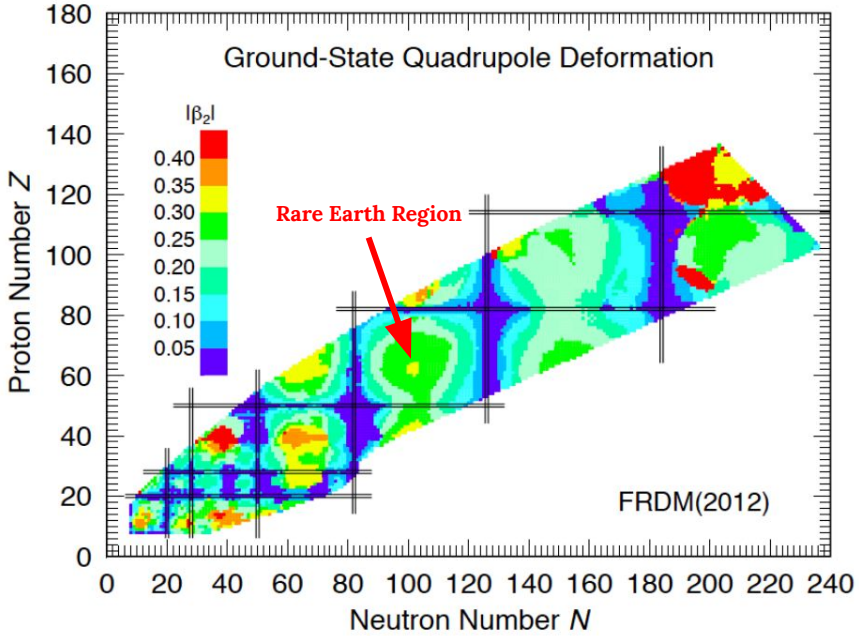

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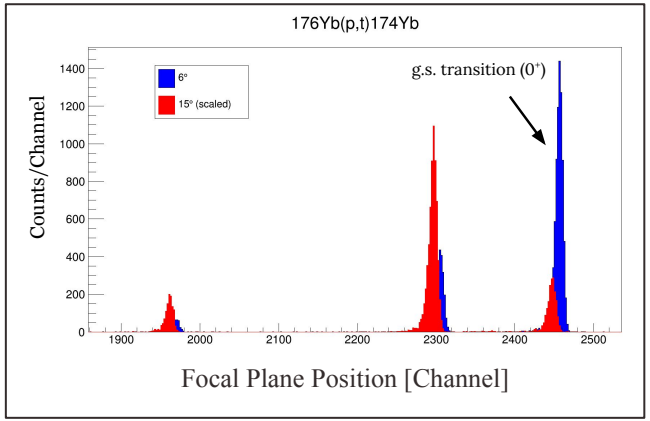
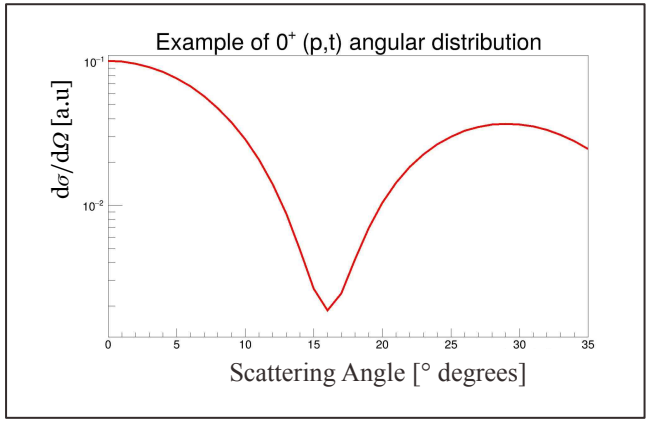
Motivation

Why (*p*,*t*) reactions and 0^+ states?

- (*p*,*t*) reactions allow for direct access to 0^+.
- (*p*,*t*) reactions and 0^+ states can give insight into pairing correlations, relative shapes between isotopes, and shape coexistence.
- Complementary to γ-spectroscopy for further structure analysis.





Experimental Procedure

- Performed using the Q3D spectrometer at the Maier-Leibnitz Laboratory at the Technical University of Munich.
- 22 MeV protons on ^{176}Yb, ^{180}Hf, and ^{170}Er, the calibration target.
- Calibrate channel spectrum in terms of magnetic rigidity ($B\rho$) to avoid q-value dependence of excitation energy (E_x).

Magnetic Rigidity: $B\rho = \frac{p}{q}$

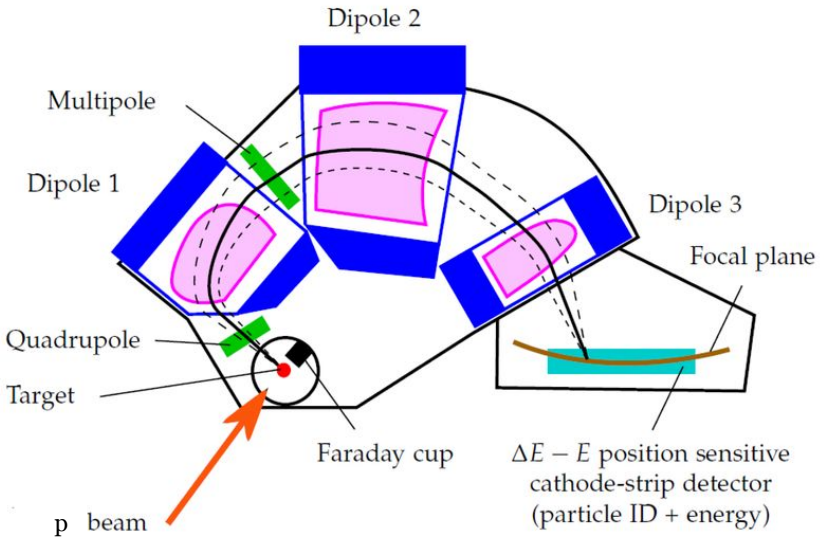
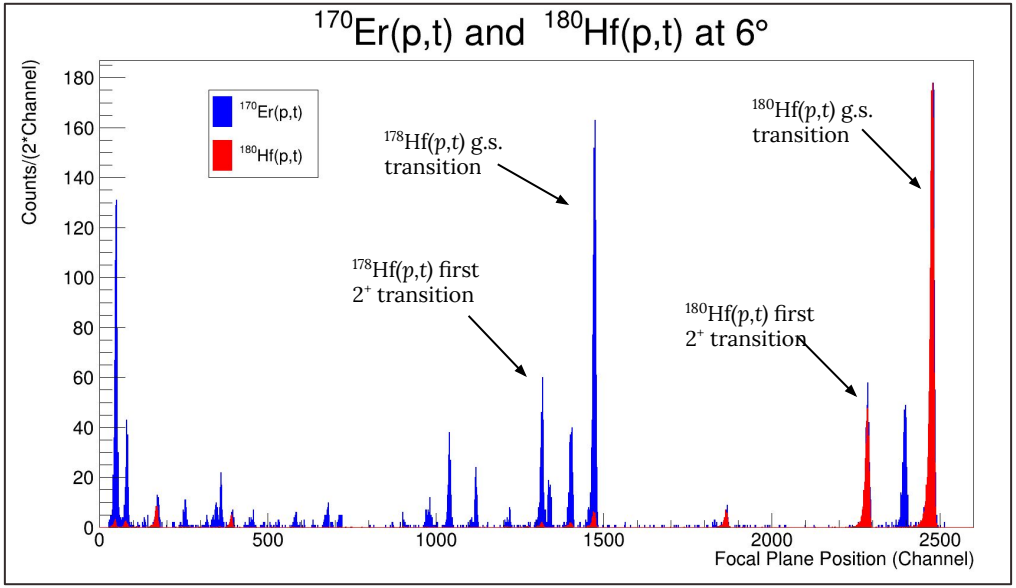


Diagram of Q3D and focal plane. [Rebiero, B. et al. (2016)]

Calibration

Complications calibration:

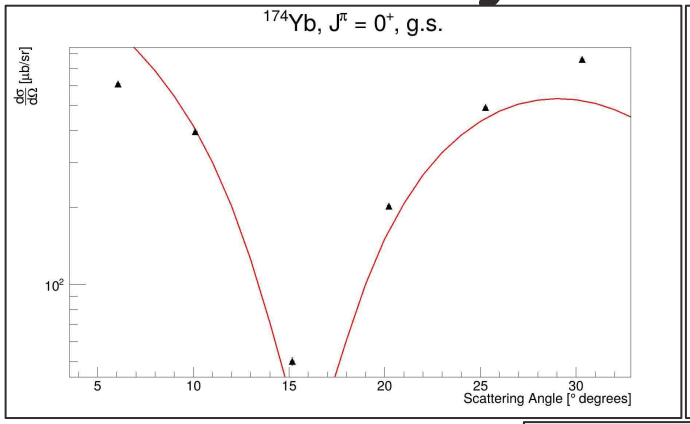
- ^{170}Er target has natural Hf contamination.
  - Hf potentially a reducing agent
- Self calibrating ^{176}Yb(*p*,*t*) and ^{180}Hf(*p*,*t*) spectra gets more difficult as E_x increases.

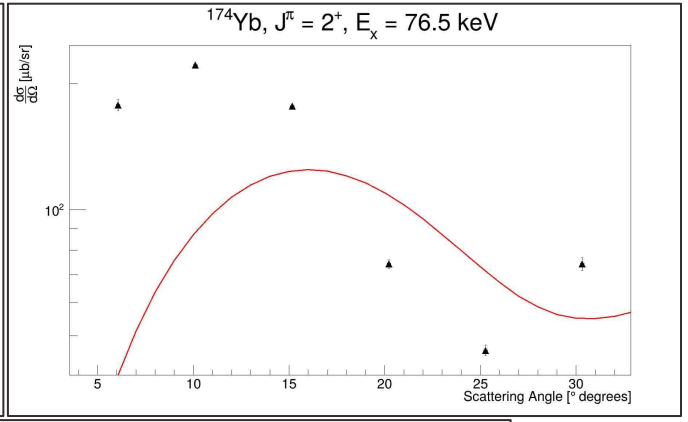


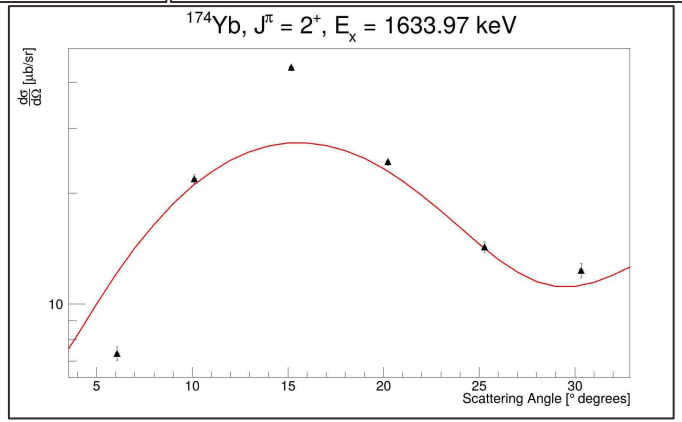
(Above) Overlay of ^{180}Hf(*p*,*t*), centered at 580 keV, and corresponding ^{170}Er(*p*,*t*) spectra at 6°

Preliminary Results

Differential cross-sections for the ^{174}Yb states with Distorted Wave Born Approximation (DWBA) calculations overlaid in red. (Uncertainties are preliminary)







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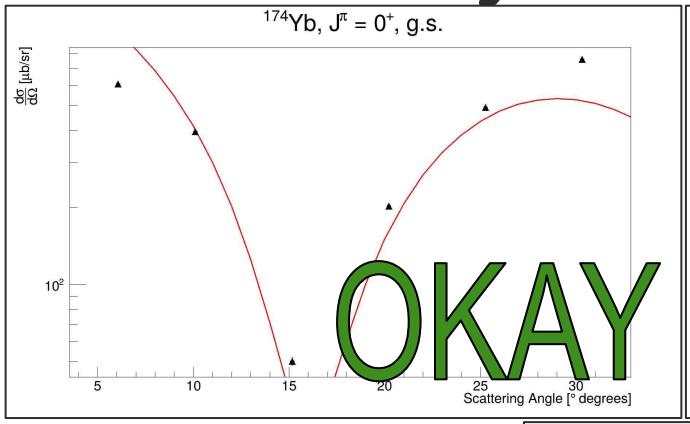

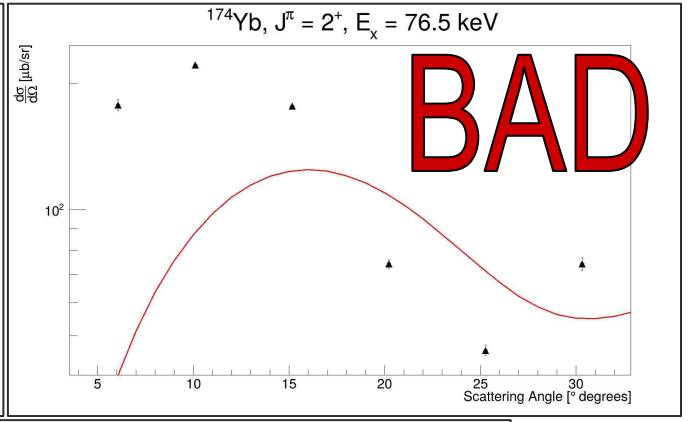

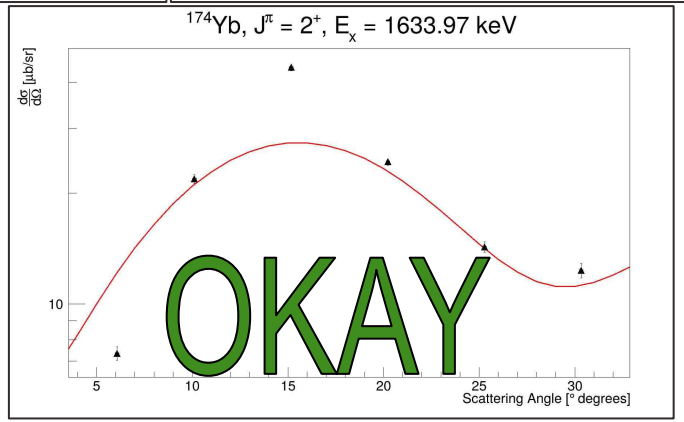

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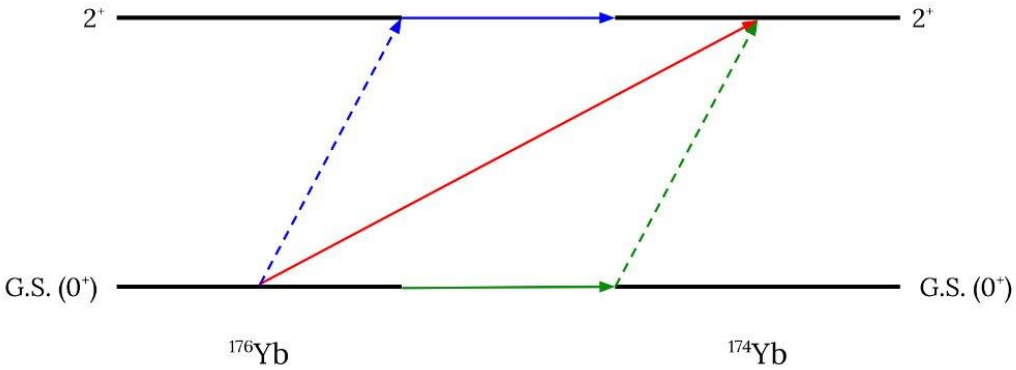
Couple Channel Calculations

Why use CCBA over 1-step DWBA?

- In most cases 1-step dominates transition strength.
- Increased deformation means increased inelastic excitation probability.
- Multi-step processes can have increased contributions.



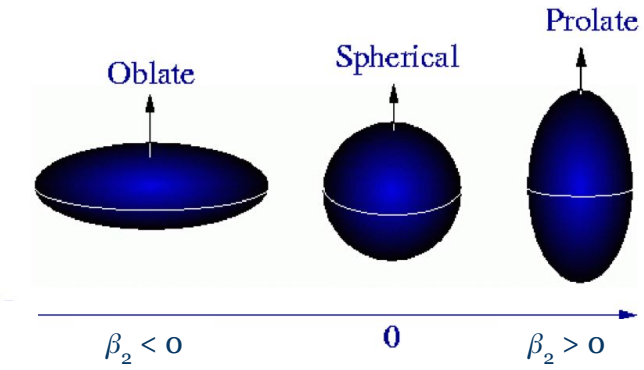
- **Red** is a 1-step process and **Blue**/**Green** are 2-step processes.
- **Solid** lines describe target nucleus to recoil nucleus transitions.
- **Dashed** lines describe inelastic excitations within their respective nucleus.

Coupled Channels Calculations

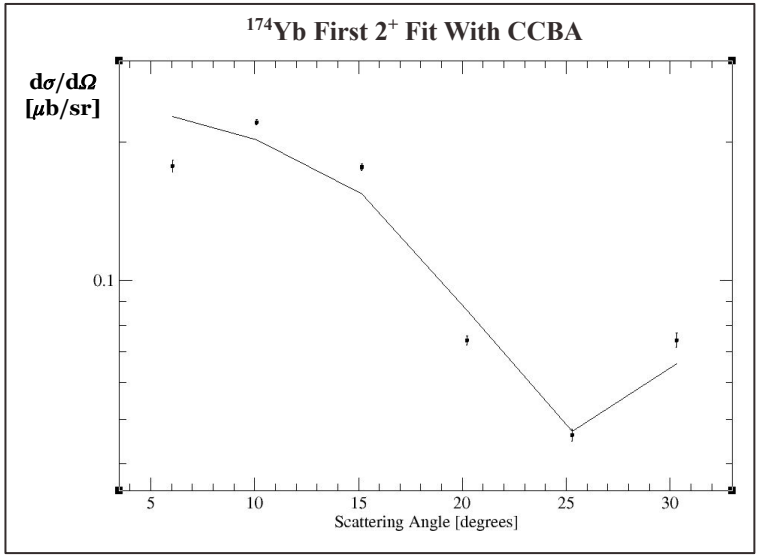
With CCBA we take the Optical Potential and add a few more degrees of freedom.

Add a Nuclear Deformation length to the potential.

Add some more coupling for states that otherwise would not have been accessible without inelastic excitation.



[Ridha, Ali. (2009)] (Axis labels slightly modified)



(Above) Preliminary fitting of first 2^+ with FRESCO

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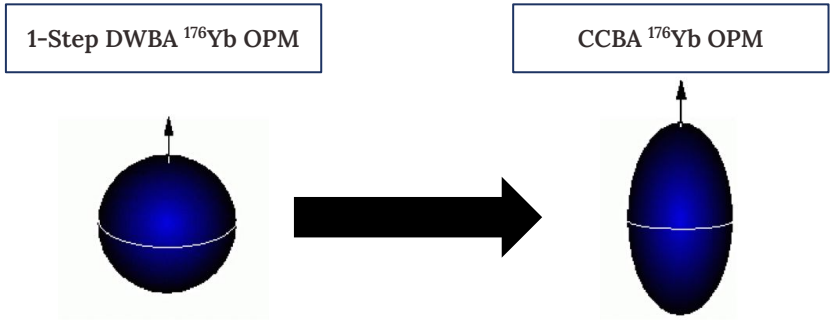

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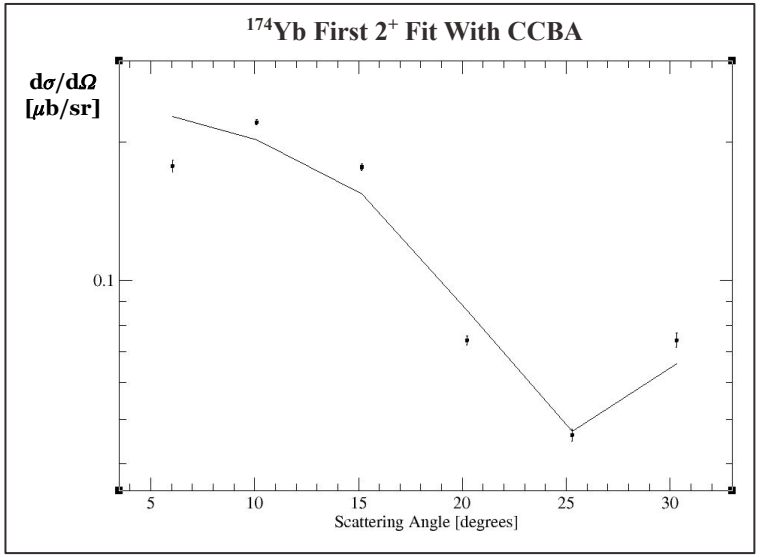

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Acknowledgements

Research Group

Dr. Philip Adsley
Benevolent Leader

Dr. Khang Pham
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Ryan Amberger & Benjamin Wellons
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Thank you
Questions?

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Michael A. Oothoudt, Norton M. Hintz, “The (p, t) reactions on nuclei in the rare earth region”, Nuclear Physics A, Volume 213, Issue 2, (1973), Pages 221-266, ISSN 0375-9474, https://doi.org/10.1016/0375-9474(73)90148-6. (https://www.sciencedirect.com/science/article/pii/0375947473901486)

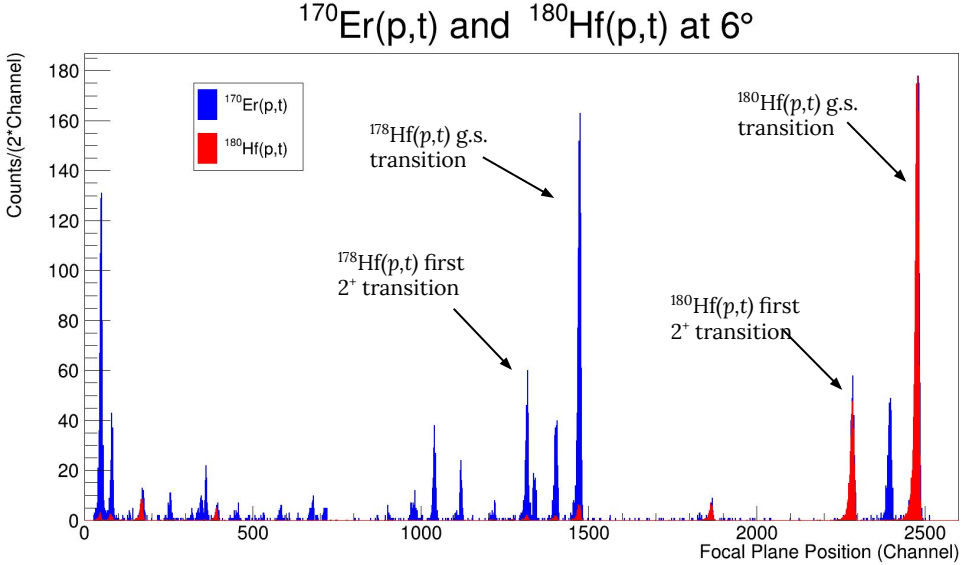
Extra Slides Barrier Slide

Summary

Calibration

Complications calibration:

- ^{170}Er target has natural Hf contamination.
  - Hf potentially used as a reducing agent
- Self calibrating ^{176}Yb(*p*,*t*) and ^{180}Hf(*p*,*t*) spectra gets more difficult as E_x increases.
- AME Mass datasheet dependencies

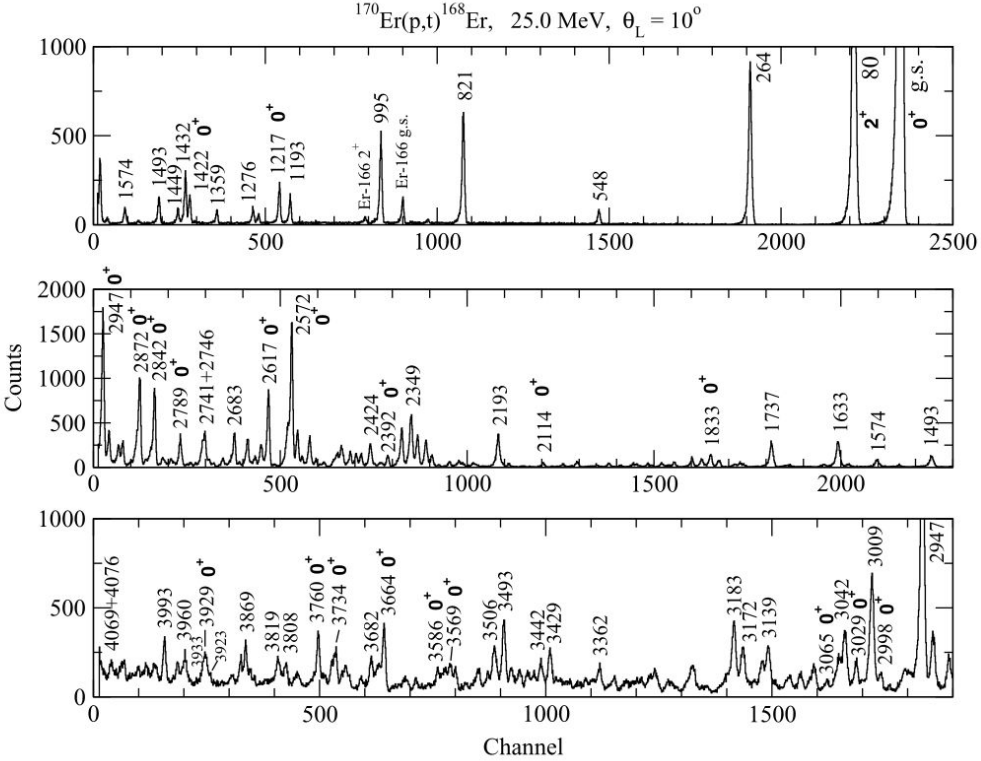


Overlay of ^{180}Hf*(p,t)*, centered at 580 keV, and corresponding ^{170}Er*(p,t)* spectra at 6°

Backup Slide Calibration

(right) ^{170}Er(p,t) spectrum at around the same proton energy as this experiment.

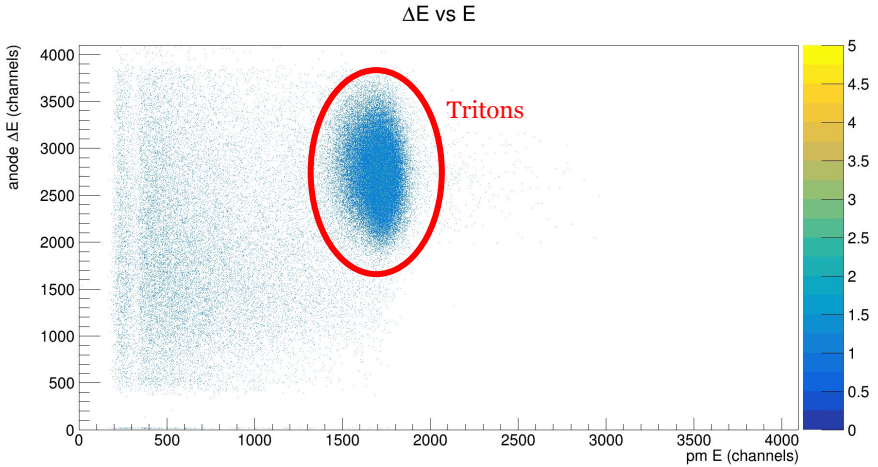
[D. Bucurescu, et. al (2006)]



Particle Identification

Particle identification is done using the differential energy loss at the focal plane.

- Partial Energy Loss - Recorded when ejectiles pass through two proportional counters at the focal plane.
- Total Energy - A plastic scintillator and PMTs record a signal proportional to the total energy of the particles.



Plot of the partial energy loss in one of the proportional counters vs. the total energy deposited in the PMTs.

Backup Slide (Focal Plane)

- The upper and lower anode wires in the second PC were used to check for vertical alignment. If misaligned, the entire detector was manually raised/lowered.
- At the focal plane, ejectiles hit a kapton window and then pass through two proportional counters filled with {~500 mbar of } isobutane.
- The ejectiles then ionize the gas in the proportional counters, creating an avalanche of free electrons.
- The electrons then drift towards the anode wires and create an ΔE_1 signal relative to the energy loss.
- Positive ions are deposited on a cathode foil.
- The second proportional counter has two anode wires which record a summed ΔE.
- Comparing ΔE_1 and ΔE allows for particle ID.

Backup Slide (Focal Plane 2)

- The second proportional counter also had a strip foil with 272 strips, separated by 0.5 mm spacing.
- These strips give positions of the ejectiles at the focal plane.
- After the proportional counters the ejectiles hit a plastic scintillator the resulting scintillation light is measuring with PMTs.
- Since the PMT signal is proportional to the total energy of the ejectiles, it is used as another particle ID method.

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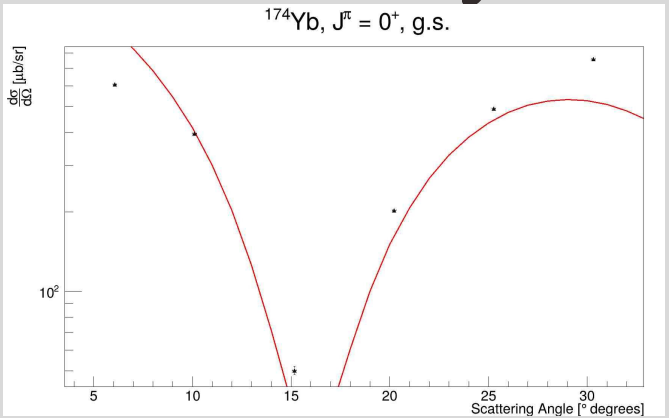

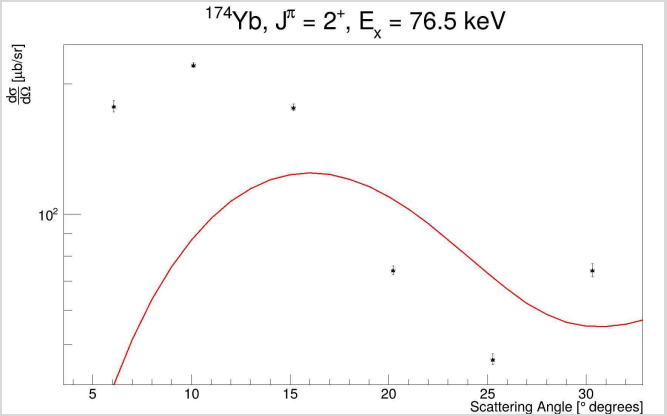

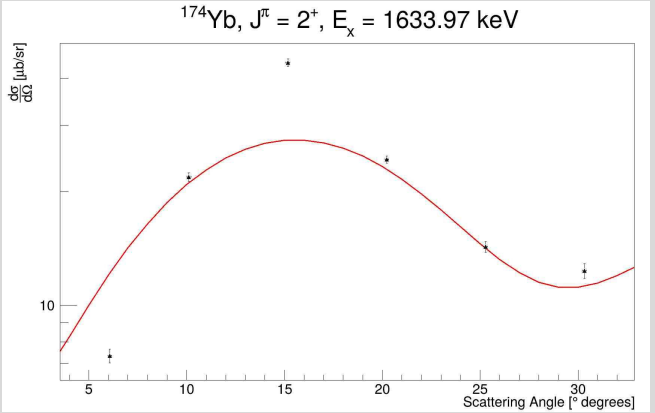

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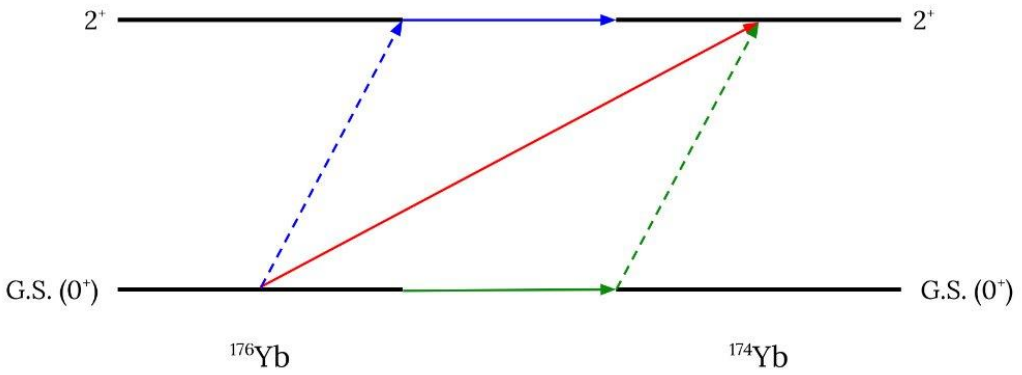

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