

Investigating the Role of α Clustering for the Synthesis of $^{144,146}\text{Sm}$ During the p Process

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Introduction

- α clustering could potentially be a key component in the production of rare-earth nuclei through the p process, more specifically, through (γ, α) reactions in stellar environments (see Figure 1) [1].
 - $J^\pi = 1^-$ states are doorway states for (γ, α) reactions since α clusters produce a dynamic electric dipole moment (E1) and γ rays excite primarily via E1 transitions.
 - It is still an open question whether α clustering contributes to the structure of excited states in rare-earth nuclei [2] - more experimental data is needed!
- The abundance ratios of some nuclei, e.g. $^{144}\text{Sm}/^{146}\text{Sm}$, can be used as chronometers for early solar system evolution. However, for such studies to be more reliable, existing uncertainties in corresponding production ratios need to be minimized [3].

$(^6\text{Li}, d)$ α -transfer experiments needed to indirectly probe potential α clustering in heavy nuclei including ^{148}Gd and ^{146}Sm as they would influence (γ, α) rates.

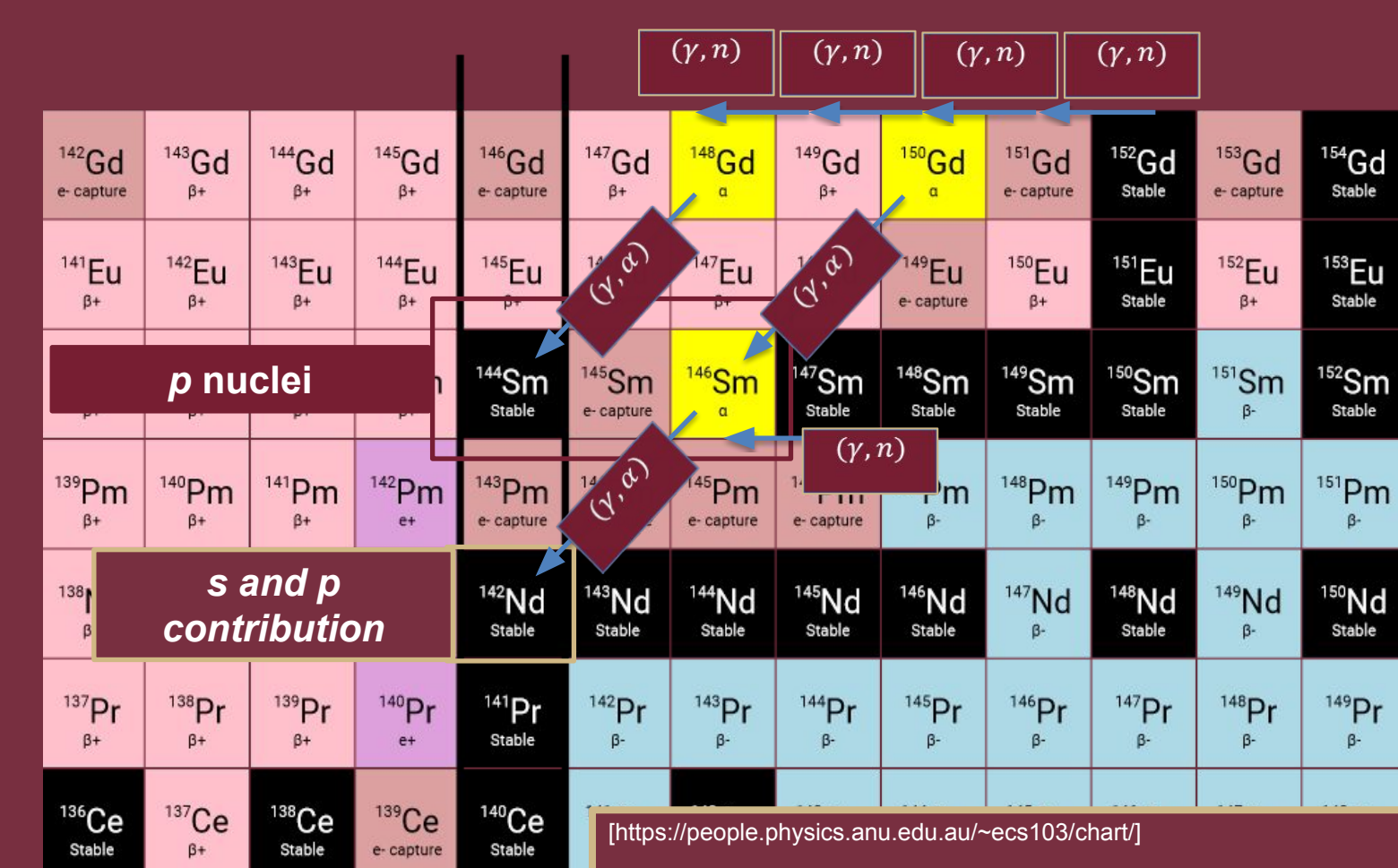


Figure 1: A diagram showing the γ process as part of the p process in the region of gadolinium and samarium isotopes.

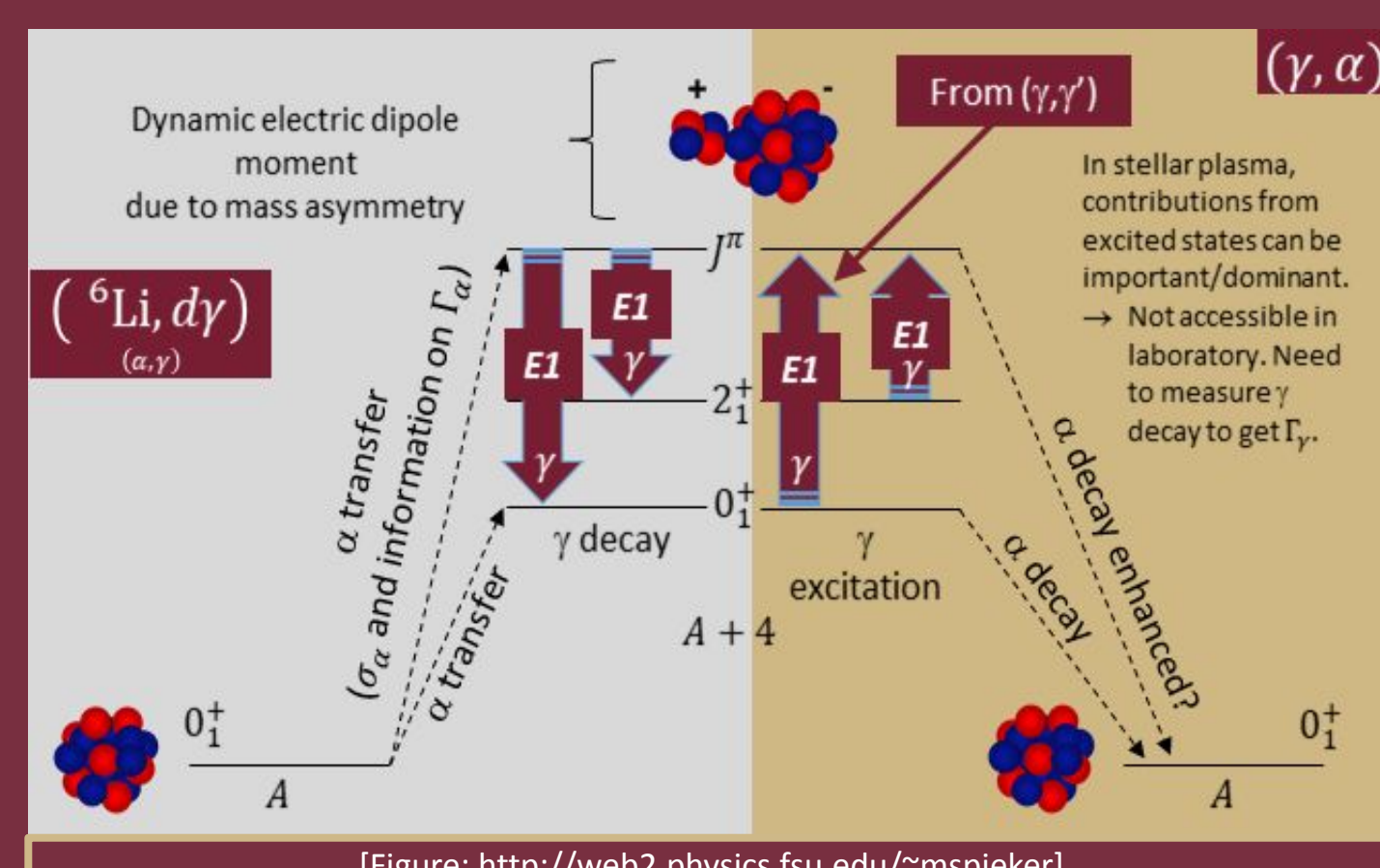


Figure 2: A schematic demonstrating how $(^6\text{Li}, d)$ is used as a surrogate reaction to indirectly study (γ, α) reactions

Experiment Details

- If an α -cluster state is formed, a dynamic electric dipole moment is generated, which in turn leads to a stronger electric dipole transition probability $B(E1)$ [4].
 - Can we link enhanced E1 strengths to strongly populated 1^- states in $(^6\text{Li}, d)$?
- We performed $^{144}\text{Sm}(^6\text{Li}, d)$ and $^{150}\text{Nd}(^6\text{Li}, d)$ test experiments using the CeBr₃ Array (CeBrA) demonstrator and the FSU Super-Engel Split-Pole Spectrograph (SE-SPS) covering the relevant excitation-energy range for (γ, α) reactions in stellar environments, i.e., within the Gamow Window.

Gamow Window - the energy window over which most reactions occur in stellar plasma for a given temperature (see Fig. 3) [5].

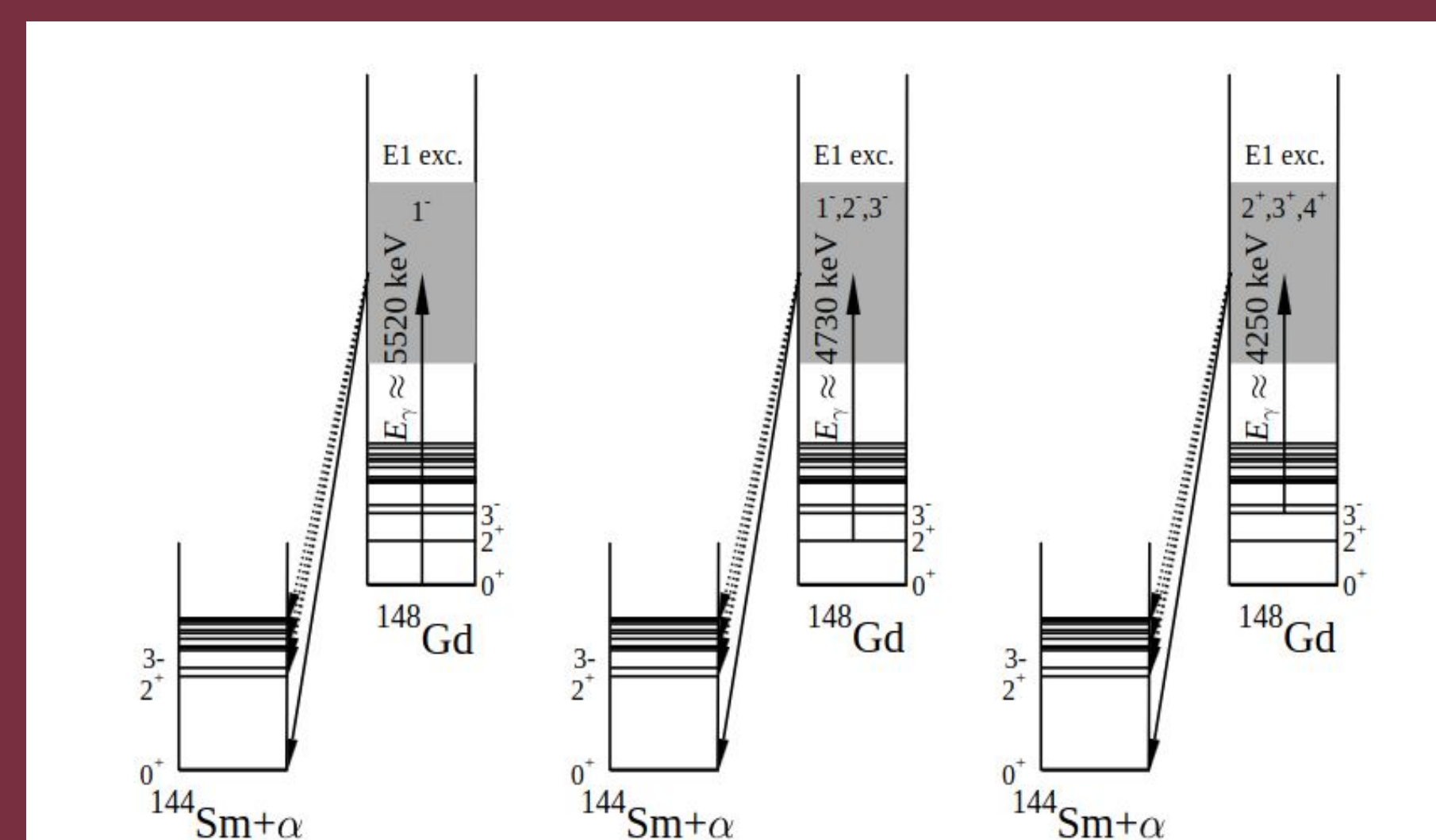


Figure 3: Gamow window (grey area) for the $^{148}\text{Gd}(\gamma, \alpha)^{144}\text{Sm}$ reaction for the ground state of ^{148}Gd (left) and the first excited states (middle and right) at a temperature of $T = 2.5$ GK [5].

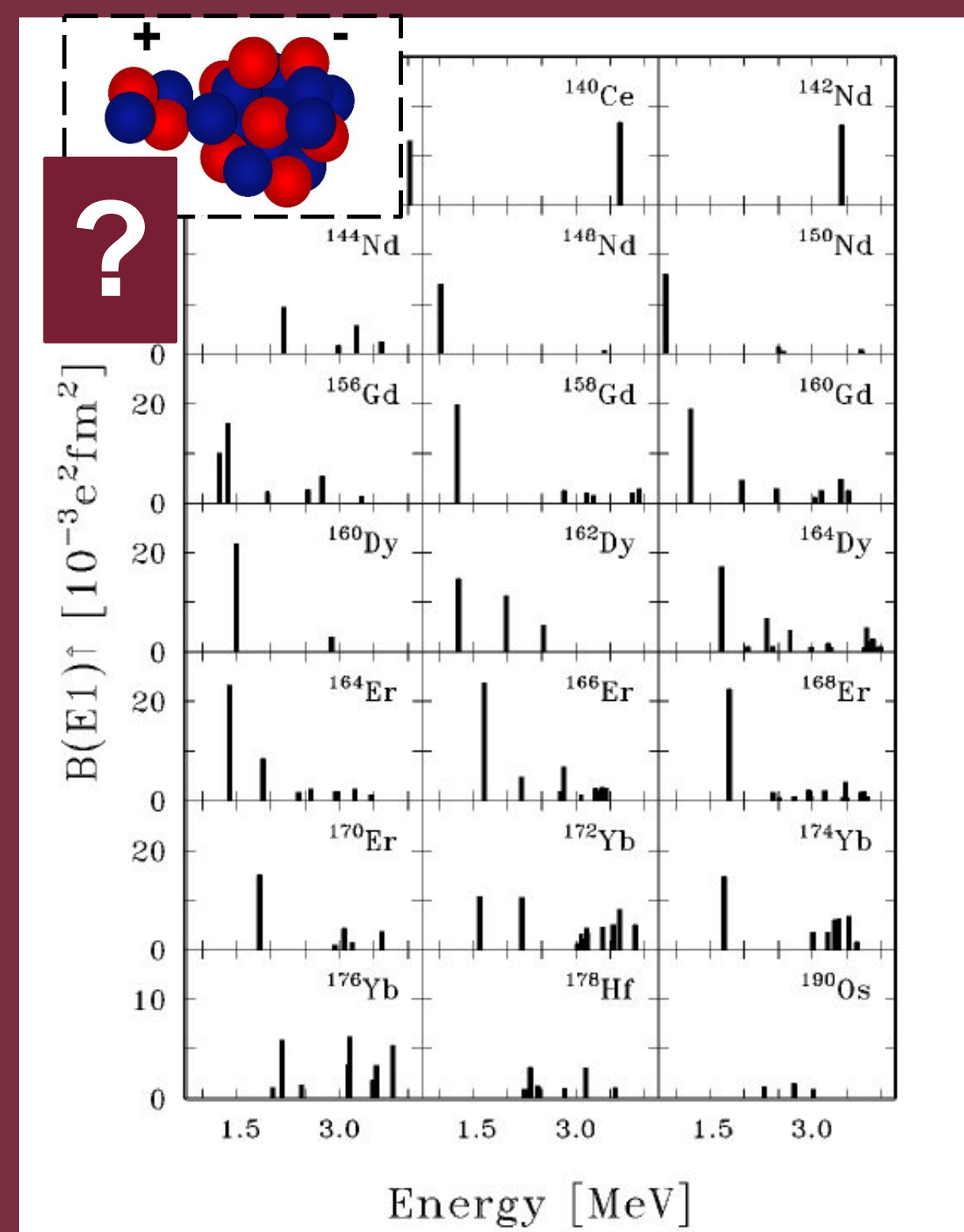
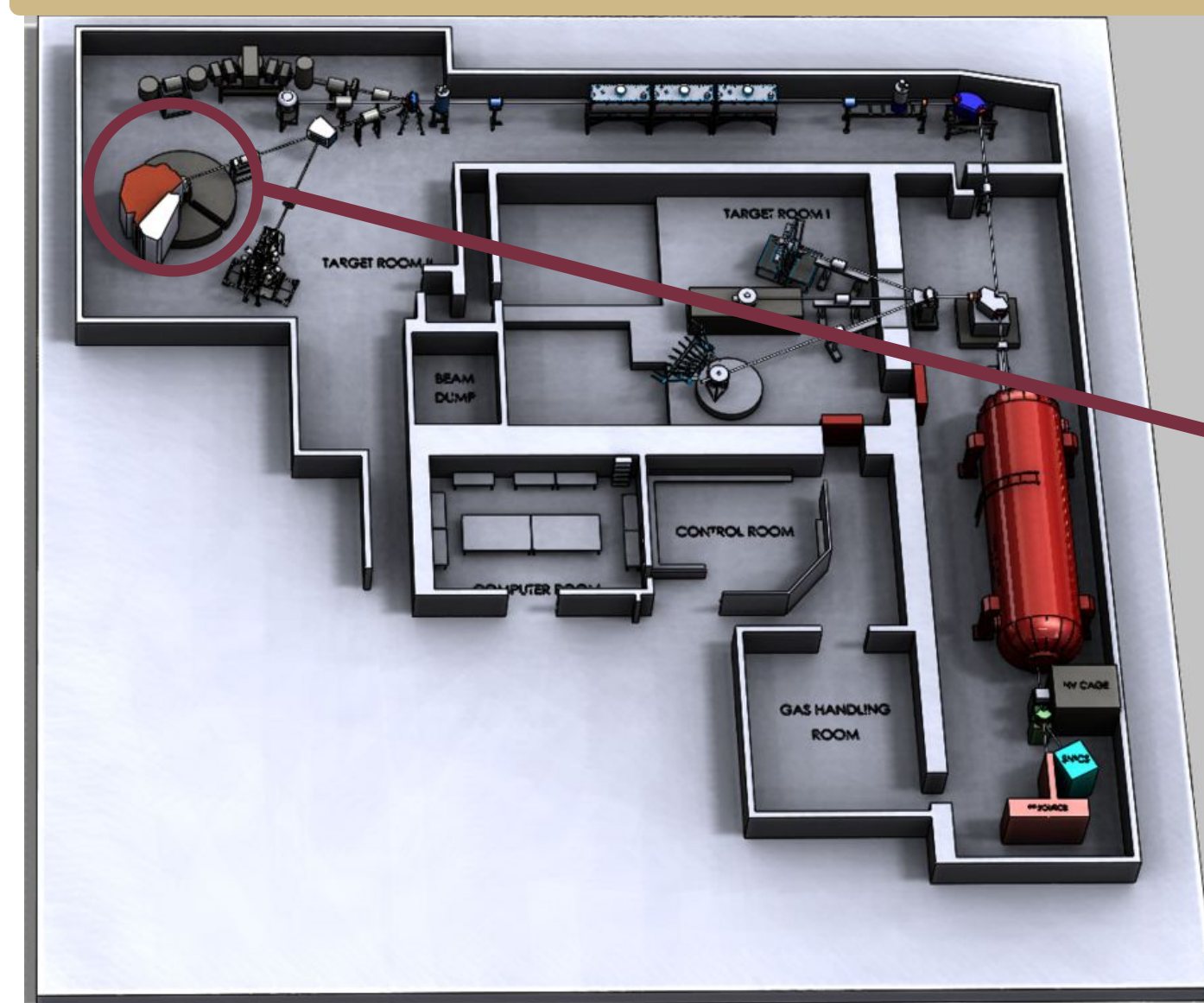
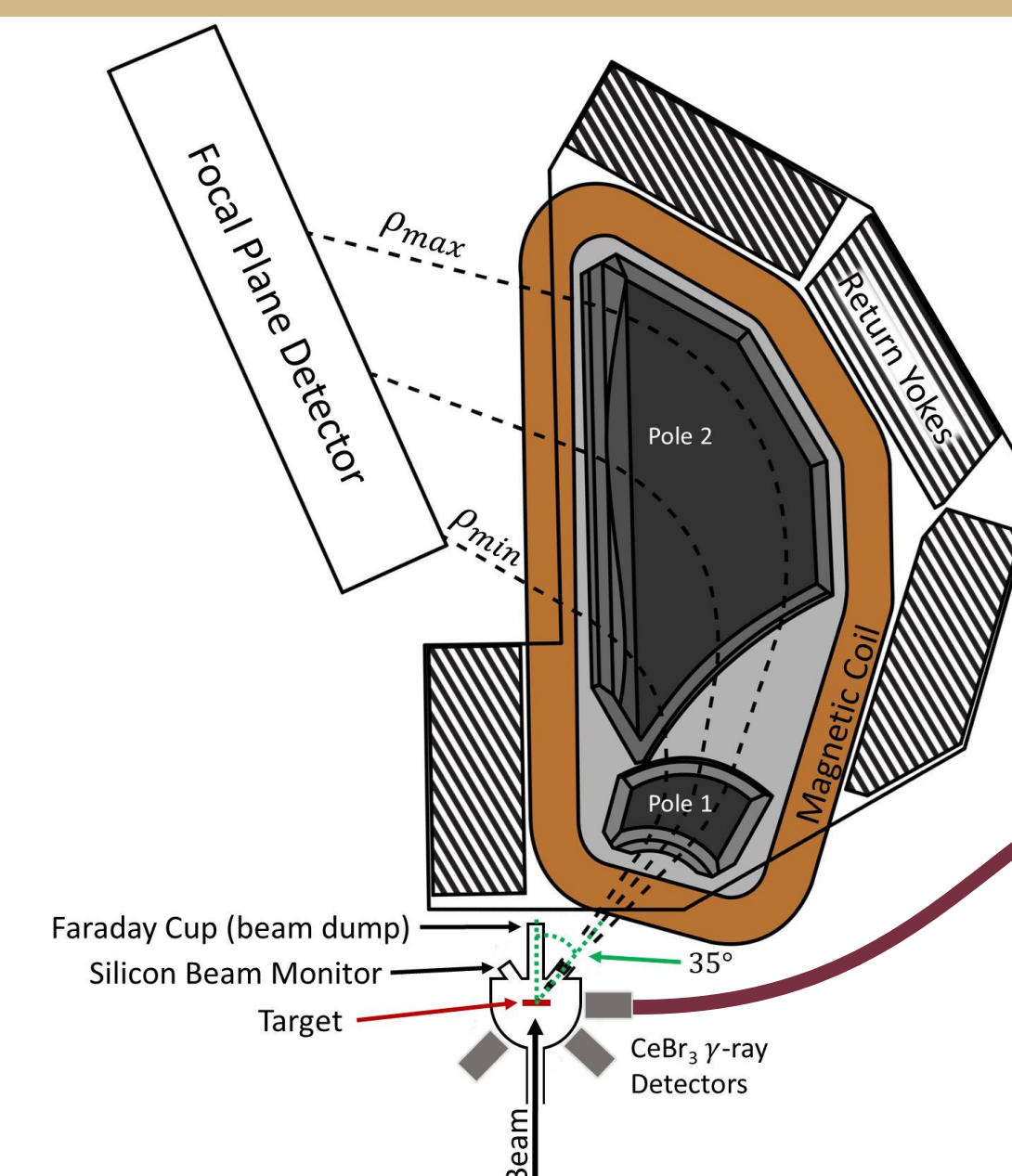


Figure 4: $B(E1)$ strength of several nuclei with mass $A = 138-190$. Our work will investigate the role of α clustering possibly generating these E1 strengths [6].

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Super-Engel Split-Pole Spectrograph



Cerium Bromide Array (CeBrA) Demonstrator

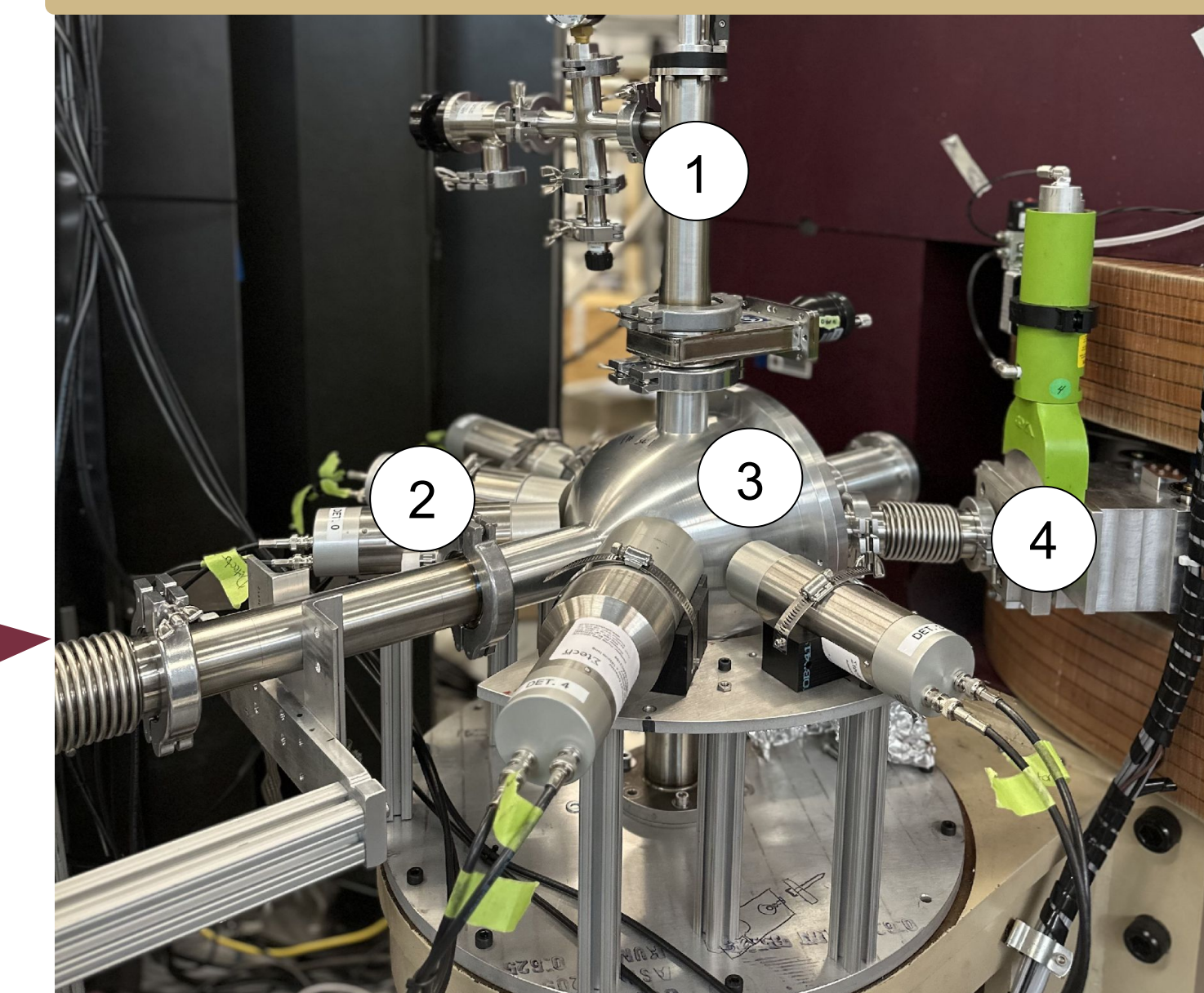


Diagram Key:

- Target Ladder
- CeBr₃ Detectors
- Target Chamber
- Beam line to SE-SPS

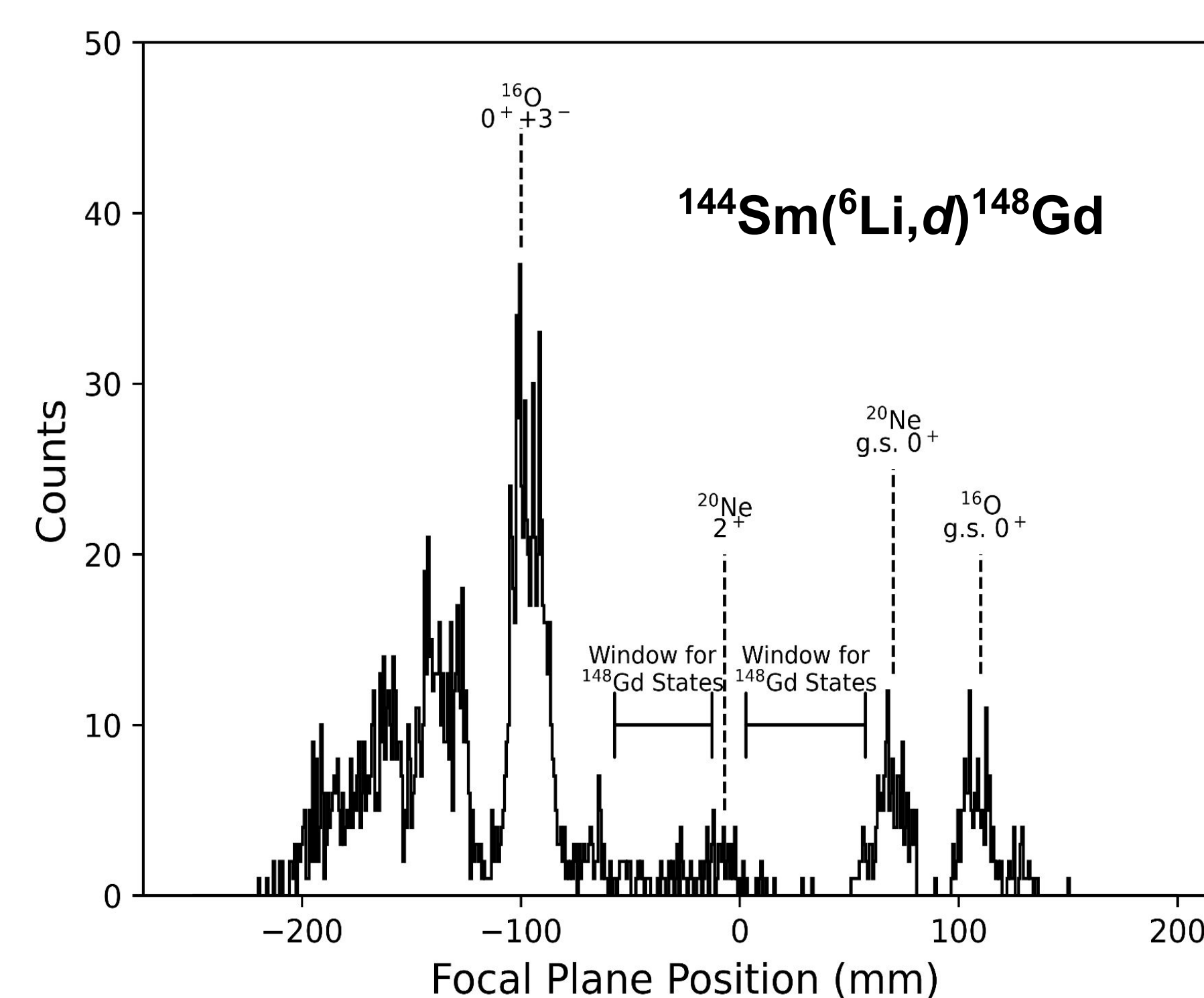


Figure 5: A spectrum of the $^{144}\text{Sm}(^6\text{Li}, d)^{148}\text{Gd}$ reaction after about two hours of run time with many of the peaks being ^{20}Ne and ^{16}O states. We expected to see ^{148}Gd states between focal plane positions -60 mm and -10 mm as well as 0 mm and 60 mm. The leftmost peaks could not be identified. Further measurements with a new target and different backing are planned.

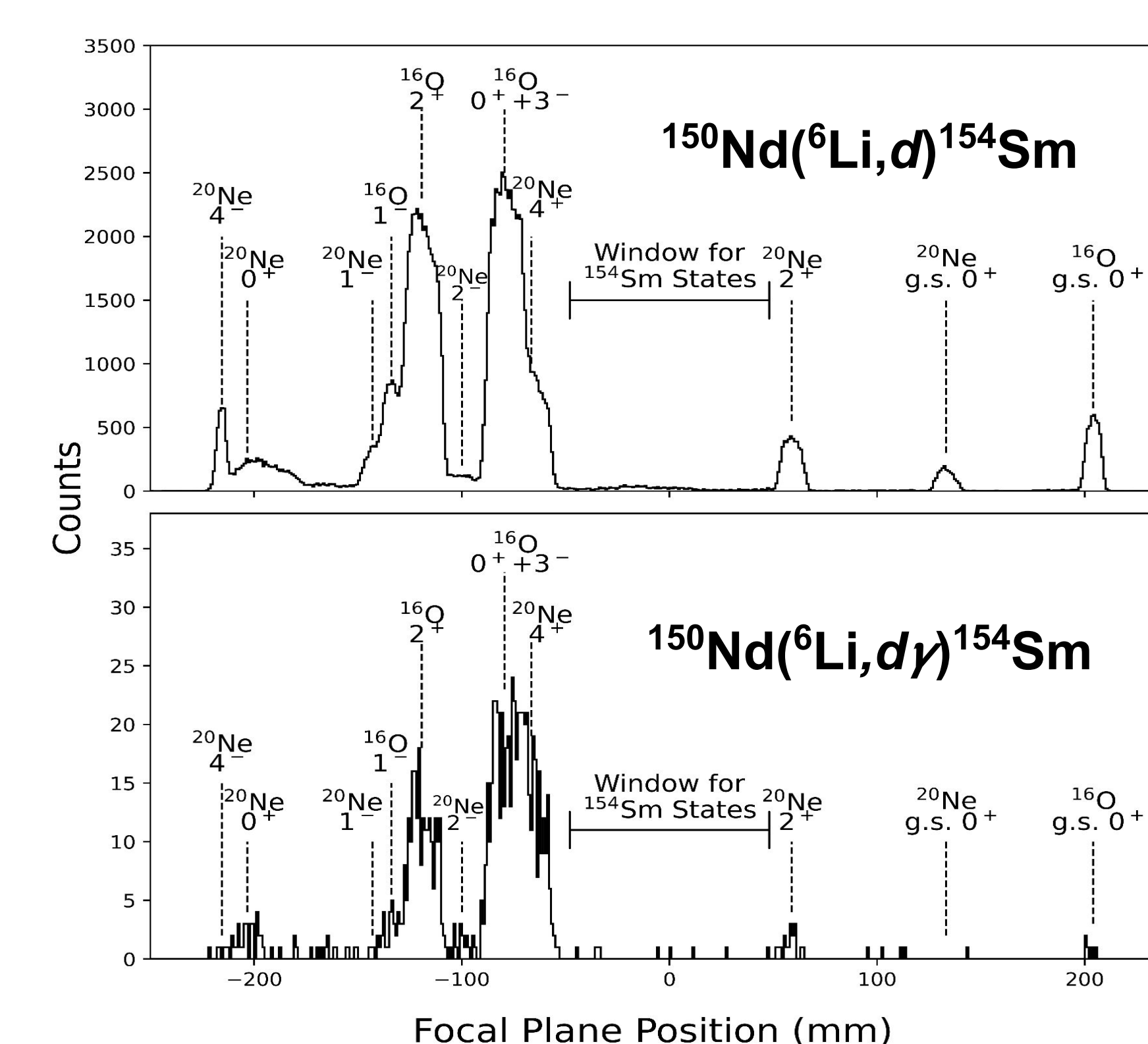


Figure 6: A spectrum of the $^{150}\text{Nd}(^6\text{Li}, d)^{154}\text{Sm}$ reaction. The top figure contains a spectrum with all detected deuterons. The bottom figure shows the spectrum after gating on coincident γ rays measured with the CeBrA demonstrator.

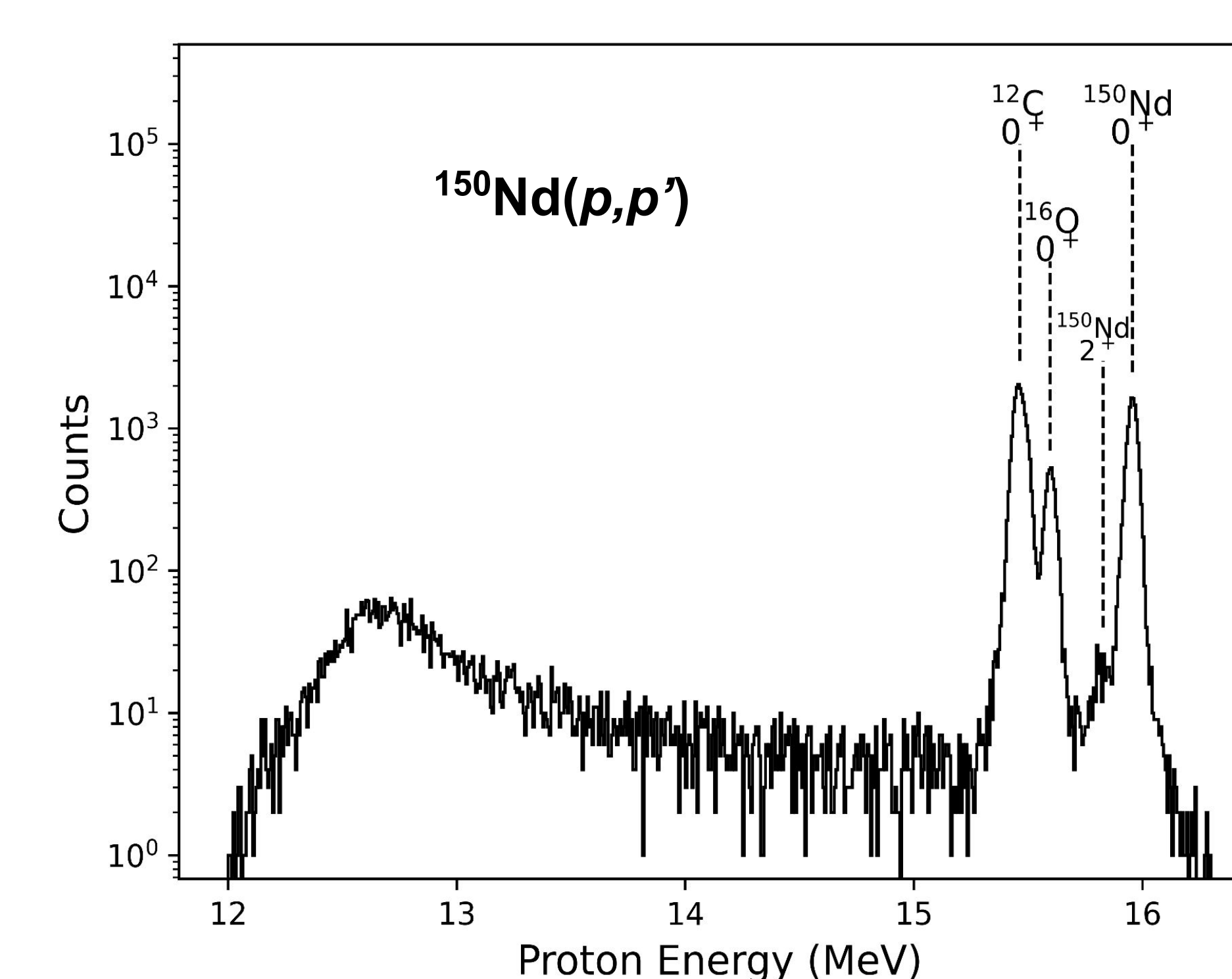


Figure 7: A spectrum of the $^{150}\text{Nd}(p, p')$ reaction energy calibrated to proton kinetic energy and not gated on coincident γ rays. The energy resolution was measured to be 56 ± 6 keV with a comparably thick target of around $250 \mu\text{g}/\text{cm}^2$.

Experiment Results and Discussion

- $^{144}\text{Sm}(^6\text{Li}, d)^{148}\text{Gd}$ (see Figure 5):**
 - The spectrum was dominated by contaminant peaks from the carbon target backing and oxidation of the target itself.
 - We could not reliably identify target states in areas where we did not expect contaminant peaks during this short (2 hr) test experiment.
- $^{150}\text{Nd}(^6\text{Li}, d)^{154}\text{Sm}$ (see Figure 6):**
 - Faced similar contaminant issues as with the older ^{144}Sm target.
 - Although gating on coincident γ rays did not significantly clean up the spectrum, several contaminant peaks were strongly suppressed.
- $^{150}\text{Nd}(p, p')$ (see Figure 7):**
 - Decided to switch to proton beam to measure $^{150}\text{Nd}(p, p')$ and to determine the energy resolution of the SE-SPS for a light-ion induced reaction on a heavy nucleus.
 - Identified the ground state (0^+) and first excited state (2^+) of ^{150}Nd .
 - Energy resolution was found to be 56 ± 6 keV.

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Future Work

- Perform more $(^6\text{Li}, d\gamma)$ experiments:
 - Future experiments include $^{92}\text{Mo}(^6\text{Li}, d\gamma)^{96}\text{Rb}$ and either $^{144}\text{Sm}(^6\text{Li}, d\gamma)^{148}\text{Gd}$ or $^{142}\text{Nd}(^6\text{Li}, d\gamma)^{146}\text{Sm}$.
- Goal:** Populate possible $A+\alpha$ structures in these nuclei via the $(^6\text{Li}, d\gamma)$ reaction by detecting γ rays in coincidence with the residual deuterons.
- Carefully transporting new ^{144}Sm and ^{142}Nd targets with gold backings to experiment will reduce contamination.
- Add more detectors to CeBrA to increase the full-energy peak detection efficiency.



Figure 8: Planned CeBrA consisting of 14 CeBr₃ detectors.

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