A New Method of Measuring the Probability of Nuclear Reactions

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Abstract

We propose a new method for measuring nuclear cross section data using the final prompt gamma ray emitted by a compound nucleus, which we call the "direct-to-ground" gamma. There is a growing need for a quick and accurate method to determine these cross sections due to the increasing demand for novel isotopes required in research.

Simulations for light-ion induced reactions yield inconsistent results, and other methods of measuring cross sections require significant time investment for researching reactions that may not be viable production mechanisms.

Our direct-to-ground approach allows us to reconstruct the cross section of nuclear reactions, and all products produced from the compound nucleus through measurements taken with GammaSphere at Argonne National Laboratory's ATLAS facility.

The advantages of the direct-to-ground method are as follows:

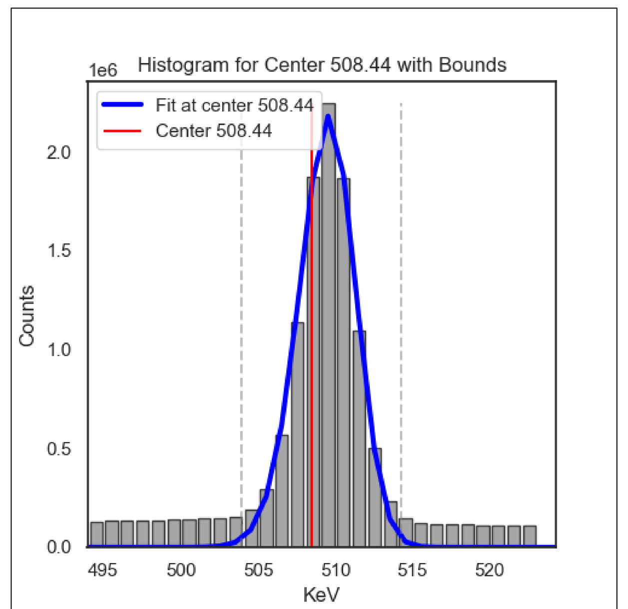
- Collection and processing of prompt gamma data can be completed in seconds, several orders of magnitude faster than the foil stack method.
- Quick data collection and processing can significantly expand our current databases of nuclear reaction cross sections. These results can be used to optimize models, thus opening more reactions to the scientific community.
- This method has the potential to revolutionize how we measure cross sections, offering quick, accurate, and precise data, which in turn offers significant potential for exploring unique reaction mechanisms.
- New approaches in cross section measurement must be developed for the viability of radiotheranostics in the clinic on a long-term scale.[2]

The methods presented in this poster focus on extracting the net peak areas of the direct-to-ground gamma rays measured from reactions using Python, with data previously collected by Renné et al. (2024).[2]

Peak Fitting

For a proper estimate of the net peak area, the first requirement is a reliable peak fitting algorithm to model and determine the edges of our peaks. After testing many Gaussian fit models, we found that a skewed Voigt curve performed the best. In gamma spectrometry, it is common to use a y-shift for the curve (shifting it up to account for the background). However, our tests indicated that using a standard curve was more consistent. The choice between these fits did not affect the results since they are only used to find the edges of the peaks.

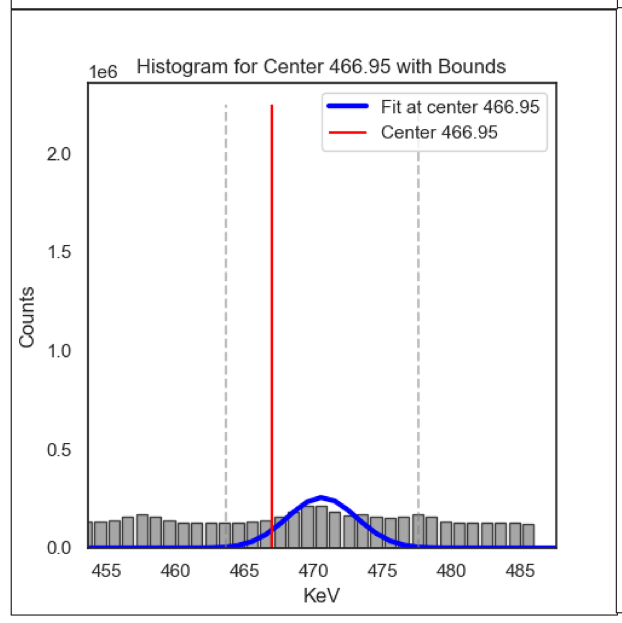
Below are three different fit cases: one normal, one where the curve is very small, and one where the curve is not visible in the data.

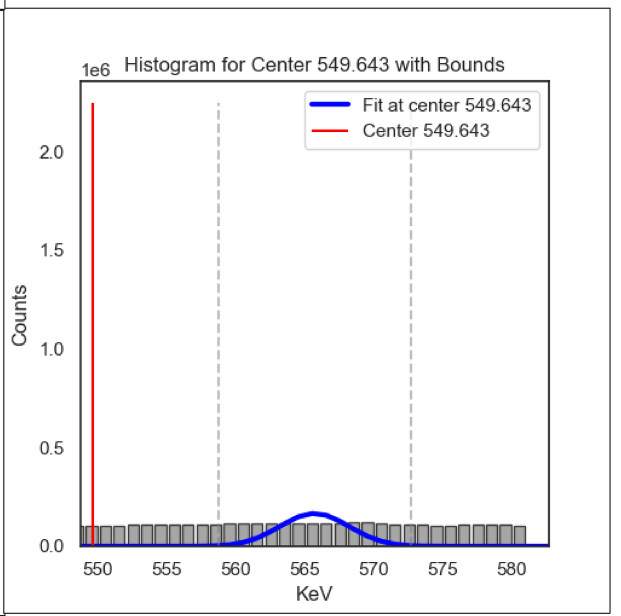


Voigt Curve Model:

$$V(x;\sigma,\gamma) \equiv \int_{-\infty}^{\infty} G(x';\sigma)L(x-x';\gamma)\,dx',$$

where x is the shift from the line center, $G(x;\sigma)$ is the centered Gaussian profile and $L(x;\gamma)$ is the centered Lorentzian profile





Background Filtering with Interpolation

To calculate the net peak area of the direct-to-ground gamma rays, we must filter out background radiation from our measurements and exclude peaks not related to our direct-to-ground gamma measurements. Since there is no separate background measurement, we interpolate the background through the peaks of interest.

1. First, we fit the curves and determine the outer bounds, as shown in **Figure 1**.
2. Next, we subtract the data outside of these curves and interpolate the expected background using the values from the outer bounds, as shown in **Figure 2**.
3. Finally, subtracting our interpolated background from the peak histogram gives us our measurements without background radiation, as shown in **Figure 3**.

Figure 1:

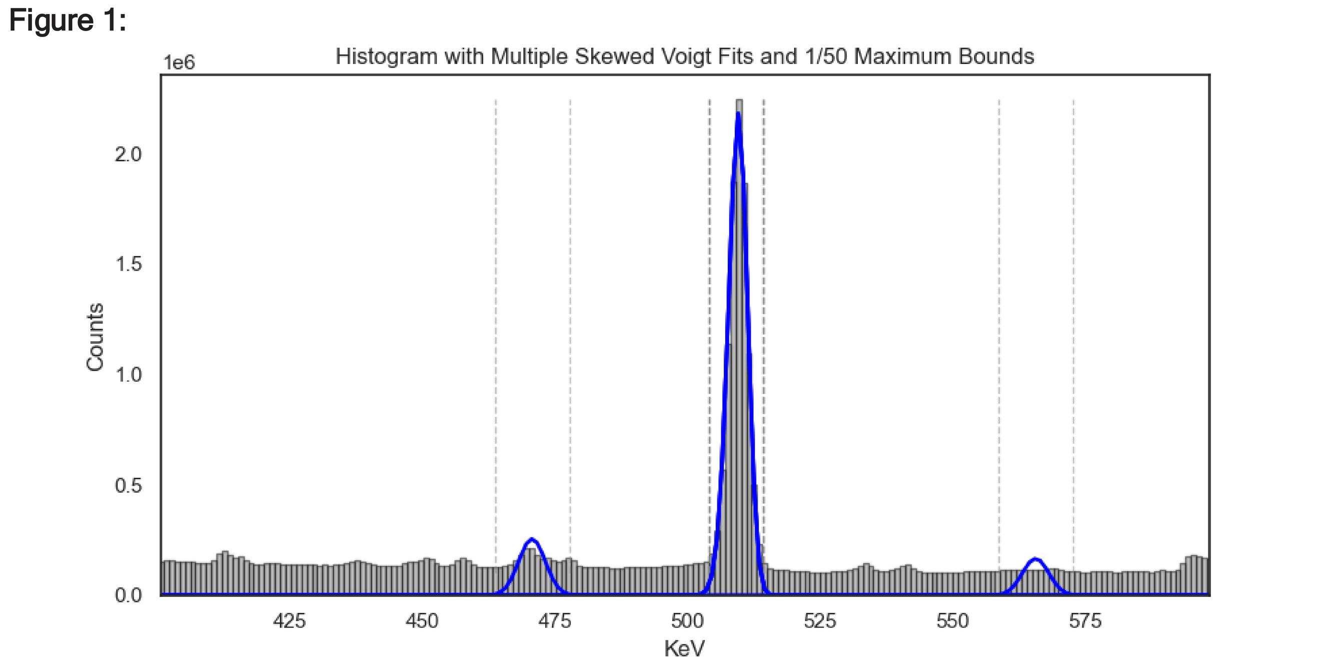


Figure 2:

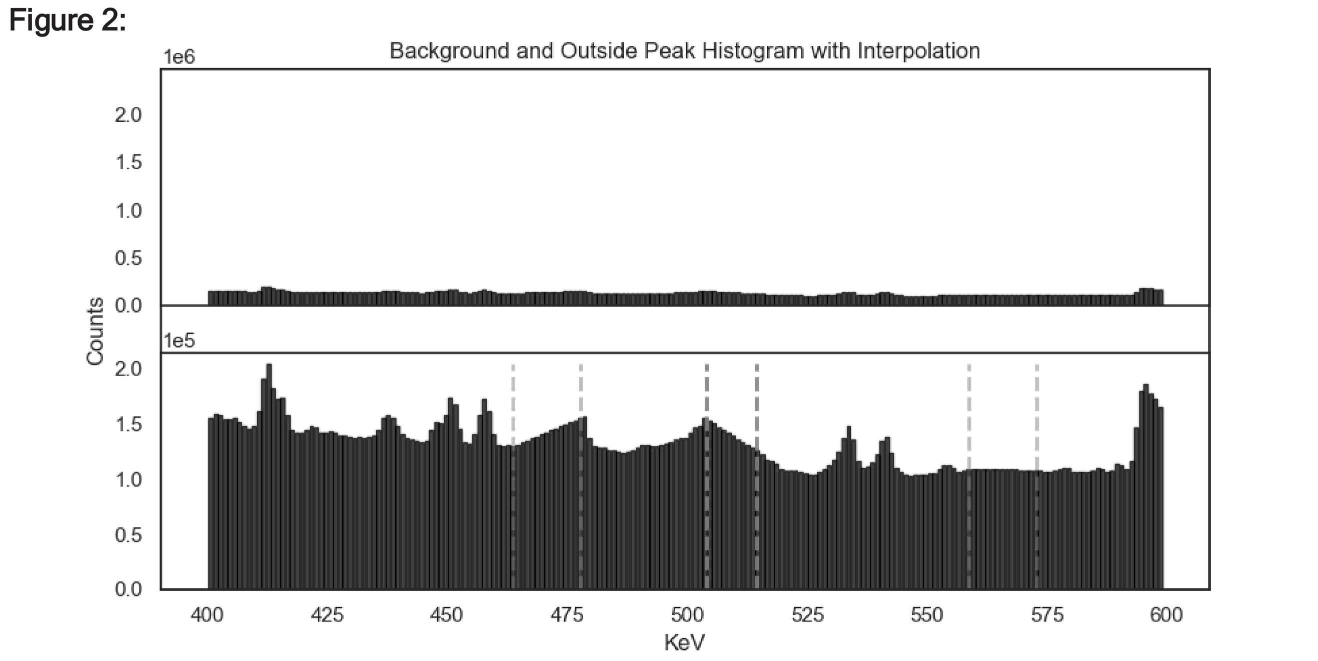
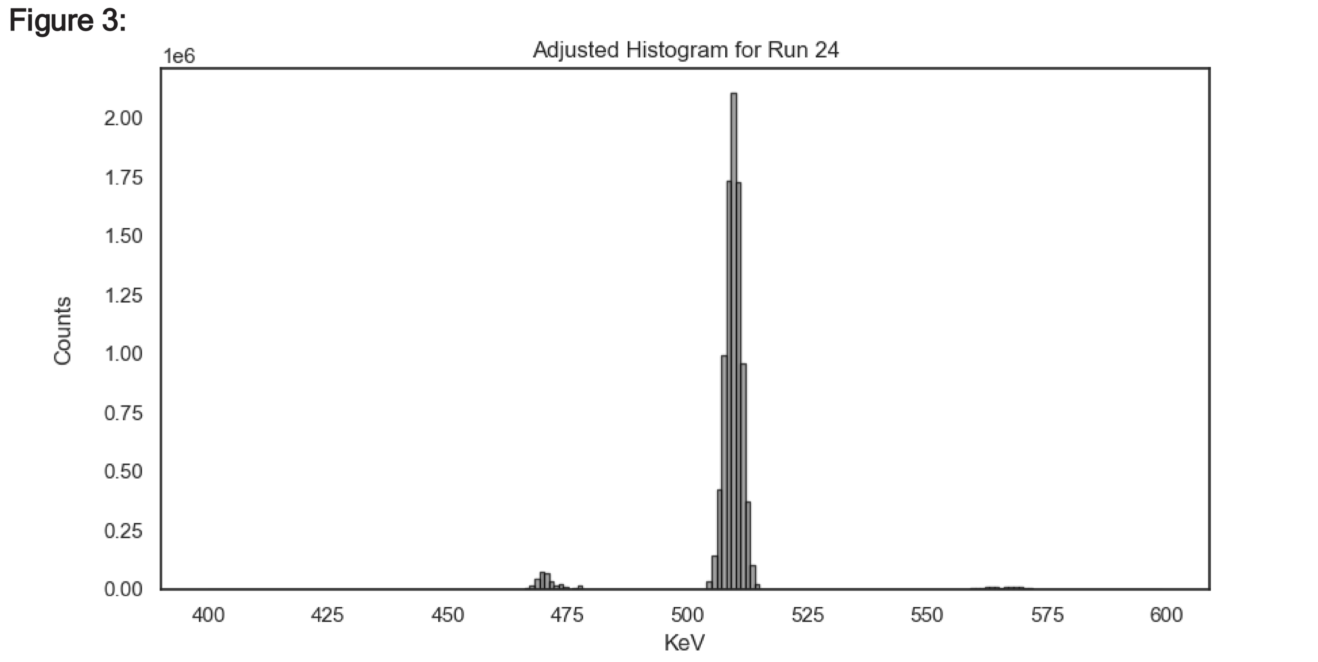


Figure 3:



Beam Current Variation

We can adjust our calculations by relating the beam current to the detected count rate of the direct-to-ground gamma rays. This adjustment is crucial due to variations in beam current. Although we did not have time to implement this idea before presenting the poster, it will be done in future work.

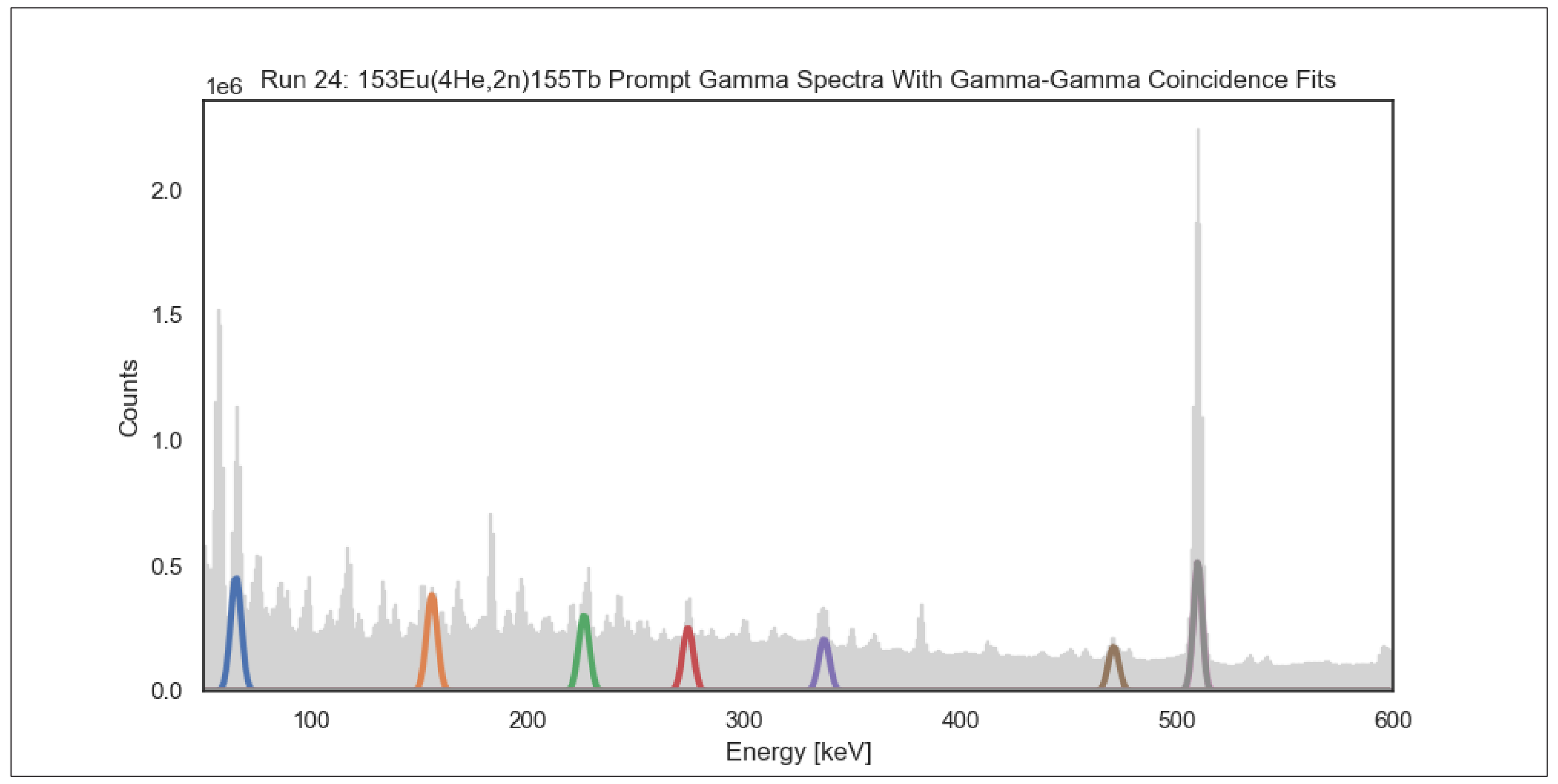
This step is preliminary until an accurate beam current monitor can be integrated into the beamline. Another intern, Arielle Ebdon, is currently working on implementing this step using a ferrite toroid and lock-in amplifier. The beam current has a present error in the 10nA range, while her design is currently in the 2nA range, and will likely further improve.[3]

Gamma-Gamma Coincidence Gating

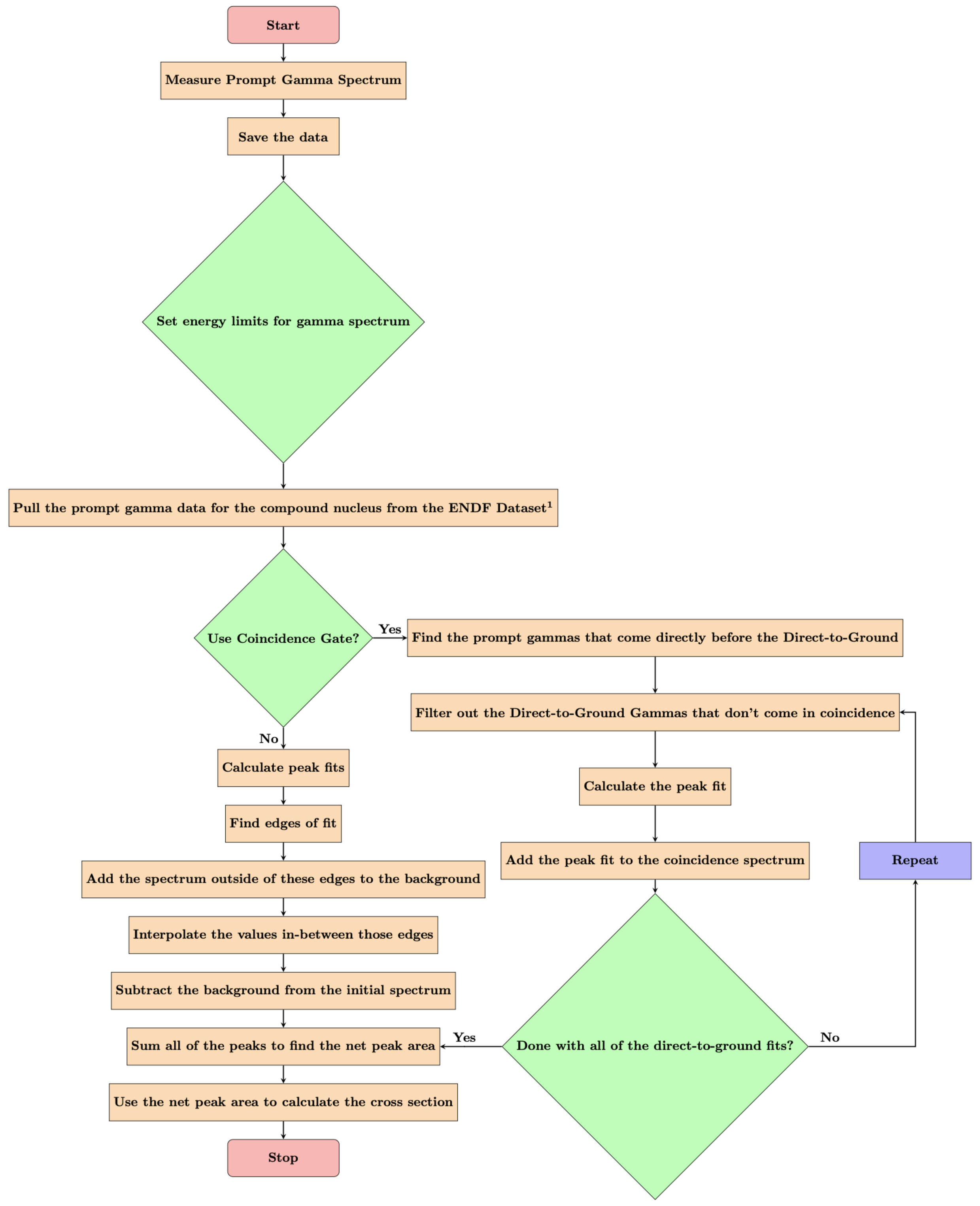
We use time data to isolate the direct-to-ground gamma ray peaks that occur immediately after the the prompt gammas directly upstream from each DTG's respective level branch, allowing us to filter out background gammas and any false positives that could arise from the interpolation method.

Using this method yields the following results:

Note: This method is effective only when most of the populated states are above the direct-to-ground gamma ray. Otherwise, there will not be multiple gamma rays to find in coincidence.



Net Peak Area Flowchart



Conclusion and Future Work

We have developed two methods for calculating the net peak area of the direct-to-ground gamma spectra with proper background subtraction. This method being coded from the ground up in Python allows for increased flexibility when handling different types of direct-to-ground spectra and expandability of codebase for future work. These calculations will support the validation of the direct-to-ground cross section measurement method against other cross section measurement techniques once accurate beam current measurements are available.

The direct-to-ground method would allow for cross sections to be measured in seconds of beam run time, greatly reducing the overhead required to verify the feasibility of a production method for a particular isotope. It cannot be overstated how much this method simplifies the measuring of reaction cross-sections.

During the writing of this poster, we conceived the idea of coupling the two approaches to determine the net peak area. A coincidence-gated fit allows for more consistent identification of peak edges with better discrimination between peaks. Using these edges, the subtraction histogram with interpolation can then find the net peak area without losing a significant number of counts from the coincidence gate. This combined approach offers the benefits of both methods. While we did not have enough time to incorporate this method for this poster, we plan to do so to evaluate its effectiveness in calculating the net peak area.

References & Acknowledgements

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[2]Renné, A., Gatermann, C. M., Korchi, A., Anderson, J., Chen, C.-T., & Nolen, J. (2024). A Novel Approach to Cross Section Measurement: Prompt Gamma Isotope Yield Reconstruction with GammaSphere. *Journal of Nuclear Medicine*, *65* (supplement 2), 242560-242560.

[3]Ebdon, A., et al. (~2024). Using a Ferrite Toroid and FPGA-based Lock-in Amplifier to Detect a Nanoampere Scale Beam Current (preliminary).

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