Developing low-energy Coulomb-excitation techniques for isomer-power research

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Introduction

Society progresses towards a higher need for electricity. For example, batteries for electric cars need a higher power and energy density to achieve greater driving distances. **Nuclear batteries** could disrupt global battery technology, as their **energy density** is a **thousand times higher** than an electrochemical battery [1].

Problem statement & objective

However, nuclear batteries face two primary challenges: identifying the optimal depletion pathway and **ensuring on-demand energy release**. This thesis addresses the latter, using a **proton beam** on a **^{155}Gd target**.

This study validates low-energy Coulomb excitation (Figure 1) for de-exciting isomers on demand.

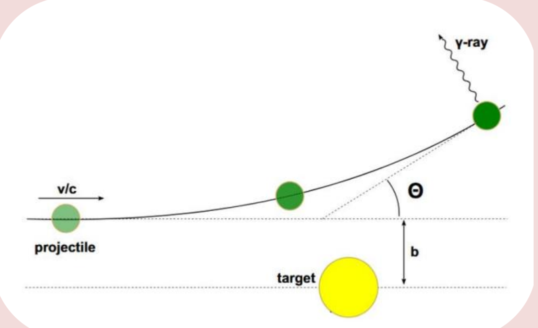


Figure 1: Fundamental process of Coulomb excitation [2]

Material & Method

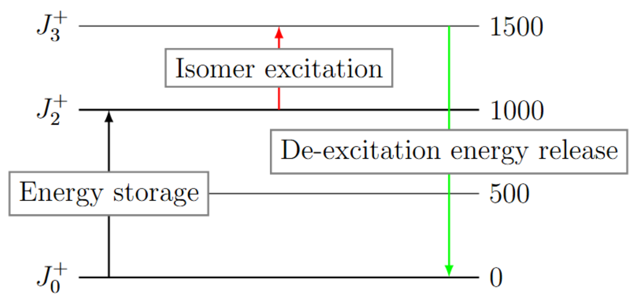


Figure 2: Energy release with Coulomb excitation

Coulomb excitation raises the isomer to a higher excited state, which then decays to a lower state as shown in Figure 2. Protons from a 14UD particle accelerator are aimed at a ^{155}Gd target.

The Light Ion (LIon) Detector was positioned in the **Enge Spectrograph** (Figure 3) to differentiate particles by magnetic rigidity, identifying two focal plane locations based on energy. Nuclear data was extracted from the **matrix elements** produced by this experiment using **GOSIA**.

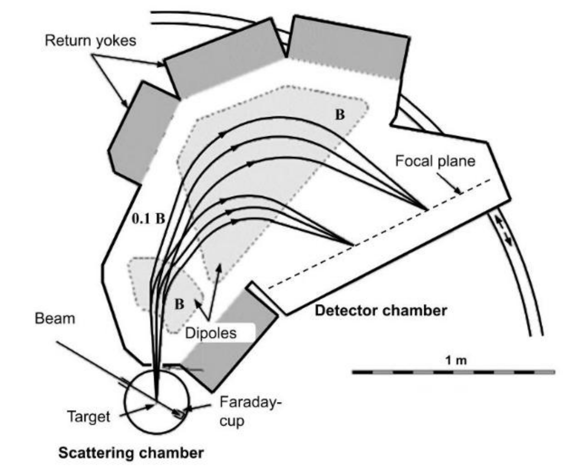


Figure 3: The Enge Spectrometer [3]

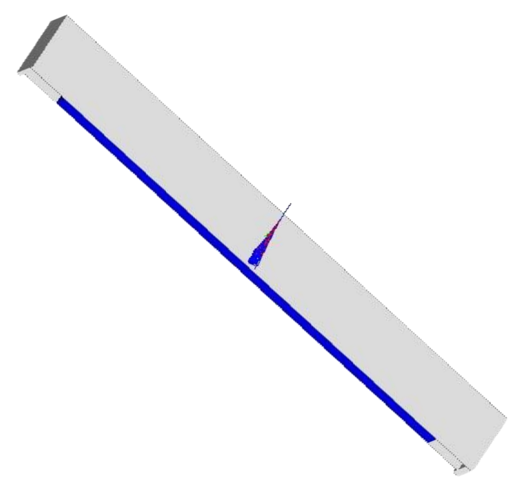


Figure 4: The GEANT4 model with real-life geometries of LIon, a 12 MeV proton beam enters the detector

To verify low-energy Coulomb excitation, which requires a thorough understanding of the detector's output at these lower energies, a **simulation** of **LIon** has been developed with **real-life geometries** using **GEANT4**, shown in Fig. 4.

Spectra of excited states from the experimental data are recreated with the Coulomb excitation fitting code GOSIA to **extract** the vital **matrix elements**. Calculating the **tau** of each excited state provides a way to **validate low-energy Coulomb excitation** by comparing it to previous research findings.

Results & Discussion

Data was collected at **20-, 25-, and 40-degree** scattering angles at 12 MeV. A time-of-flight measurement indicates the particle's position, which correlates to energy. Figure 5 shows the results for a 25-degree scattering angle, with the probability of the first excited state at **1.62E-4** and the ground state at **9.992E-1**. The red line indicates the position of the first excited level (60 keV).

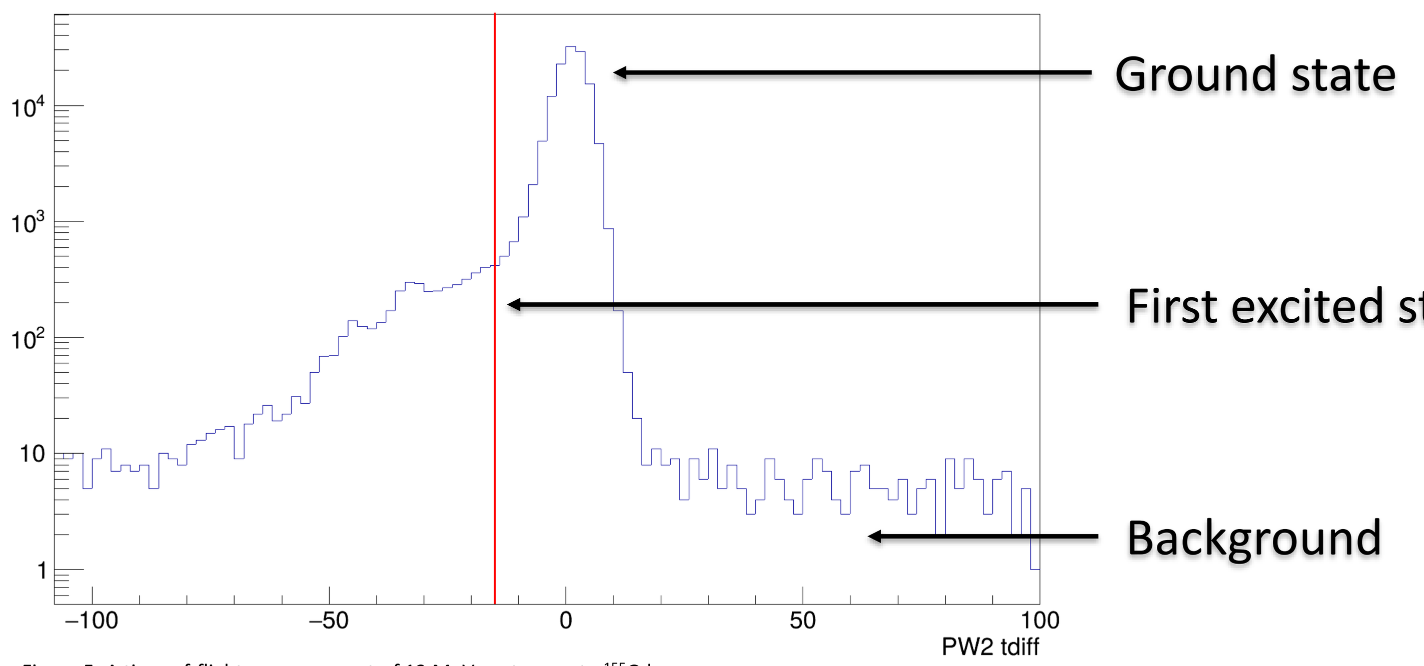


Figure 5: A time-of-flight measurement of 12 MeV protons onto ^{155}Gd

Probability simulation with GOSIA

Ground state

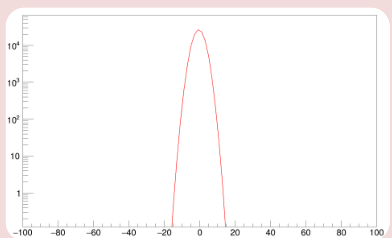


Figure 6: Expected peak from the ground state calculated with GOSIA

First excited state

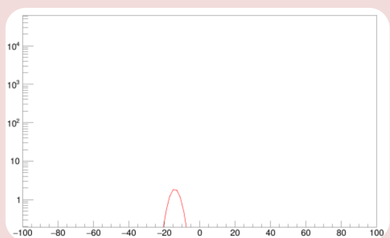
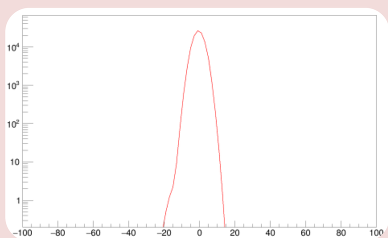


Figure 7: Expected peak from the first excited state calculated with GOSIA

Summed



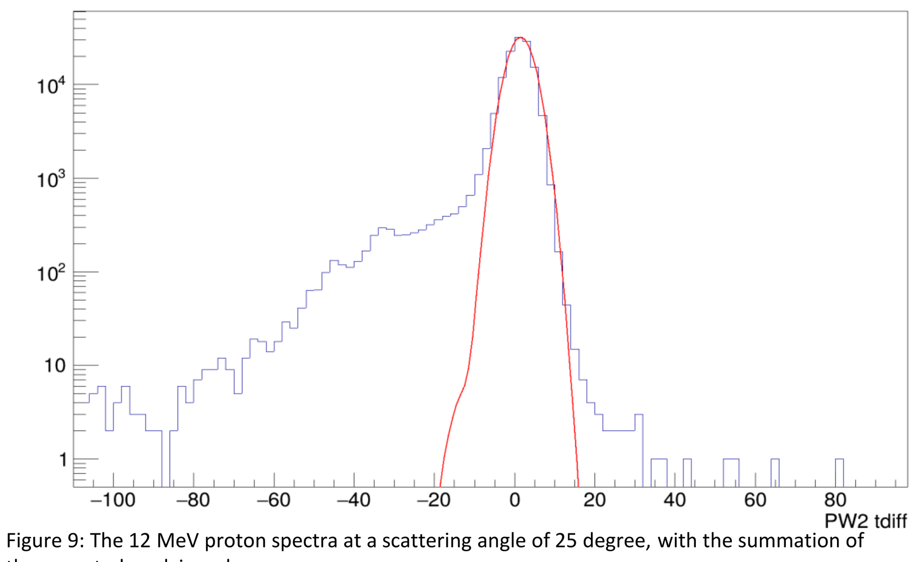


Figure 9: The 12 MeV proton spectra at a scattering angle of 25 degree, with the summation of the expected peak in red

The **probability** of the first excited level is **too low** to form any significant peak in the spectra. No significant peak of the level of interest is seen in Fig. 9. Furthermore, do the tail of the Rutherford peak, high density of close-lying states complicate the spectra.

Conclusion

The results show that low-energy Coulomb excitation with the Enge and LIon does **not allow** the **ratio** between the **two states** to be **measured**. The presence of closely spaced excited states and the tail of the Rutherford peak complicates the enhancement of the 60 keV level due to the notably low probabilities at such low energies.

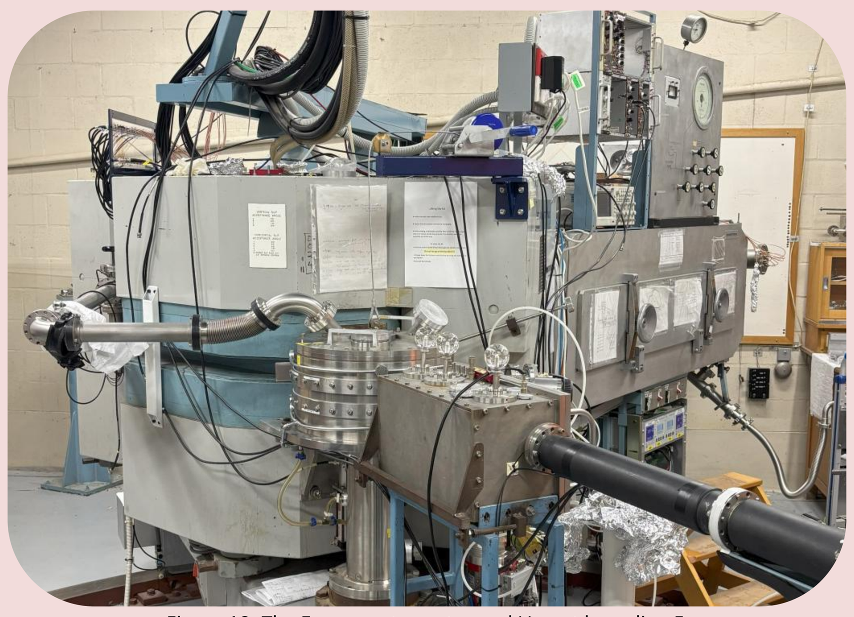


Figure 10: The Enge spectrometer and LIon at beamline 5

A lower energy would enhance the resolution yet decrease the probability of excitation. However, lower energies struggle with straggling in the target. Hence, a thinner target would enhance the resolution. If these do not aid, gamma spectroscopy could be the solution.

Supervisors / Co-supervisors / Advisors: Prof. Dr. AJ Mitchell
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[1] A. Hill, "Sub-barrier Coulomb Excitation of 112, 116, 120Sn," Michigan State University, East Lansing, MI, USA, unpublished document, Apr. 2022.
[2] S. Carmichael, T. Braunroth, A. L. Conley, A. Gade, S. N. Liddick, D. Rhodes, and A. Shore, "The Enge Split-Pole Spectrograph at the University of Notre Dame," *EPJ Web Conf.*, vol. 304, p. 02002, 2024, doi: 10.1051/epjconf/202430402002.