

I. Abstract

Ultrafast high-power lasers may be used to generate short pulses of energetic ions that can be used for nuclear activation cross section measurements. The Short-Lived Isotope Counting System (SLICS) was developed to count the beta decays of radioactive product nuclei resulting from light ion reactions generated in this way. One important SLICS parameter, which has been determined using a Geant4 simulation, is the detection efficiency, the ratio of detected betas to number of product nuclei. To test this prediction, an experiment was carried out using the SUNY Geneseo Pelletron. A deuteron beam incident on a thin natural Li target created 840 ms half-life ^8Li via the $^7\text{Li}(d,p)^8\text{Li}$ reaction. The beta particles from the ^8Li decay were identified and counted by the SLICS detector, a dE-E phoswich detector telescope. Alpha particles from $^6\text{Li}(d,\alpha)^4\text{He}$ on the same natural lithium target were counted by a silicon surface barrier detector at various backward angles. The efficiency of the SLICS detector was determined using the number of the α and β particles counted by the two detectors and the previously measured cross-sections and Li isotopic abundances.

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II. Cross sections for nucleosynthesis models

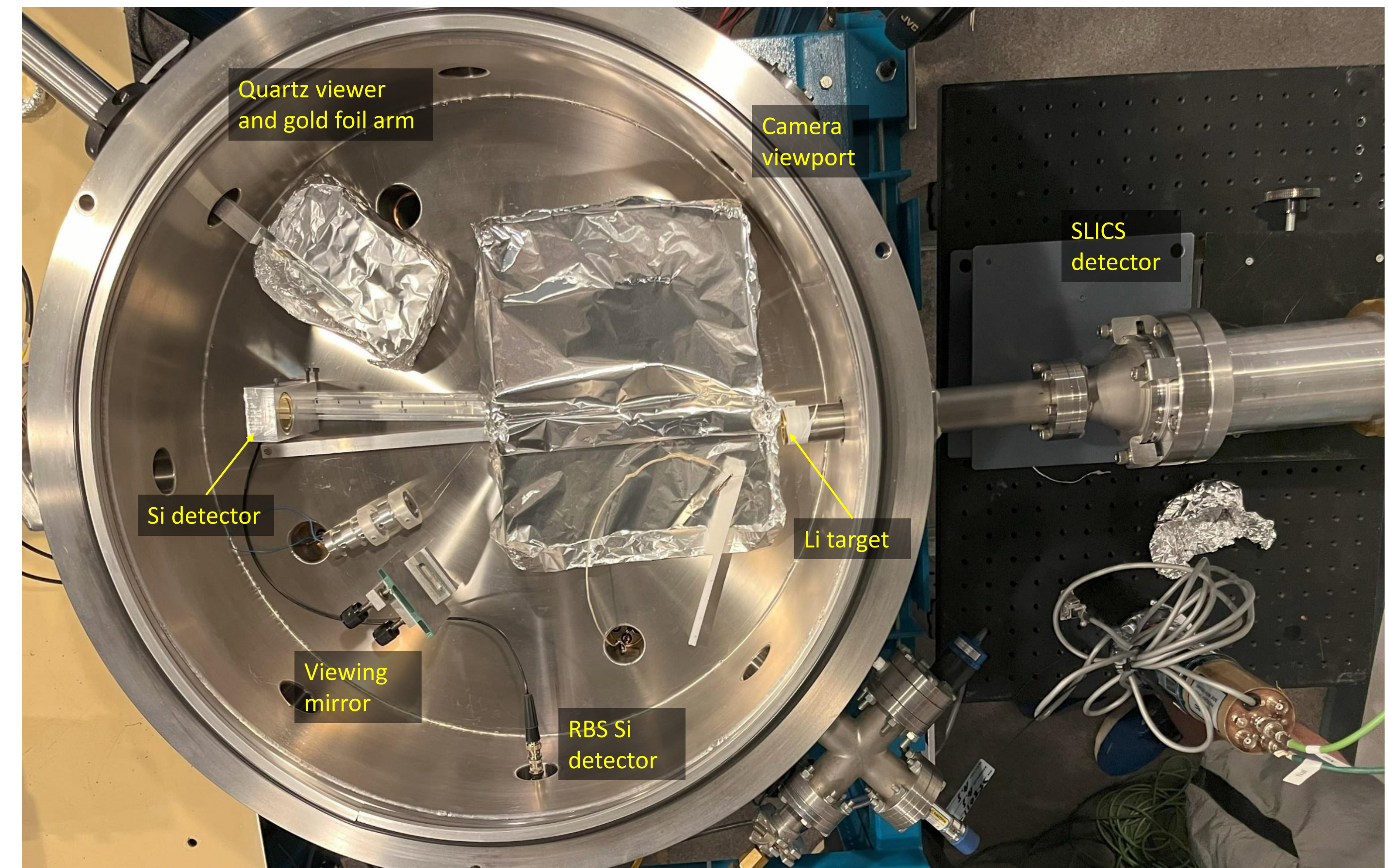
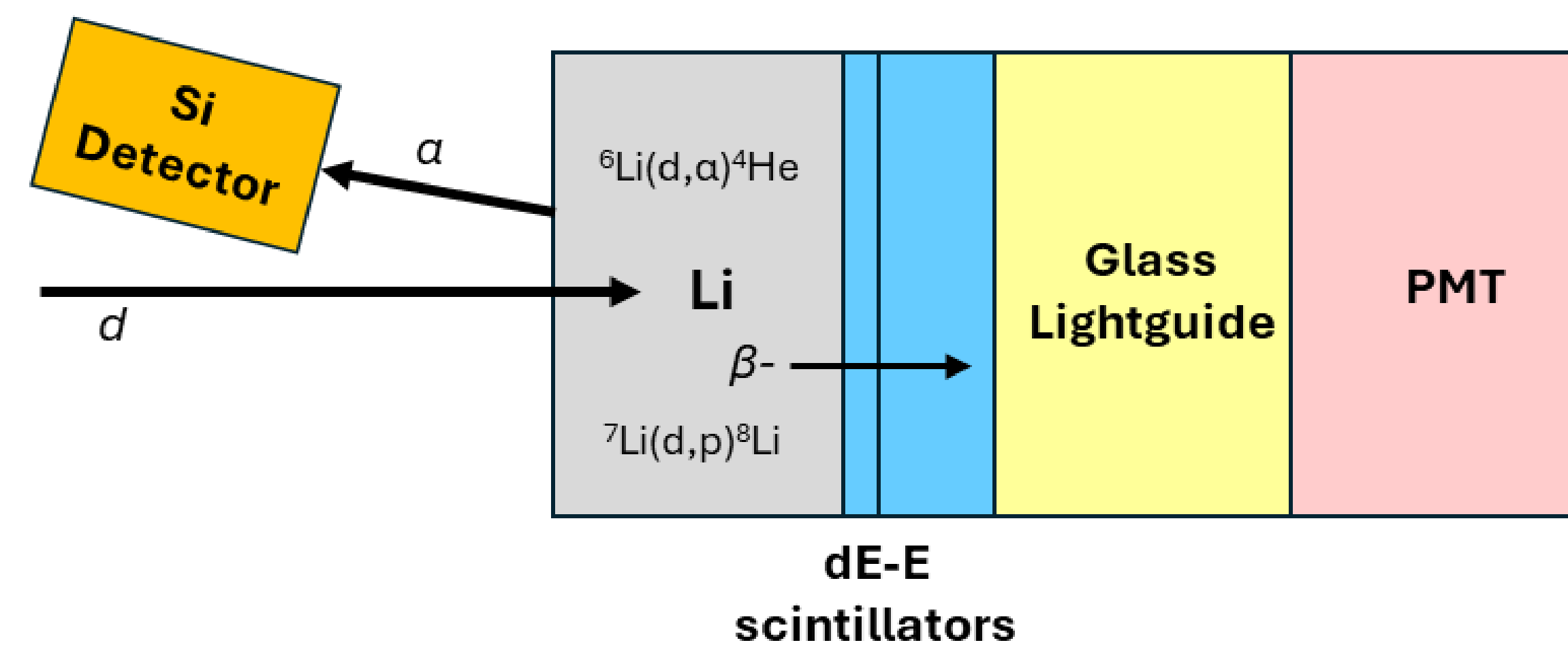
Nucleosynthesis is the process by which smaller nuclei come together to form larger ones in stars or in the early universe. Understanding this process is essential for Big Bang and stellar models. However, most of the nuclear cross sections for these reactions have not been measured at the relevant low energies. Thus, the current models are usually based on extrapolations of cross-sections downward in energy, up to 7 orders of magnitude, from accelerator-based cross section measurements. Moreover, for tritium very few measurements have been made at any energy, since very few accelerator laboratories will accelerate tritium due to tritium contaminating the beamline. By using high-power ultra-short pulse lasers to transfer energy to light ions using Inertial Confinement Fusion (ICF) or Target Normal Sheath Acceleration (TNSA), experiments to determine these unknown cross sections may become possible. The Short Lived Isotope Counting System (SLICS) has been developed to measure these cross sections for light-ion reactions leading to radioactive products that beta decay with half-lives in the range 20 ms to 20 s. By counting the beta decays, the number of product nuclei can be determined if the detector efficiency, or detected fraction of the total number of decays, is known.

III. Experiment to measure the detector efficiency

During the summer of 2024, the 1.7 MV Tandem Pelletron at SUNY Geneseo was used to measure the efficiency of the SLICS detector. To accomplish this, an approximately 5 nA beam of 1.5 MeV deuterons was allowed to strike an approximately 1 μm thick natural lithium target, which released alphas via $^6\text{Li}(d,\alpha)^4\text{He}$ and created ^8Li by the $^7\text{Li}(d,p)^8\text{Li}$ reaction. The alphas were counted by a silicon detector to measure the beam current striking the target, the ^8Li beta decays were counted by SLICS for 30 seconds after beam off to determine the efficiency. Subsequently, the same beam of deuterons was allowed to elastically scatter from a 0.12 μm thick gold foil to as an additional measurement of the beam current. The efficiency predicted by a Geant4 simulation was compared to the measured efficiency in order to validate its accuracy.

Figure 1 (below): As deuterons interacted with the natural lithium target, the nuclear reactions $^6\text{Li}(d,\alpha)^4\text{He}$ and $^7\text{Li}(d,p)^8\text{Li}$ took place. Some of the alpha particles were detected by the silicon detector at 173°. The ^8Li beta decayed and some of the beta particles were detected in the SLICS detector, which utilized a thin and thick scintillator phoswich to identify beta events.

Figure 2 (right): Top view of the target chamber. Deuterons entered from the left opposite the SLICS detector. A Si detector at 90° detected elastically scattered deuterons from the gold foil. Another Si detector at 173° detected alpha particles from the deuterons hitting the Li.



IV. Short-Lived Isotope Counting System (SLICS)

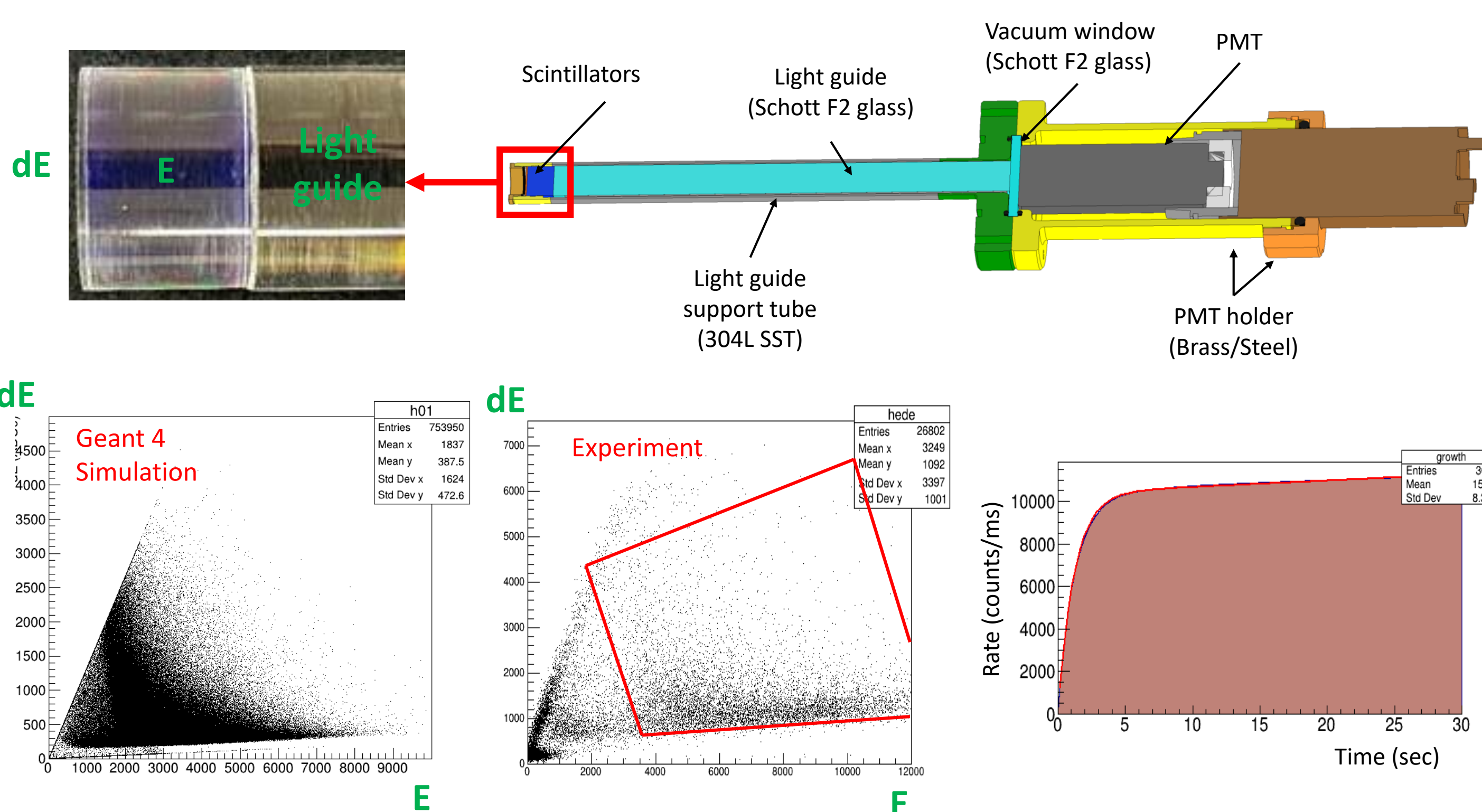


Figure 3: Beta particles from the ^8Li decay in the activated target (on the end of the phoswich) pass through both the dE and E scintillators depositing different amounts of energy. By looking at the simulated 2D dE-E histogram (left), betas within a selected region (red) of the measured histogram (center) were counted as a function of time to produce the growth curve (right), which was then fit to obtain the total number of ^8Li decays (red curve).

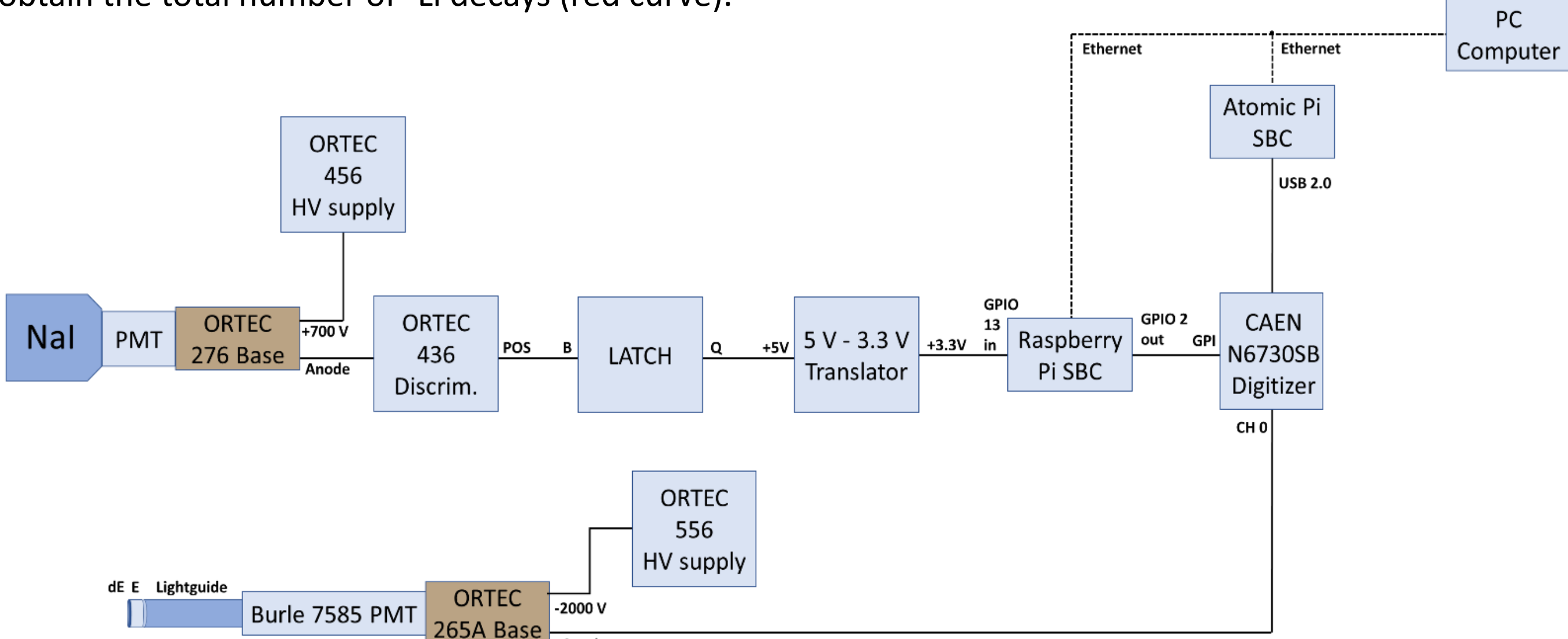


Figure 4: Radiation created by the beam triggered the external NaI detector and hence the latch circuit. Once the beam was off for about 10 ms the latch circuit triggered the CAEN digitizer to start collecting data. The digitizer sampled and recorded the PMT signal every 2 ns for about 800 ns around each pulse.

V. Experiment procedure

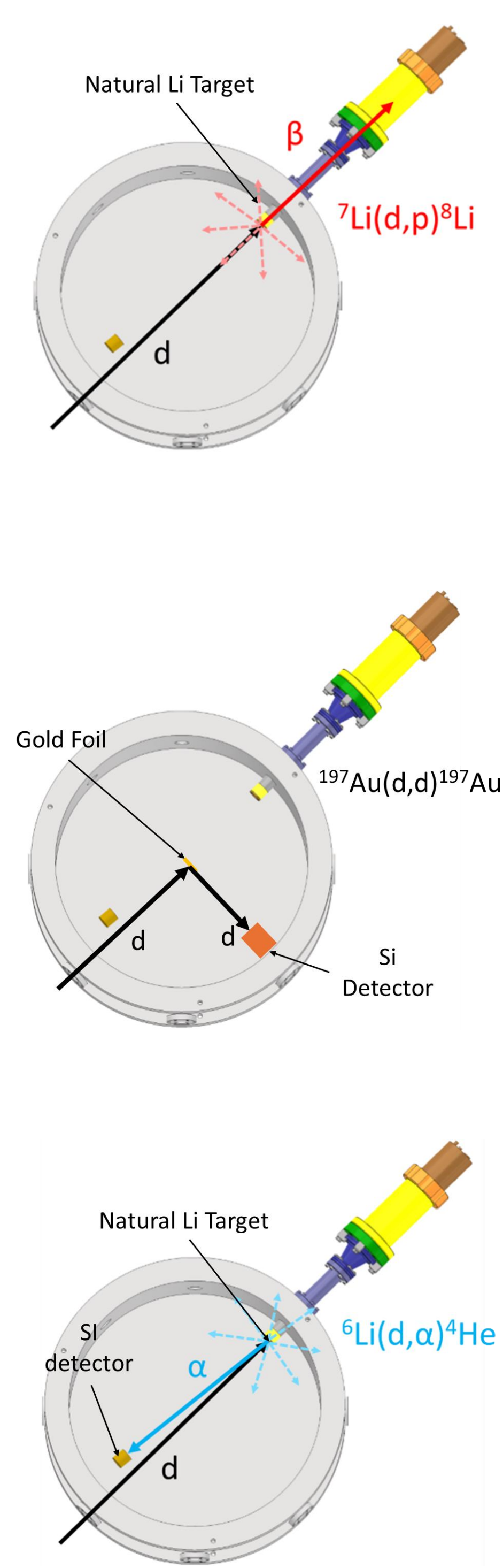


Figure 5: The beam of deuterons first struck the quartz viewing slide covering the target, allowing the beam to be aligned on the target. It then was allowed to strike the natural lithium target for 5 seconds, forming ^8Li . The ^8Li beta decayed, and a fraction of the beta particles were detected by the SLICS detector.

Figure 6: Next the beam of deuterons hit a thin gold foil for 30 seconds, and deuterons elastically scattered at 90-degrees were detected by a silicon detector. Using the known elastic scattering cross section allowed the beam current to be determined.

Figure 7: Finally, the deuteron beam struck the natural lithium target again for 290 seconds, emitting alphas which were detected by another Si detector. This provided another measurement of beam current, which, along with direct measurements using an electrometer, was used as a check of the gold foil current.

VI. Preliminary Results

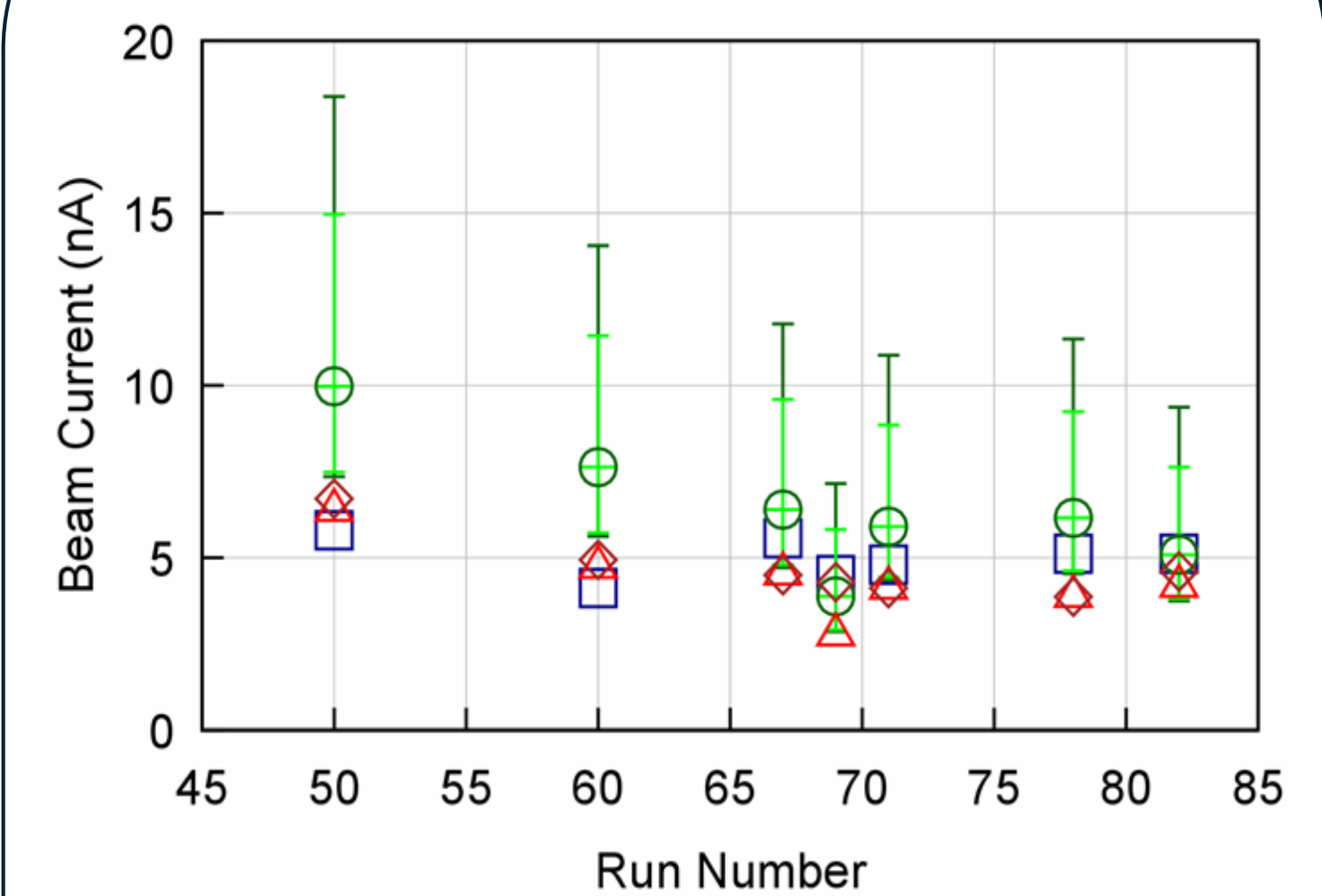


Figure 8: Beam current measured by alpha particles (green circles), elastically scattered deuterons (blue squares), directly measuring current hitting target with electrometer for 290 seconds from $^6\text{Li}(d,\alpha)^4\text{He}$ decays (red triangles), and 5 seconds (brown diamonds). The error bars show the range due to cross sections used to determine target thickness (dark green) and $^6\text{Li}(d,\alpha)^4\text{He}$ (light green).

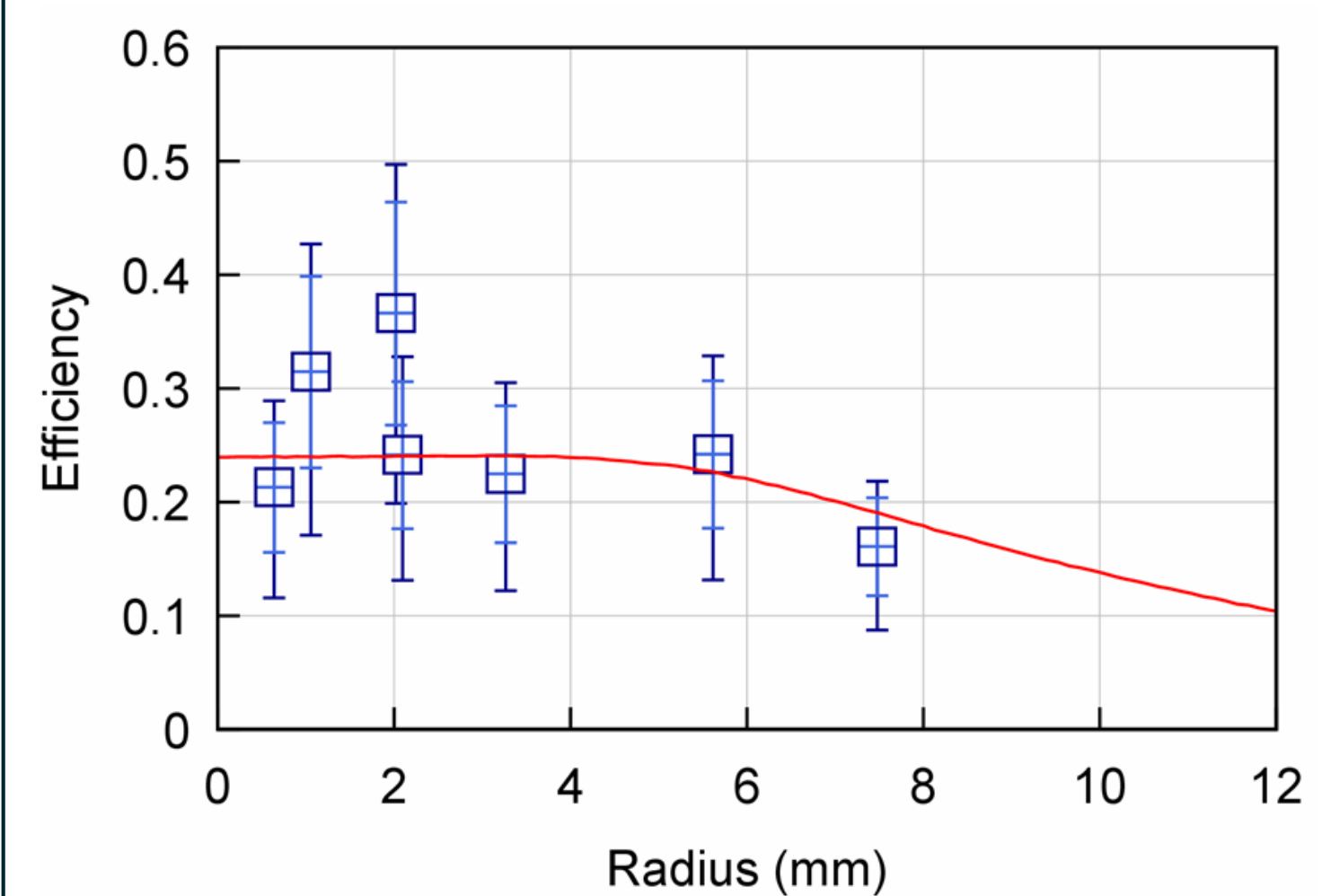


Figure 9: Blue squares are the measured efficiency of the SLICS detector as a function of distance from the center of the detector. The error bars show the range due to cross sections used to determine target thickness (dark blue) and $^7\text{Li}(d,p)^8\text{Li}$ (light blue). The red line shows the Geant4 simulation.

VII. Future Plans

We are currently working on a design to insert the SLICS into a Ten-Inch Manipulator (TIM) for insertion into the OMEGA-EP or OMEGA-60 target chambers at the Lab for Laser Energetics (LLE). This will allow the SLICS detector to be used in TNSA experiments with tritium and ICF getter experiments. This detector is also a prototype for a diagnostic to operate in the short-pulse, high shot rate environment of the proposed NSF OPAL laser system.

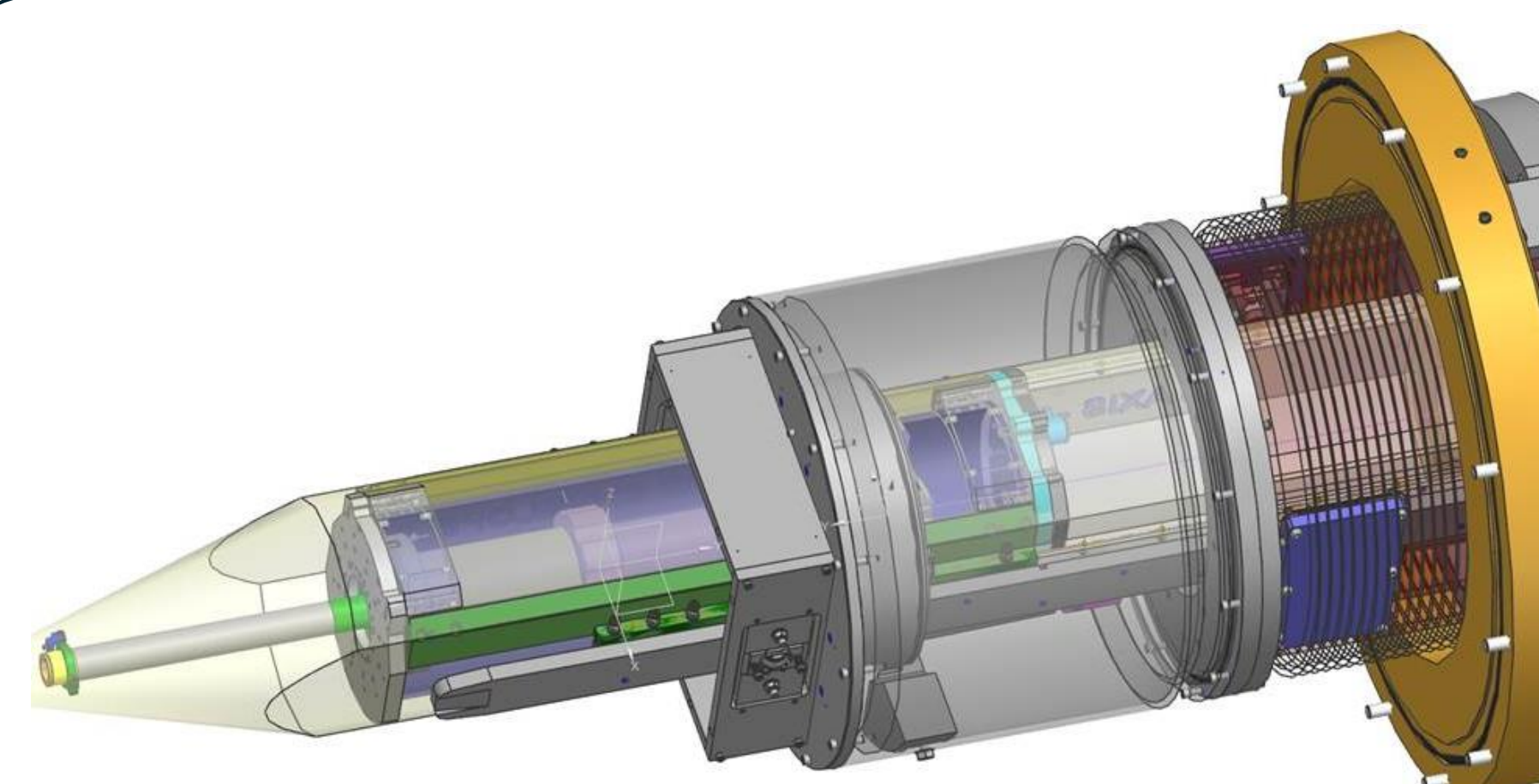


Figure 10: A CAD drawing of the SLICS detector inside an air bubble in a TIM. The SLICS detector is mounted to a rail allowing it to be inserted within a few cm of the target chamber center of OMEGA-EP or OMEGA-60. Cables are attached to a cable chain allowing the detector to move.