Initial Test of the Ten-Inch Manipulator-Based Short Lived Isotope Counting System

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Abstract

The Short-Lived Isotope Counting System (SLICS) is designed to measure cross sections for astrophysically relevant light-ion reactions and energies. The dE-E phoswich detector telescope, which identifies beta particles from decaying 20 ms to 20 s half-life reaction product nuclei, has been redesigned to fit in a Ten-Inch Manipulator (TIM) for insertion in the OMEGA-60 and OMEGA-EP target chambers at the Laboratory for Laser Energetics. In the first test of the new design, ^{8}Li decays were detected after the ^{7}Li(d,p)^{8}Li reaction was triggered by a pulse of OMEGA-EP target normal sheath acceleration (TSNA) deuterons. This poster presents a description of the new design and preliminary test results.

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Introduction

Nucleosynthesis is the process where smaller nuclei come together to form larger nuclei. Understanding the nucleosynthesis of light ions is important for modeling the big bang and stars. At thermonuclear energies, these reactions have very small cross sections, making the use of traditional particle accelerators to measure them impractical, if not infeasible. Because the rate of decay of radioactive product nuclei is proportional to the number, with a particle accelerator the rate of decay eventually approaches the rate of production and the number ceases growing, requiring the beam to be pulsed and the decays counted between pulses. High power short-pulse lasers using Target Normal Sheath Acceleration (TNSA) and Inertial Confinement Fusion (ICF) produce a single huge pulse of ions, causing all the reactions to occur so quickly there is essentially no time for products to decay. Moreover, tritium reactions can be studied which would otherwise contaminate the beamline of a traditional particle accelerator. The Short-lived Isotope Counting System (SLICS) uses a phoswich scintillator detector to count the 20 ms-20 s half-life beta decays of these light ion reaction products.

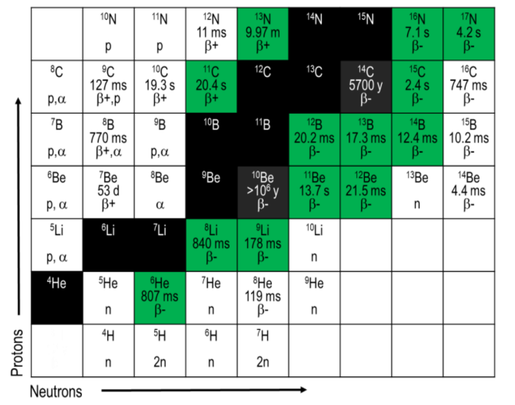


Figure 1: A chart of the stable isotopes (black), and isotopes that beta decay with half-lives of 20 ms-20 s (green) that are formed from light ion reactions.

Target Normal Sheath Acceleration (TNSA)

In target normal sheath acceleration (TNSA), a laser pre-pulse strikes a laser target with the desired isotopes on its surface, creating a plasma. A high-power short-pulse laser then transfers energy to the electrons, blasting them off the target and creating an electric field that accelerates the desired ions off the opposite face of the laser target. These ions strike the nuclear target causing nuclear reactions to occur.

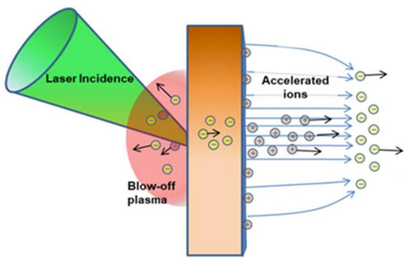


Figure 2: In TNSA, electrons create and electric field that accelerates the desired ions towards a nuclear target.

Short-Lived Isotope Counting System (SLICS)

The short-lived isotope counting system (SLICS) phoswich dE-E scintillator telescope consists of two plastic scintillators: a 1 mm fast (dE) layer and an 18 mm slow (E) layer. When a charged particle passes through the dE layer it loses energy, and light proportional to this energy loss is emitted. Likewise, when the charged particle passes through the E layer, it loses more energy and emits light proportional to the energy lost. The light from the dE and the E layers passes through the lightguide into a photomultiplier tube (PMT), which converts the light to an electrical pulse. The light from each layer, and hence the energy lost in each, can be separated electronically using the scintillation decay time, allowing good beta decay events to be identified. A particle time of flight (PTOF) detector in front of the phoswich detector is used to measure the energy distribution of the incident ions.

The SLICS has been designed to fit inside a ten-inch manipulator (TIM) to insert it into OMEGA-60 and OMEGA-EP laser chambers at the Laboratory for Laser Energetics (LLE). Due to the PMT and PMT base needing to be kept at atmosphere, the detector was placed inside an air bubble inside the TIM. The TIM allows the detector to be inserted and retracted as needed throughout the experiment, allowing it to be used as a diagnostic and detector for future experiments.

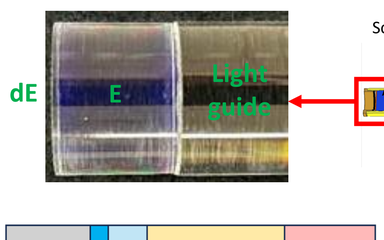


Figure 3: (Right) The SLICS consists of a thin fast (dE) scintillator and a thick slow (E) scintillator. The light from the scintillators travels down the lightguide to the PMT.

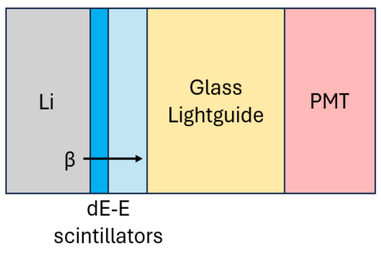


Figure 4: (Right) A block diagram of the SLICS. A thin natural lithium target was placed upstream of the detector. When struck by incident deuterons the ^{7}Li(d,p)^{8}Li reaction occurred. The beta decays of the ^{8}Li were identified and counted using the dE-E scintillator telescope.

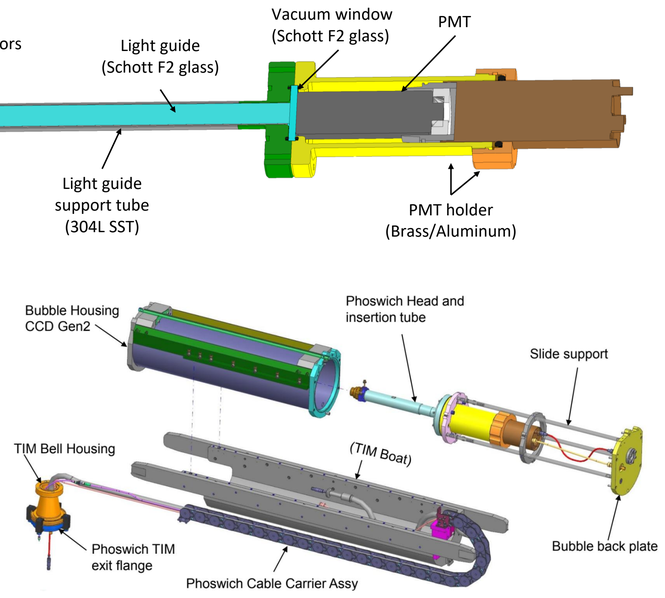
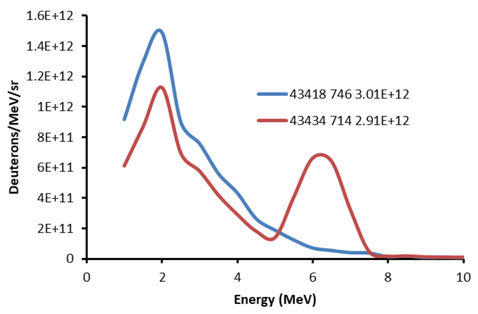


Figure 5: (Right) An exploded drawing of the TIM based SLICS detector. The bubble housing keeps the PMT in air.

LLE Experiment

In August 2025, the new TIM based SLICS was deployed for the first OMEGA-EP TNSA experiment. A thin (~2-6 μm) natural lithium film deposited on a 25 μm stainless-steel substrate was allowed to oxidize before being placed just upstream of SLICS detector. The laser target was a 25 μm thick stainless-steel flag onto which deuterium or hydrogen was absorbed either directly or by a thin titanium coating. The laser target was alternately turned to face either the Thompson Parabola (TPIE) or SLICS, causing deuterons accelerated by backlighter or sidelighter laser to strike each detector, respectively. The same laser parameters were used in each case, so that the deuterons ostensibly had the same energy distribution in each case.

The first SLICS laser shot at 35 cm yielded ^{8}Li, but not ensuing shots. It was found that the lithium had been scrubbed from the nuclear target by debris from the laser target. Subsequently, SLICS was retracted to 100 cm and a fresh lithium target was used for each shot. Shot-to-shot variation of the deuteron spectrum was also problematic.



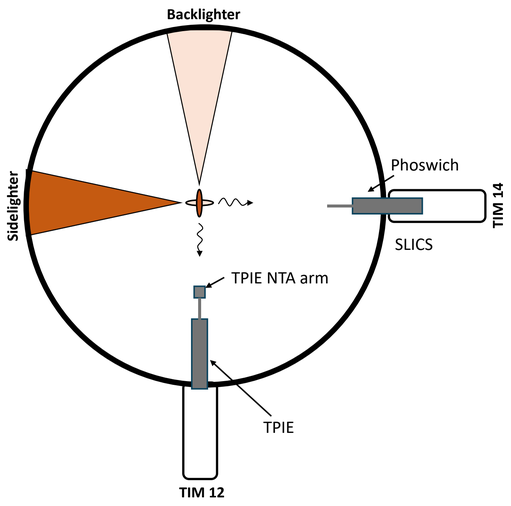


Figure 6: (Above) A backlighter laser shot accelerates deuterons towards the TPIE detector, then a sidelighter shot accelerates deuterons towards the natural Li target of the SLICS phoswich detector. **(Left)** TPIE –measured incident deuteron energy spectra for ~730 J laser shots.

Results

OMEGA-EP shots at energies between about 140 and 730 J yielded ^{8}Li product nuclei, demonstrating the TIM-based SLICS is able to measure nuclear yields using TNSA. It was discovered that if the nuclear target is too close to the laser target, both the nuclear target and the coating on the PTOF detector are scoured by the shrapnel from the stainless-steel laser target.

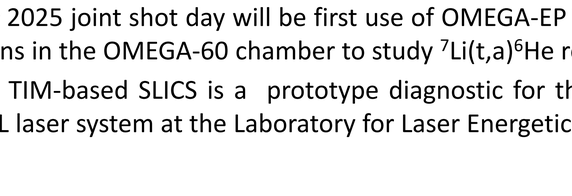


Figure 7. (Above) A 2D dE-E histogram. The selected ^{8}Li beta decays fall inside the red box. Detector efficiency was calculated using a GEANT4 simulation and which was calibrated using the 1 MeV electrons from ^{207}Bi.

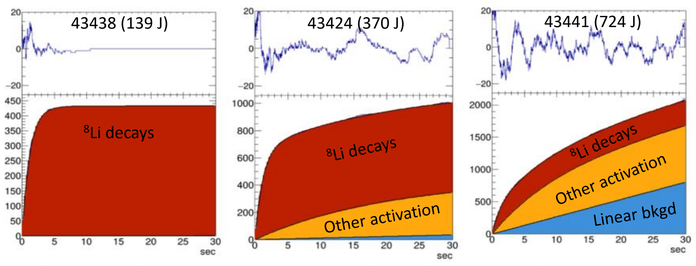


Figure 9. (Above) Growth curve fits (bottom) with their corresponding residuals (top) for OMEGA-EP shots 43438 (139 J) (left), 43424 (370 J) (center) and 43441 (724 J) (right). The red area indicates ^{8}Li decays, the blue indicates the background, and the yellow indicates the decays from an unknown isotope.

Figure 8. (Right) Target 34 initially and after three laser shots. Most of the lithium carbonate was scoured off the target except the slice behind the TPIE detector, causing subsequent shots on the target to create little to no ^{8}Li.

Figure 10. (Right) The measured yield of ^{8}Li per Li atom (blue) compared to the predicted yield (orange). The predicted yields were calculated using the TPIE deuteron energy spectrum for shots with approximately the same laser energy. Most of the uncertainty in the measured yield comes from the spread in the previously measured ^{7}Li(p,a)^{4}He cross-section used to measure target thickness. The uncertainty in the predicted values comes mostly from spread in previously measured ^{7}Li(d,p)^{8}Li cross sections.

Future Plans

May 2025 joint shot day will be first use of OMEGA-EP TNSA accelerated tritons in the OMEGA-60 chamber to study ^{7}Li(t,a)^{6}He reaction.

The TIM-based SLICS is a prototype diagnostic for the proposed NSF-OPAL laser system at the Laboratory for Laser Energetics.