Inertial Confinement Fusion as a Tool to Study Fundamental Nuclear Science

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I. Abstract

Inertial confinement fusion may be used to make fundamental nuclear science measurements of low-energy light-ion cross sections also of interest in astrophysics and fusion research. The feasibility of collecting and counting the beta decay of the reaction products (half-life 20 ms to 20 s) in the expanding neutral gas after the ICF shot is being studied using a special vacuum system that allows gas to be released, trapped, and counted in-situ using different techniques. Initial experiments use a turbopump to trap the gas in the foreline, where it can be counted by a 4π phoswich beta detector. The construction of this detector and tests using ^{41}Ar gas produced via the ^{40}Ar(d,p)^{41}Ar reaction will be described, as well as an OMEGA laser ride-along experiment to measure background rates from milliseconds to seconds after the laser shot.

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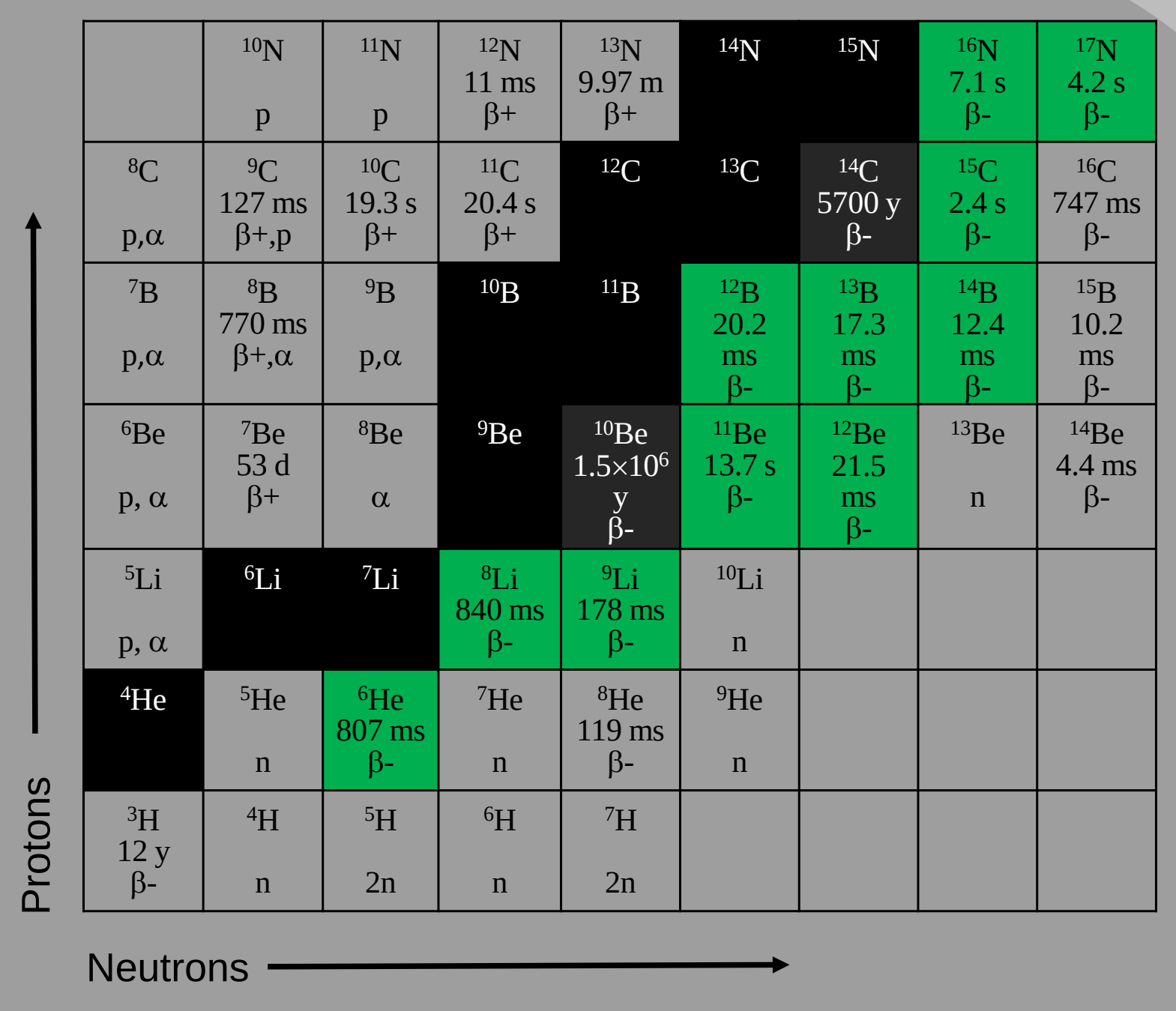
II. Introduction

Light-ion nuclear cross sections are usually measured using accelerators. This method is impractical at low energies because of the time required to collect adequate statistics. A single ICF shot can, in less than a nanosecond, yield the same number of product nuclei as tens or even hundreds of years of accelerator beam time.

Estimates show certain light-ion radiative capture (t,γ) and (d,γ) and stripping (t,p) and (d,p) reactions may have measurable yields using OMEGA.



	^{10}N p	^{11}N p	^{12}N 11 ms β+	^{13}N 9.97 m β+	^{14}N	^{15}N	^{16}N 7.1 s β-	^{17}N 4.2 s β-
^{8}C p,α	^{9}C 127 ms β+,p	^{10}C 19.3 s β+	^{11}C 20.4 s β+	^{12}C	^{13}C	^{14}C 5700 y β-	^{15}C 2.4 s β-	^{16}C 747 ms β-
^{7}B p,α	^{8}B 770 ms β+,α	^{9}B p,α	^{10}B	^{11}B	^{12}B 20.2 ms β-	^{13}B 17.3 ms β-	^{14}B 12.4 ms β-	^{15}B 10.2 ms β-
^{6}Be p, α	^{7}Be 53 d β+	^{8}Be α	^{9}Be	^{10}Be 1.5×10^{6} y β-	^{11}Be 13.7 s β-	^{12}Be 21.5 ms β-	^{13}Be n	^{14}Be 4.4 ms β-
^{5}Li p, α	^{6}Li	^{7}Li	^{8}Li 840 ms β-	^{9}Li 178 ms β-	^{10}Li n			
^{4}He	^{5}He n	^{6}He 807 ms β-	^{7}He n	^{8}He 119 ms β-	^{9}He n			
^{3}H 12 y β-	^{4}H n	^{5}H 2n	^{6}H n	^{7}H 2n				

Figure 1. Chart of nuclides. Stable light ions (black) undergo thermonuclear reactions forming products that beta decay (green) with half-lives of 10s to 100s of milliseconds.

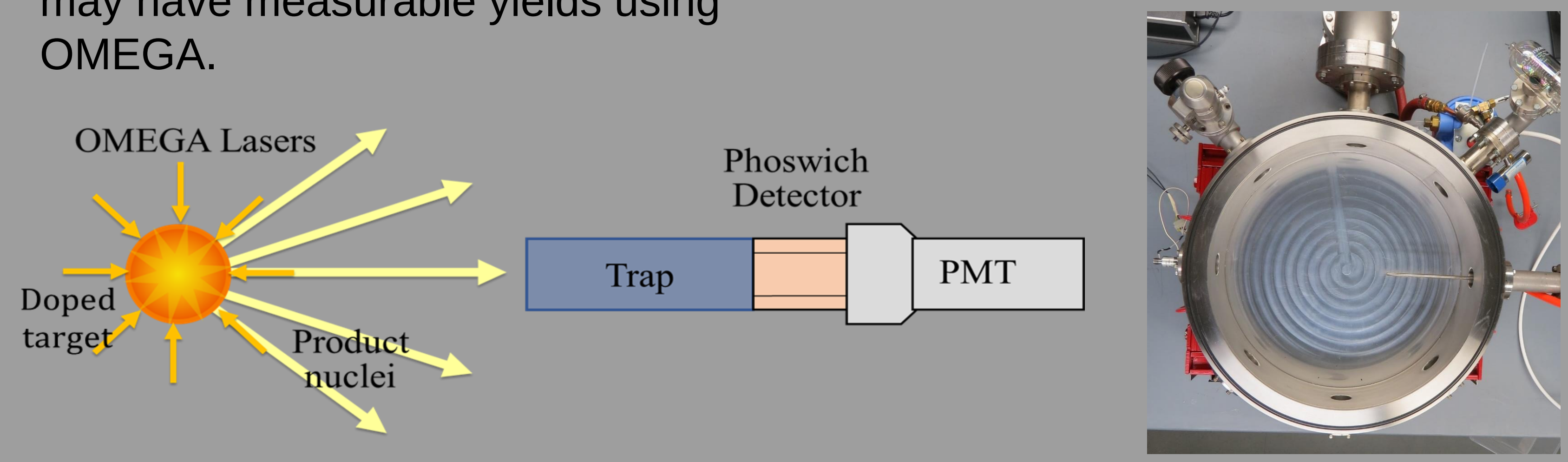


Figure 2. Conceptual drawing of the proposed method; Houghton test Chamber. (Left) The expanding neutral gas is captured within a trap where product nuclei decays can be counted by a phoswich detector. (Right) A Test chamber constructed at Houghton College for testing collection methods.

Product nuclei in the expanding neutral gas after the shot will be collected and their decays counted in the relatively low background environment milliseconds after the shot.

III. Phoswich Detector

A phoswich detector that attaches to the turbopump fore line was built in order to count the decays of the trapped radioactive product nuclei. A thin, fast decay time scintillator (EJ-212) is optically coupled to a thick, slow decay time scintillator (EJ-240), allowing the detector to identify particles by comparing the energy deposited in each scintillator. A hollow rectangular prism of the slow scintillator was internally lined with fast scintillator so that the decay of nuclei within the volume of the detector could be measured. The scintillator was optically coupled to a 5” PMT, which was connected to electronics which processed the PMT pulses.

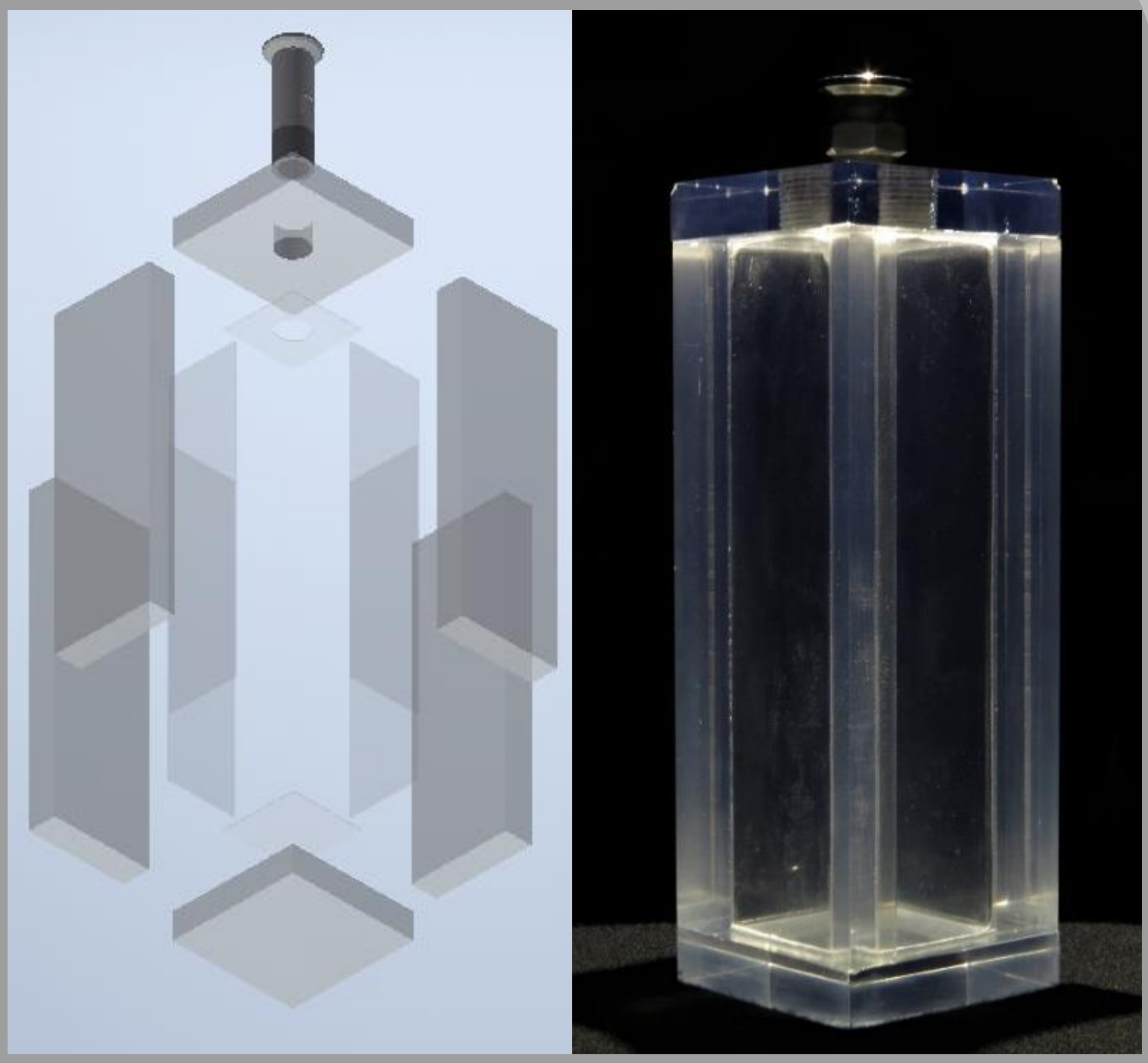


Figure 3. CAD drawing of the phoswich detector (left) compared to the finished detector (right). The dimensions are roughly 4”x4”x12”

IV. 2019 SUNY Geneseo Experiment

The detector assembly and processing electronics were brought to SUNY Geneseo in August of 2019, where Ar-41 could be created with SUNY Geneseo’s Pelletron accelerator. Ar-41 was produced via ${}^{40}_{18}Ar(d,p){}^{41}_{18}Ar$ reaction and was transported within a gas cell to the detector system. The beta decay of the Ar-41 was then recorded on a Si surface barrier detector and the constructed phoswich detector.

This experiment showed that the phoswich detector could detect the beta decay of an inert gas within its inner volume.

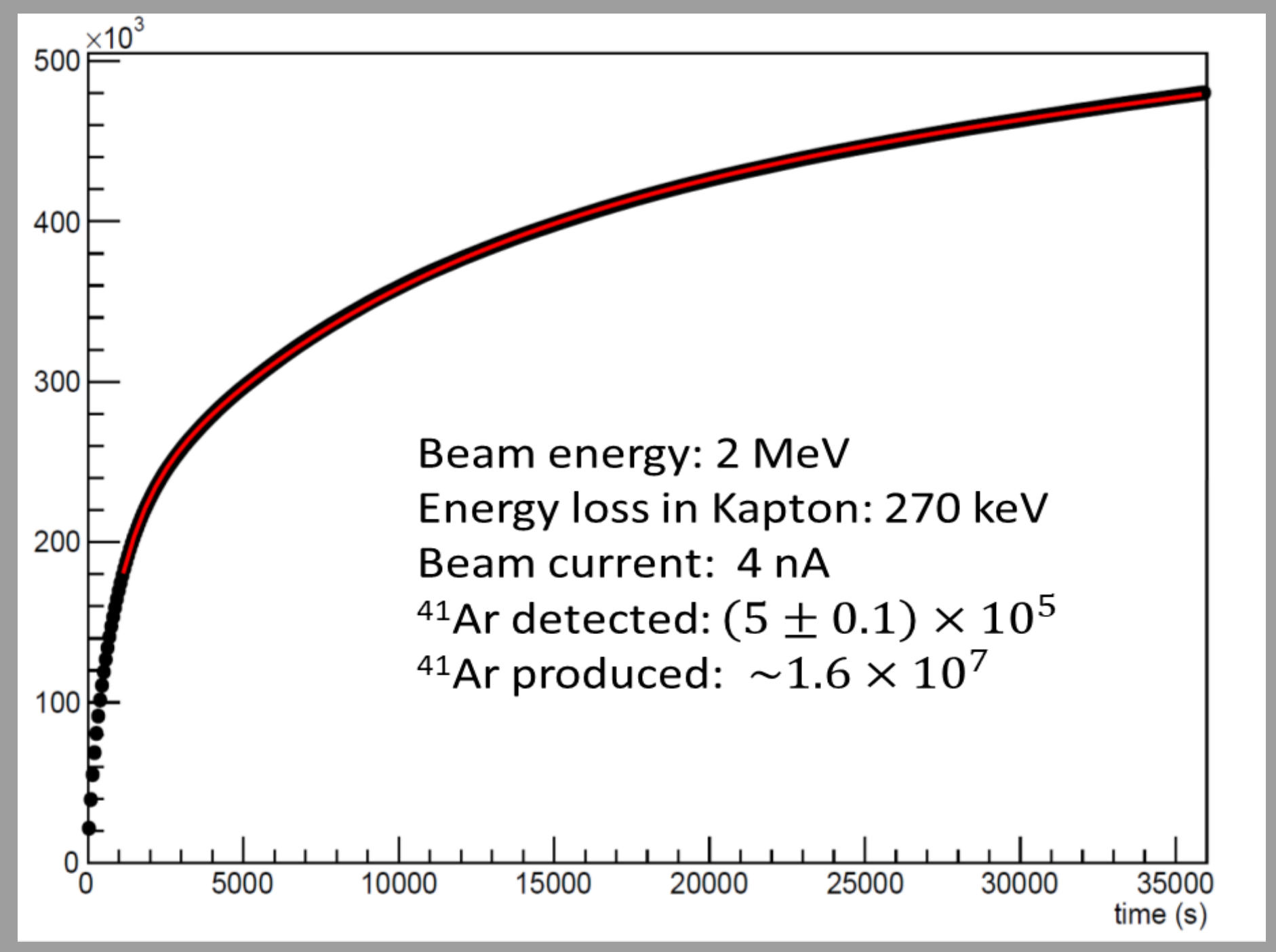


Figure 4. 2-D Histogram of Ar-41 decays within the phoswich detector. A growth curve produced from integrating the number of good beta events over the course of multiple half-lives of Ar-41.

V. LLE Ride Along Experiment

Due to the expected low cross sections of reactions that could be measured with this method, an accurate background count rate after a shot must be obtained. In December of 2019, a ride-along experiment at LLE was conducted where the phoswich detector was be placed near the OMEGA-60 target chamber and measured the post-shot background rate. Additionally, a circuit which protects the processing electronics from the post-shot EMP was also tested.

Background counts across the time interval of 2 ms to 600 s after several high-yield D-T shots were obtained. It was found that in the milliseconds to seconds after the shot the count rate was higher than the rate at which the data acquisition computer could digitize and write pulses to a file. Additionally, multiple possible sources of background radiation were possible identified. These include Al-26 via the Al-27(n,2n)Al-26 reaction and N-16 via the O-16(n,p)N-16 reaction.

Through this ride-along it was determined that more shielding needed to be put in place to block background radiation caused by activated materials in the target area and a faster data acquisition computer needed to be used to record the incoming pulses

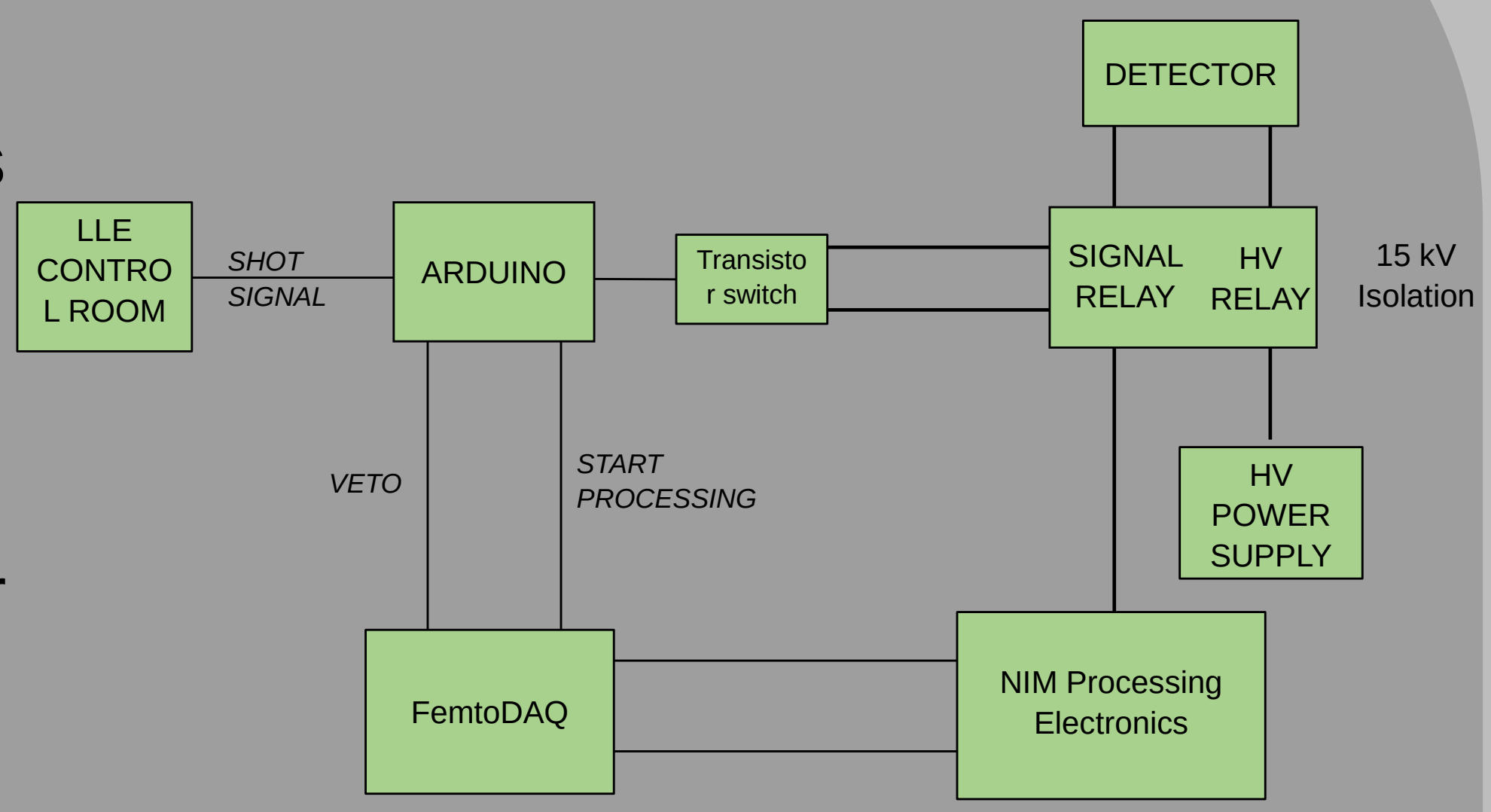


Figure 6. Block diagram of the control and isolation circuit that will be used during the LLE ride-along. Signal is sent from control telling the system that a shot has occurred. Then, a set of relays are closed, allowing the electronics to begin counting.

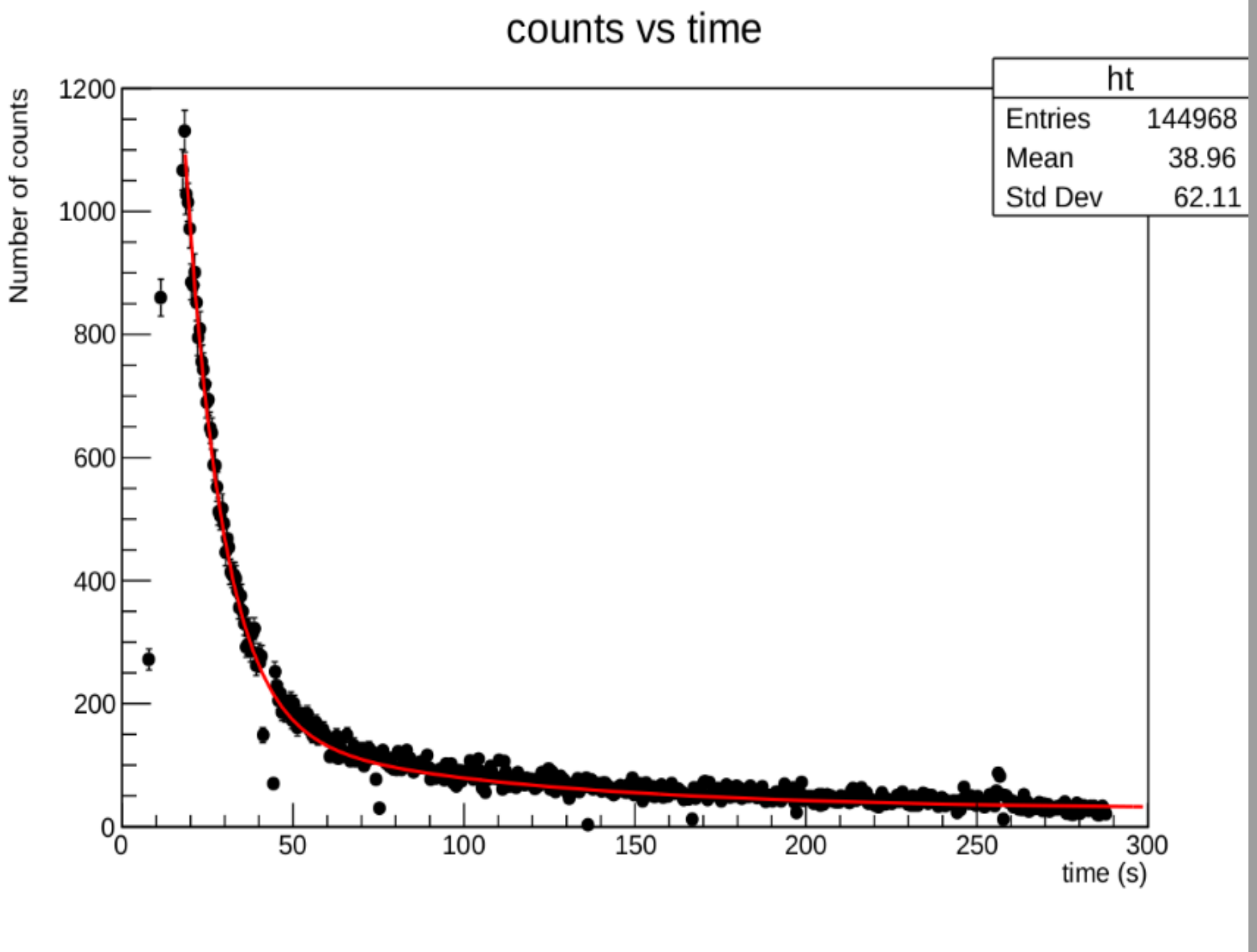


Figure 7. Decay curve obtained from the phoswich detector data after a high-yield D-T shot of the OMEGA-60 system.

VI. Detector Simulations

In order to further describe the behavior of the detector system, a simulation of the detector was constructed using GEANT4. The goal of the simulation was to provide insight for calculating the absolute efficiency of the detector and for identifying possible sources of background events.

Instances of the detector that included background radiation coming from the environment as well as from inside the detector were simulated and are currently being compared to the data obtained during the ride along experiment.

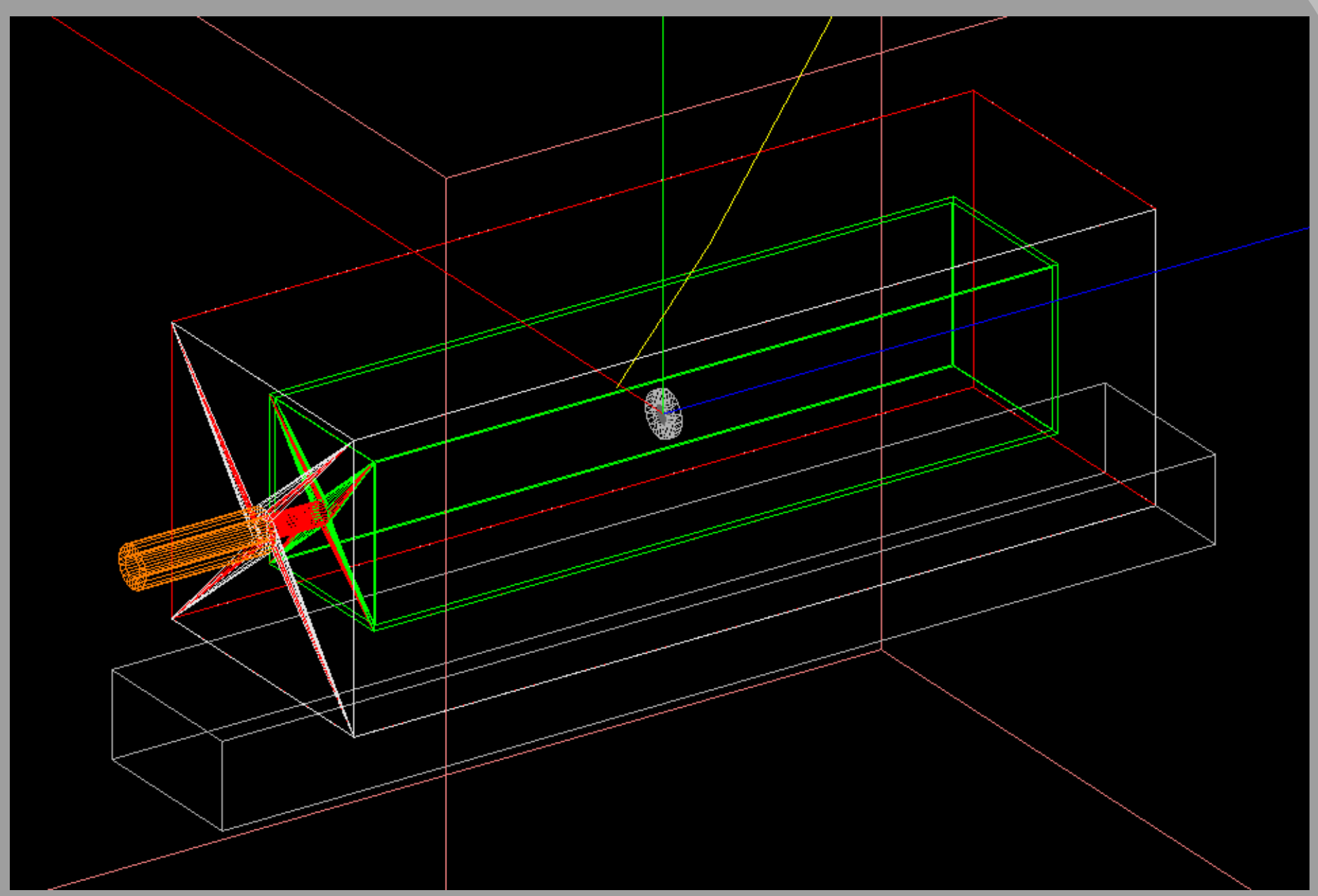


Figure 8. Visual Simulation of the phoswich detector resting on an aluminum support beam within the target chamber room. The track of one simulated particle is seen in yellow.