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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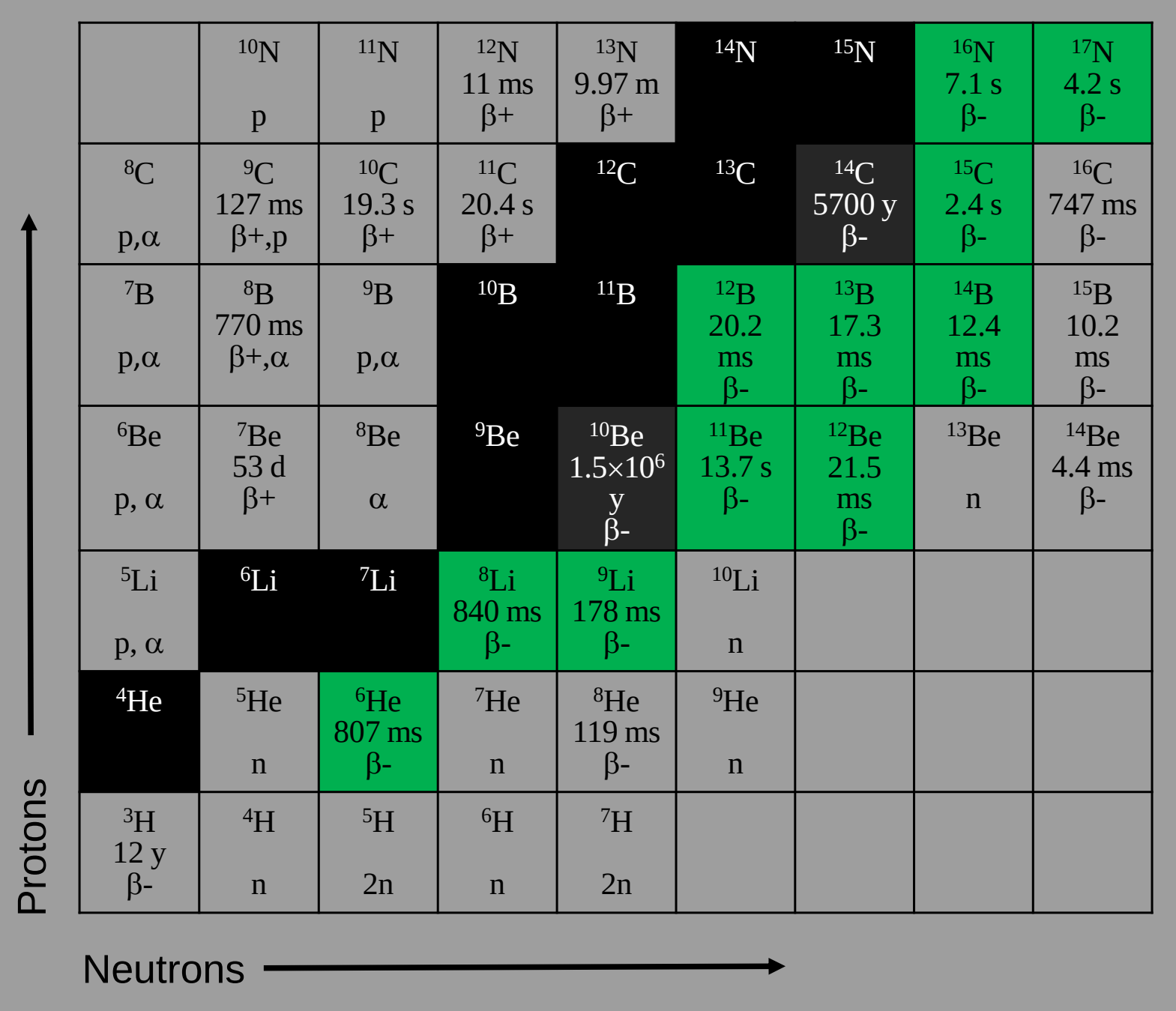
II. Introduction

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.

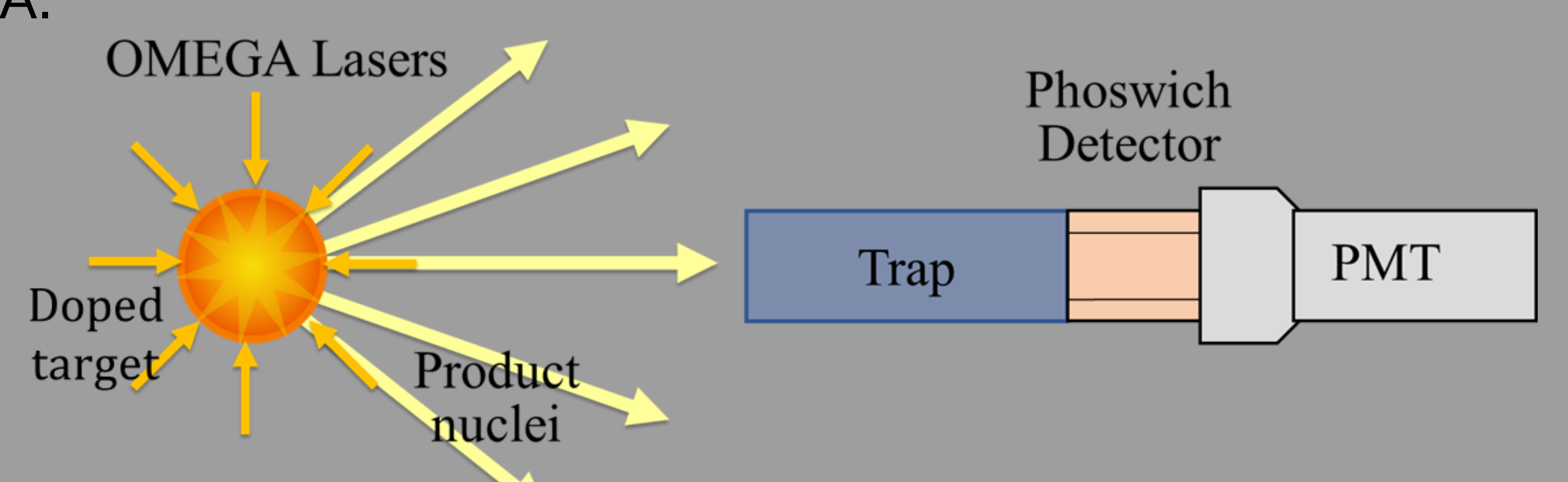


Figure 2. Conceptual drawing of the proposed method for measuring low energy, light-ion cross sections. The expanding neutral gas is captured within a trap where product nuclei decays can be counted by a phoswich detector.

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.

Three methods of trapping the gas are being studied:

(1) **Turbopump** – gas travels down a long tube near the target to a turbopump, and decays are counted in the foreline.

(2) **Ion Pump** – gas travels down a long tube near the target to an ion pump, where they become embedded in a titanium electrode and decays are counted on electrode.

(3) **Getter** – product atoms stick to getter place near target, decays are counted in-situ.

III. Test System

In order to test different methods for trapping the expanding neutral gas, a test chamber was constructed. The cylindrical chamber houses ports in the lid for fast ion gauges, have a timing resolution of about 100 μs. Radioactive ^{41}Ar gas, created using the ^{40}Ar(d,p)^{41}Ar reaction using the Pelletron at SUNY Geneseo can be injected using the fast valve, travel down the collection tube and be trapped in the foreline of the turbopump and counted.

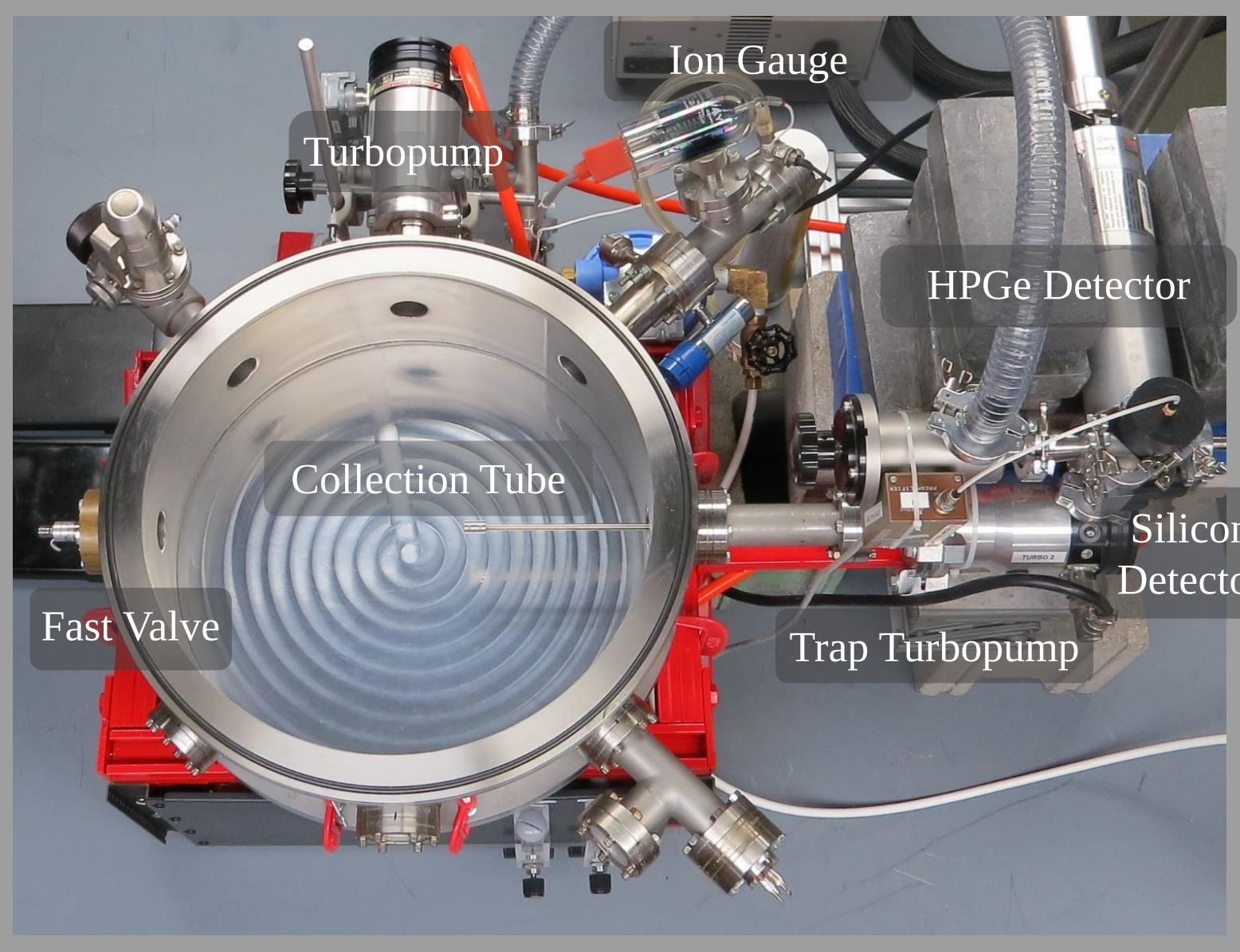


Figure 3. Test Chamber. The trapping and decay counting of radioactive gas can be studied.

IV. Phoswich Detector

A phoswich detector was built to attach to the turbopump foreline in order to count the decays of the trapped product nuclei. A thin, fast plastic scintillator (EJ-212) was optically coupled to a thick, slow plastic scintillator (EJ-240), allowing particles to be identified by the energy deposited in each scintillator. A hollow rectangular prism of slow scintillator was internally lined with fast scintillator so that the beta decays of nuclei within its volume of the detector could identified and counted. The scintillator was optically coupled to a ADIT B133D01 133 mm diameter phototube. Fast and slow components were separated electronically and then digitized using a FemtoDAQ acquisition system.

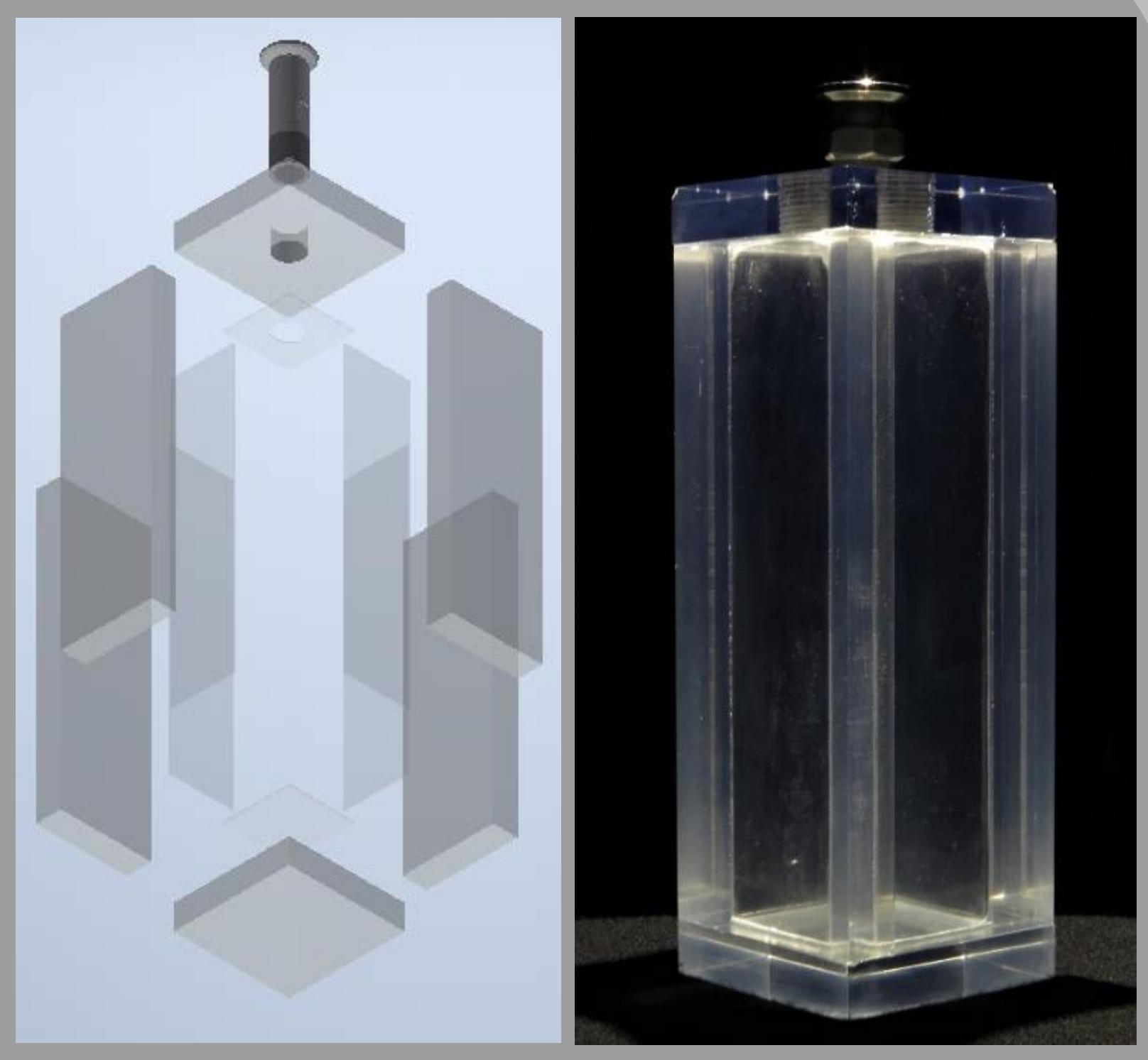


Figure 4. The phoswich detector. CAD drawing of the phoswich detector (left) and finished detector (right). The dimensions are roughly 10.2 cm x 10.2 cm x 30.5 cm.

V. SUNY Geneseo Pelletron Experiment

The detector assembly and processing electronics were brought to SUNY Geneseo, where ^{41}Ar was created in a gas cell via the ^{40}Ar(d,p)^{41}Ar reaction using the Pelletron accelerator. The ^{41}Ar was transported and injected into the evacuated phoswich detector. Beta decay events fall into a band on a dE-E histogram, which allowed them to be identified and counted as a function of time. A fit to the resulting growth curve yielded the initial number of ^{41}Ar nuclei.

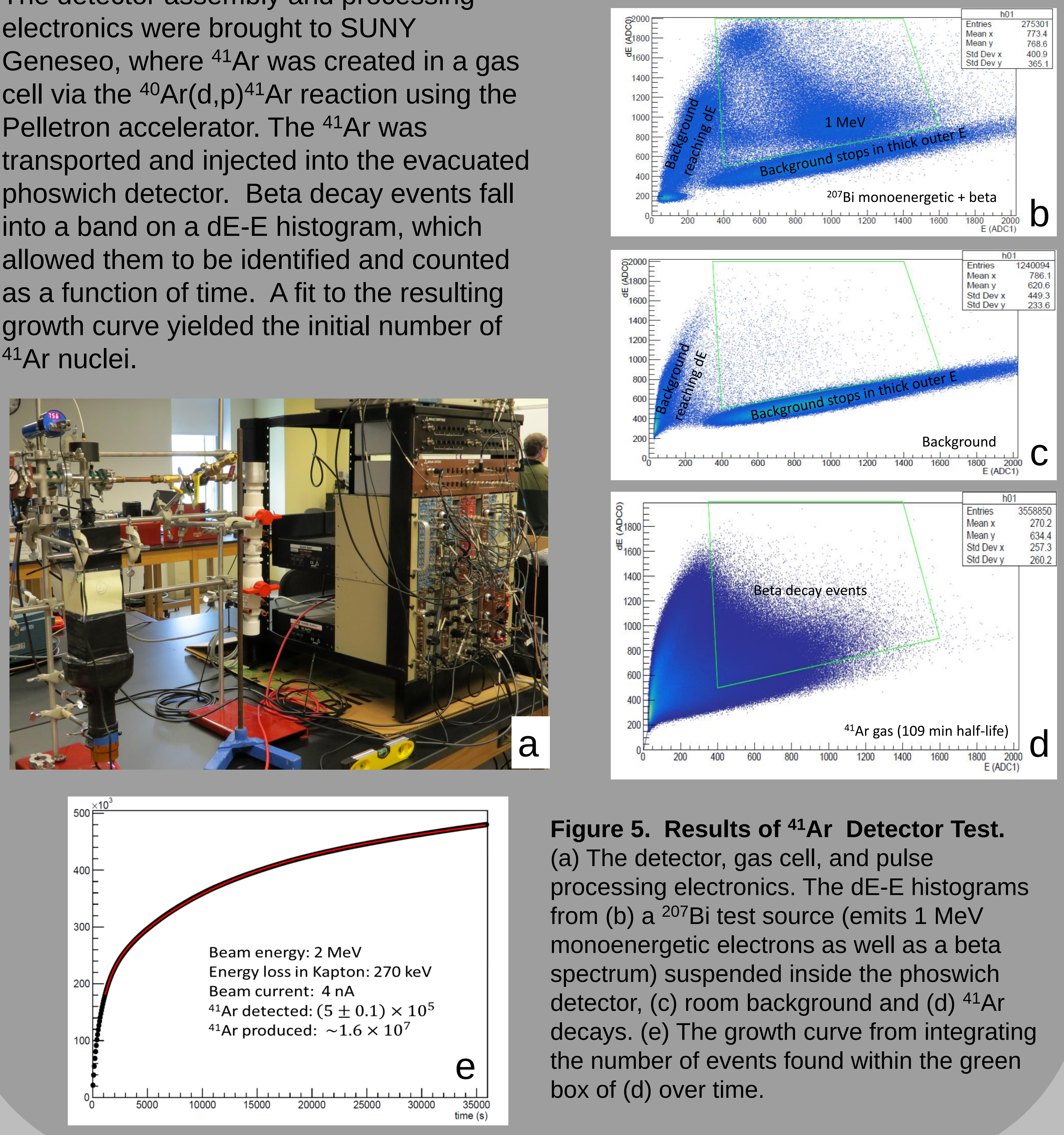


Figure 5. Results of ^{41}Ar Detector Test. (a) The detector, gas cell, and pulse processing electronics. The dE-E histograms from (b) a ^{207}Bi test source (emits 1 MeV monoenergetic electrons as well as a beta spectrum) suspended inside the phoswich detector, (c) room background and (d) ^{41}Ar decays. (e) The growth curve from integrating the number of events found within the green box of (d) over time.

VI. Ride Along Experiment at OMEGA

One critical assumption has been a low background rate milliseconds after the shot. An OMEGA ride-along experiment to test this is planned for December 2019. Estimates for OMEGA give approximately 10^5-10^6 nuclei produced, of which perhaps 1% might be trapped, yielding 500-5000 decays in the first second. Background rates need to be significantly lower than this. For the ride-along experiment the phoswich detector will be placed near the OMEGA-60 target chamber to measure the post-shot background rate.

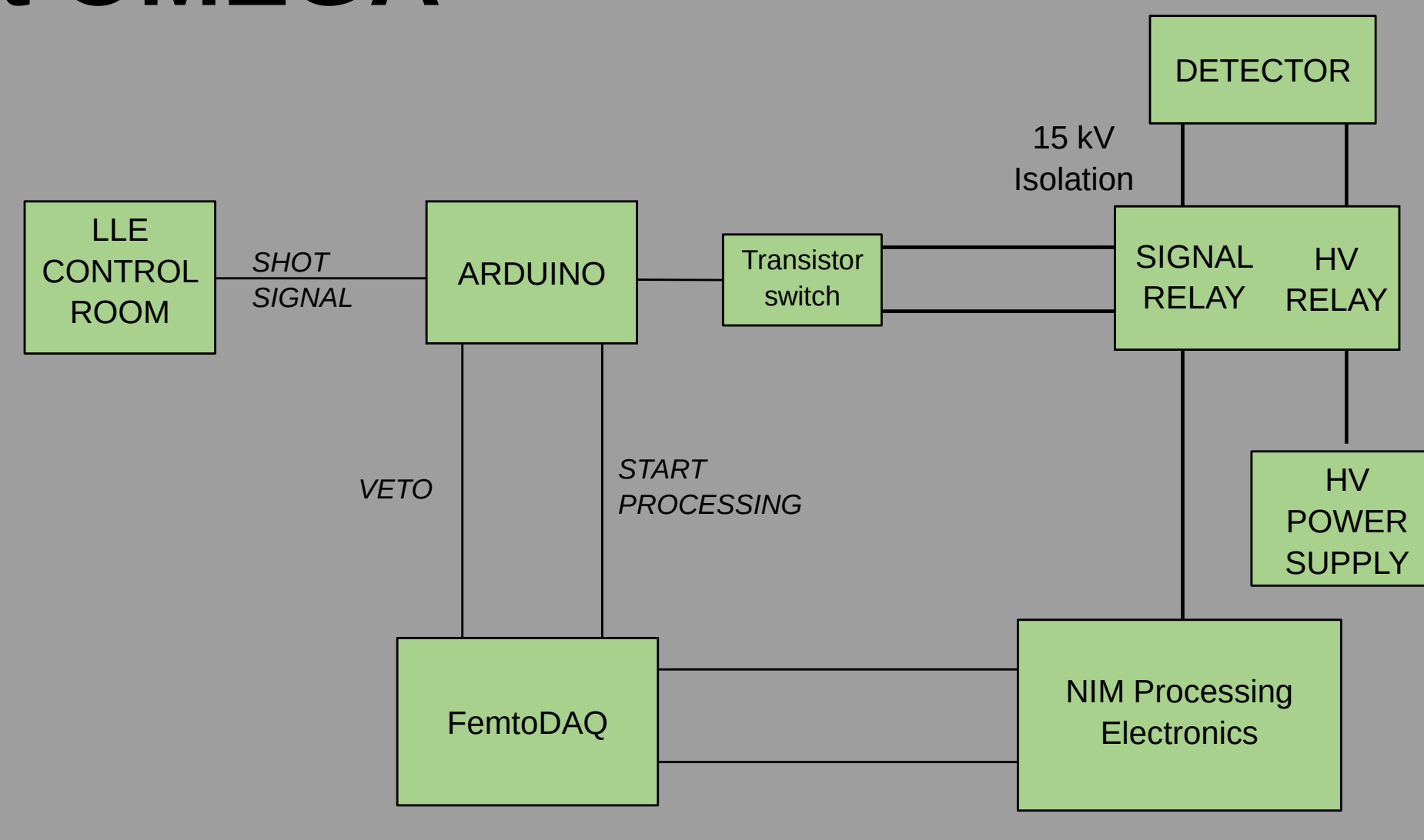


Figure 6. Block diagram of the control and isolation circuit. About 1 ms after the shot the Arduino closes the isolation relays connecting the detector power and signal. About 1 ms later the FemtoDAQ begins digitizing and recording pulses.