An Experiment Simulating the Production, Capture, and Detection of ^{8}Li from an ICF Implosion

Adam E. Brown, Andrew L. Martin, Mark E. Yuly. Department of Physics, Houghton University, One Willard Ave, Houghton, NY 14744

James G. McLean, Stephen J. Padalino. Department of Physics, SUNY Geneseo, One College Circle, Geneseo, NY 14454

Chad J. Forrest, Thomas C. Sangster, Sean P. Regan. Laboratory for Laser Energetics, 250 E. River Rd, Rochester, NY 14612

I. Abstract

Inertial confinement fusion (ICF) is a possible tool for measuring light-ion nuclear cross sections. One way to do this might be to trap and detect the radioactive decays of the product nuclei produced using a doped target capsule. Some of the highest yield light-ion reactions that could be studied using this technique are ^{6}Li(t,p)^{8}Li and ^{9}Be(t,α)^{8}Li, both of which produce ^{8}Li . In order to simulate this method, a natural lithium film was deposited onto a tungsten substrate, which was then activated via the ^{7}Li(d,p)^{8}Li reaction using the SUNY Geneseo Pelletron accelerator. A current pulse of up to 1000 A was discharged through the tungsten raising its temperature to as high as about 1500 °C in less than a few milliseconds, causing the lithium to rapidly evaporate and produce a gas of neutral lithium atoms which then travelled outward and stuck to the aluminum getter detector foil of the Short-Lived Isotope Counting System (SLICS). This phoswich detector was used to identify beta particles and count in situ the 840 ms beta decay curve for ^{8}Li as a function of time in order to estimate the efficiency of SLICS for trapping and detecting ICF reaction products. Funded in part by a grant from the DOE through the Laboratory for Laser Energetics, and by SUNY Geneseo and Houghton University.

II. Introduction and Motivation

Many light ion nuclear cross sections have never been measured at low energies, even though they are the foundation of big bang and stellar nucleosynthesis models, because of the difficulty in measuring such small cross sections using traditional accelerator experiments. One possible solution is ICF, which uses powerful lasers to isotropically heat a target capsule containing a macroscopic amount of nuclear fuel to create thermonuclear reactions, resulting, because of the tremendous number of interacting nuclei in the target, in a sizable yield in the timespan of a few ns. For example, a traditional accelerator experiment using a 1 μA, 25 keV beam striking a 1.2 μm thick lithium target would take about 100 years to produce one million ^{7}Li(t,α)^{6}He reactions. This number could be reached in less than 1 ns in an ICF experiment on OMEGA.

Reaction	Product Half-life	Predicted Yield
^{3}H(t,γ)^{6}He	807 ms	8×10^4
^{6}Li(t,p)^{8}Li	840 ms	0.2-1×10^7
^{7}Li(t,α)^{6}He	807 ms	0.7-2×10^6
^{9}Be(t,α)^{8}Li	840 ms	5×10^5

Table 1. Estimated yields for some prolific light ion reactions that may be studied using ICF. The target capsule was assumed to be doped with 1% of the appropriate reactant isotope. Shot parameters for OMEGA shot 77951 were used, a tritium-filled SiO$_2$ capsule "exploding pusher" that reached T_i = 18.3 keV. The ^{3}H(t,γ)^{6}He predicted yield assumes a branching ratio of 10^{-7}, which is simply an estimated "best case". For other reactions, reactivities were calculated using S-factor extrapolations and TALYS-1.9.

After the ICF implosion, the reaction products expand outward in a neutral gas. Two systems designed to collect the gas and detect the beta decays of the radioactive products.
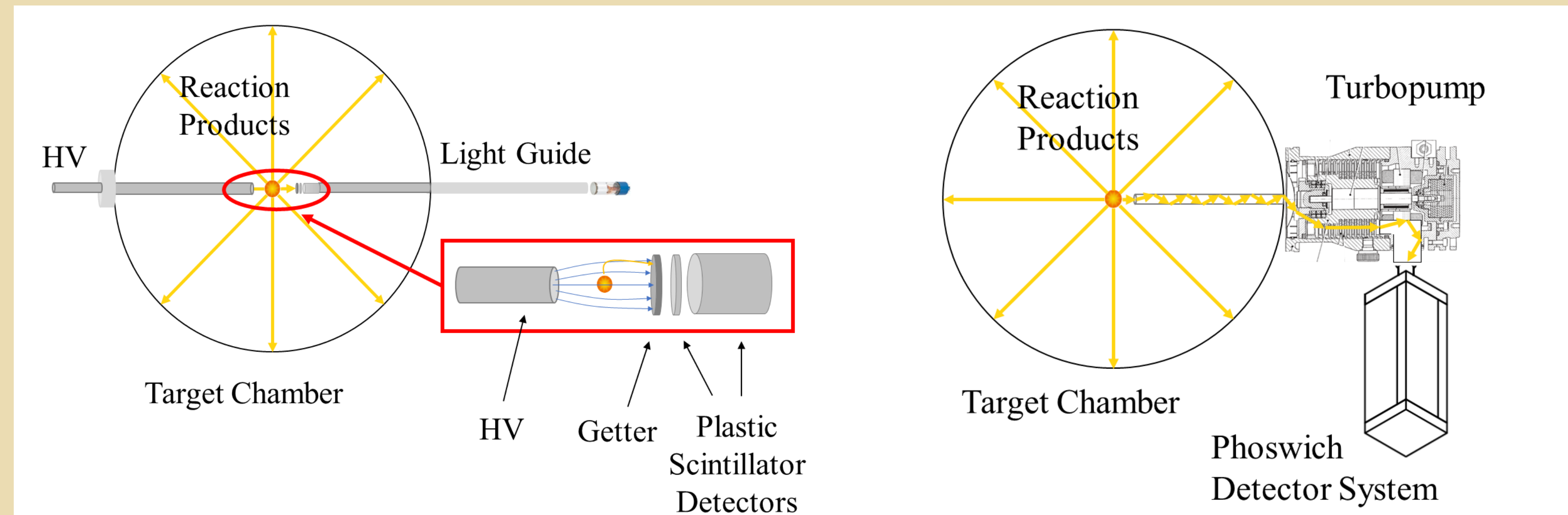

Figure 1. (Above Left) Getter trap. Chemically reactive products stick to a getter foil in front of a phoswich scintillator. Light travels down the glass lightguide to the photomultiplier tube outside the target chamber. A high voltage may also be applied to accelerate ions towards the getter foil. **(Above Right) Turbopump Trap**. Reaction products travel down a collection tube to a turbopump that traps it inside a hollow rectangular prism phoswich detector.

III. Block Diagram and Setup

This poster describes an experiment to simulate an ICF implosion in order to measure the efficiency of the getter detector for capturing and detecting ^{8}Li (one of the products in Table 1) and the turbopump detector for relatively inert compounds containing ^{20}F.

Figure 2. A 20-30 nA beam of 1.5 MeV deuterons from the SUNY Geneseo Pelletron struck the thin natural lithium or Teflon film on the tungsten target, producing ^{8}Li via ^{7}Li(d,p)^{8}Li or ^{20}F via ^{19}F(d,p)^{20}F. When the deuteron beam was cut off, the count rate in a nearby NaI detector droppped, which signaled a Raspberry Pi SBC to discharge a large capacitor through the tungsten foil, evaporating the film. Phoswich detector pulses from the beta decay of reaction products that were trapped by the getter or turbopump were digitized and read out by the Atomic Pi SBC.
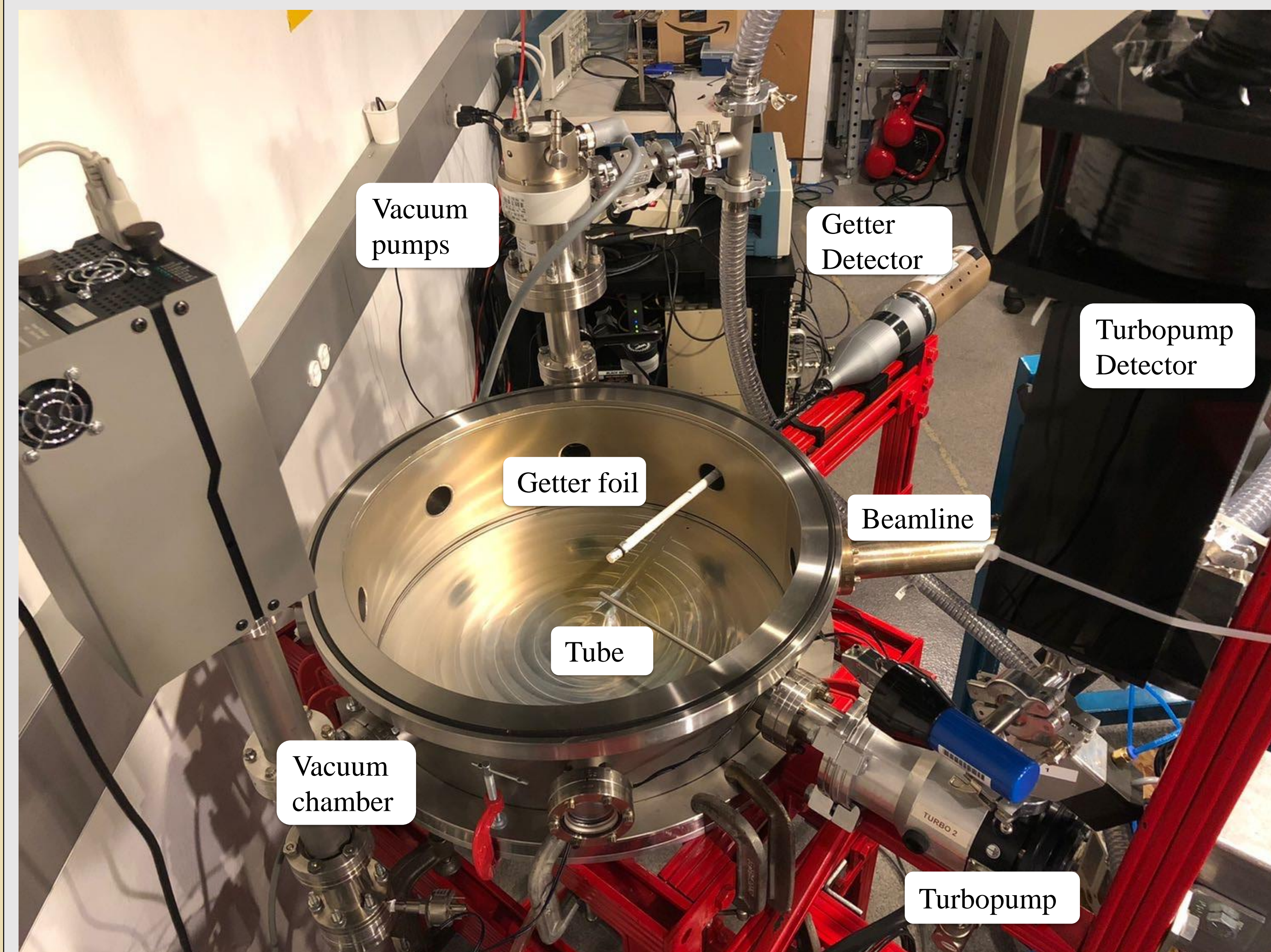
Figure 3. Photograph of the vacuum chamber with the getter and turbopump trap detectors. The tungsten foil is attached to a feedthrough that comes down from the lid (not shown).

IV. Results

A preliminary estimate of the efficiency can be made by using approximate solid angles and ignoring the intrinsic detector efficiency.

N_1, N_2, N_3 are the number detected on the foil before and after the discharge, and on the getter, respectively.

$$f_1 = \frac{\pi r^2}{4\pi d^2}$$
Detected fraction of beta particles from the target.

$$f_2 = \frac{1}{2}$$
Detected fraction of beta particle from getter foil.

$$N_S = \frac{N_1}{f_1}$$
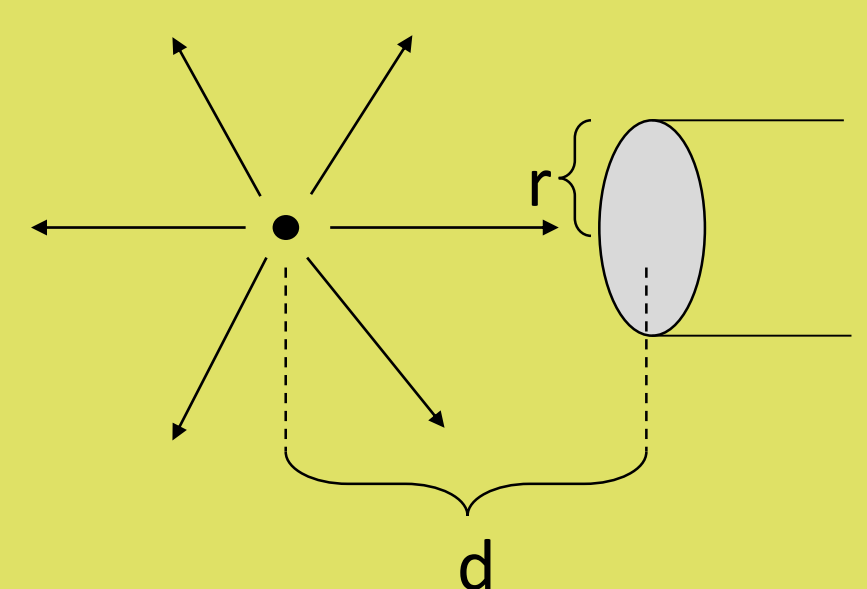Number of ^{8}Li on target foil before discharge.

$$N_R = \frac{N_2}{f_1}$$
Number of ^{8}Li on target foil after discharge.

$$N_C = \frac{N_3}{f_2}$$
Number of ^{8}Li on getter after discharge.

$$e = \frac{N_C}{N_S - N_R}$$
Efficiency

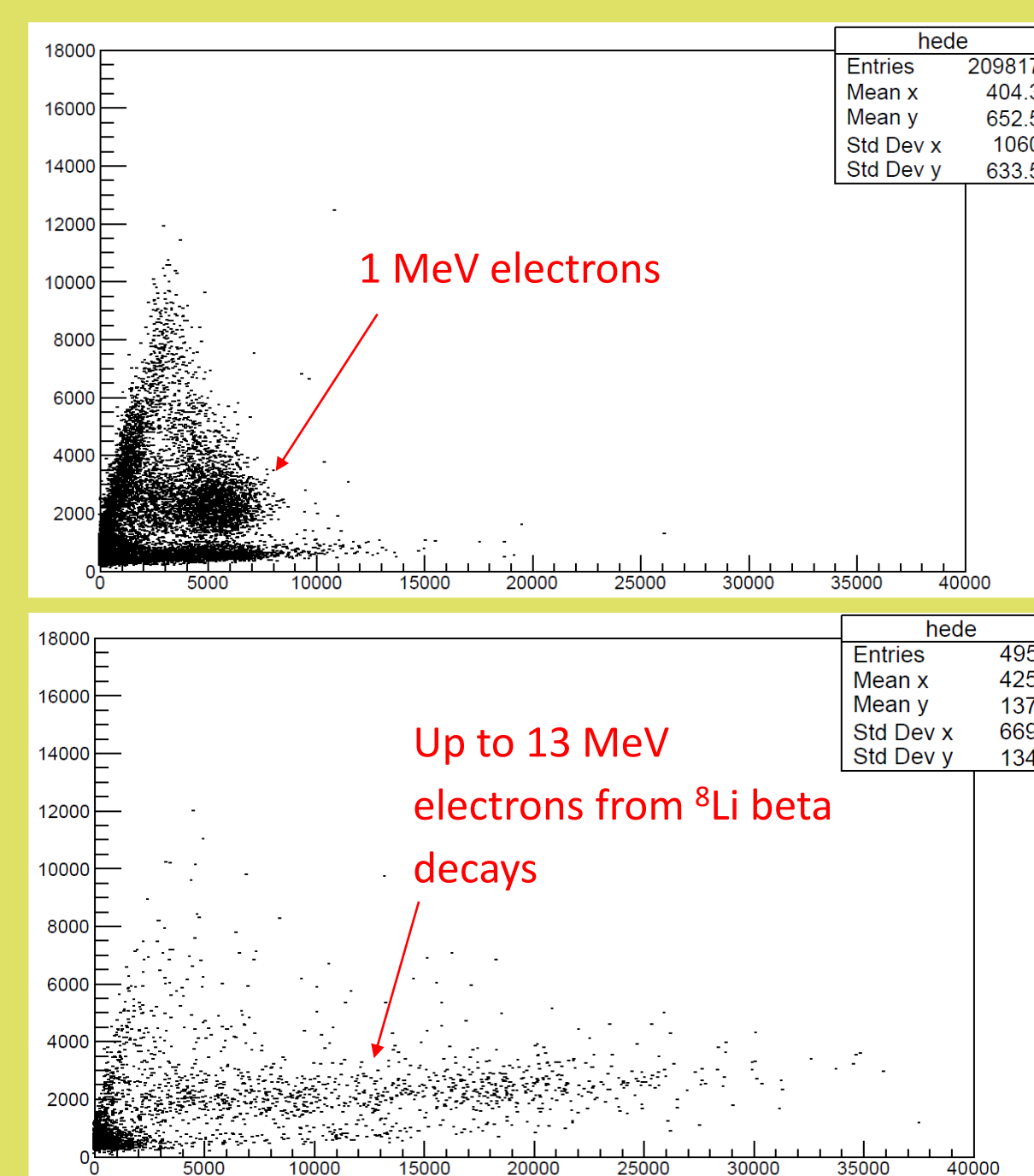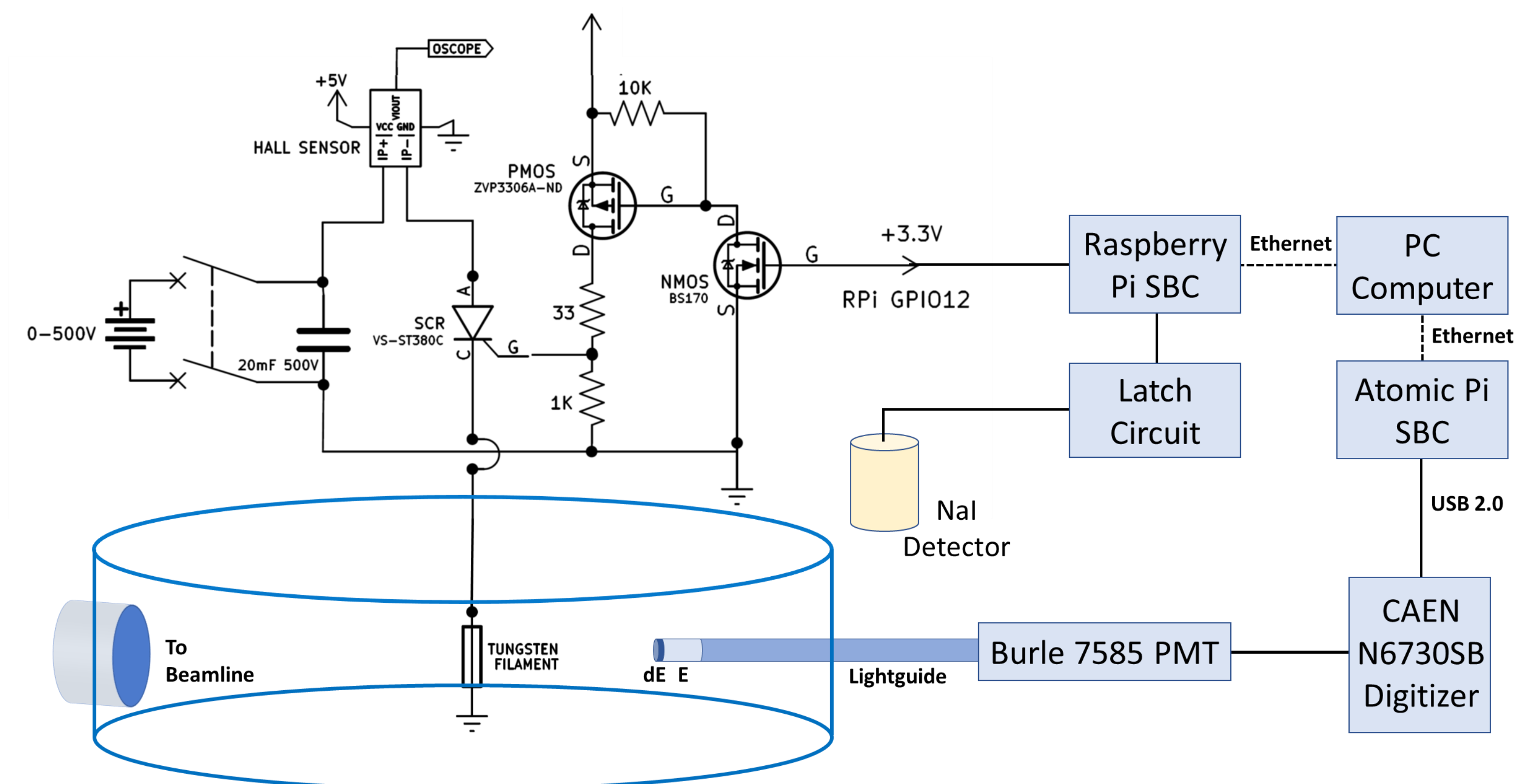| Run Numbers	Efficiency
10-12	2.17%
33-35	15.79%
40-42	3.43%
Average Efficiency:	7.13%

Figure 4. Getter detector histograms with the thin dE detector on the vertical axis and the thick E detector on the horizontal, in arbitrary units, for the ^{207}Bi calibration source **(top)** and lithium on the getter detector after discharging the capacitor **(bottom)**. Beta events were selected (blue quadrangle) to create time spectra.

1 MeV electrons

Up to 13 MeV electrons from ^{8}Li beta decays

Figure 5. Fits to typical growth curves created by integrating the beta decays counted using the getter detector. **(Top)** Fit to activated natural Lithium on tungsten foil prior to capacitor discharge gave $N_1 = 2384 \pm 4$ with half-life 835 ± 3.5 ms. **(Bottom)** Fit to decays from material collected on the getter after discharging the capacitor gave $N_3 = 1962 \pm 4$ with half-life 835 ± 4 ms. The half-life of ^{8}Li is 840 ms. The value of N_2 was similarly obtained by activating the residual Lithium on the tungsten foil after the capacitor was discharged.

V. Future Plans

Geant4 simulation and validation. The Geant4 simulation of our detectors created in 2020 will be used to calculate the efficiency, then the simulation predictions will be validated using radioactive sources, and finally used to calculate the efficiency for ^{8}Li. This plus the data we collect this summer will allow the fraction trapped and detected to be accurately determined.

New OMEGA ride-along experiment. Test the effect of shielding to reduce the background count rate in the turbopump detector, the effect of including the lightguide on the getter detector, and the ability of the CAE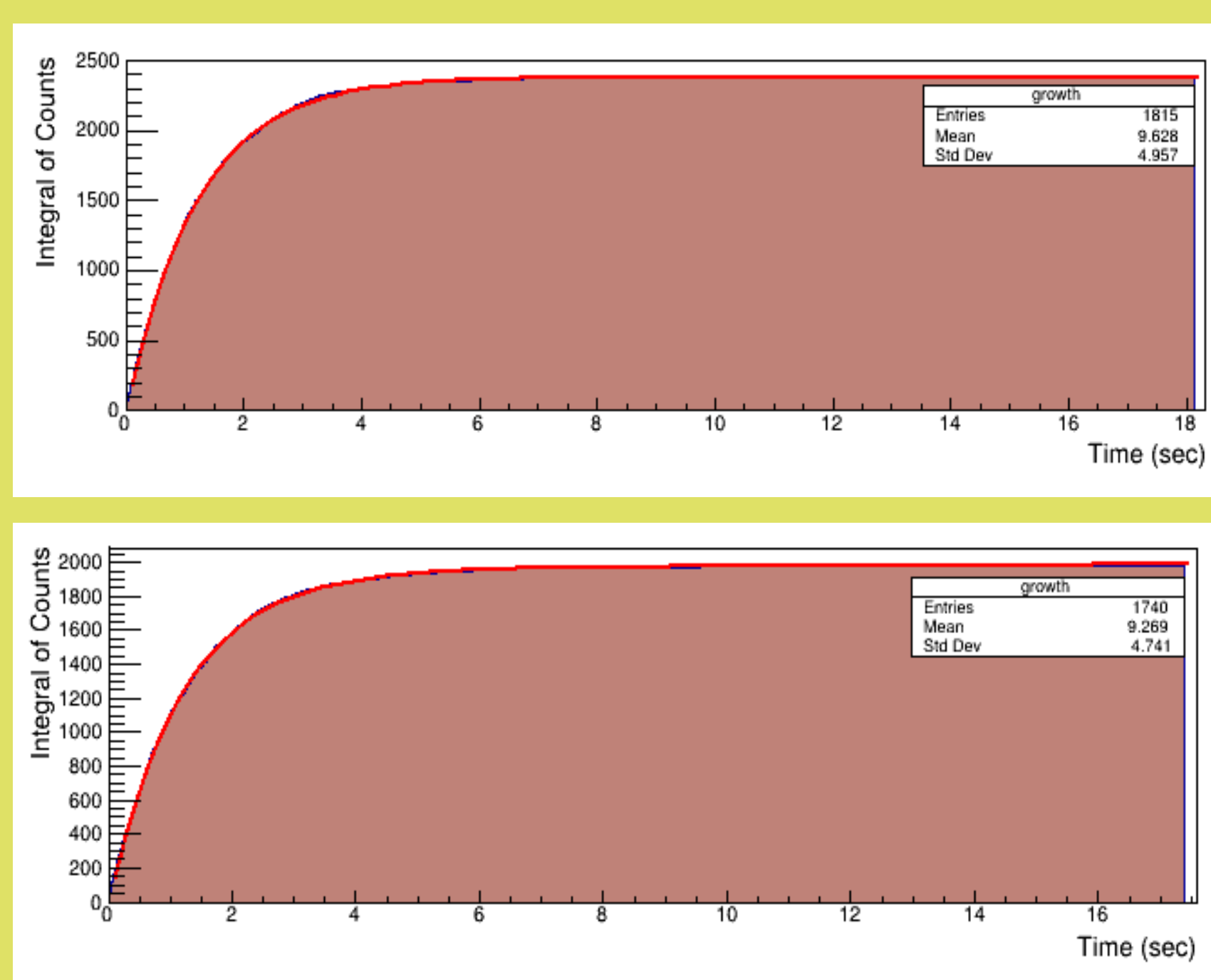N digitizer to keep up at high rates.