Design and construction of a Modular NaI(Tl) Detector Array for NOPTREX

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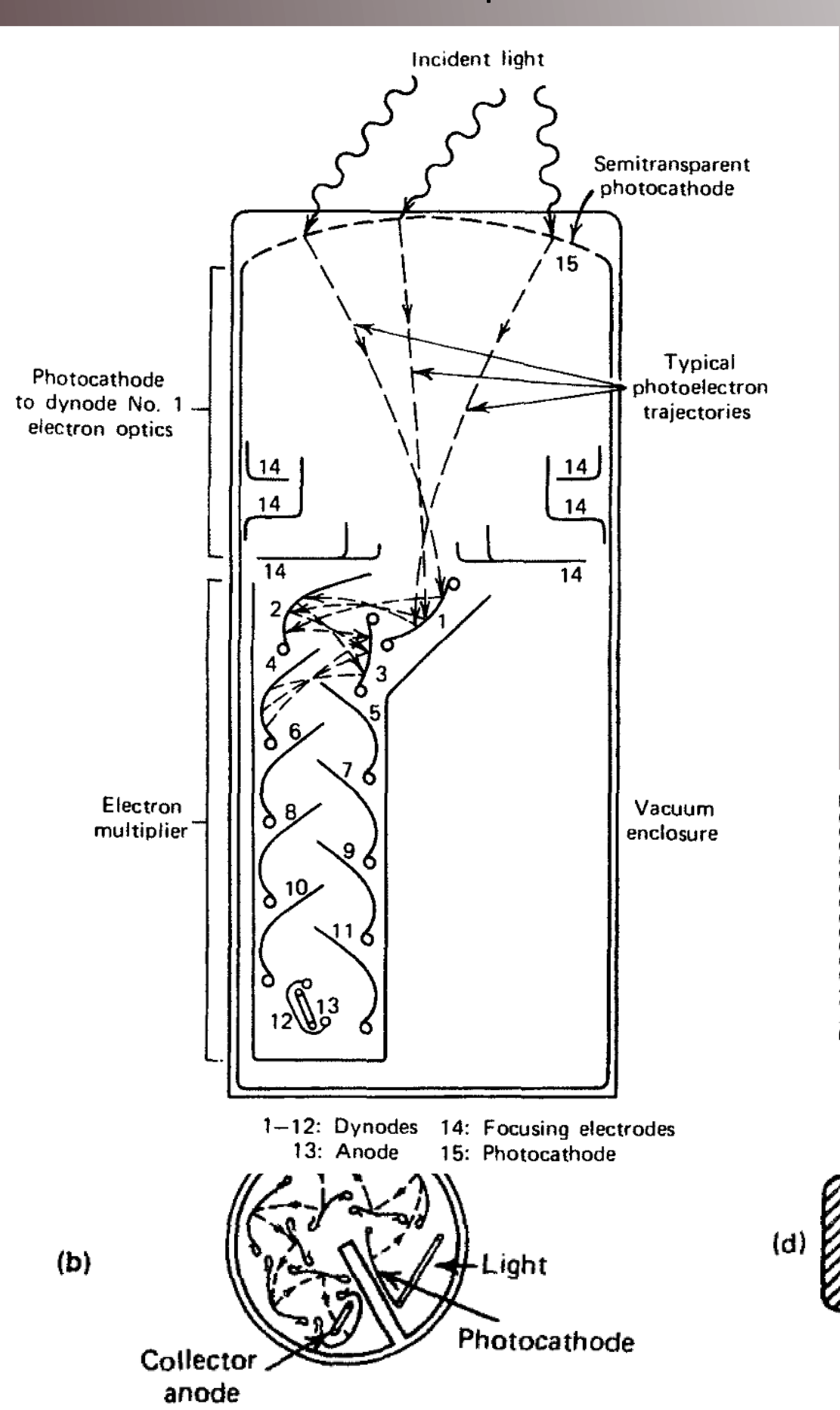
Background

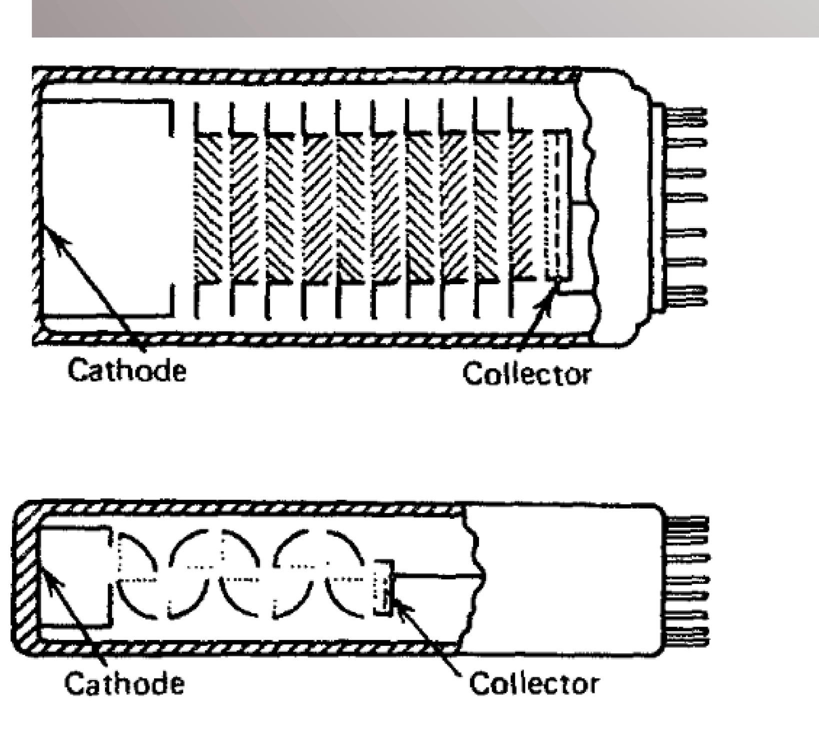
The Neutron Optics Parity and Time Reversal Experiment (NOPTREX) collaboration seeks to answer one of the most fundamental and pressing questions of nuclear, particle, and astrophysics today: the search for new time-reversal symmetry violation candidates. The discovery of CP-symmetry (charge/parity) violation implied the existence of T-symmetry (time-reversal) violation as well. However, in order to account for the matter-antimatter asymmetry in the Big Bang, it is required that T-symmetry violation must be much greater than that which has been previously observed. Thus, the search has been ongoing for new candidates which may exhibit time-reversal violation effects great enough to explain the origin of our matter-filled universe.

Detector Physics

The detectors operate through the process known as scintillation, in which radiation is absorbed by a material, causing the excitation of electrons within the material and thus the emission of a spectrum of light. The scintillators used in our detectors consist of a sodium iodide (NaI) crystal activated with a small amount of thallium (Tl). The photomultiplier tube (PMT) uses the pulse to free an electron from a thin layer of photoemissive material, known as the photocathode.

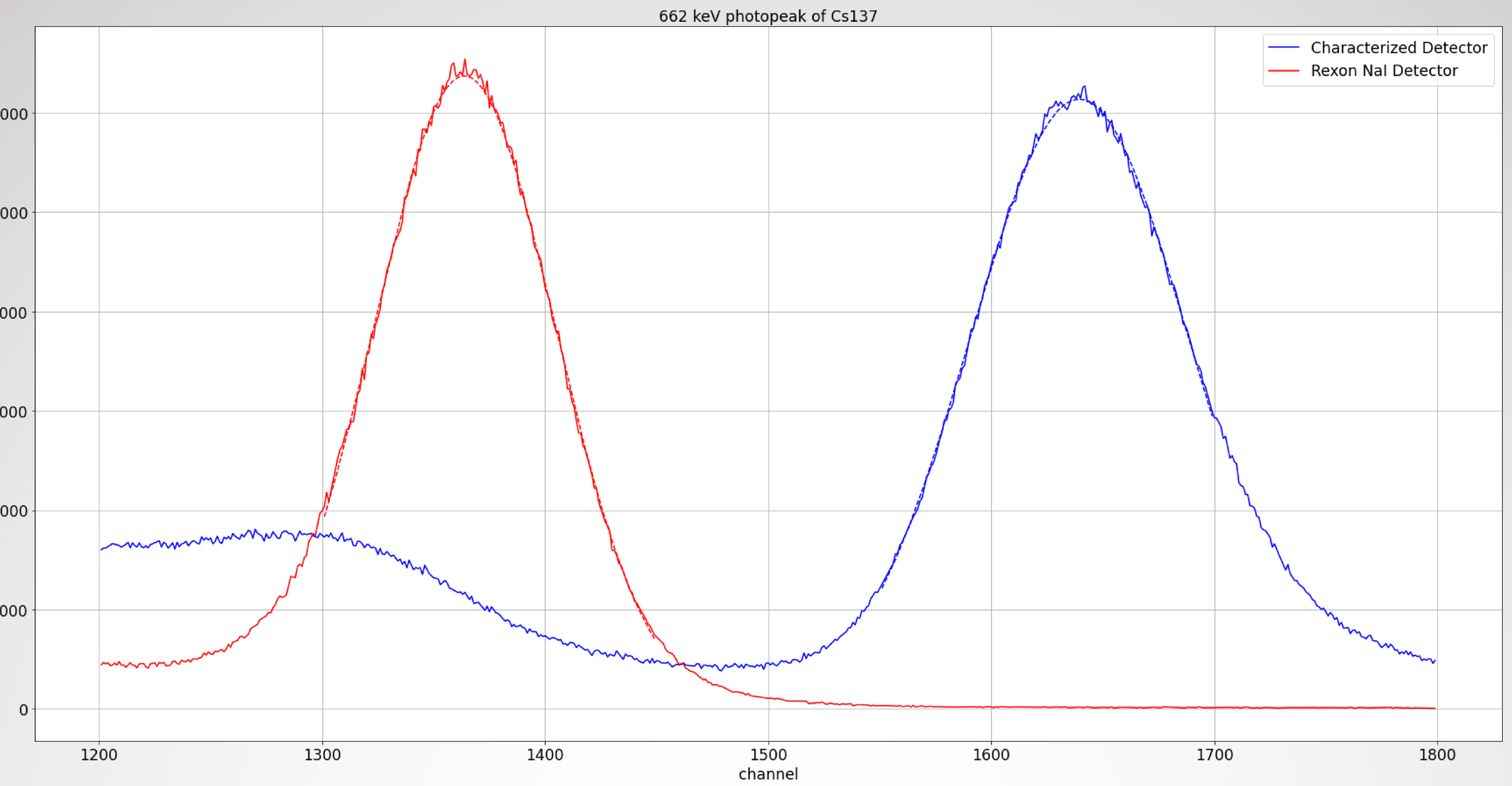
The high voltage applied to the PMT then motivates this electron forward into the multiplier stage. This portion of the apparatus consists of multiple plates, also known as dynodes, each with their own potential difference. As the electrons collide into these plates, they cause the emission of more electrons which continue down the stream. Ultimately, the resultant electron stream is significant enough to be measured as a current, which is directly related to the energy and timing of the incident light pulse from the scintillator.





Detector Characterization

In order to ensure optimal energy resolution for each of the detectors we build for the array, we compared our results for a Cs137 spectrum to that of a characterized detector using the full width at half maximum (FWHM). Our results showed the same FWHM of 7.6% as the datasheet. Overall, we concluded that our detector characterization is adequate compared to that of the known detector. In order to improve on our experimental setup and detector characterization, we plan to conduct simulations of the array using the Geant 4 and MCNP programs.

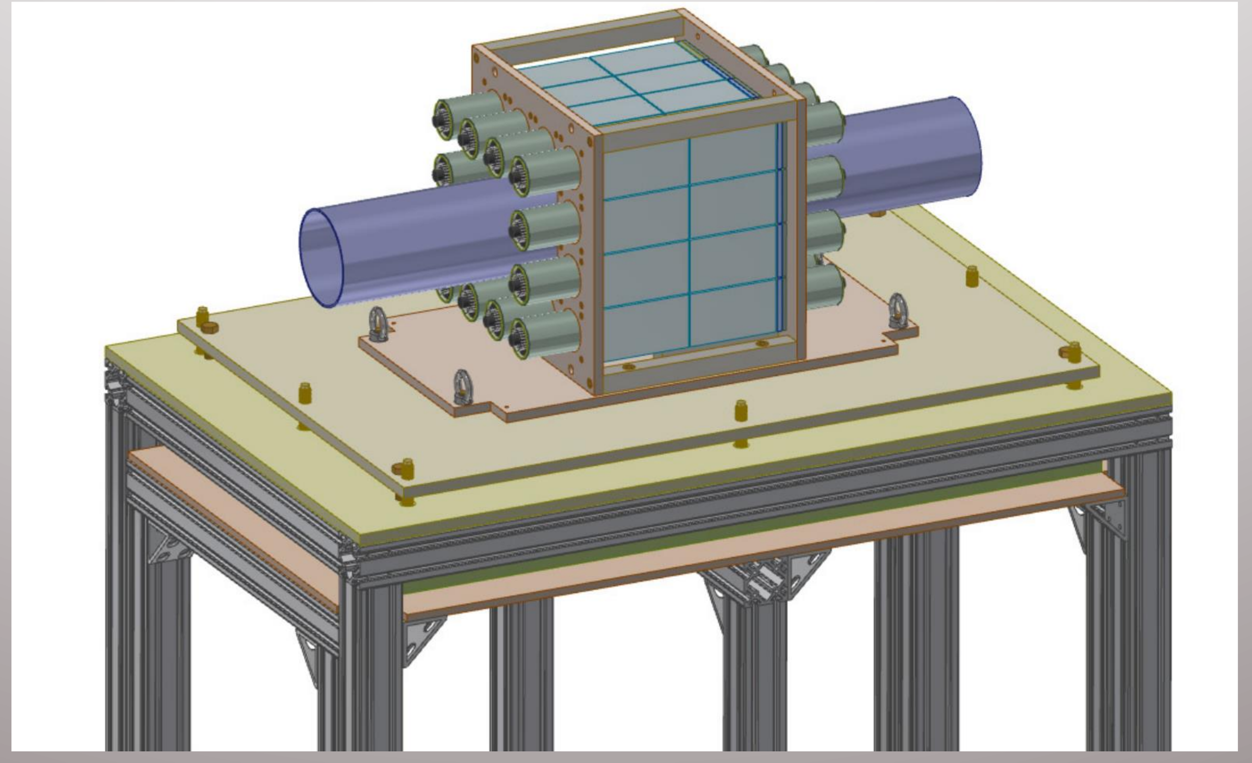


The goal of the NOPTREX collaboration is to probe the Standard Model by utilizing the properties of low energy neutron-nucleus resonances to find evidence of parity- and time-reversal-odd violations. In order to conduct these sensitive experiments, it is needed to design and simulate an array of modular, high precision NaI(Tl) detectors. These detectors will be be designed to be operated in both pulse and current modes. We will discuss the results of our experiments to determine the most efficient design of the detectors, electronics, and magnetic shielding, as well as our progress on the construction and characterization of the array. We have tentative beam time at LANSCE to perform a search for new parity violation in heavy nuclei as candidates for time reversal and to perform a research and development effort on the n+d=t+gamma experiment.

Array Design

The NaI detector array to be used in the NOPTREX experiment will consist of 24 detectors arranged in two squares of 12. These two blocks will be set up back-to-back on a shielded 80/20 aluminum table. The detectors will also be surrounded with a significant amount of shielding, and the target of the polarized neutron beam will be located within the block of detectors.

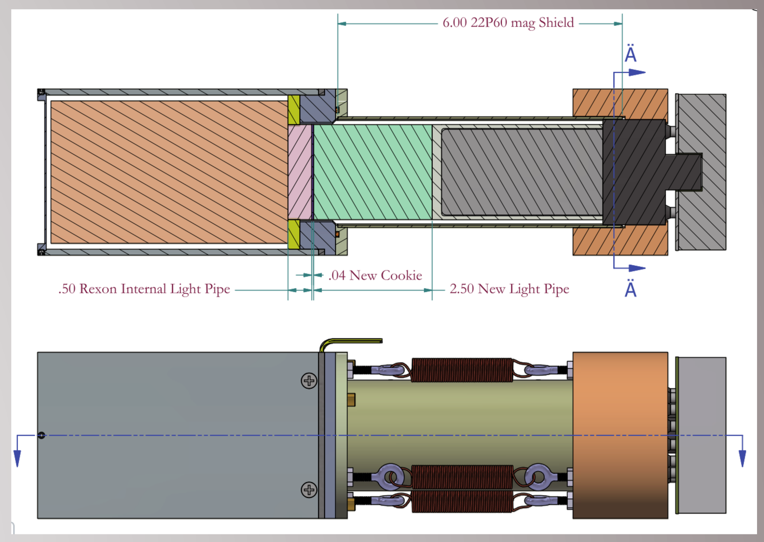
Each detector will be enclosed in a light-tight mu metal shield, which will be held using a spring-loaded set of phalanges. The design of these components has been undertaken by our collaborators at IU, the machining will be done at IU and UK, and the ultimate construction of each detector and the array will take place at EKU. Our experiments mentioned here have been conducted in order to assist with the design process, and the final design decisions are currently underway.

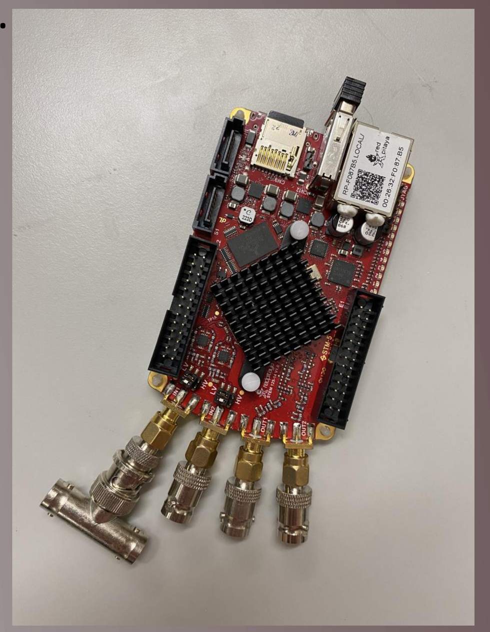


Experimental Setup and Data Collection

For each detector test, the NaI(Tl) scintillator is coupled to a Hamamatsu R550 photomultiplier tube with a transparent plastic light guide to separate the two. This is coupled to an Ortec 276L PMT base; for the final array, however, we will use electronics custom built by IU. The assembly is placed inside a dark box. In order to supply high voltage to the PMT base, we use a CAEN N1470 remotely controlled HV supply. This supply can be controlled using the CAEN GECO software on a Linux machine

To collect the data for these experiments, I used a multichannel pulse-height analyzer program on a Red Pitaya. This program assigns ADC channels to the different energy levels of the events and keeps track of the number of counts received per ADC channel. This data is then exported as a single column array and moved to a Python notebook to fit the curves of the spectra.

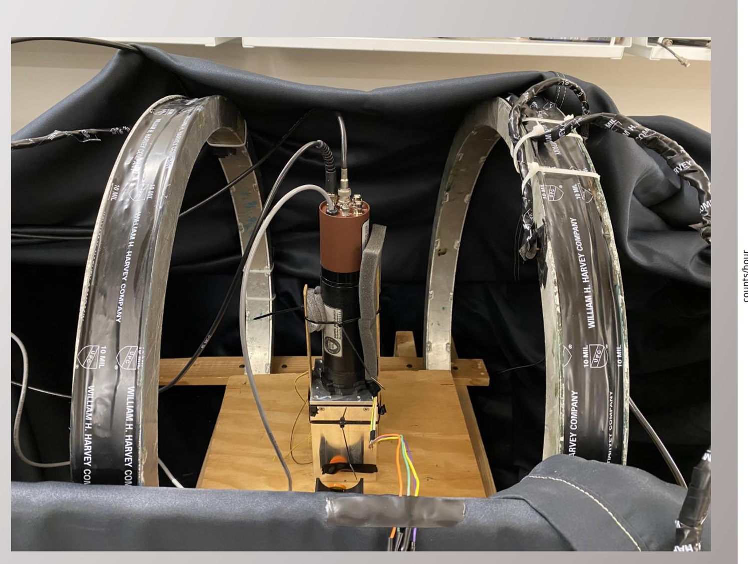


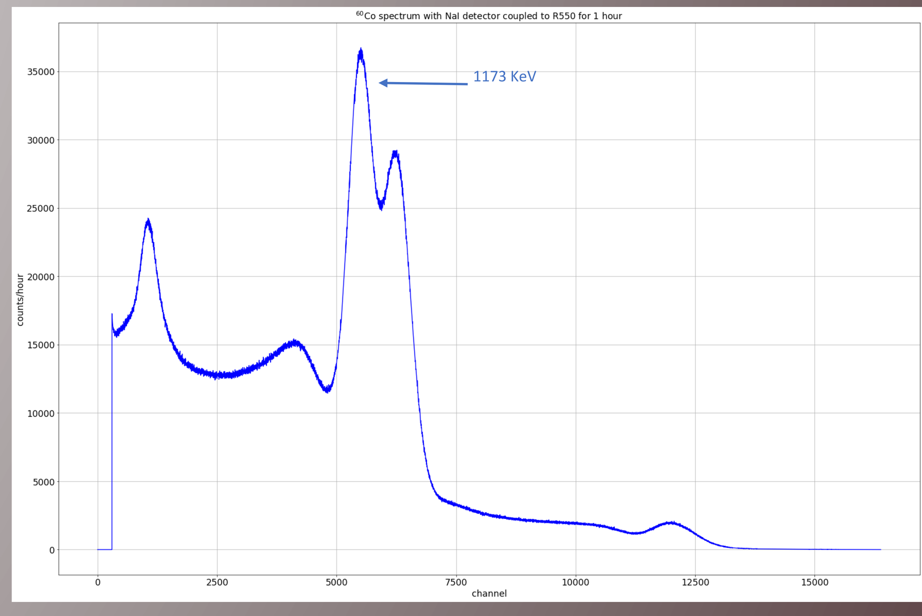


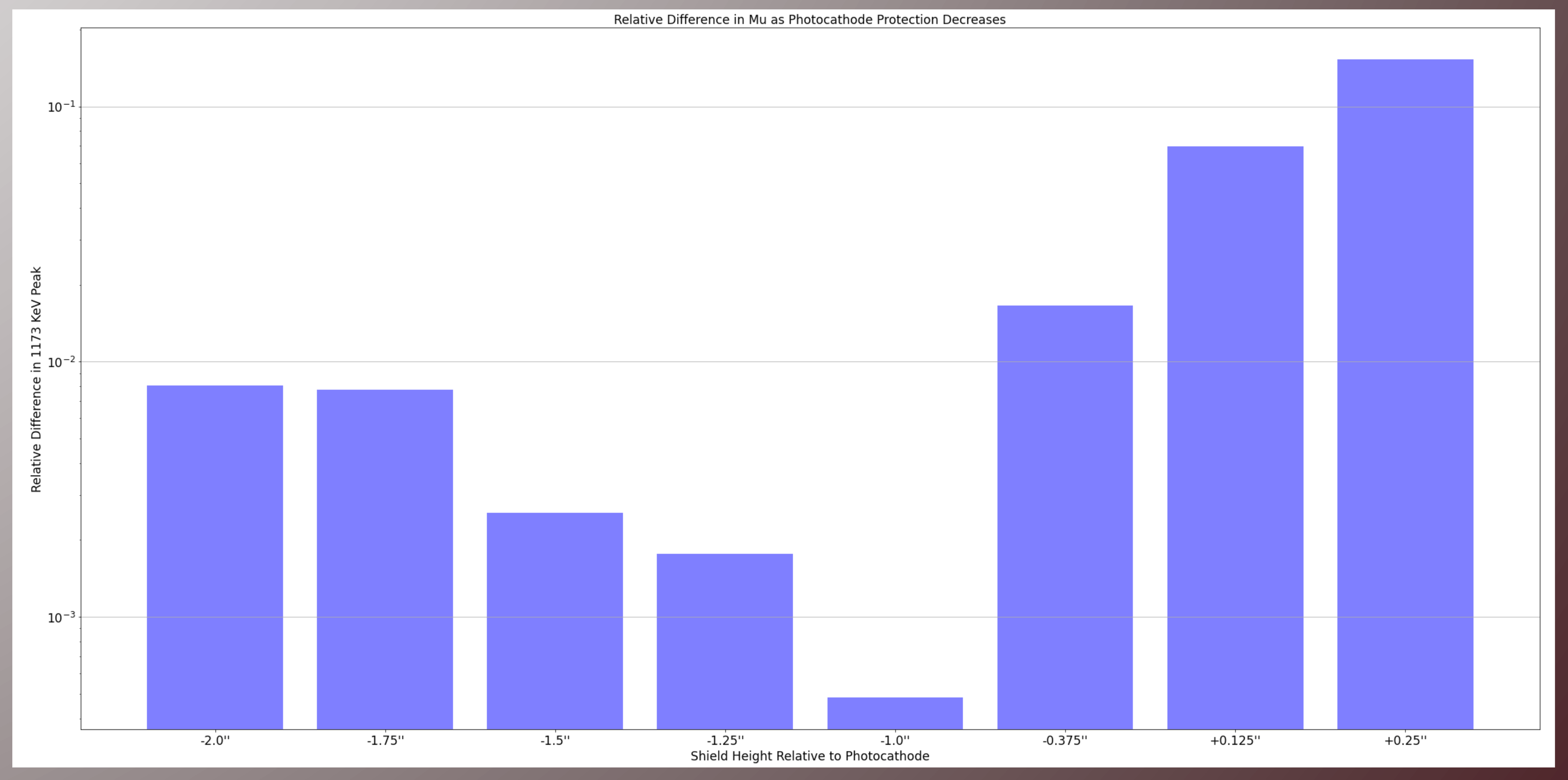
Magnetic Shield Tests

In order to determine the length of the light guide, we used 3D printed spacers to elevate the magnetic shield, with a Helmholtz coil producing a field in either the longitudinal or transverse direction.

We analyzed the difference in the 1173 KeV photopeak for each spectrum. According to the height of the bottom of the shield relative to the photocathode, we saw relatively little difference below a height of -1.5’’. Therefore, a 1-1.5’’ length of lightguide should be sufficient.







[1]: Snow, W. M. (2020). NOPTREX: A Neutron OPtics Time Reversal EXperiment to search for Time Reversal Violation in Neutron-Nucleus Resonance Interactions.

[2]: Knoll, G. F. (2020). Scintillation Detector Principles. In *Radiation detection and measurement* (pp. 231–247). essay, John Wiley.

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