# Building a Moving LED Device for Calibrating the NuLat Detector

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## Introduction

The Neutrino Lattice Experiment (NuLat), pictured in figure 1, is a neutrino detector consisting of 125 plastic scintillating cubes arranged in a 5 x 5 x 5 geometry based on the concept of a Raghavan Optical Lattice (ROL), which utilizes total internal reflection to direct light along a certain path, allowing for geometric reconstructions of reactions within the detector. The main purposes for the NuLat detector include detecting electron antineutrinos from nuclear reactors and searching for possible "sterile" neutrinos, which are called so because they do not participate in the weak force like the neutrinos currently allowed by the Standard Model. NuLat uses photomultiplier tubes (PMTs), currently on three sides of the detector, to amplify signals from positron annihilation and neutron capture resulting from inverse beta decay. [1] Before data can be taken, the PMTs must be calibrated. This summer, I assisted in the design, assembly, operation, and testing of an x-y stage for calibrating the PMTs on the NuLat detector.

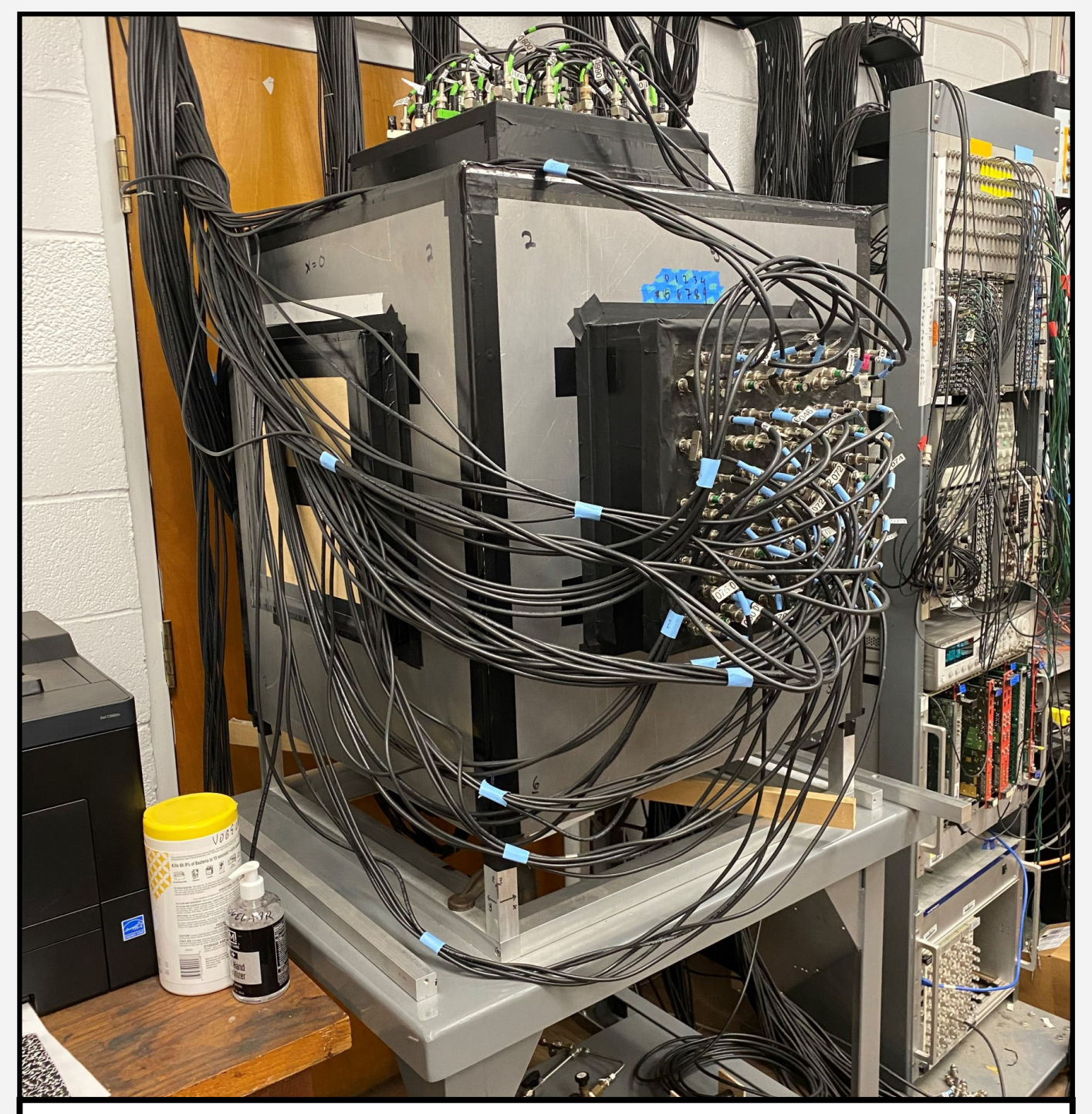

**Figure 1:** Exterior of the NuLat detector.

## Background

In **inverse beta decay**, an antineutrino is captured by a proton, resulting in a neutron and a positron[3] (figure 2). This leads to the time coincident events of positron energy deposition and annihilation and neutron capture, which make up the "signature" of an antineutrino detection. NuLat uses $^6$Li for neutron capture due to its large neutron cross-section and clear signature of decay products (i.e. beta/gamma-like events are separable by pulse shape discrimination).[1]

$$\overline{\nu} + p^+ \rightarrow n + e^+$$

**Figure 2:** Inverse beta decay.

Because of the detector's ROL design, light is directed through the detector by a **total internal reflection** process. Total internal reflection occurs when light is completely reflected at the boundary between materials with different indices of refraction when the light hits the boundary at an angle greater than a certain angle, known as the "critical angle."[2] This forces light to only have the ability to travel in certain directions through the detector, as NuLat is made of 125 plastic scintillating cubes ($n = 1.52$) separated by air ($n = 1.00$).[1]

After NuLat receives a signal which then travels through the detector, the signal is caught and amplified by **photomultiplier tubes (PMTs)**, of which there are currently 75, one for each outward-facing surface on each cube on three faces of the detector. In a PMT, photons hit a photocathode, which releases electrons that are multiplied in a series of dynodes.[4] Before taking data with NuLat, the voltages which control the gains of the PMTs must be calibrated by sending an identical signal into each cube on the faces of the detector without PMTs.

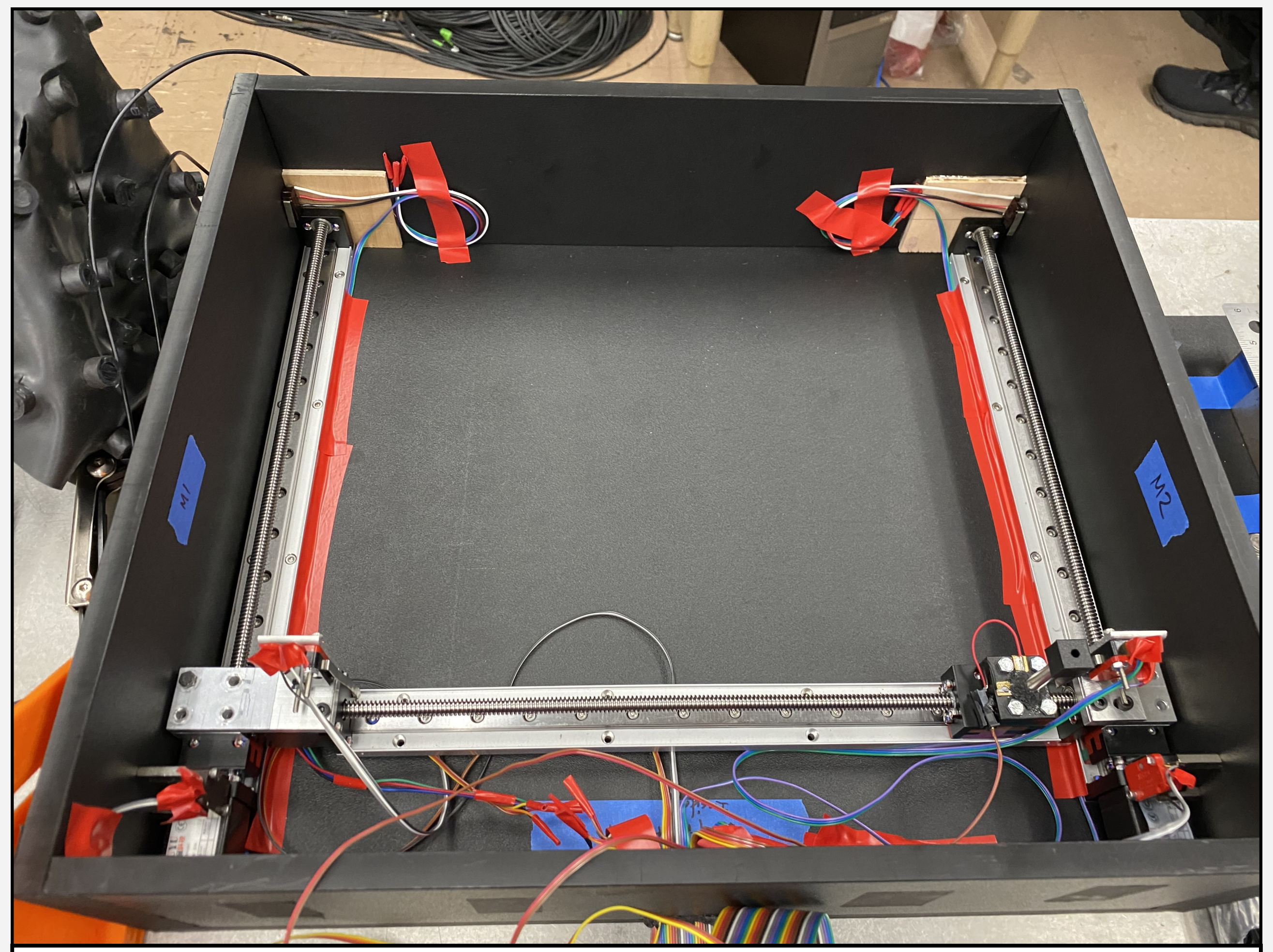

**Figure 3:** Top view of the moving LED calibration apparatus.

## The Moving LED Device

The basic design of the device that will be used to calibrate the NuLat detector consists of an fast LED which can mimic a scintillation event mounted on three linear actuators run by stepper motors to allow for travel in two dimensions (figure 3). A 300 mm length was chosen to ensure that the LED would be able to reach the center of each 2.5 inch (63.5 mm) cube[1] on one face of the detector without needing to move the entire apparatus.

The stepper motors are controlled by two Adafruit DC and Stepper Motor HAT drivers[5] stacked on a 3B+ Raspberry Pi computer[6] (figure 4). The code for operating the motors and switches is written in the CircuitPython programming language.[7] Using the Adafruit CircuitPython MotorKit library,[8] we can easily control the direction and stepping style of the stepper motors.

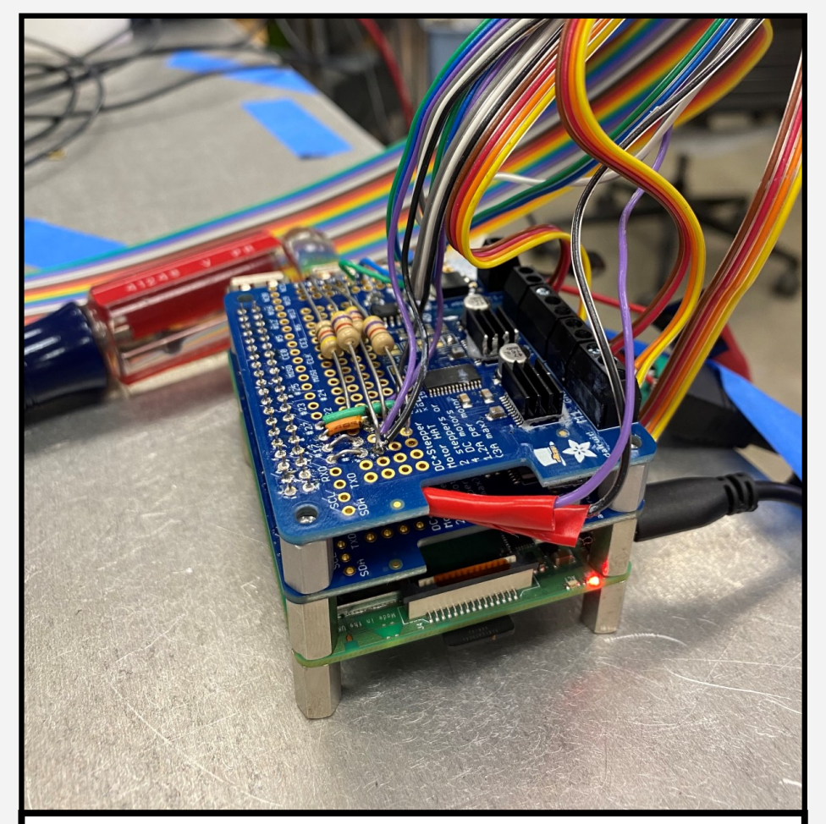

**Figure 4:** The Raspberry Pi with Adafruit Stepper Motor HATs.

Limit switches are installed on both ends of the linear actuators that are programmed to stop the stepper motors if they are activated. The limit switches are controlled from general purpose input-output (GPIO) pins on the Raspberry Pi.

The detector will be calibrated with a LED that will be mounted on the travel car running in the y-direction, which will send a signal using a pulse generator so that the LED can pulse on the order of nanoseconds. The LED will be at the base of a tube with a small aperture to collimate the light so that it is focused when sent into the center of a cube (figure 5).

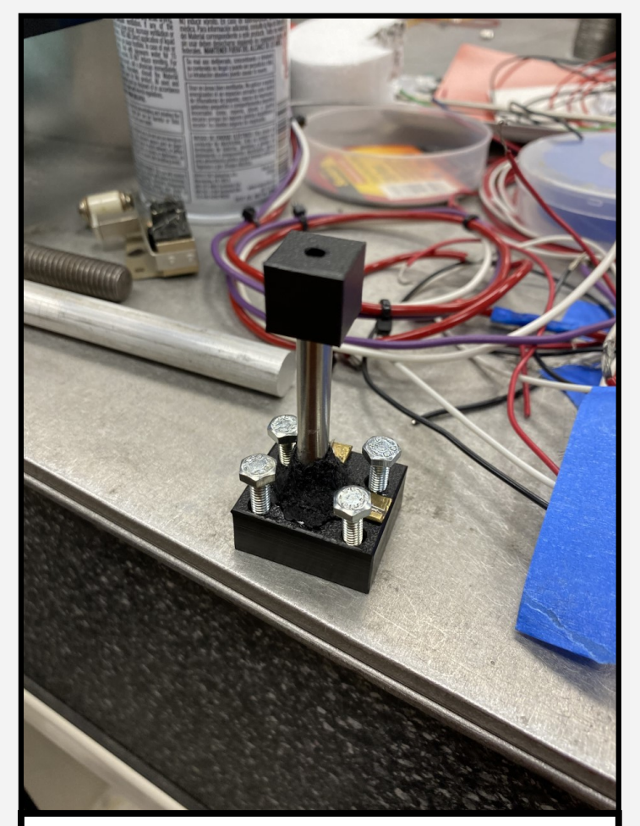

**Figure 5:** The LED light collimator mounted on the apparatus.

The entire apparatus is inside of a light-tight box to prevent light sources other than the LED from reaching the detector.

## Operation

Currently, we have the ability to program the stepper motors to run for a certain amount of steps corresponding to a linear distance travelled by the travel cars; on our linear actuators, 100 steps ≈ 1 mm. We are also able to "zero" the cars to one side of its total available travel length by using the limit switches.

As soon as the device is fully assembled and operational, we can run some preliminary tests before mounting it onto the detector. One of these tests includes situating a PMT in the center of the apparatus and scanning the LED around to multiple x-y positions in order to find the responsiveness of the PMT with respect to its position in relation to the LED. This test can also be run with the PMT stacked on a few cubes like the ones used in the detector to find how much light from the LED is lost after going through the cubes.

After testing, the device will be ready for use in calibrating the PMTs on the detector. The box will be mounted onto each face of the detector without PMTs (figure 6), and the LED will be able to move around to the center of the face of each cube and send a signal which will propagate through the detector to the PMTs directly across from and orthogonal to the cube where the signal was sent. The strengths of the signals from the PMTs will then be read and measured by the detector's data acquisition system so that the gains of the PMTs can be calibrated.

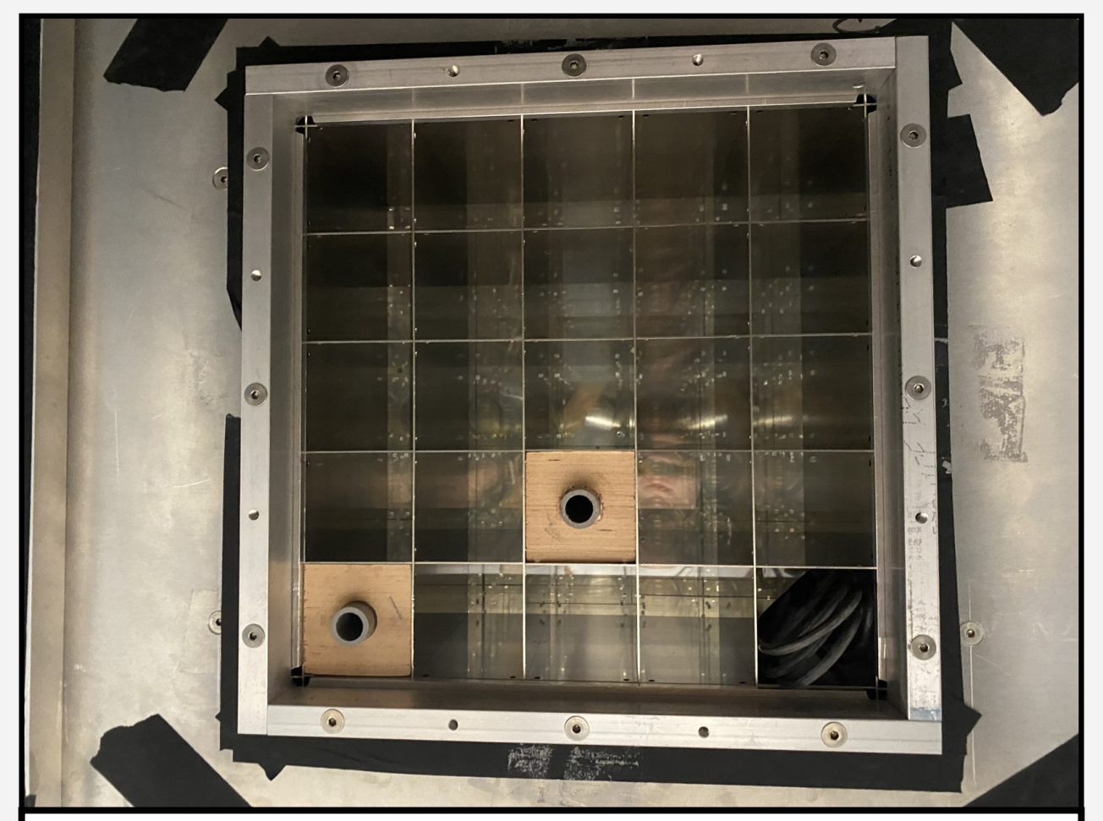

**Figure 6:** Interior of the NuLat detector, viewed from the bottom face.

## Conclusions

Once the device is fully operational and ready for use with the NuLat detector, it will be useful in calibrating the gains of the PMTs due to its ability to send an identical signal into each cube. At this time, further testing is required before the device can confidently be used as a way to calibrate the detector before taking data.

## Acknowledgments

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