Passive Attenuation to Allow Muon Callibration of NuLat Detector

Andrew Gunsch, Coe College

INTRODUCTION

Neutrinos present numerous paths to discovering physics beyond the Standard Model. In order to make the observations and take the measurements needed to discover such phenomena, innovative neutrino detection methods must be used. The NuLat (Neutrino Lattice experiment) is a neutrino detector with a novel geometry that can be used to identify the particle interactions occurring within it. Before it can be used to observe these events, the detector needs to be calibrated.

BACKGROUND

Neutrinos are tiny particles with neutral charge. They come in three flavors, one for each of the charged leptons.
Through neutrino oscillation, neutrinos can change flavor and mass[1]. However, under the Standard Model, neutrinos should be massless[2]. Studies of neutrino oscillation have founded unexpected changes in flavor that suggest the possibility of a sterile neutrino[1].

The NuLat detector is a 5x5x5 lattice of cubes that emit light when they interact with energetic particles. On three of its faces, there are 25 photomultiplier tubes, which collect light from the cubes and send an electric signal proportional to the number of photons they receive.

NuLat primarily strives to detect antineutrinos through the Inverse Beta Decay (IBD) reaction, in which an electron antineutrino interacts with a proton to produce a neutron and a positron[1]. To detect the neutron capture and positron-annihilation signals that come of this, NuLat is designed to read signals of around 2 MeV[2].

NuLat can be calibrated with muons, for their average energy deposition in a plastic scintillator is 2MeV/cm.
Unfortunately, this results in 12.7MeV per cube, **saturating the system**, leaving no way to measure the signal for calibration.

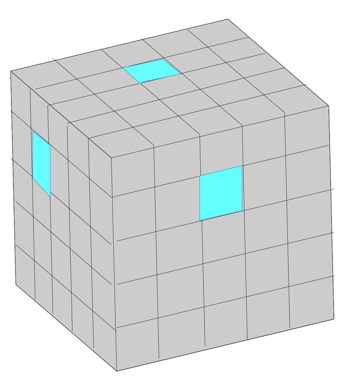


Fig. 1: By detecting the location of the signal on each face of NuLat, the location of the event can be determined.

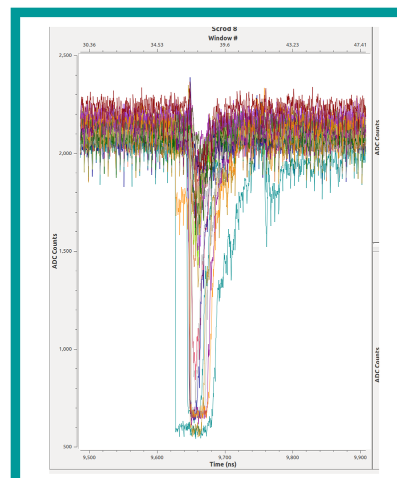


Fig. 2: The signal of a muon is cut off at the limit of the range, leaving no accurate value for its energy.

METHODS

To avoid saturation of the muon signal, resistive pads were constructed. To attenuate the muon signal by a factor of one-tenth, about 500 Ω resistance were needed. I used 470 Ω resistors. On two boards, there were 220 nF capacitors linking 32 RG-58 coaxial cables from the photomultiplier tubes with 32 connections to a path that split between a 50 Ω resistor and the transient digitizer.

The existing connections were removed, the lengths of the capacitor components were shortened, and the new resistors were soldered to the boards. The boards were plugged into the transient digitizers and data was collected.

Fig. 3: Schematic for the attenuating pads built

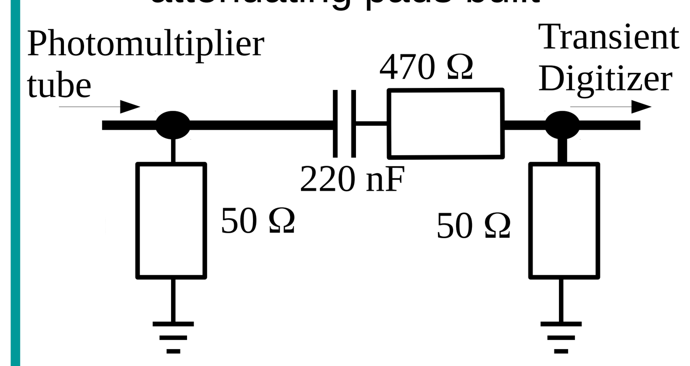
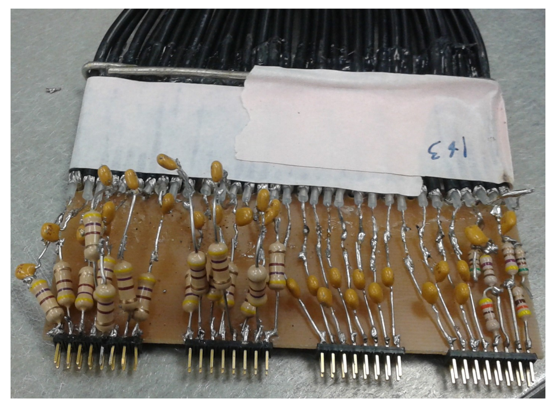
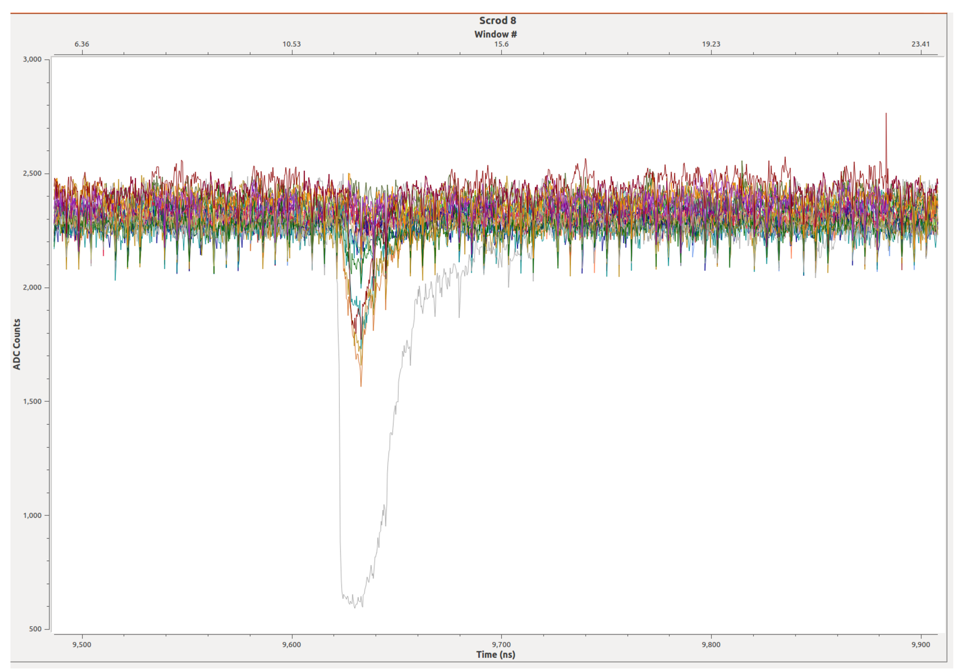


Fig. 4: One of the attenuating pads during assembly



The detector's data collection is triggered when coincidence occurs on both of the two isolated cubes beneath the center of the detector. These two cubes are placed vertically so that the system triggers on muons traveling vertically through the middle of the detector.

Fig. 5: A muon signal to the digitizer is attenuated, so the full height of the signal is counted. In this event, one particular photomultiplier tube receives most of the energy.



When events were found to have only one channel or a few channels responsible for most of the energy, they were deemed possible muons. For these events, the responses from each photomultiplier tube were integrated to determine the event's location. Muon events through the same vertical channel were then simulated using a Fortran algorithm designed to calculate the behavior of light rays in the NuLat detector.

RESULTS

An event was discovered that behaved like a muon passing vertically through the center of the detector. On the front and left faces, the middle column showed the greatest output, with more energy at its top and bottom than at its center. The highest signal on the top face comes from its central channel, with its adjacent cubes also showing more energy than those further away. This event was compared to simulation.

Fig. 6: Experimental and Simulated Muon Events

Simulated Muon: Top Face				
0	2	45	0	0
7	4	258	12	1
57	268	29061	312	62
3	15	275	6	1
0	4	42	0	0

Experimental Muon: Top Face				
0	4788	25794	3286	4835
1557	1184	25652	4258	2037
3938	17607	139291	9292	5510
11253	0	49226	143	1747
2823	13078	14781	0	25847

Simulated Muon: Left Face				
18	79	6275	95	14
9	67	5962	66	12
13	64	6092	52	12
8	72	5800	60	12
10	54	5560	66	11

Simulated Muon: Front Face				
13	60	6184	82	10
15	66	5994	55	22
13	44	5851	59	19
10	61	5897	58	10
14	58	5522	60	18

Experimental Muon: Left Face				
2719	19853	158553	26588	32834
14413	6592	132180	7610	6268
4121	8782	75459	6305	3748
2130	3615	73103	1968	5733
13587	19762	148249	18052	19073

Experimental Muon: Front Face				
9480	10947	70289	26985	13195
14763	13864	42742	5718	0
0	9191	11486	14832	8065
8841	5220	15570	0	0
0	0	40695	591	0

The energy distribution between the two events is similar to the simulated event. The simulated muon gradually loses energy during its descent, while the real event shows high energy at the top and bottom, but not in the center. The central 3x3x3 cubes of the detector are doped with Lithium-6, giving them a different light-yield compared to the other cubes. It seems clear that this is a real muon event.

CONCLUSION

The pads reduced the amplitude of the signals enough for the detector to measure the energy of a muon.

Now that the detector can record a muon event without losing the scale of the signal due to saturation, NuLat may begin to be calibrated to muons. Then the current attenuator pads can be replaced with variable-ranged voltage dividers, so that the same detector configuration can perform muon calibration and detect antineutrinos.

BIBLIOGRAPHY

[1.] X. Ding. "Development and calibration of NuLat, A new type of neutrino detector," 2017.
[2.] Z. Yokely. "Solar and Sterile Neutrino Physics with the Raghavan Optical Lattice," 2016.

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