John Ndungu
University of Washington
Department of Physics

Search for Neutrino Mass.

Abstract:

Since the neutrino was theorized of in 1930 by Wolfgang Pauli, little has been known on the mass of this mysterious particle. According to the standard model, it was known that the neutrino should be massless for a long time. However, due to the observation of neutrino flavor oscillation, it was shown that it had to have mass. To this day, scientists have been trying, in many various ways to find the elusive mass of the neutrino. Nevertheless, since neutrinos are so small and hard to detect, it has been difficult to measure their mass. This is the problem that my research over the summer tried to address. In order to better define the mass of the neutrino, I had to create a prototype of a machine that would find the mass of a neutrino (radiated from the beta decay of tritium) through the detection of electron energy.

Intro:

As stated before, the standard model considered neutrinos to be massless for a long time. However, through the discovery of neutrino flavor oscillation, it was concluded that the particle had to have a mass (1). Thus physicists were tasked with finding the particle's mass. One theory that has started to be addressed is the use of tritium beta decay. When tritium decays it releases an electron and a (anti)neutrino. The energy of the electron and the neutrino must add up to the total energy of the decay. Thus by measuring the energy of the electron released, one can be able to find the mass of the neutrino that was released to a very specific degree, but currently scientists are limited by electron energy resolution. A more precise measurement method has been proposed in B. Monreal and J Formaggio's paper, "Relativistic Cyclotron Radiation Detection of Tritium Decay Electrons as a New Technique for Measuring the Neutrino Mass." However, it requires the development of antennas that can detect single electrons (4). The Mainz (neutrino mass) experiment showed that neutrinos are under 2.3 eV (2), but the upcoming KATRIN experiment hopes to lower the number to, as low as, 0.2 eV (3).

My research:

My part of this research was to construct a prototype of the antenna design described in G. Rybka's paper, "A Proposal to Detect Single Electrons through their Radiation of Power into a Two-Wire Transmission Line" (5). I then had to measure the actual reception of the antennas vs. the theoretical reception in order to guide in the design of further prototypes. In the place of an electron, we decided to use a small dipole antenna that, combined with a signal generator, would imitate an electron energy signal. The device that was created was the first of Project 8 (the name of the project based on this theory). It utilized two wires, connected to a spectrum analyzer that would detect the signal intensity of the dipole antenna at different positions. I then gathered the data from the device and attempted to fit it to the function that the theory is based on.

John Ndungu
University of Washington
Department of Physics


Image of the device I built.


The BNC cable dipole antenna.

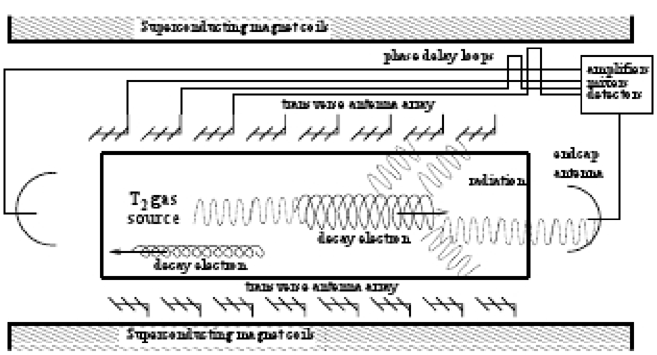
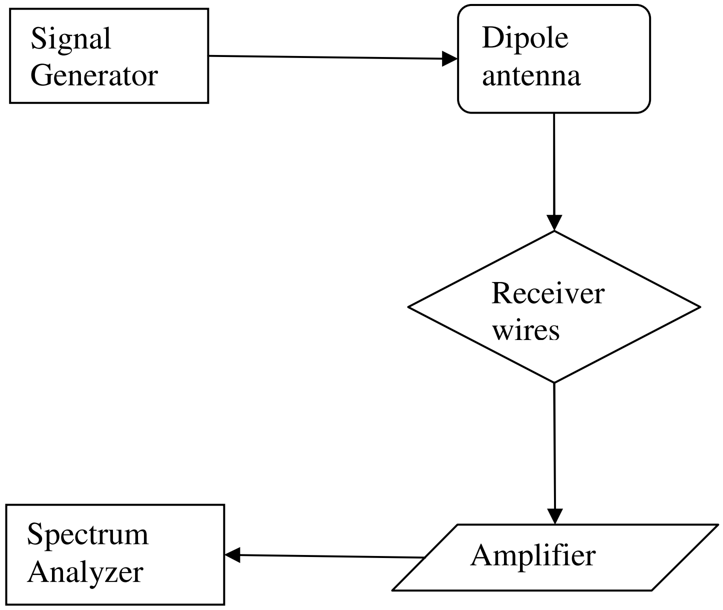


FIG. 1: Schematic of the proposed experiment. A chamber encloses a diffuse gaseous tritium source under a uniform magnetic field. Electrons produced from beta decay undergo cyclotron motion and emit cyclotron radiation, which is detected by an antenna array. See text for more details.

Schematic of proposed device.

John Ndungu
University of Washington
Department of Physics

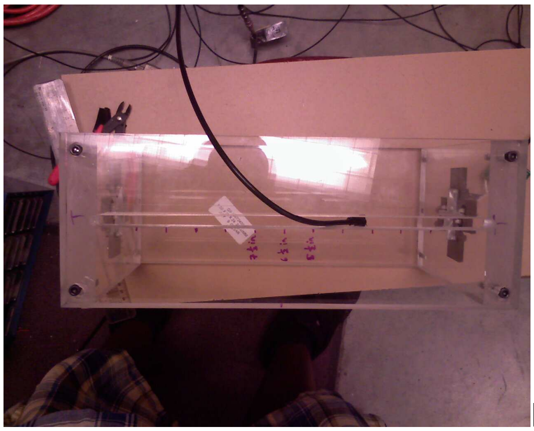
Diagram of how my device worked:

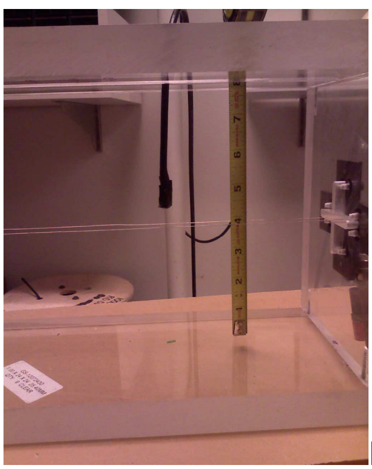


Procedure:

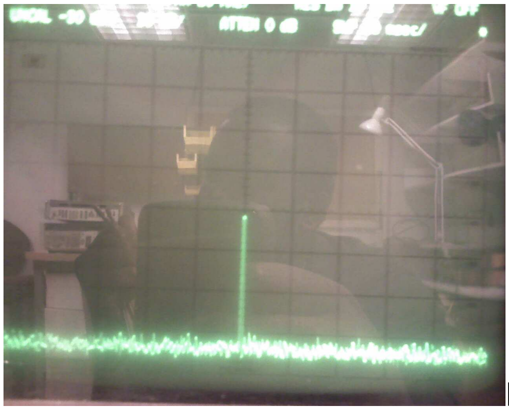
After designing and assembling the device, the data gathering began. The device that was created is a four sided clear acrylic box that houses the two wires used in the detection. It has a bottom, top, front and back. However the sides of the box were not included since the inside of the box needed to be available in order to position the dipole antenna (made from a BNC cable that was stripped and soldiered to two wires).

The plan was simple; the dipole antenna would be positioned at different positions along the length of the wire and at different heights with respect to the wire. It was decided that the increments along the length of the wire (that the dipole antenna would be placed) would be divided up into five, two inch increments; one in the center and two on either side of the center along the length of the line. The total length of the wire was about 15 in. For the height increments, it was decided that we would measure the signal up to two inches above and below the wire level, in one quarter inch increments. This meant that there was 85 data points to collect, for each wire spacing (one at 1.125 in and the other at 0.53125 in).


I divided length of wire into 1 in. increments.


I then measured the height of the antenna.

John Ndungu
University of Washington
Department of Physics



Example of signal seen on the spectrum analyzer.

The process that I used to collect data was fairly straight forward. It began with the dipole antenna being placed at a measuring increment along the length of the wire, turning on the signal generator in order to emit a -10 dBm signal at a frequency of 500 MHz. Then the signal that was able to get through to the spectrum analyzer through the wires was recorded on the data table. This process was repeated 170 times until I had gotten data on the two wire spacings.

1.125 in. of spacing between the wires:

Height	Watts at 2.5 in.	Watts at 4.5 in.	Watts at 6.5 in.	Watts at 8.5 in.	Watts at 10.5 in.
0.047625	1000	3981.072	3981.072	3981.072	1995.262
0.053975	1584.893	630.9573	3981.072	3981.072	1995.262
0.060325	5011.872	1000	3981.072	2511.886	1995.262
0.066675	6309.573	2511.886	6309.573	2511.886	2511.886
0.073025	15848.93	2511.886	3981.072	3981.072	3981.072
0.079375	12589.25	3981.072	6309.573	7943.282	5011.872
0.085725	15848.93	6309.573	10000	10000	3981.072
0.092075	19952.62	3162.278	15848.93	12589.25	5011.872
0.098425	15848.93	10000	31622.78	10000	3162.278
0.104775	10000	10000	15848.93	6309.573	2511.886
0.111125	6309.573	7943.282	10000	3162.278	1995.262
0.117475	3981.072	7943.282	6309.573	2511.886	1258.925
0.123825	12589.25	6309.573	6309.573	1995.262	1000
0.130175	10000	5011.872	3981.072	1258.925	794.3282
0.136525	7943.282	5011.872	3981.072	1000	794.3282
0.142875	5011.872	3981.072	3981.072	794.3282	630.9573
0.149225	10000	3630.781	2818.383	398.1072	79.43282

0.5625 in. of spacing between the wires:

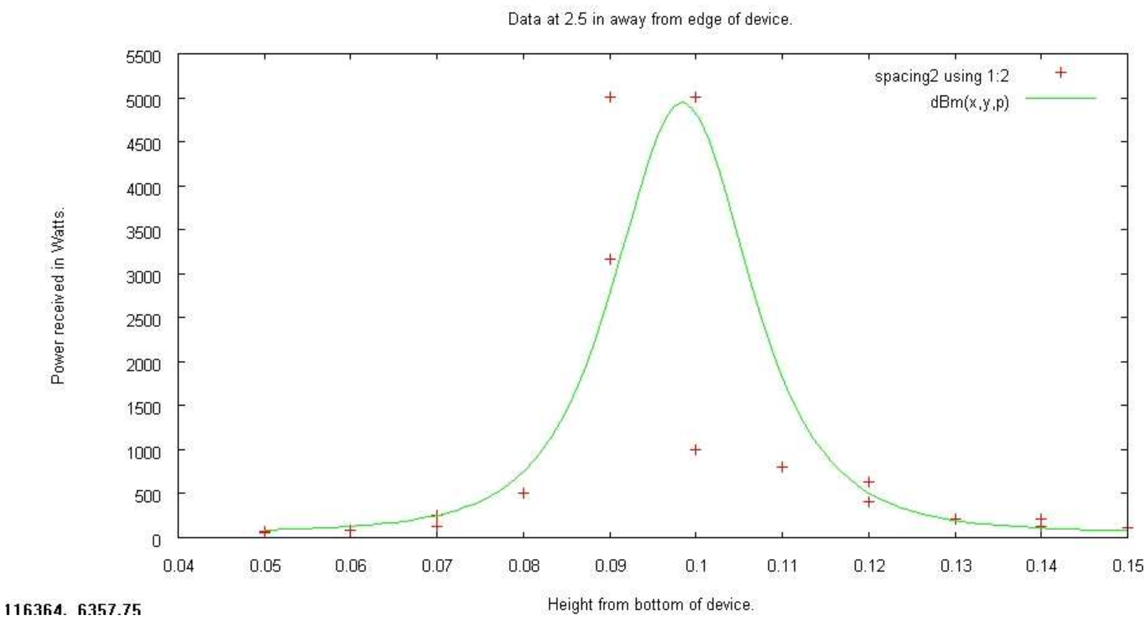
Height	Watts at 2.5 in.	Watts at 4.5 in.	Watts at 6.5 in.	Watts at 8.5 in.	Watts at 10.5 in.
0.047625	63.09573	79.43282	794.3282	251.1886	50.11872
0.053975	50.11872	125.8925	398.1072	316.2278	50.11872
0.060325	79.43282	199.5262	398.1072	398.1072	158.4893
0.066675	125.8925	316.2278	316.2278	630.9573	199.5262
0.073025	251.1886	398.1072	630.9573	794.3282	316.2278
0.079375	501.1872	794.3282	1995.262	794.3282	501.1872
0.085725	3162.278	1584.893	5011.872	3162.278	794.3282
0.092075	5011.872	6309.573	6309.573	2511.886	1258.925
0.098425	5011.872	10000	10000	3981.072	10000
0.104775	1000	794.3282	1000	1000	1258.925
0.111125	794.3282	501.1872	794.3282	794.3282	1000
0.117475	630.9573	398.1072	501.1872	398.1072	794.3282
0.123825	398.1072	251.1886	316.2278	316.2278	630.9573
0.130175	199.5262	316.2278	251.1886	199.5262	501.1872
0.136525	199.5262	125.8925	199.5262	199.5262	501.1872
0.142875	125.8925	158.4893	125.8925	100	39.81072
0.149225	100	63.09573	100	794.3282	316.2278

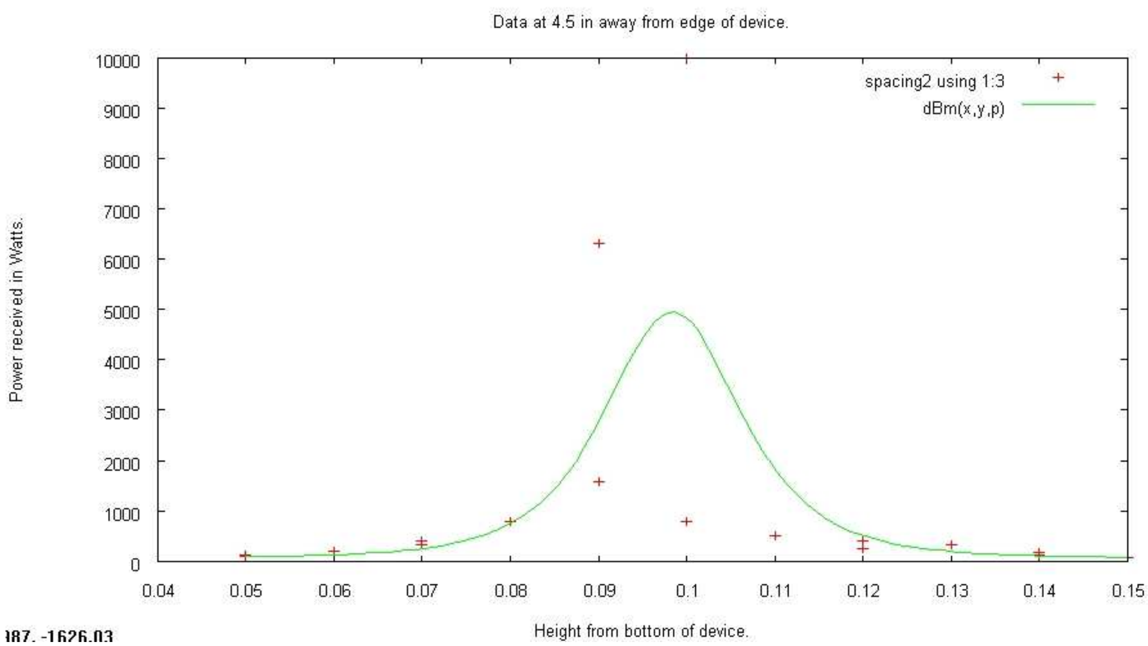
Then came the task of finding out whether our theory was sound. According to our theory, the power transmitted from a dipole at height y to an infinitely long two wire line is proportional to $p(x) \propto \frac{(p_0 \cdot y^2)}{\left[\left(\frac{y}{2}\right)^2 + x^2\right]^2} \bullet \frac{\lambda^2 \cdot l^2}{R}$. Where

P(x) = total power, p_0 = original power, y = wire spacing, x = height with respect to the wire, and C = a constant. Our experiment used a more realistic approach to wire length.

John Ndungu
University of Washington
Department of Physics

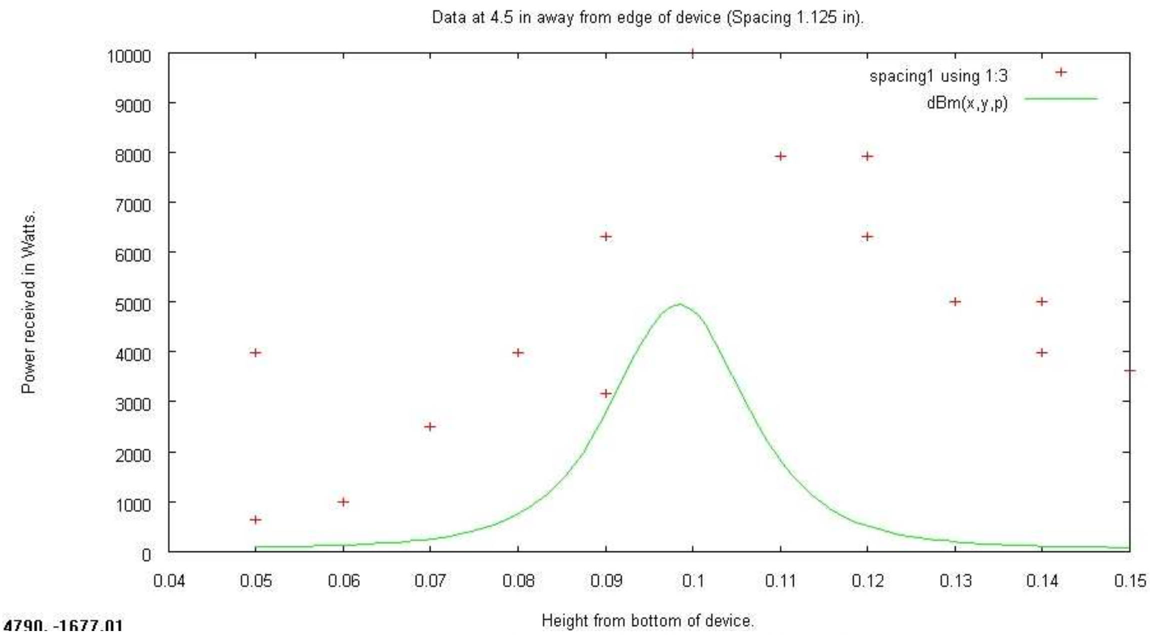
Example of data vs. function with 1.125 in. of spacing between the wires:

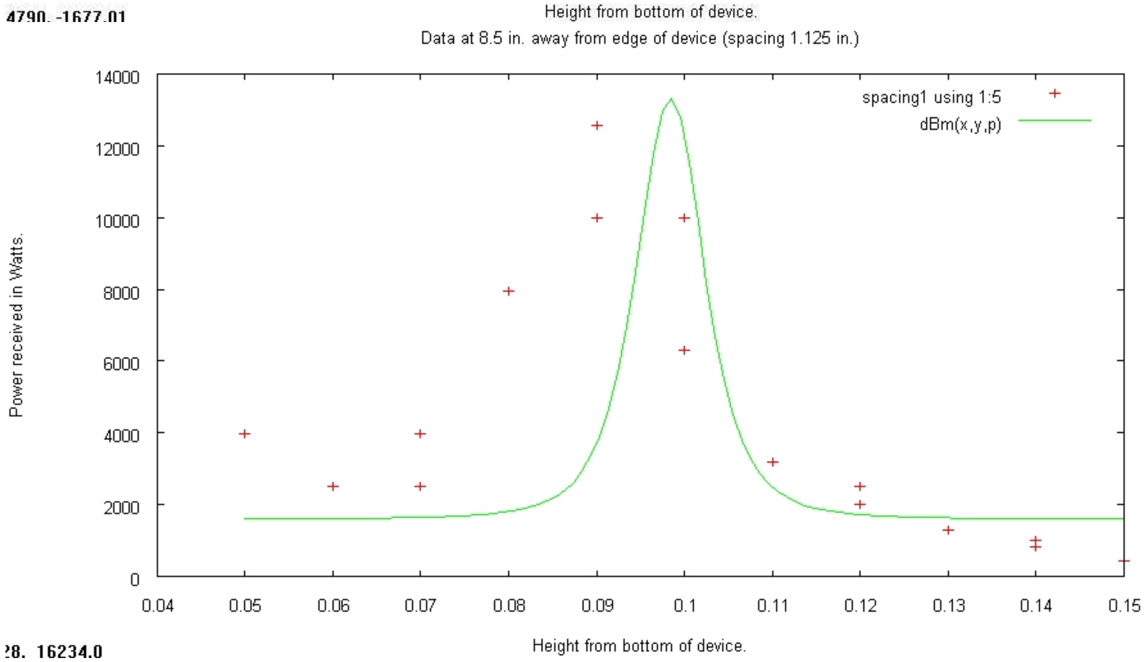




John Ndungu
University of Washington
Department of Physics

Example of data vs. function with 1.125 in. of spacing between the wires:





After gathering the data and comparing it to our function, we saw that for the most part, the function held true. However, there were a few hiccups in the data (i.e. the data points that didn't match the function). It is possible that these hiccups could have been caused by interference from an external source (i.e. stray signals, wire was bent, & dipole antenna moved around while measuring). It is also clear from the data gathered that wire spacing plays a crucial role in the amount of reliability of the signal. In the data of the narrow wire spacing, compared to the wide spacing, the data points (of the narrow spacing) formed a pattern that better represented our theoretical model.

Conclusion:

I learned a great deal of information about waves, particle physics, and expecting the unexpected over the summer REU experience. Though our data did not match up perfectly with our theory, we learned that it is still a sound theory, even though some parts of it need to be modified. There are a plethora of reasons for the "bumps" that occurred in the measurements. One of these reasons is the fact that the experiment was being held in a room half full of metal that could have been reflecting stray signals. Another reason could have been the imperfect design of the dipole antenna and device itself. However, the theoretical model, despite accounting for most things, may need to be modified to account for these effects once shielded and at a higher frequency.

There were some unexpected observations that I witnessed during the experimental period. One of which was the fact that the data, when plotted on the graph seemed to show that the signal reception was better and more steady below the wire. This could have been caused by stray energy radiating from the coaxial coat of the BNC cable I used for the dipole antenna. Since I was placing the dipole antenna through the middle of the two wires to get the signal below them, the wires could have also picked up some of the signal that was going through the cable and to the tip of the antenna.

For the future researchers that will continue project 8, I would suggest that they pursue ways in which to reduce interference in order to get a clearer and more consistent signal. One way this could be achieved would be to use thinner wires while making the spacing of the wires less. I would also suggest moving the device to a place without a lot of metal or signal generating devices. If this is not possible, shielding the device setup would be an alternative. With a better signal, there would be a better consensus on how accurately the reception is modelled. I wish all the luck to the future of this experiment and all the people that will be involved.

John Ndungu
University of Washington
Department of Physics

References:

1.R Davis et al. Phys. Rev. Lett. 20. 1205-1209, 1968.

J. Bahcall and H. Bethe. Phys. Rev. Lett. 65. 2233-2235, 1990.

2.C. Kraus et al. Eur. Phys. J. C. 40, 447-468, 2005.

3.J. Angric et al. KATRIN Design Report. 2005. http://www-ik.fzk.de/tritium/

4.B. Monreal and J. Formaggio. "Relativistic Cyclotron Radiation Detection of Tritium Decay Electrons as a New Technique for Measuring the Neutrino Mass" 2009. arXiv:0904-2860v1 [nucl-ex].

5.G. Rybka. "A Proposal to Detect Single Electrons through their Radiation of Power into a Two-Wire Transmission Line" Project 8 Internal Note 2009.