Characterization of Sensors for Cryogenic Particle Detectors at the Milli-Kelvin Scale

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Abstract

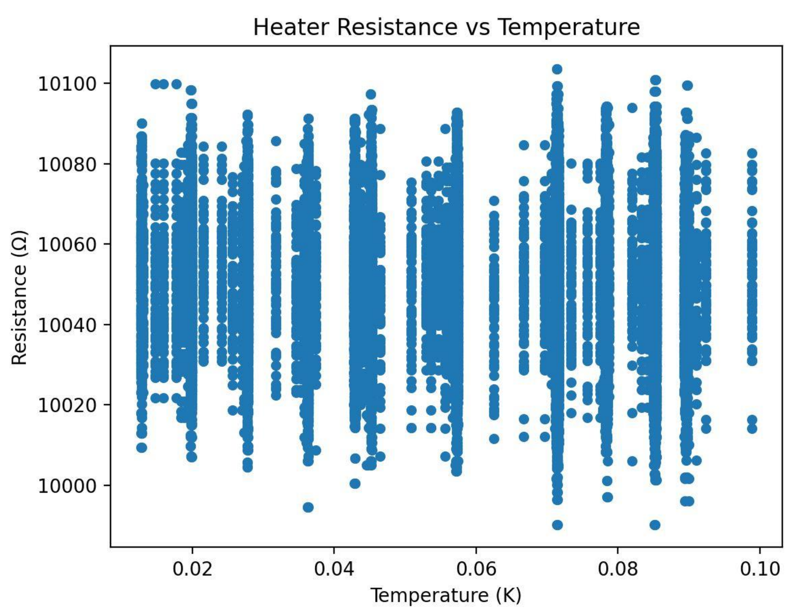
Cryogenic particle detectors are a useful tool in neutrino research, particularly neutrinoless double beta decay searches, due to their excellent energy resolution, potential to be made with high radiopurity and their high detection efficiency. To maximize energy resolution, such detectors are operated at extremely low temperatures (~10mK), where the low heat capacity of the detector maximizes the intrinsic detector response to energy depositions. Such detectors require high-sensitivity thermometers that can operate in an ultra-low temperature environment. In this project we explore neutron transmutation doped germanium thermistors (NTD's) and superconducting tungsten thin films, both of which are expected to exhibit very strong resistance vs. temperature behavior. We will also explore the resistance vs. temperature curve of metal foil resistors (referred to as heaters) to determine if they are suitable to use as reference heaters to monitor detector thermal response.

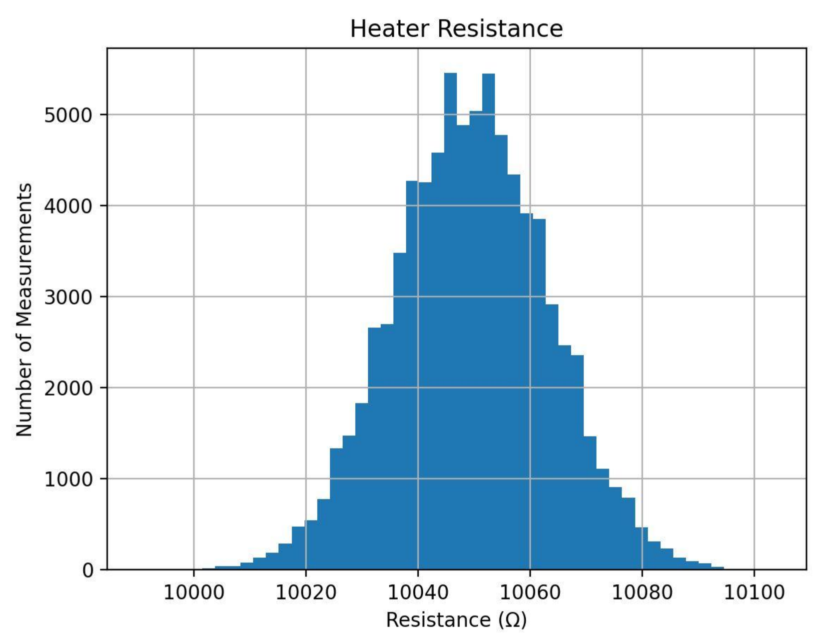
Introduction

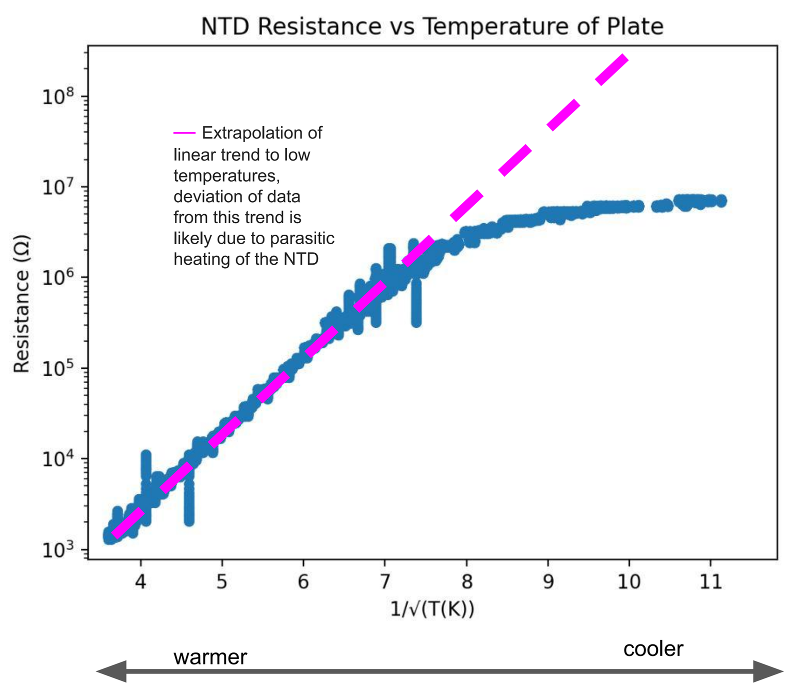
Neutrinoless double beta decay attempts to solve the mystery of why matter exists in the universe when in theory the matter and antimatter should have annihilated each other. The theory is that when an isotope undergoes double beta decay, it emits two electrons and two antineutrinos. The antineutrinos annihilate each other, leaving two electrons behind, thus creating matter. This has not been proven, but is being searched for using cryogenic particle detectors, which we want to optimize.

Results

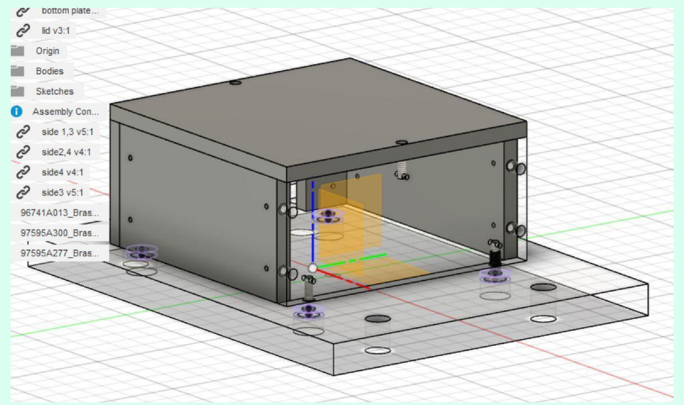
Using python, we graphed the resistance vs temperature for the one functional heater and for the NTD (the tungsten film data was inconclusive). Our NTD was not working during this cooldown, but we had data for another NTD from a cooldown the previous week, so we used that data. There is no evidence that the resistance exhibits a temperature dependance. Further analysis shows that the average resistance is 10050±14 Ω, meaning the resistance is actually very stable, with only ~0.1% change overall due to noise. Thus these heaters may be used as a reference heater as they have no temperature dependence.The NTD data shows a strong correlation between resistance and temperature, although it appears to lessen as the temperature decreases. This is likely because the samples were not actually at the temperature of the plate when it got that cold, which may have been caused by a variety of things, such as the electrons in the wires (they carry RF radiation) or poor thermal contact with the cooling plate.



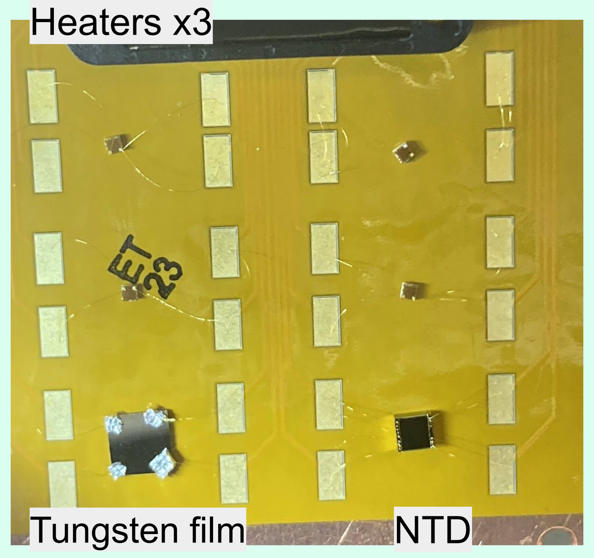




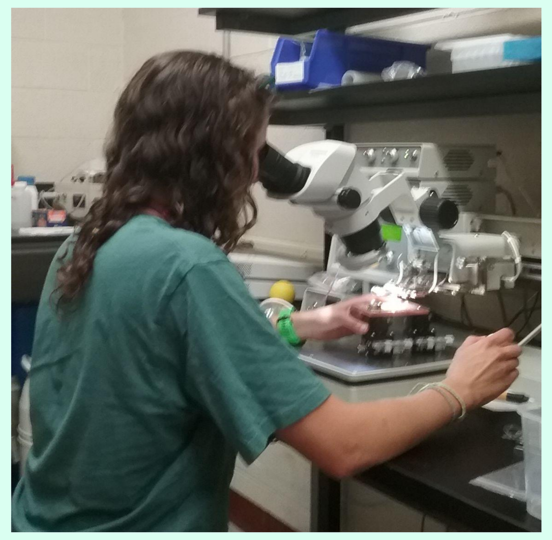
Process



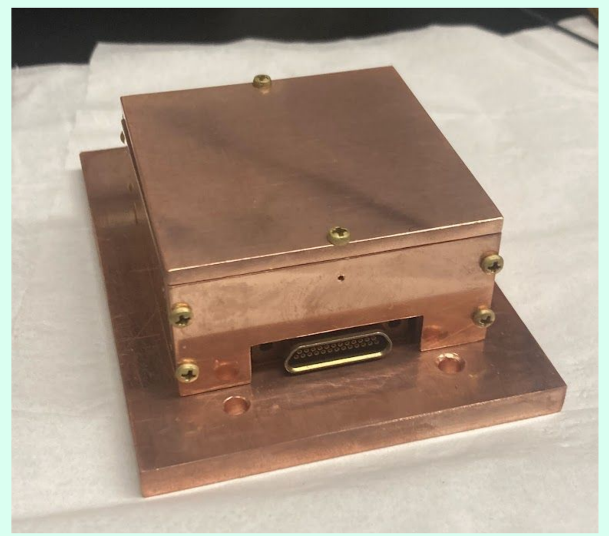
1. Design box to hold samples in Fusion 360



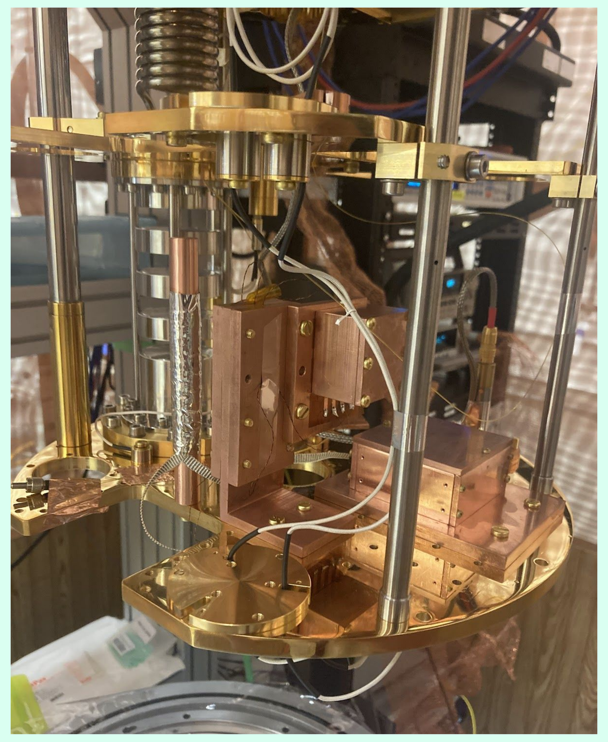
2. Glue sample holder to plate and samples to holder with thermally conductive, electrically insulating epoxy



3. Wirebond each sample to the copper pads on the holder



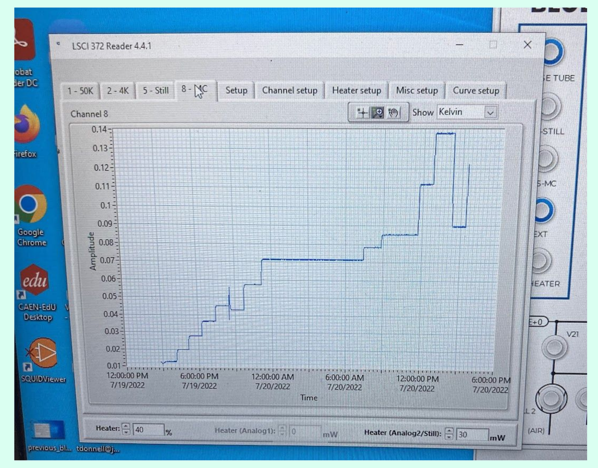
4. Screw box together using brass M2 screws



5. Screw box onto cooling plate

6. Test the resistance of the samples to ensure they work and close the refrigerator

7. Do a leak check and start the cooldown



8. collect data for the heater at different power percentages. Also collect data by changing the power for the tungsten film

Conclusion

Both the NTD and the heater behaved as we hoped, thus it may be possible to use them in future cryogenic particle detection experiments. However, this needs to be researched further, as there were a number of limitations on this experiment that may have affected the data. Firstly, only one heater was able to be tested. It would be ideal if we had data from multiple heaters to ensure they are also unaffected by temperature. Also, the NTD in this experiment did not respond after the cooldown so it should probably be tested again. Also, the tungsten films need to be re-tested, as we were unable to obtain conclusive data for it. Our NTD data is promising, and should continue to be tested. If we are able to show a strong temperature dependence at colder temperatures as well, these NTD's could be used as thermometers in future particle detectors.

Acknowledgements

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2. Joe Camilleri, for making the sample holder and bottom plate of box
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4. We thank Prof. S. Emori (Virginia Tech Physics Department) for providing the tungsten film sample, the CUPID collaboration for providing the NTD samples and VPG Foil Resistors for providing the heater samples.
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