Searching for Axions with Superconducting Nanowires

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BREAD

The Broadband Reflector Experiment for Axion Detection (BREAD) uses a strong magnetic field that is parallel to an outer cylindrical dish antenna to generate photons via coupling with incident axions. Photons are then directed to a detector by the optics of the reflector.

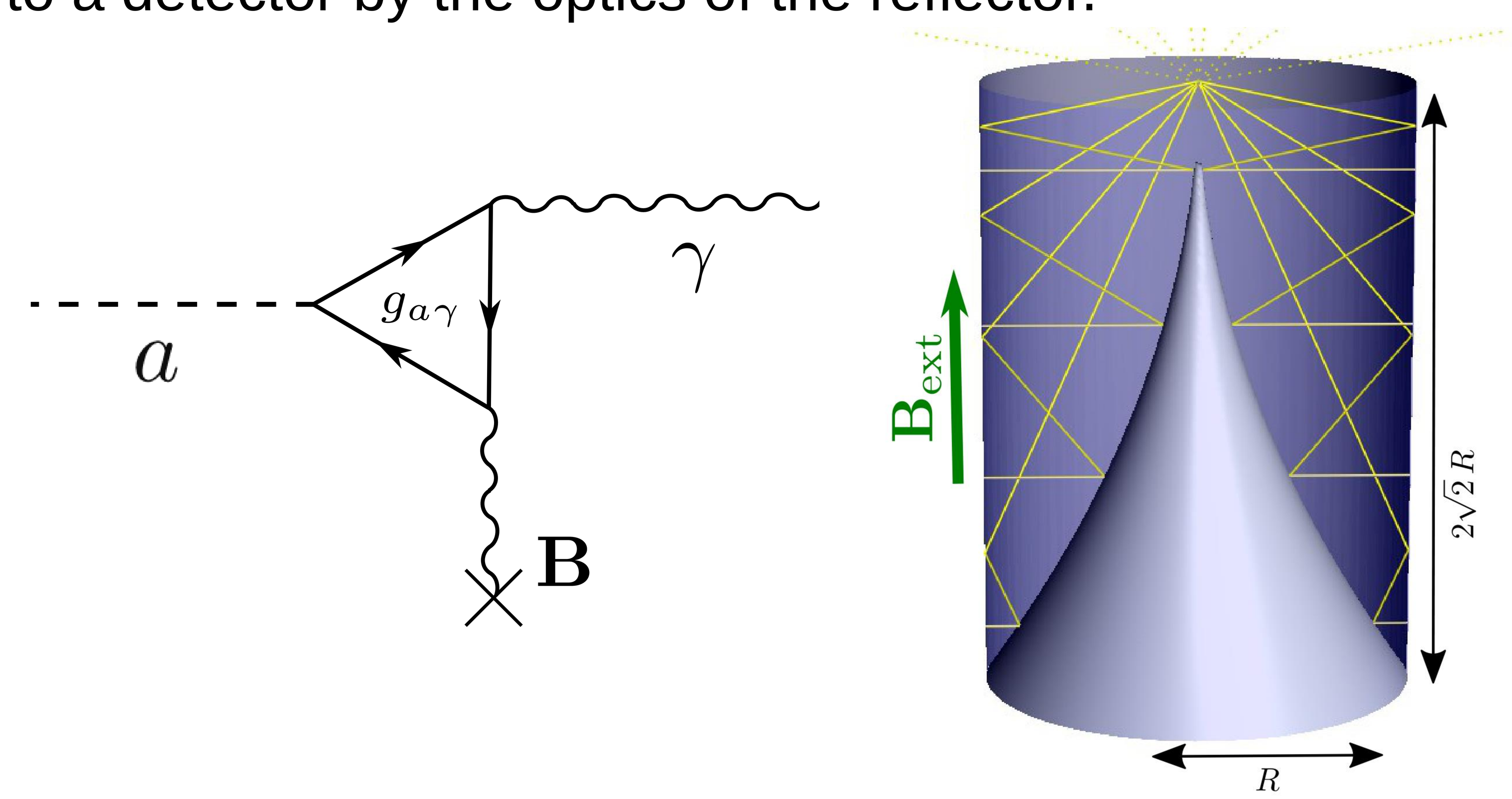

Fig 1. – The image on the right depicts the coupling between axions and photons. The image on the right depicts how the optics direct the photons to the detector.

SNSPDs

In the optical regime of photon wavelengths, BREAD uses Superconducting Nanowire Single Photon Detectors (SNSPDs) to detect when a photon has been generated by the axion coupling system. SNSPDS are superconducting periodic structures. When a photon becomes incident on the SNSPD, the superconductivity of the wires is broken. This can be measured, and photon events can be counted.

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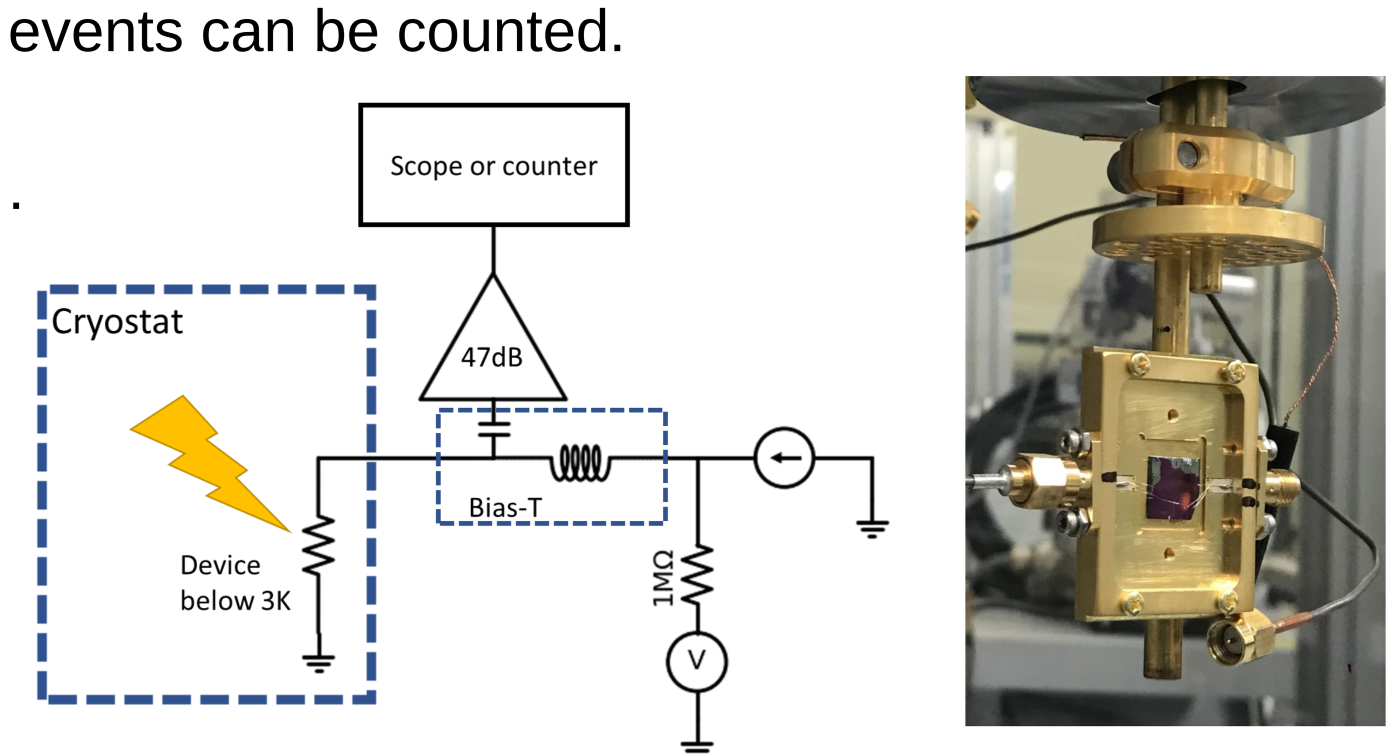

Fig 2. – The image on the left is a circuit diagram which represents how superconductivity breaking can be sensed with bias tees and amplifiers. The image on the right is an SNSPD chip.

Optical Absorption Model and Results

An important consideration of this experiment is how the detection efficiency of the SNSPD is affected by the angle of incidence and polarization of the photon. Photons can be incident from a polar angle of 0 to π/2 radians, and an azimuthal angle of 0 to 2π radians. Comsol Multiphysics software was used to construct an optical model of the SNSPDs.

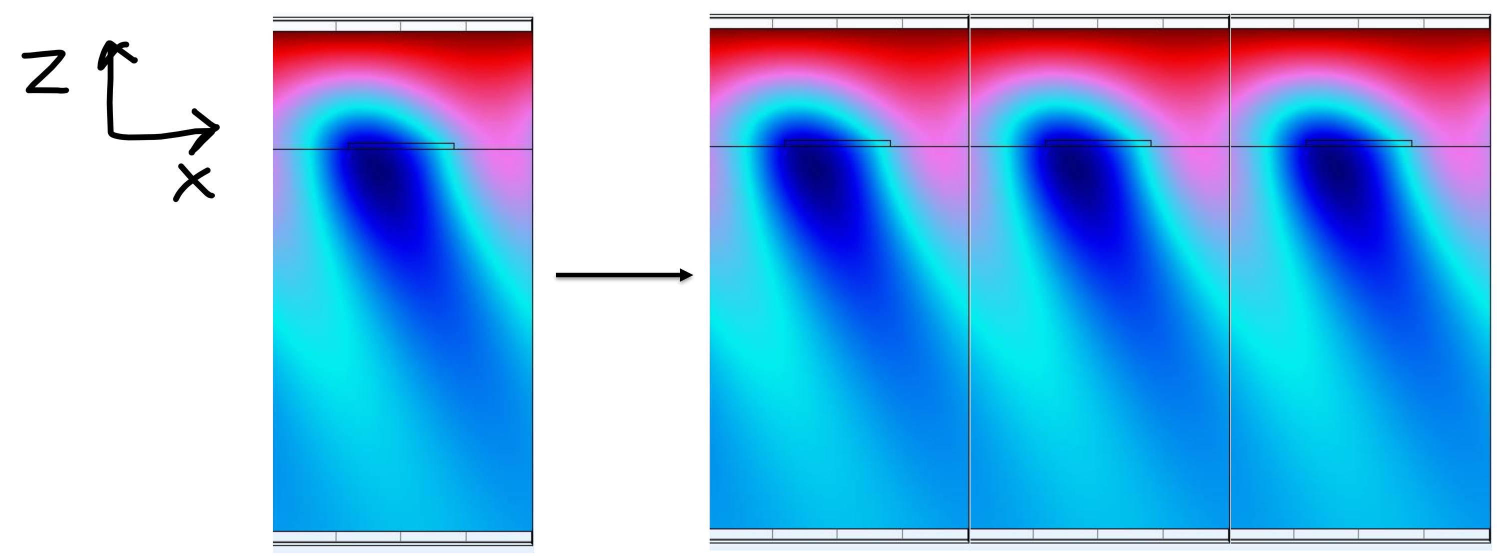

Fig 3. – On the left is a plot for the electric field norm in a unit cell of the SNSPD structure. On the right is the same plot repeated to emphasize how the periodicity of the structure was solved for with a single unit cell and periodic boundary conditions. The cross section of the wire is located near the darkest blue part of the plot.

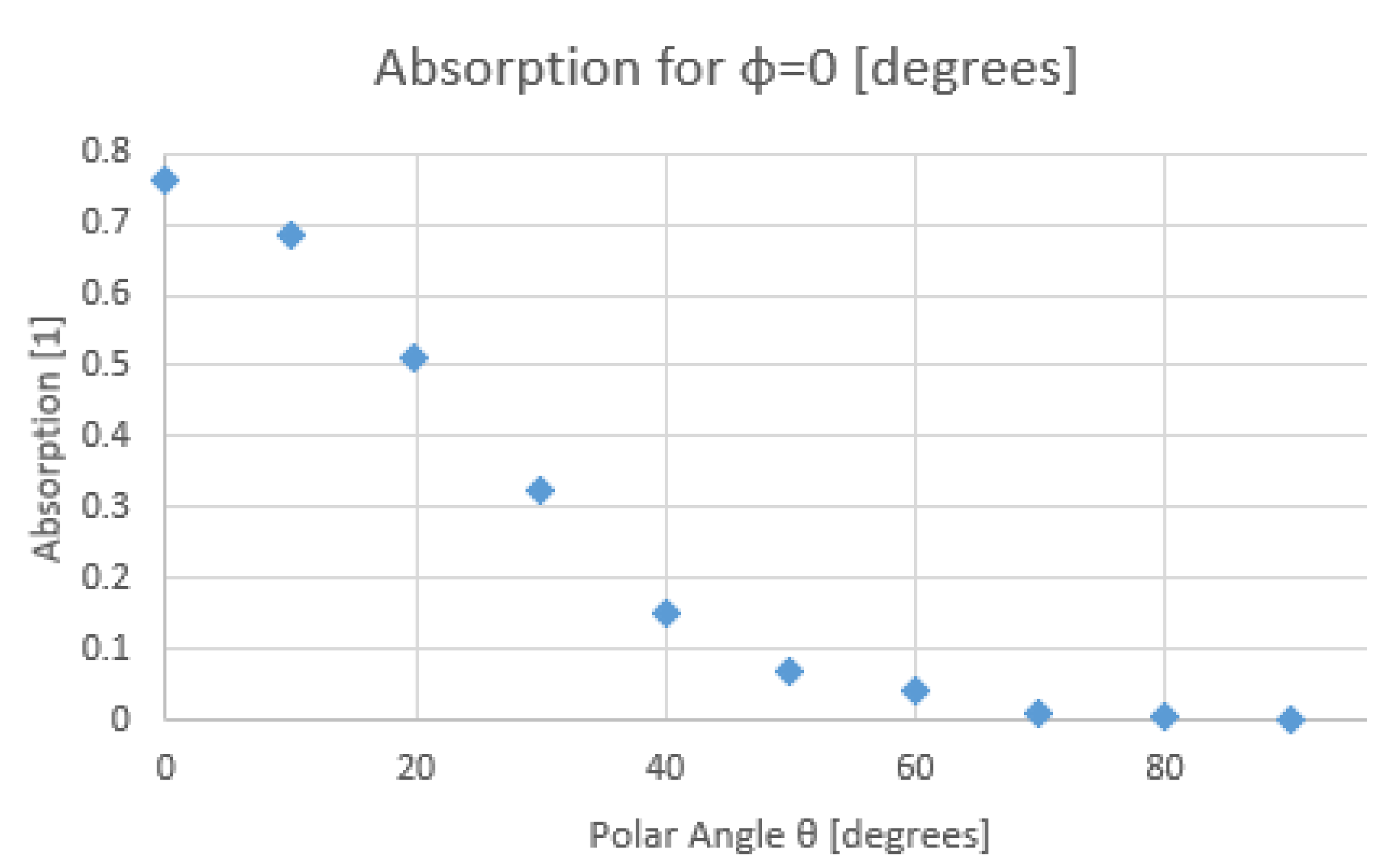

Fig 4. – A plot of the optical absorbance of a TEM plane wave for a constant azimuthal angle of zero degrees. Here, polar angle is the angle from the normal of the substrate, or the angle from the z-axis in figure 3.

References

Broadband Solenoidal Haloscope for Terahertz Axion Detection – (Liu, 2022)

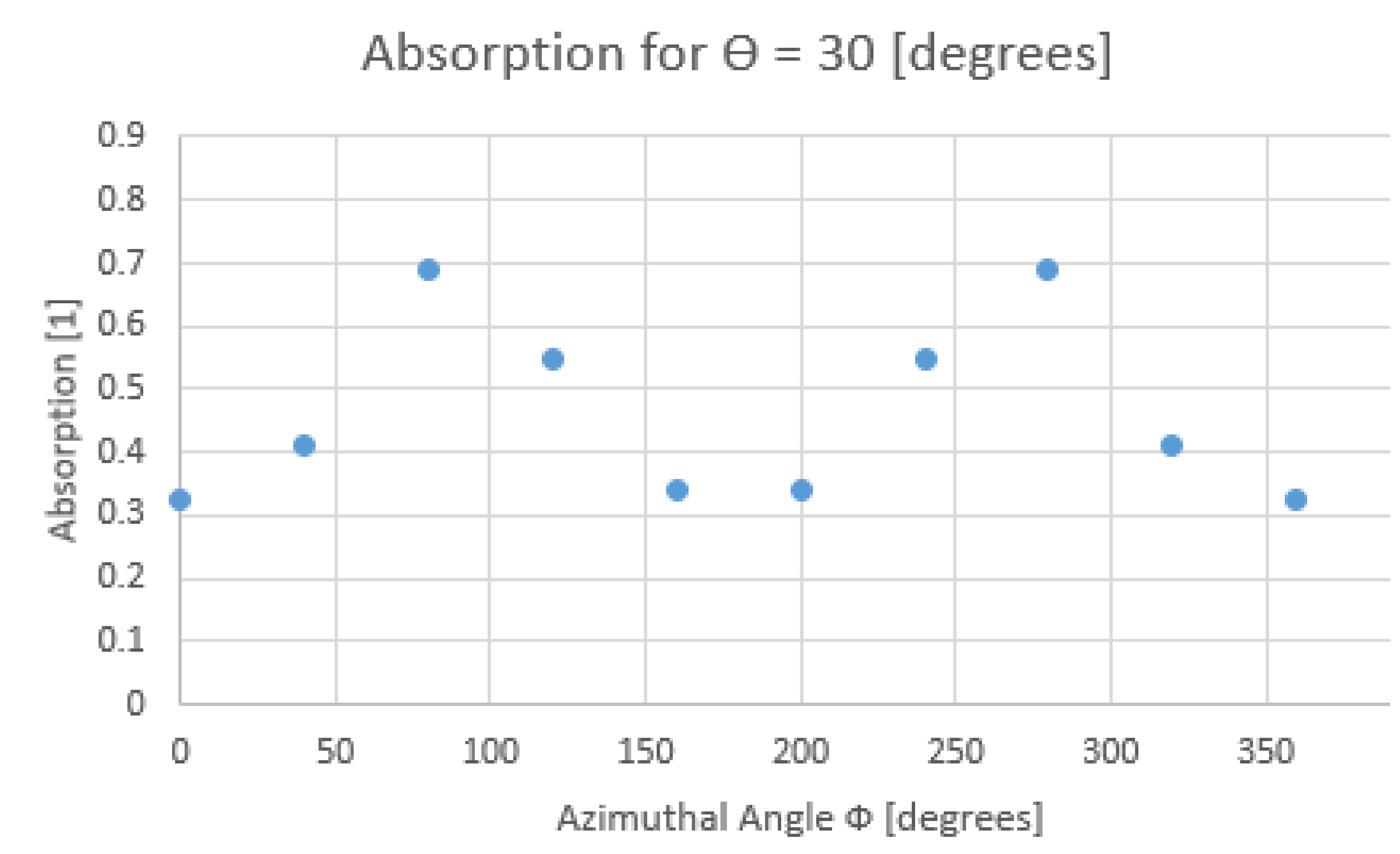

Fig 5. – A plot of the optical absorbance of a TEM plane wave for a constant polar angle of 30 degrees. Here, the azimuthal angle is the angle from the x-axis in figure 3.

Conclusions

The optical absorption model yielded a theoretical upper limit on the detection efficiency of the devices and a qualitative understanding of the relationship between angle of incidence and detection efficiency. However, It is also important to experimentally characterize the performance of the SNSPD devices at millikelvin temperatures. To this end, the SNSPDs were installed in an Adiabatic Demagnetization Refrigerator (ADR). The SNSPDs were mounted in the ADR and connected to amplifiers and bias tees that allow for the sensing of superconductivity breaking. Next steps include characterizing the switching current and the dark count rate of the SNSPDs.

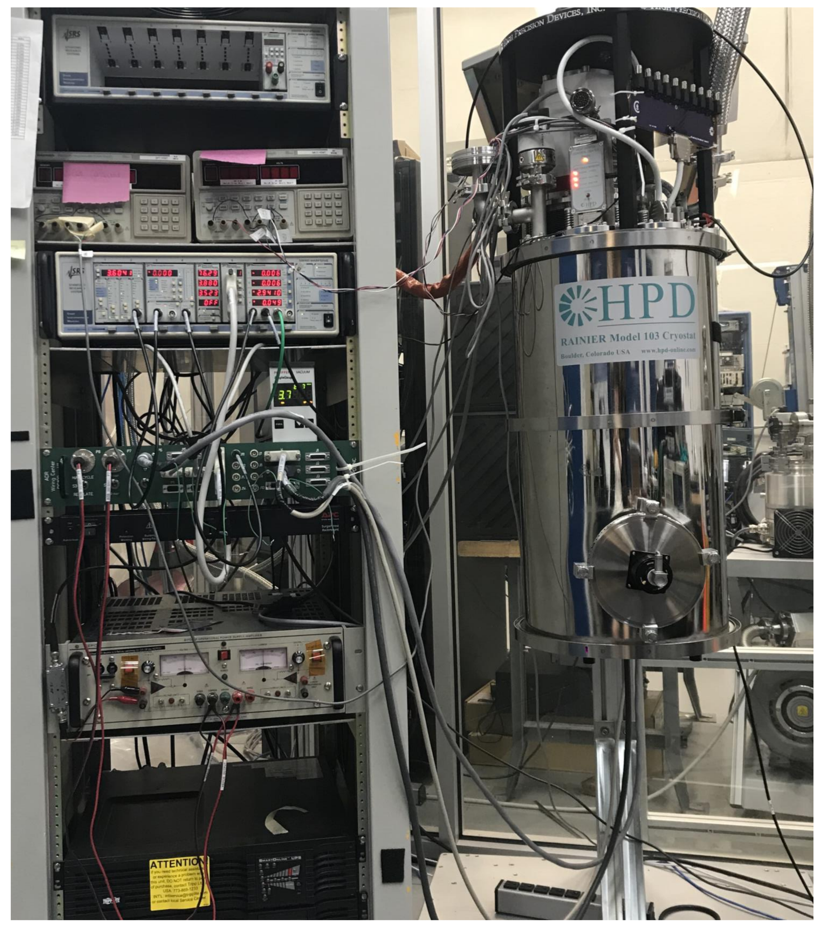

Fig 3. – On the right is the ADR with the SNSPD and amplifier board installed. On the left is a rack containing temperature, pressure, current, and voltage measurement devices as well as a power supply for the ADR magnet and an uninterruptible power supply and battery pack that aid in preventing the magnet from quenching.

This work was produced by Fermi Research Alliance, LLC under Contract No. DE-AC02-07CH11359 with the U.S. Department of Energy. Publisher acknowledges the U.S. Government license to provide public access under the DOE Public Access Plan DOE Public Access Plan. FERMILAB-POSTER-22-116-STUDENT