The Phonon Observation of Neutrinos via Optical Nanodefects (PHONON) Project

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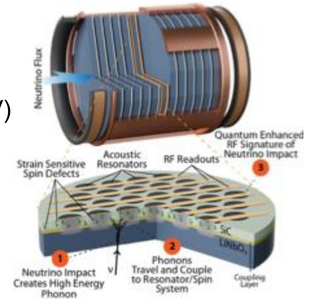
The PHONON Concept

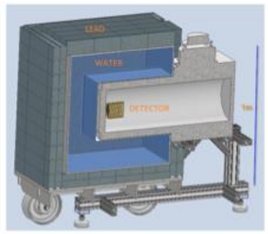
- Quantum sensing-enabled coherent elastic neutrino nucleus scattering (CEvNS) detector
- Very low threshold goal (<= 0.1 eV) in a kilogram-scale detector
- Aiming for reactor neutrino measurement at Oak Ridge National Laboratory's High Flux Isotope Reactor (HFIR)

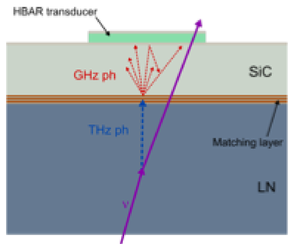


- Takes advantage of using a color center spin ensemble providing a significant enhancement in the signal-noise ratio (SNR)
- Enables quantum-limited measurements of phonons inside the cavity

- Initial THz phonons generated by neutrino interactions in lithium niobate (LN) target downconverted in silicon carbide (SiC) layer and then detected by sensitive transducers

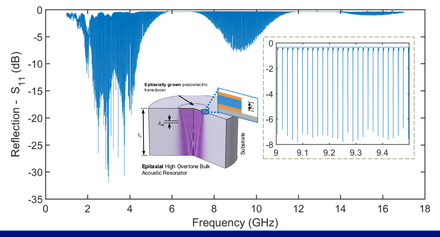
- Shielding package to reduce reactor backgrounds such as gammas/neutrons that can mimic CEvNS signal

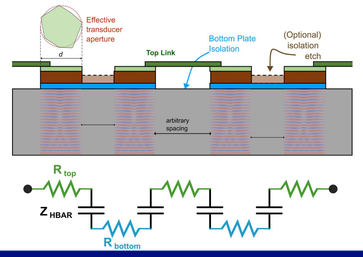




Detector Design Work

- Detecting GHz phonons via coupling to a selected cavity mode (one of many) in an epitaxial high-overtone bulk acoustic resonator fabricated on SiC
- Development of electrically coupled HBAR arrays; increasing effective sensing area while maintaining cavity quality factor and controlling readout SNR

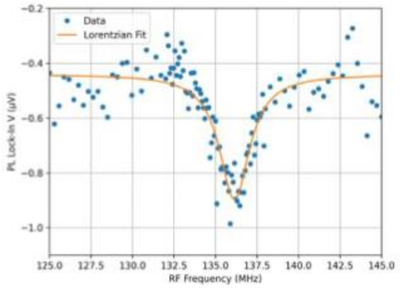




Detector Design Work

- Successful tests of HBARs at 4K

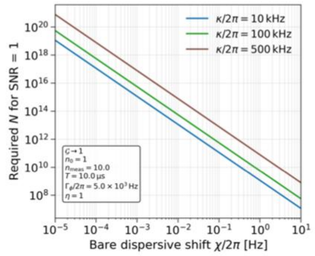
- Optical excitation of test HBAR samples shows clear optically detector magnetic resonance (ODMR) signature



- Test stand developed and in progress for testing HBARs at mK temperatures needed for PHONON using dilution-refrigerator

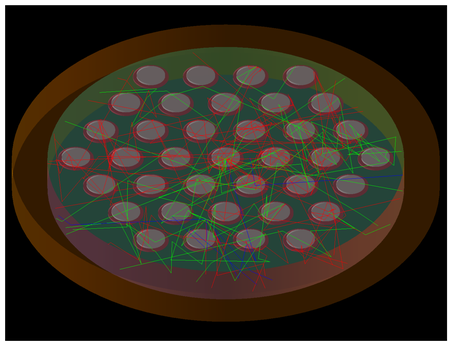
- Readout relies on reading out multiplexed HBARs, use commercial RFSoC system

- Preparing additional tests for:
- Irradiation effects on color center/HBAR system
- Spin-acoustic coupling rate and system coherence times



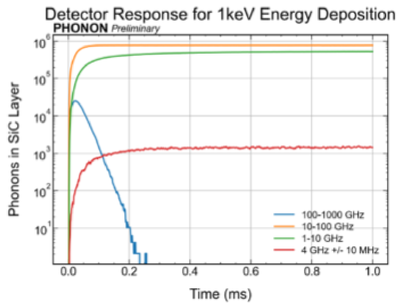
Simulating Phonon Signals

- Mockup of LN/SiC/HBAR detector using Geant4 package
- The G4CMP package provides the additional physics needed for phonon transport and collection
- Important lattice parameters for LN and SiC computed via DFT calculations



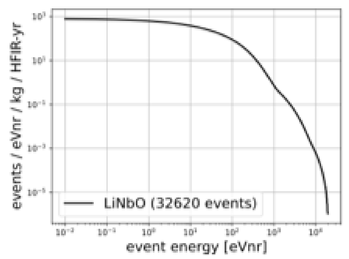
Simulating Phonon Signals

- HBAR is sensitive to a smaller frequency range
- We collect single phonons at the eV-scale



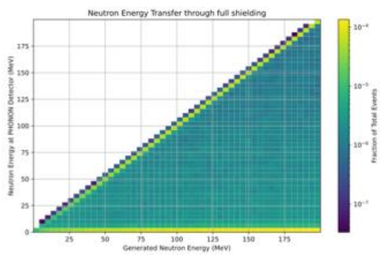
Signal/Background Expectation

- Use existing CEvNS rate code to estimate event rates at reactor for a kilogram-scale detector
- Thresholds <= 1 eV allow for large event rate for nominal HFIR operation time
- Reactor event rate levels off with 100-meV thresholds

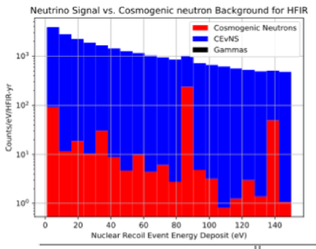


Large raw event rate of 32620 events/kg/HFIR-yr

- Neutrons are expected to be a main background mimicking the CEvNS signal
- Studying energy transfer through 10 cm lead/ 20 cm water based shielding package shows large reduction in neutron backgrounds



- Comparing energy depositions inside the LN from both CEvNS and open predicted neutron and gamma fluxes for HFIR
- Shows good capability to reject backgrounds with limited background statistics!



- Future work will combine this with the phonon modeling creating a full model of the readout signal from the detector response to CEvNS
- Currently refining signal/background estimates for realistic HFIR deployment

	HFIR
Threshold (eV)	1
Signal (1-yr)	29412
Background (1-yr)	887
S/B	33

Note: This research was developed with funding from the Defense Advanced Research Projects Agency (DARPA). Any opinions, findings, conclusions, or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of DARPA.