Superconducting Sensors for Neutrino Detection: Potential Applications

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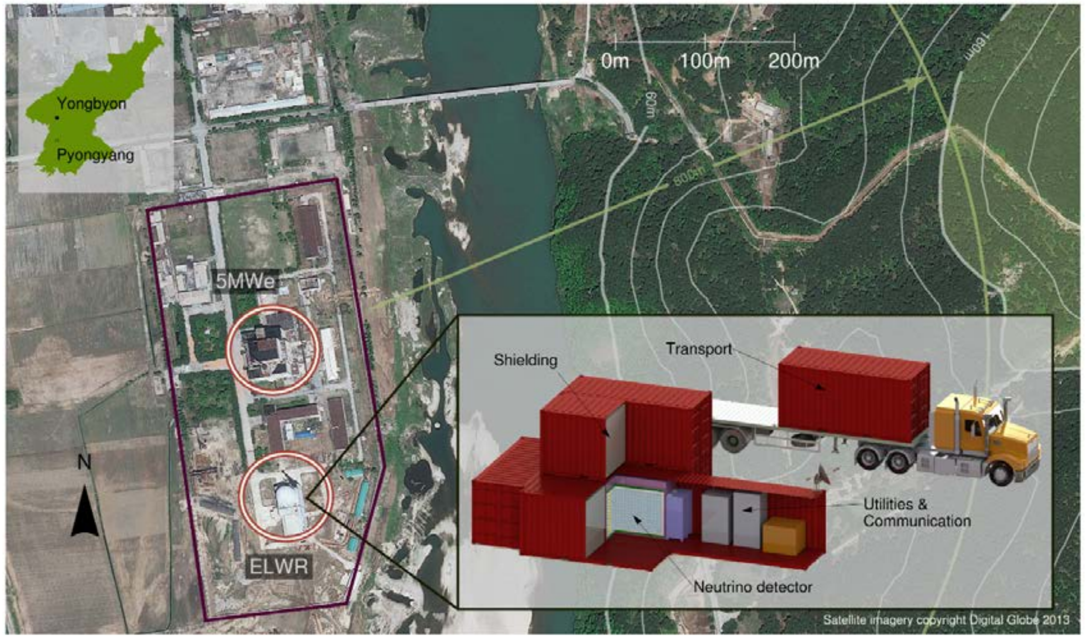
Neutrino detection for nuclear monitoring

Technological goal: compact remote sensor of reactor neutrinos

Background

- Nuclear reactors produce low-energy neutrinos (<100 eV)
- Can be detected by conventional techniques (inverse Beta decay), or potentially by more novel techniques (CEvNS)
- Can determine reactor ON/OFF, power levels, and fuel composition[1]
- Tradeoffs between detector size, standoff distance, and event rate

Nuclear monitoring concept for conventional neutrino detectors

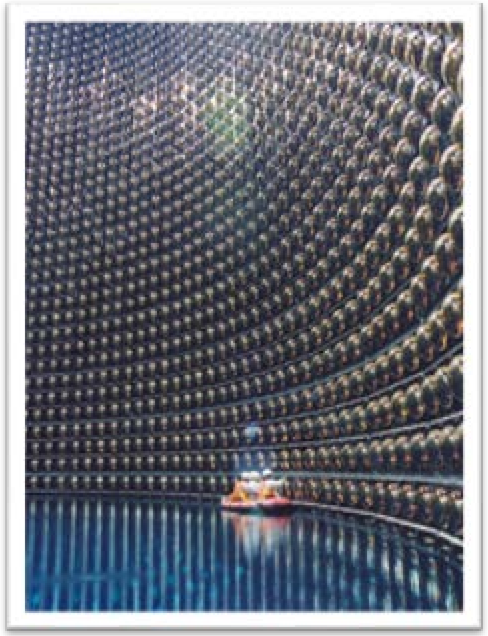


[1]R. Carr et al., Science & Global Security (2019)

Coherent Neutrino Scattering

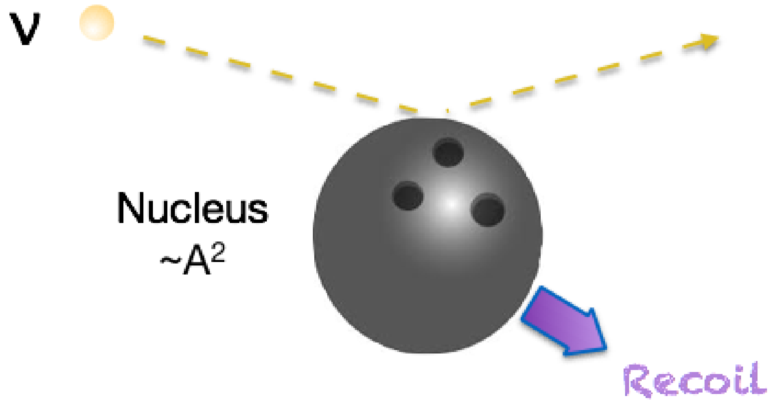
Coherent elastic neutrino-nucleus scattering (CEvNS)

- **A new process that achieves a huge increase in the probability for neutrinos to interact with matter**
  - **Significant reduction (10-100x) in required target mass**
  - **Technique recently demonstrated with high energy neutrinos from spallation source**



The Super-Kamiokande detector in Japan, which helped establish neutrino has a mass (a violation of the Standard Model).

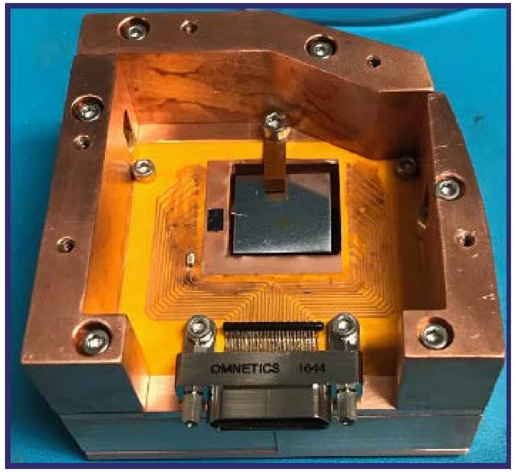
Target: 50 kilotons of water

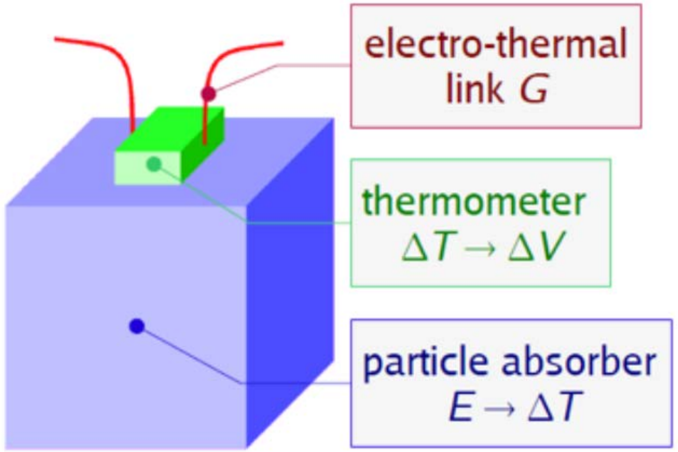


16 kg NaI detector from COHERENT collaboration

Superconducting Bolometers For Neutrino Detection: The Ricochet Collaboration

Overall goal: Detect neutrinos from a nuclear reactor using coherent scattering



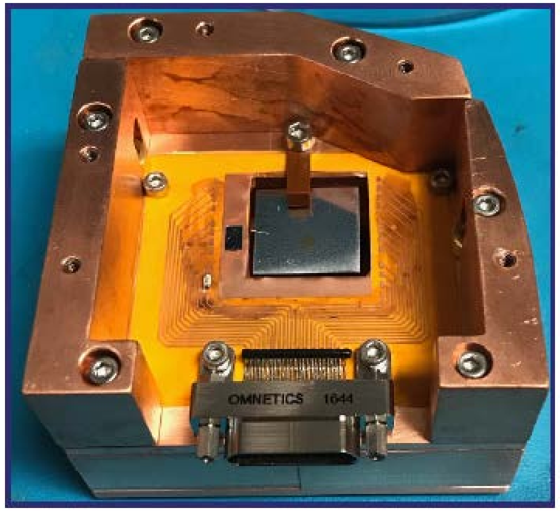


Using low temperature bolometers in order to detect coherent elastic neutrino nuclear scattering (CEvNS).

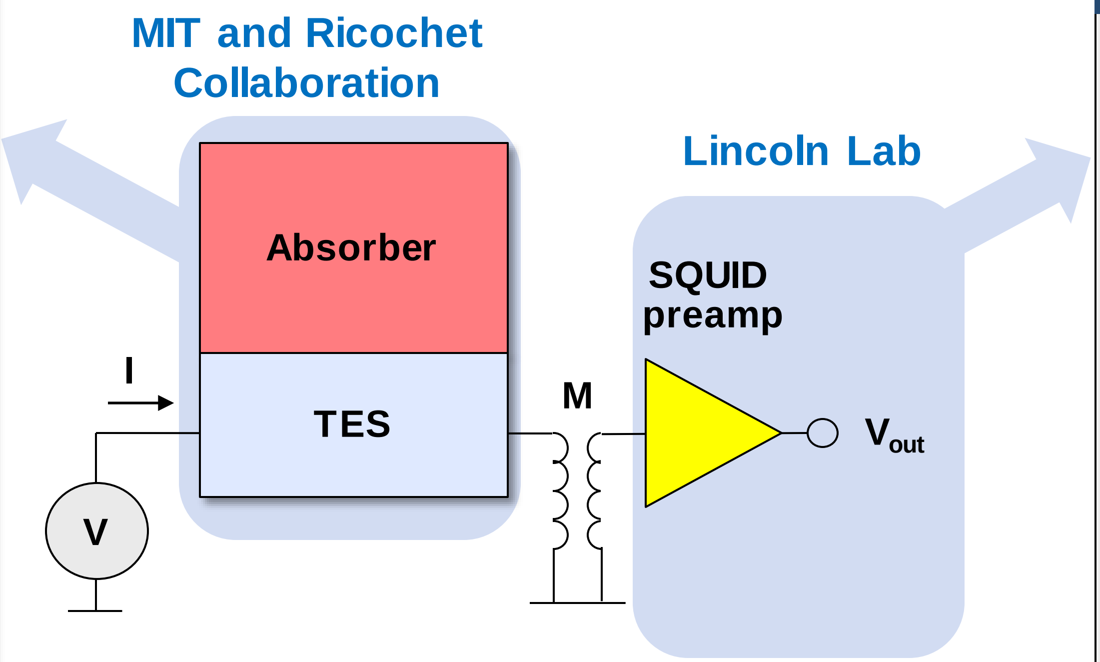
Plan to measure process from nuclear reactors. (ILL, Grenoble France)

Superconducting Bolometers for Neutrino Detection

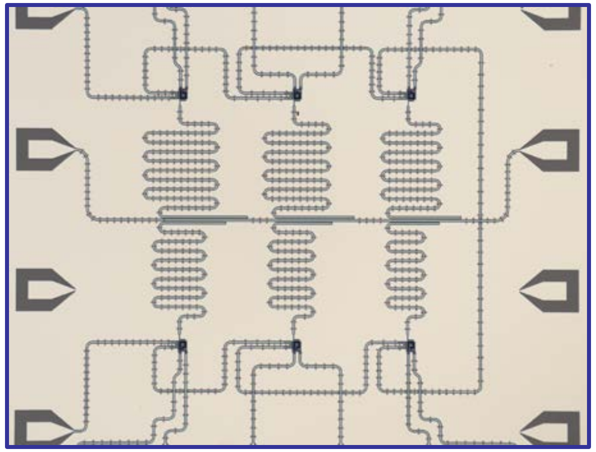
High-sensitivity bolometers



- Low temperature transition edge sensors
- Superconducting target material



High-sensitivity readout



- Use high-Q aluminum process to reduce noise
- Optimizing design parameters for high sensitivity

Summary

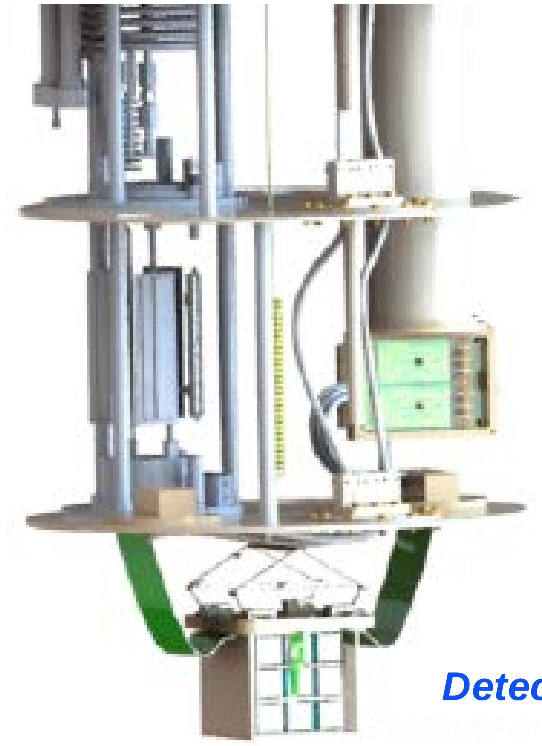
- Neutrino detection is a proven capability for monitoring nuclear reactors.
- Any deployable monitoring system will face tradeoffs between detector size, standoff distance, and detection rate.
- The CEvNS process may enable a significant reduction in detector size.
- The Ricochet Collaboration is working to demonstrate a first detection of reactor neutrinos via CEvNS.

Backup Slides

Technical Approach

Long-term goal: Detect neutrinos from a nuclear reactor using coherent scattering

- Technical challenge: Recoil energy from a nuclear reactor neutrino is 100x smaller than that from a spallation neutron source
  - Low energy thresholds are required (< 100 eV)
- Proposed solution: Use an array of *superconducting bolometers* with highly sensitive amplifiers
  - Small target size lowers the heat capacity; increases sensitivity to small ΔT
  - An *array* of these detectors increases the target mass to interact with neutrinos



Lincoln Lab effort: Develop arrays of highly-sensitive superconducting amplifiers for detecting reactor neutrinos

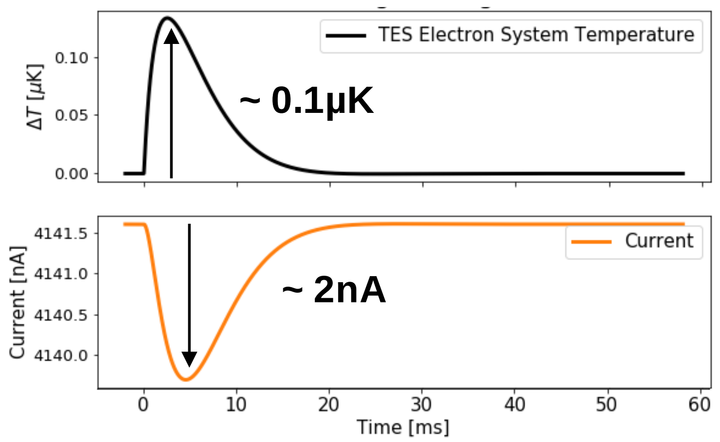
Readout Requirements

- **Long-term goal:** detect <100 eV neutrinos
  (with ~1 kHz detection bandwidth)
- **Current noise requirement:** <3 pA/$\sqrt{\text{Hz}}$
  (using an array of 25 g Zn targets and 15 mK TESs)

Microwave Multiplexed Readout

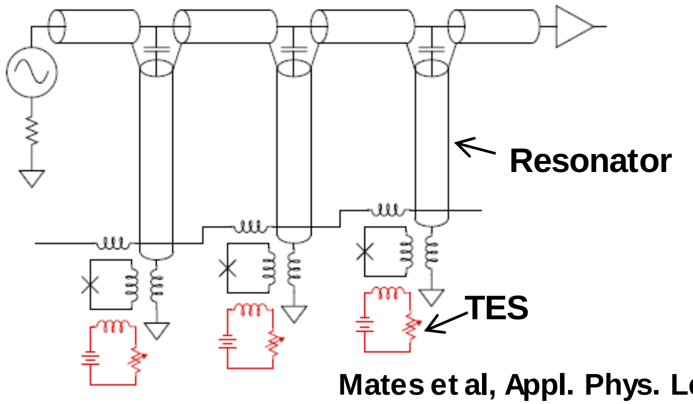
- Enables high-density arrays with limited control lines
- 128 TES readout demonstrated on the NIST SLEDGEHAMMER gamma-ray spectrometer
- **State-of-the-art current noise:** 19 pA/$\sqrt{\text{Hz}}$

Simulated Results for 100 eV Neutrino



Simulation courtesy of Doug Pinckney

Readout Schematic



Mates et al, Appl. Phys. Lett. (2017)

Need to improve readout arrays to achieve required noise performance

Amplifier Design Optimization

- New amplifier designs
  - Exploring design space to optimize for sensitivity
  - Using high-Q Aluminum fabrication process
  - Design variations targeting current noise as low as 1 pA/$\sqrt{\text{Hz}}$

Microwave Multiplexed Readout

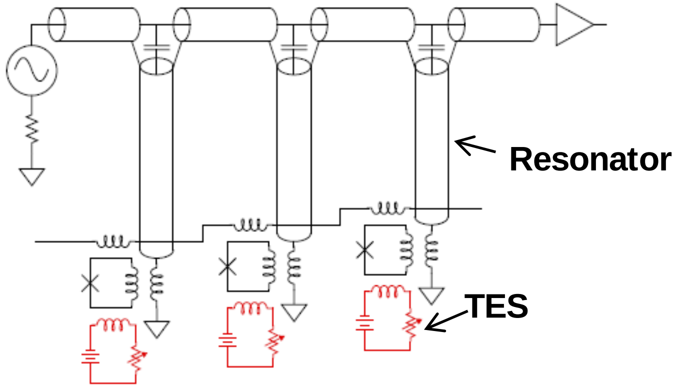


Image of 6-channel prototype