The Cryogenic Underground Test Facility at SNOLAB

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Need for low-temperature low-background facility

- Some of the most competitive low-mass dark matter search limits come from cryogenic detectors.
- A low background environment becomes essential for studying such detectors.
- A low-temperature low-background facility benefits development of technologies that use superconductivity or superfluidity.

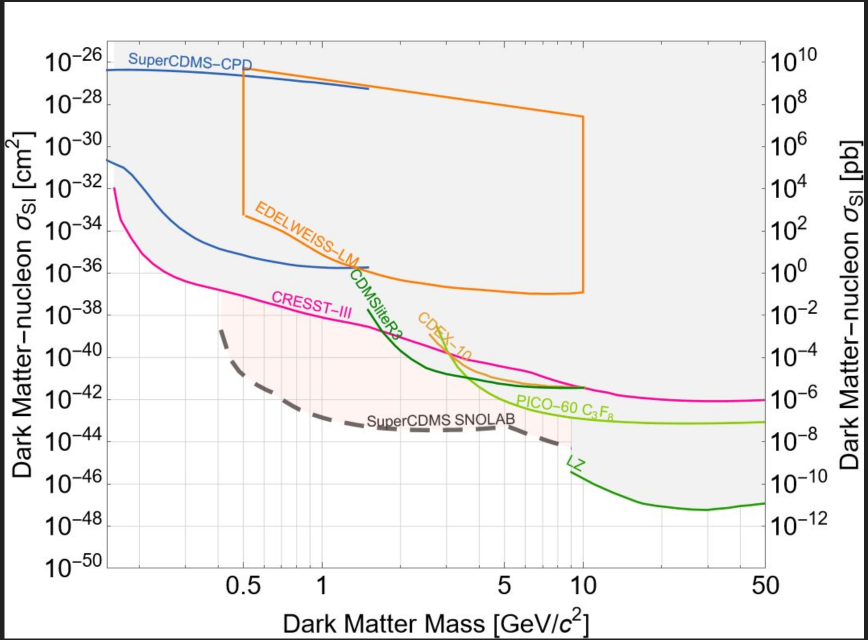


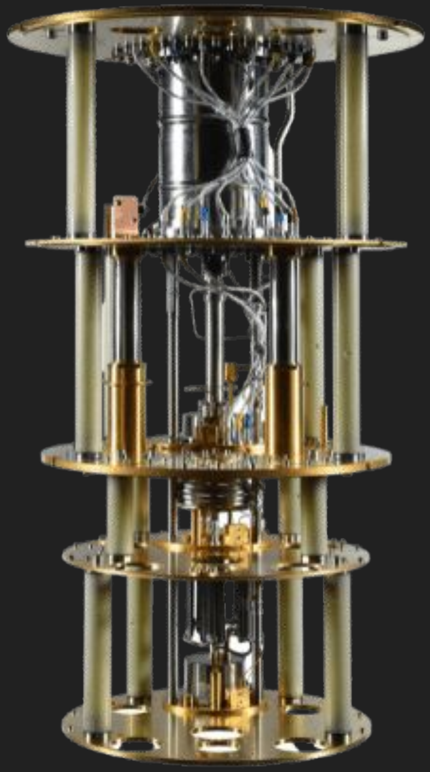
Image credit: SuperCDMS dark matter limit plotter

The Cryogenic Underground TEst facility

CUTE: A Cryogenic Underground TEst facility at SNOLAB. *Front. Phys.* 11:1319879. doi: 10.3389/fphy.2023.1319879

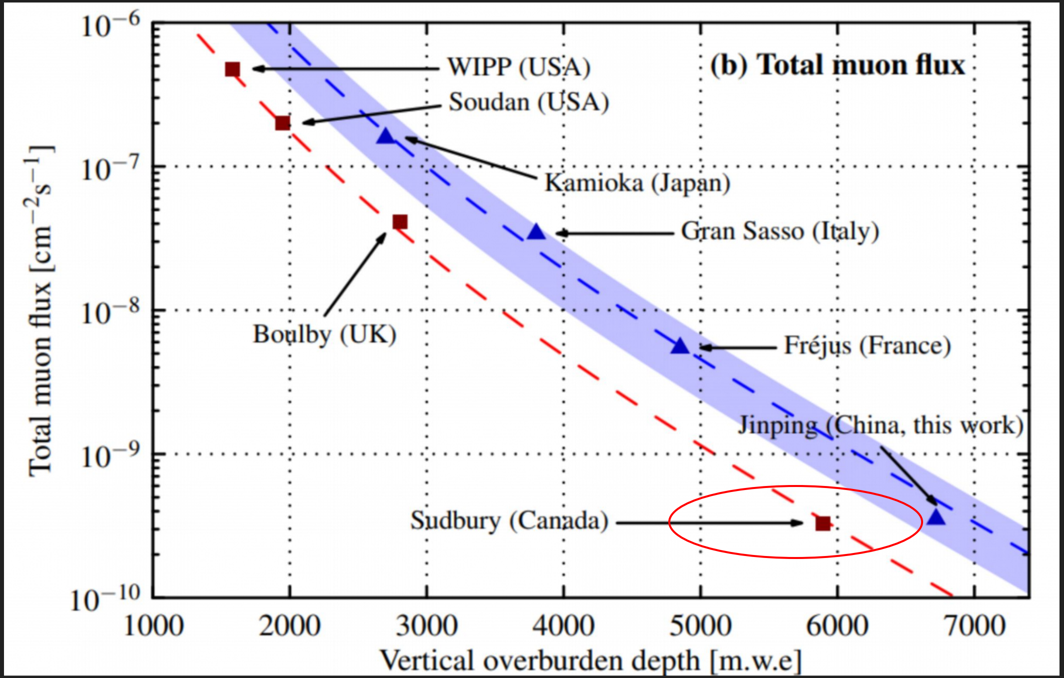
Published: 11 January, 2024

Cryogenic



- Has a dry dilution refrigerator.
- Base temperature: ~12 mK with payload.
- Up to a 20 kg payload.
- Thermal Cycle: ~1 week
  - 3.5 days cooldown.
  - 3 day warm-up.
- Can run unattended for extended periods (order of months).

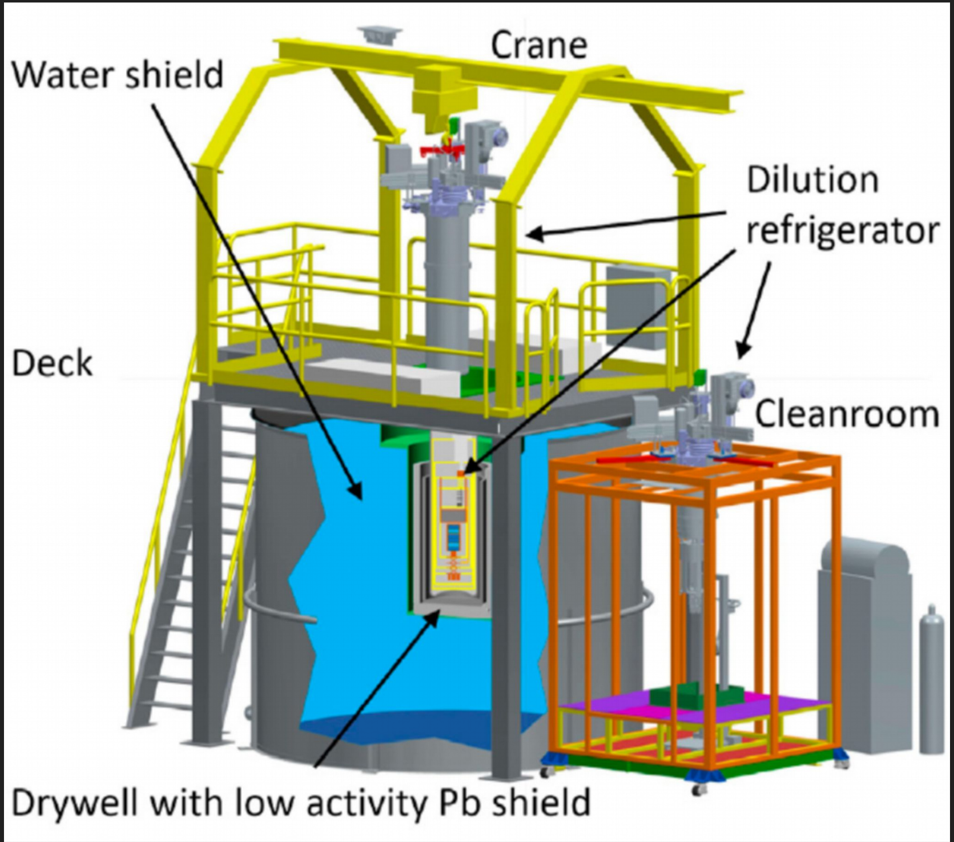
Cryogenic Underground

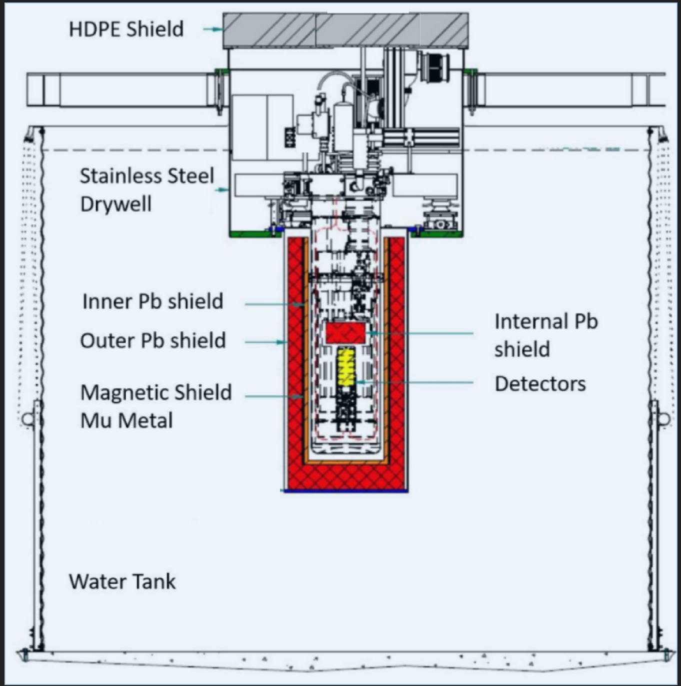


[Zi-yi Guo *et al* 2021 *Chinese Phys. C* **45** 025001]

SNOLAB: One of the lowest muon flux environments in the world.

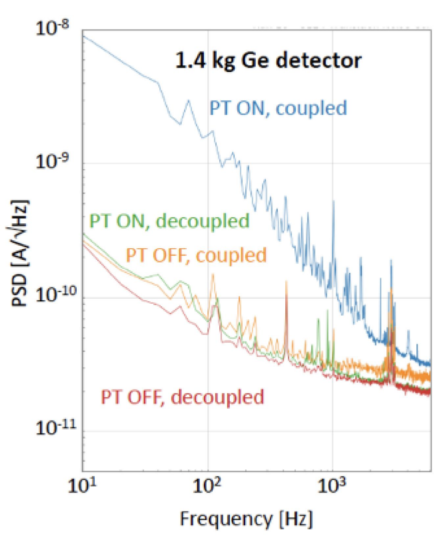
Cryogenic Underground TEst facility





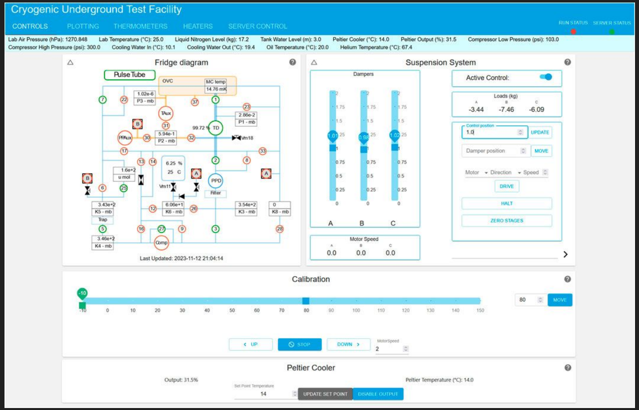
Provides: Shielding against gammas and neutrons, mu-metal for reduction in magnetic fields, an active Rn purge.

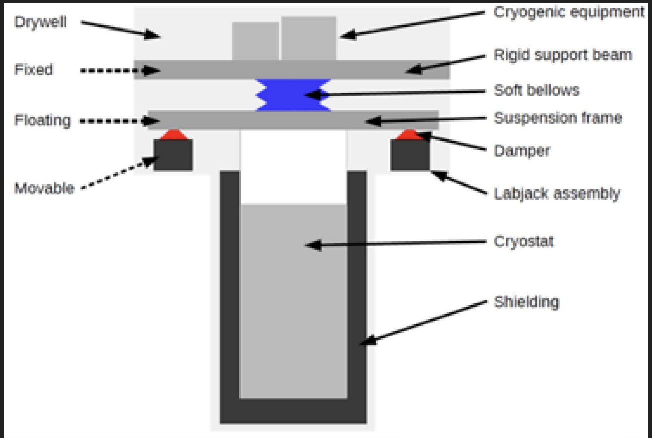
Cryogenic **U**nderground **TE**st facility



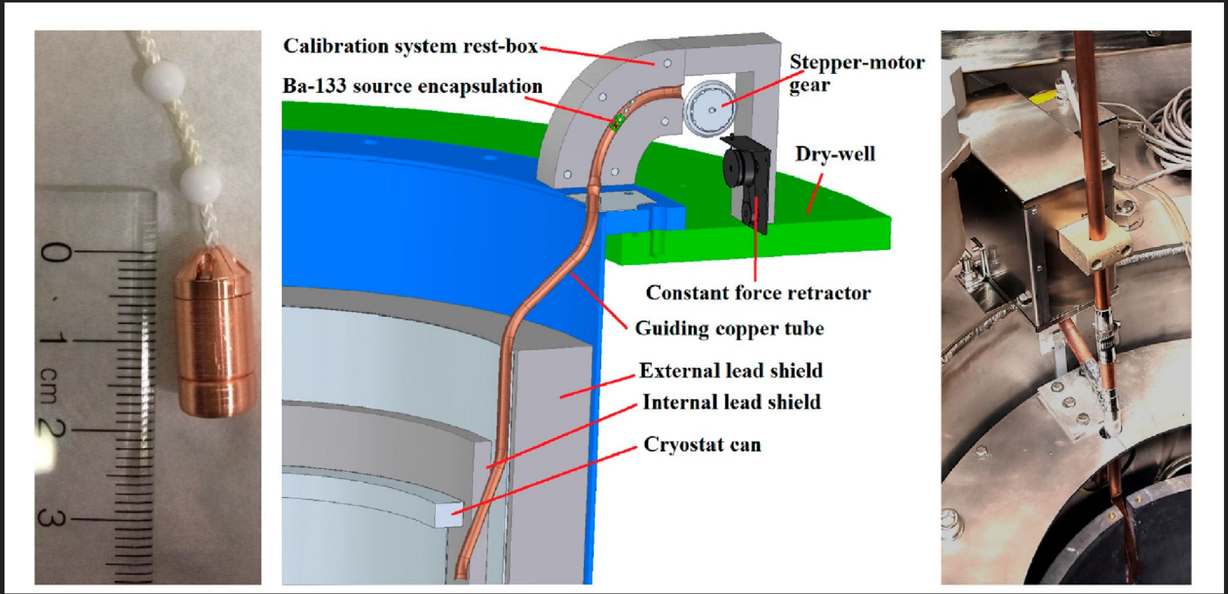
- Cryogenic devices can be highly sensitive to vibrations.
- Cryostat and pulse tube are decoupled through a suspension system.

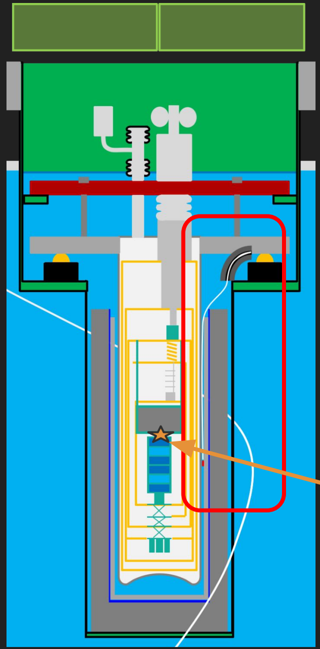
The slow controls webpage





Cryogenic Underground TEst facility

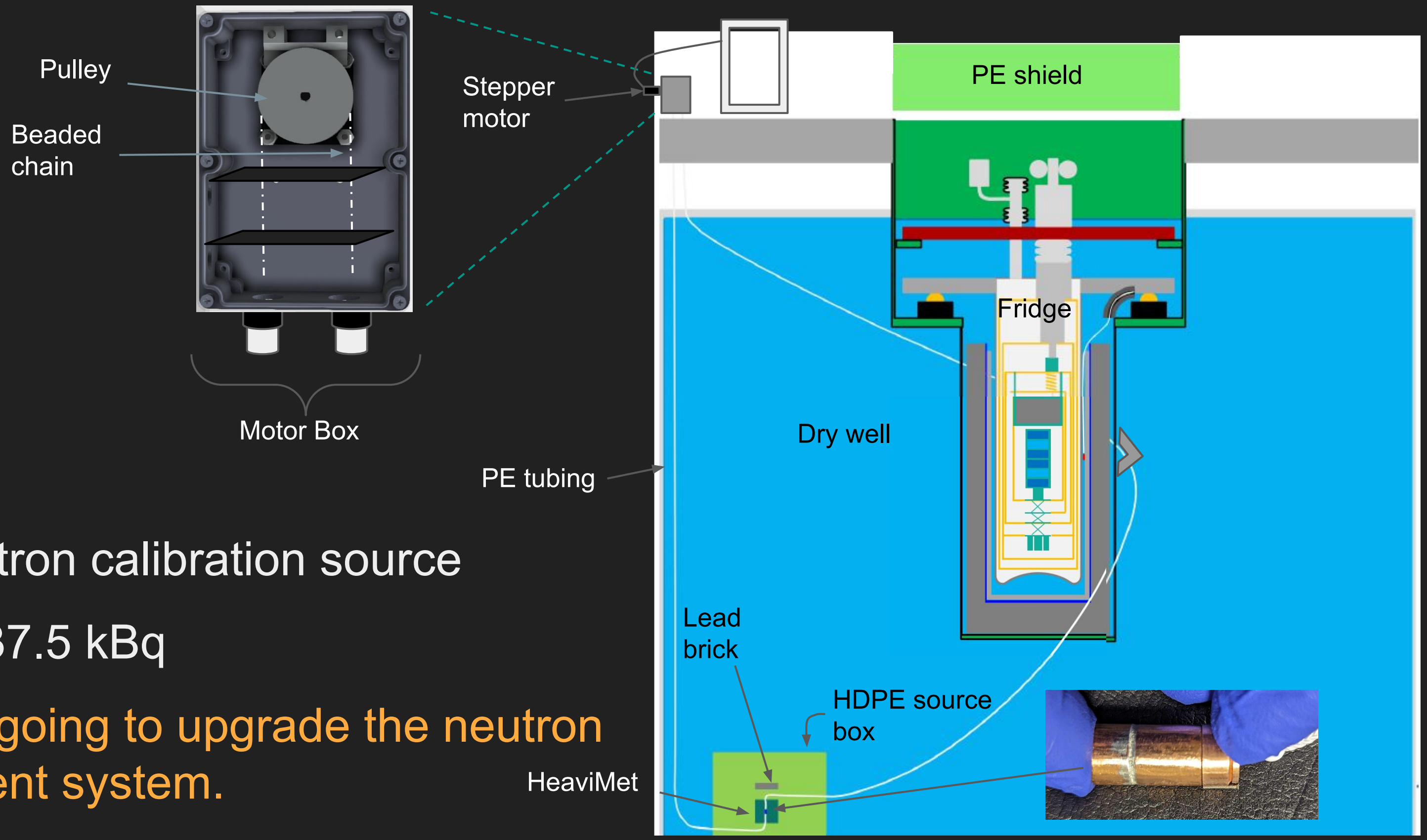




Gamma sources at CUTE

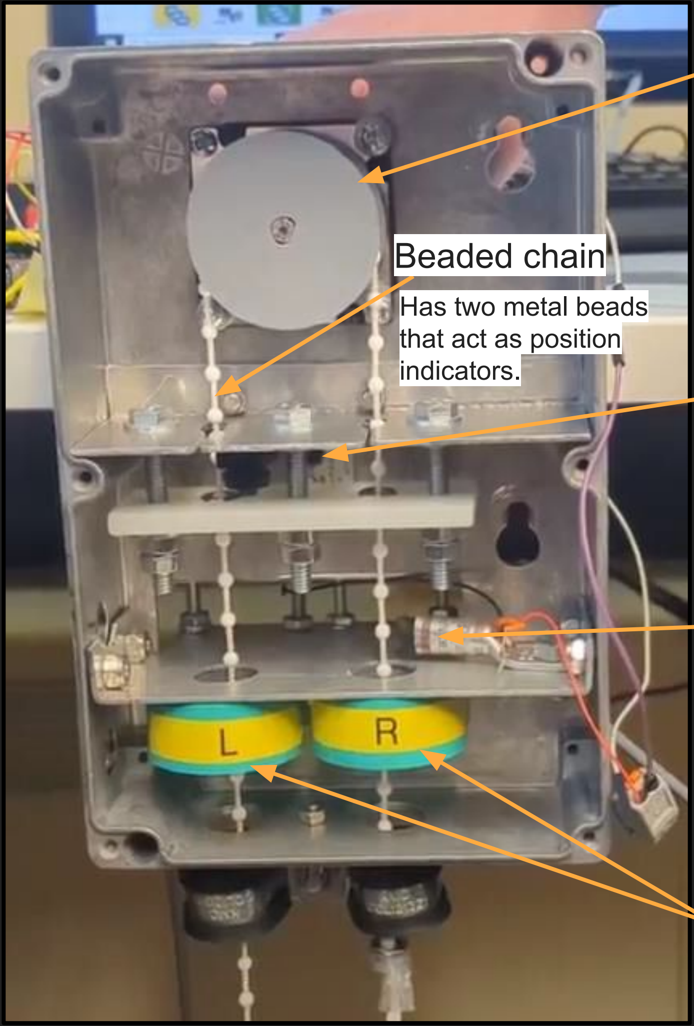
- ^{133}Ba calibration source (356 keV gammas, 37 kBq)
  - Can be deployed along the length of the cryostat
  - **Work planned this summer on upgrading this system for ease of implementation and accessibility.**
- ^{55}Fe source (5.9 keV) with Al fluorescence (1.5 keV) available for mounting inside the cryostat.

Cryogenic Underground TEst facility



- ^{252}Cf neutron calibration source
- Activity: 37.5 kBq
- Work on-going to upgrade the neutron deployment system.

Motor controls



Beaded chain

Has two metal beads that act as position indicators.

Pulley/sprocket attached to stepper motor

- Has groves for the beads to sit in so chain doesn't slip.
- A keeper to prevent chain from falling out

Push button

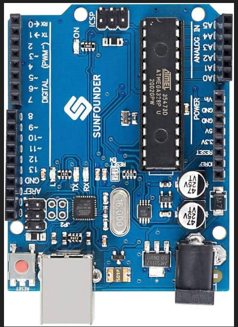
- Normally closed.
- Will create an open-circuit when engaged.

Motion sensor

- Provides a live graph when chain is in motion.
- Pattern of the graphs gives indication of its state.

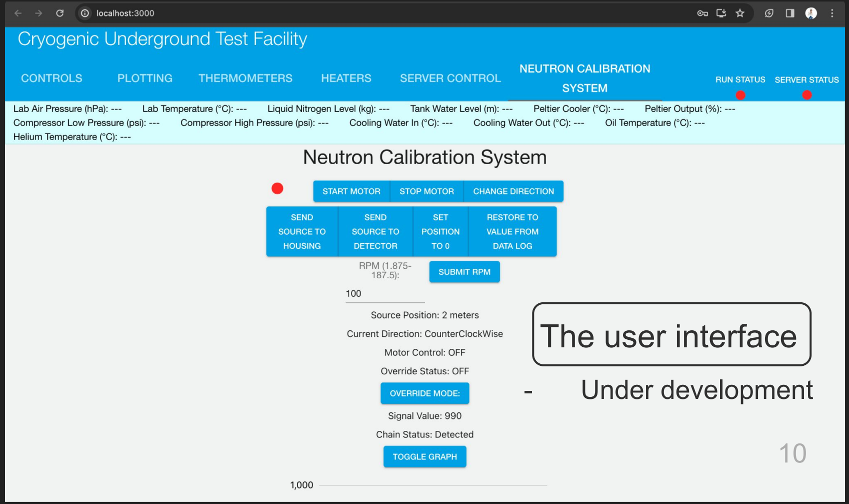
Induction sensors

- Detect the metal beads.



The microcontroller

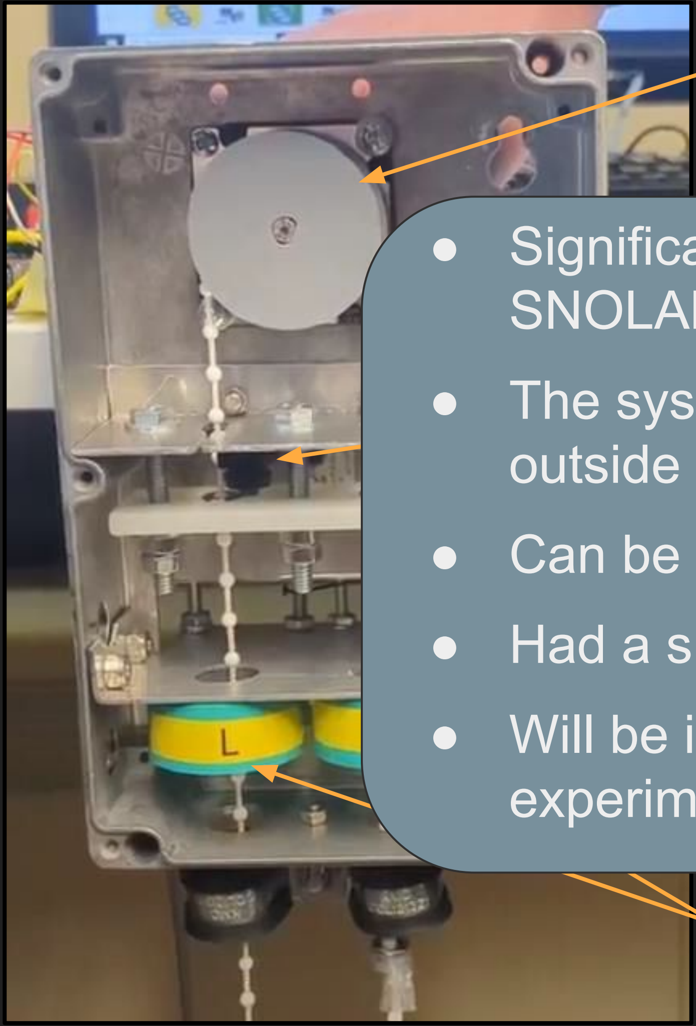
- Programmed to control the stepper motor and sensor functions.



The user interface

- Under development

Motor controls



Pulley/sprocket attached to stepper motor

- Has groves for the beads to sit in so chain doesn't

roller

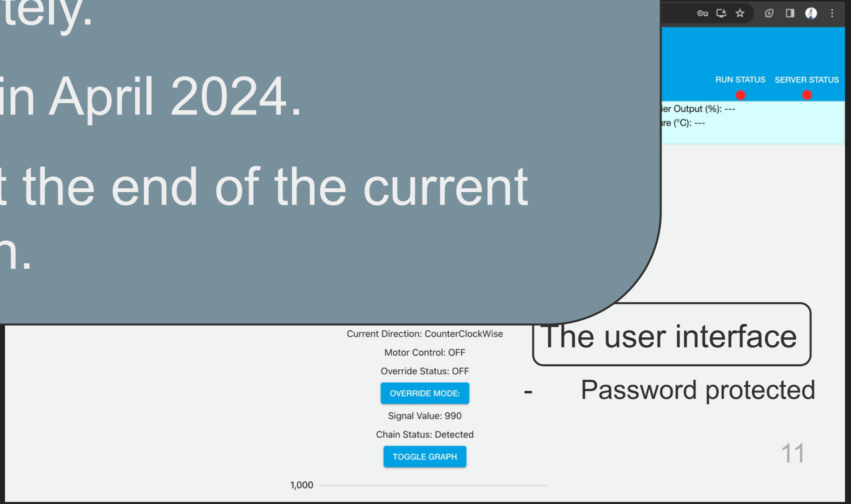
control the

nd sensor

- Significant contributions in this effort from SNOLAB co-op students.
- The system has been successfully tested outside the water tank.
- Can be operated remotely.
- Had a successful IRR in April 2024.
- Will be implemented at the end of the current experimental campaign.

Induction sensors

- Detect the metal beads.



The user interface

- Password protected

Projects at CUTE

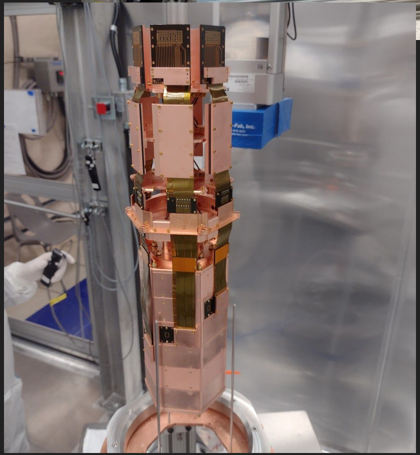
Past : SuperCDMS HV tower test
Present : HVeV run at CUTE
Future : Characterising superconducting qubits

SuperCDMS HV tower test

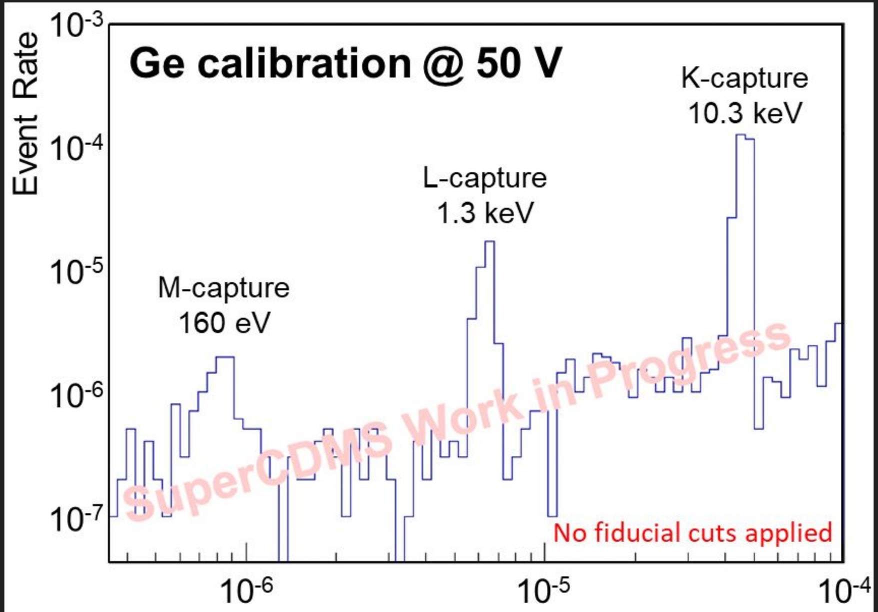
- HV: High voltage used for intrinsic signal amplification
- October 23, 2023 - March 13, 2024.
- A tower of 6 cryogenic detectors:
    - 2 Silicon and 4 Germanium.
    - 33.3 mm thick, 100 mm diameter.
    - Each Ge detector = 1.39 kg, Si detector 0.61 kg.
    - Operated at a max voltage of 100 V.

Major milestone

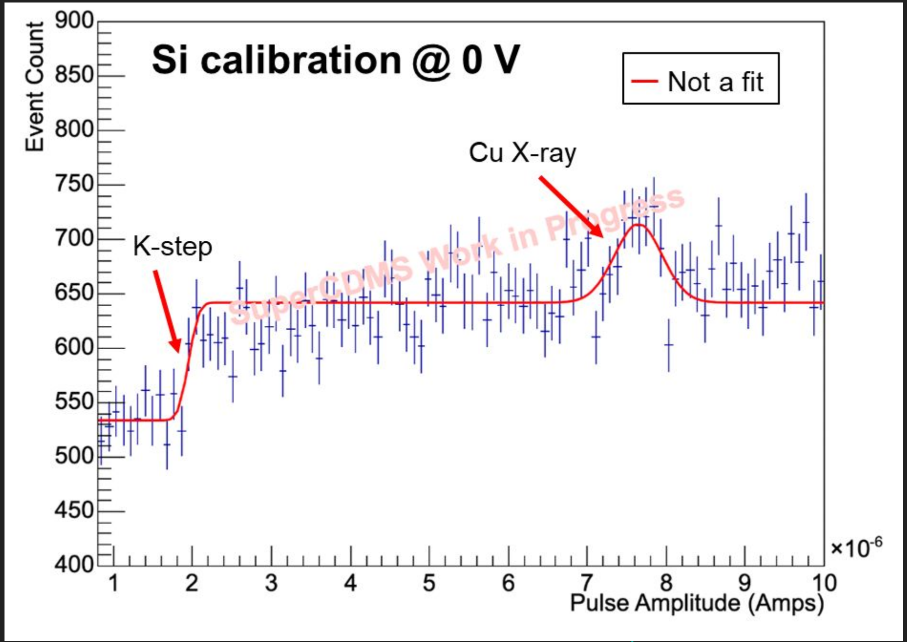
- ~151 days covering 4 thermal cycles.
    - ~2 months of calibration data.
    - ~2 weeks of low background data.
    - Several weeks on sensor performance testing, HV testing, developing detector conditioning protocols.



SuperCDMS HV tower test



"First Glimpses of the SuperCDMS High Voltage Detectors", Y. Liu, CAP Congress 2024.



Peaks from Germanium activation due to neutron irradiation

Demonstrating calibration method for Si detectors was an important goal for CUTE tower testing

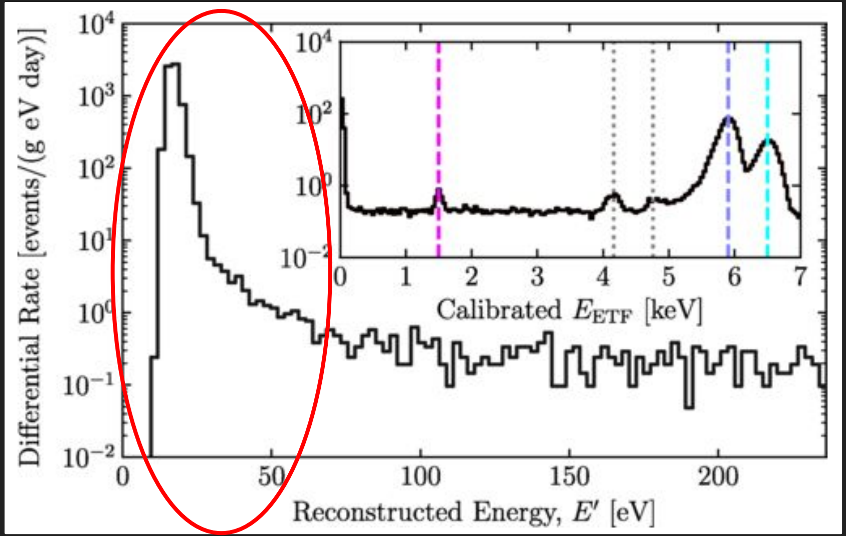
SuperCDMS HV tower test

- CUTE was originally conceived as a test bed for SuperCDMS detectors at SNOLAB.
- SuperCDMS tower testing was the first major use-case for CUTE.
- Major milestone for both, SuperCDMS and CUTE.
- Since 2021 CUTE is transitioning to a SNOLAB facility.

HVeV run at CUTE - ongoing

- Modern rare event search experiments have reached sub-eV recoil energy threshold.
- At energies below 1 keV, many experiments observe an excess of events.
- The cause for this low energy excess (LEE) is unknown.
- Strongly impacts the sensitivities at low energies.

“Light Dark Matter Search with a High-Resolution Athermal Phonon Detector Operated above Ground”, SuperCDMS Collaboration, Phys. Rev. Lett. 127, 061801



SuperCDMS Cryogenic PhotoDetector (CPD)

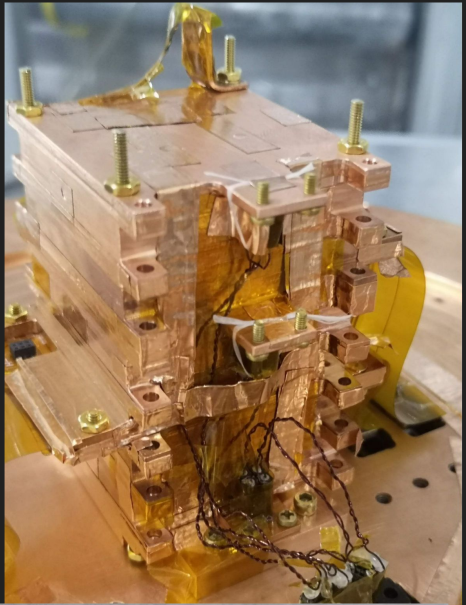
HVeV run at CUTE - ongoing

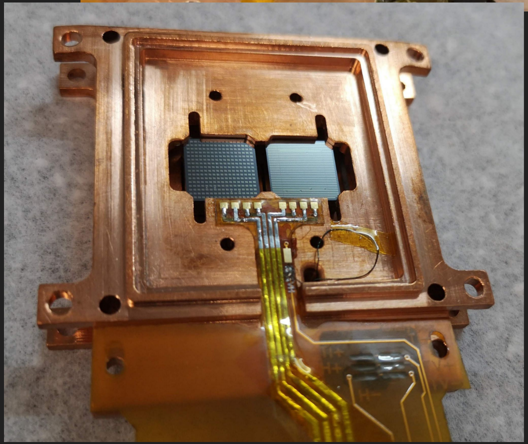
Goal: Investigate origin of LEE.

- Is it a fully detector intrinsic background, or does switching to “quieter” facility affect it ? Can be resolved by comparison to data taken elsewhere.
- Is the LEE impacted by vibrations ?
- Study LEE rate as a function of time since cooldown.
- Does LEE change with voltage bias ? If so, how ?
- Do external radiation sources (Ba/Cf) affect it?
- Does sensor layout affect the LEE ?

HVeV run at CUTE - ongoing

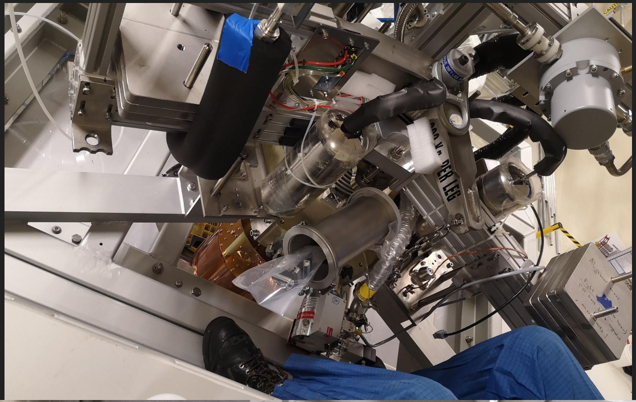
- Running a tower of six detectors,
  - Mass: 1 g per detector
  - Material: Silicon
  - Baseline energy resolution: O(1 eV).
- Detector tower was put into CUTE at the end of March after SuperCDMS HV tower run.
- Current run plan will go to mid-August.

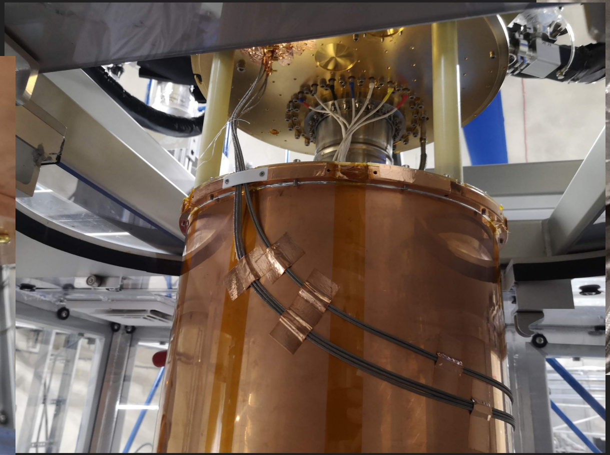
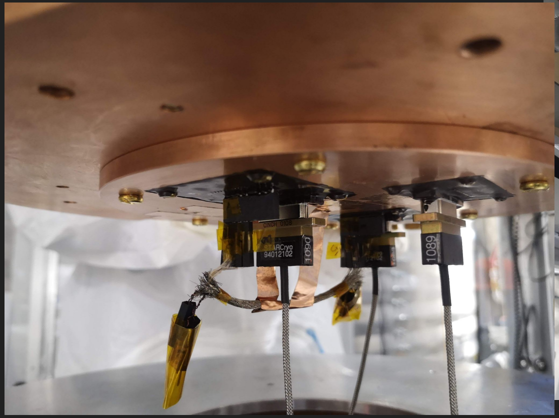




HVeV run at CUTE - ongoing

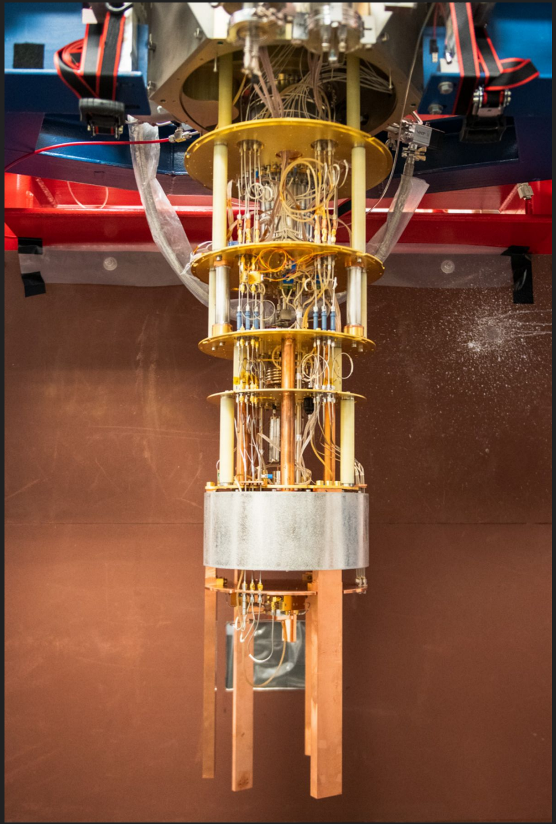
- Uses SuperCDMS Detector Control and Readout Cards
- Designed and implemented new cabling solution.
- Implemented new vacuum feedthroughs for cabling.



Characterising superconducting qubits at CUTE

- Collaboration between SNOLAB, University of Waterloo and Chalmers University.
- Study of qubits in a low-radiation environment.
- Understand how ionizing radiation affects the coherence of qubits and causes correlated errors.
- Large upgrade required to the fridge setup for readout cabling.
- See talk given by Richard Germond on 26 June, 2024, at 4:25 PM for more details.
    - Indico presentation link



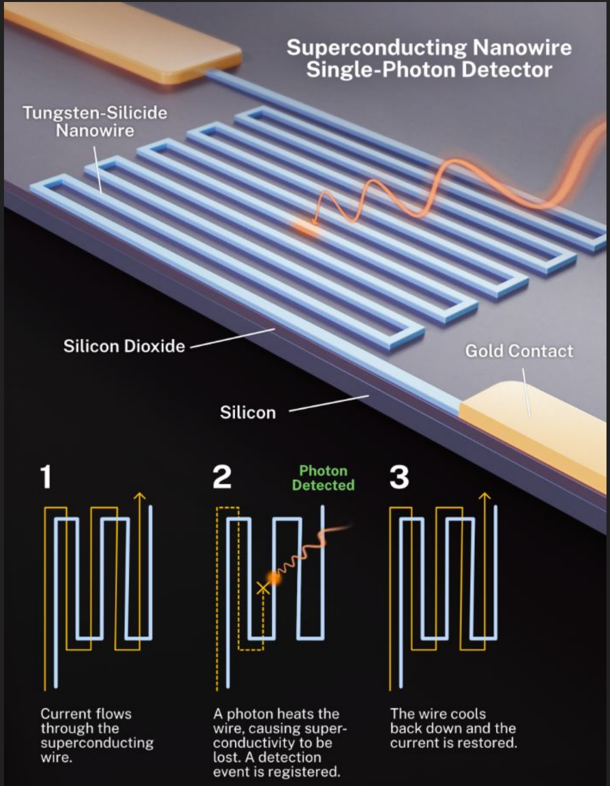
Cabling for qubit readout in a similar refrigerator.

Summary and conclusion

- CUTE is a SNOLAB user facility that provides a low background, low temperature, vibrationally isolated environment.
- Successfully ran SuperCDMS tower for 5 months.
- HVeV project is currently investigating the LEE.
- Qubit investigation in the coming fall/winter.
- If you have a project you would like to run at CUTE:
    - Contact: cute_proposals@snolab.ca.

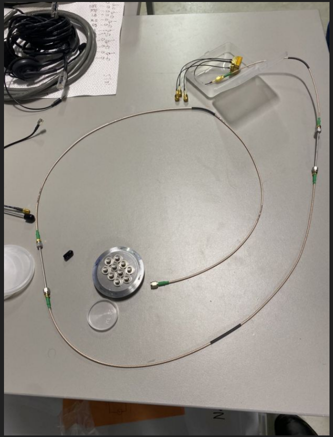
Back up

Projects at CUTE - Past (Superconducting nanowires)



Credit: S. Kelley/NIST

- Collaboration between SNOLAB and NIST.
- Purpose: Understand the non-ionizing radiation environment at CUTE.
- Important as we move to lower and lower energy threshold.



- Measures the infrared photons using Superconducting Nanowire Single-Photon Detectors (SNSPDs).
- Potential for dark matter searches as well.

- 8.7 cm of low-activity lead in the sides of the drywell
- 13 cm of low-activity lead in the bottom of the drywell
- 2 cm of low-activity lead in drywell as inner gamma shield
- 15 cm lead encased in coppe
- Mu-metal shielding reduces the magnetic field by a factor of 50.
- Water tank 3.5 m diameter. 1.5 m shielding sides, 1 m shielding bottom. Reduces external gamma radiation by factor of 200.
- 20 cm of HDPE
- 200 micro Watt Cooling Power

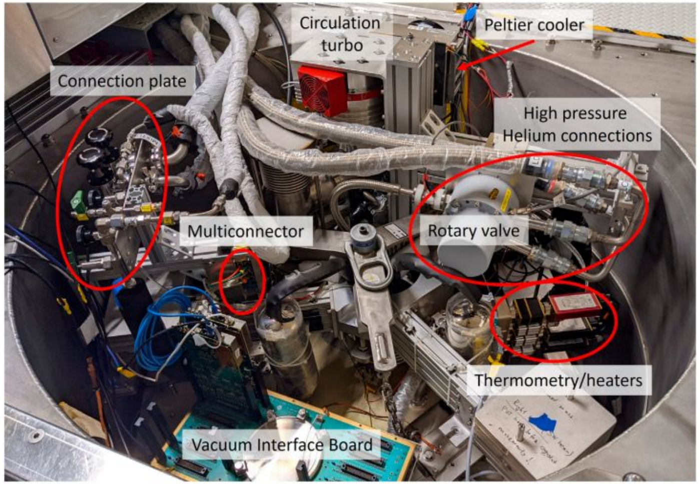


FIGURE 2
Top view of the cryostat when installed and fully connected in its operating location inside the drywell. Labelled in the picture are (starting near the centre and going clockwise): the multiconnector for the pressurized air lines for the pneumatic valves; the connection plate collecting all vacuum and helium-mixture lines that need to be disconnected for moving the fridge; the turbo pump for the helium mixture, and attached behind it the Peltier cooler; the connection points for the high-pressure helium lines, next to the rotary valve the thermometry and heater connections; and the Vacuum Interface Board (VIB) for connecting the SuperCDMS readout electronics.

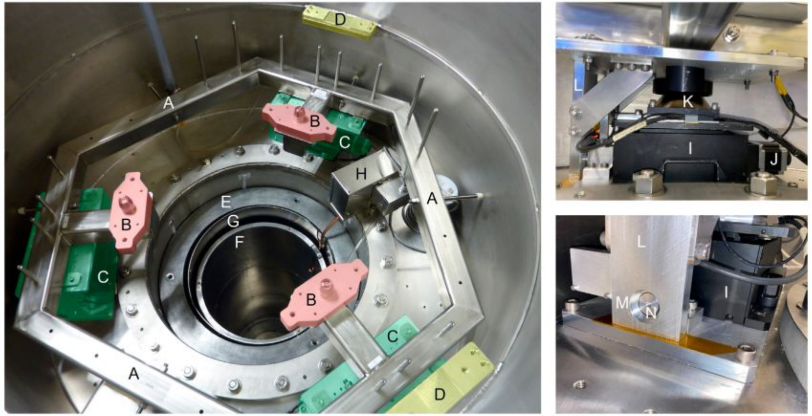


FIGURE 3
Left: The suspension system's steel frame **(A)** with the mounting points for the cryostat [**(B)**, red highlights] sits on three dampers (damper assemblies **(C)** highlighted in green) to mechanically isolate the cryostat from the vibrations transmitted through the drywell. Also visible are two of the mounting points **(D)** for the upper part of the refrigerator on the drywell (yellow highlights), as well as the shielding inside the lower part of the drywell (outer **(E)** and inner **(F)** layers of lead with a thin magnetic shield **(G)** in between; see Sec. 5). Located on the top right in the left picture is the gamma calibration system **(H)** (see Sec. 6). Top right: one of the three damper assemblies. A labjack **(I)** (black) driven by a stepper motor **(J)** (to the right of the labjack) sits on the drywell; the elastomer cup damper **(K)** is mounted on the movable stage of the labjack and carries the suspension frame. The positions of both, the movable labjack stage and the suspension frame are measured relative to the drywell (see text). Visible to the left of the labjack is a vertical aluminum bar **(L)** rigidly attached to the suspension frame. Right bottom: The vertical aluminum bar has a circular cutout **(M)**. A rod **(N)** attached to the drywell penetrates this cutout with a nominal clearance of 1.0 mm all around, limiting the movement of the suspension frame relative to the drywell.

The 50K and 4 K stages are cooled by a pulse-tube cryocooler (PTC), while the lower thermal stages are cooled by the dilution unit (DU). In order to minimize the coupling of vibrations from the PTC into the cryostat, CryoConcept developed a technique that avoids mechanical connections between the cold stages of the PTC and the cryostat (the Ultra-Quiet Technology™, UQT). Thermal contact is instead provided by the helium mixture that pumped out of the Still. This is achieved by installing the PTC's cold head inside the Still pumping line of the DU. Gold-plated copper disks with a concentric ring structure mounted on the cold head stages are interleaved with corresponding disks that are connected to the 50K and 4 K stages of the cryostat. This compact design provides a large effective heat transfer surface and a narrow gas gap (~1 mm) as the circulating gas meanders through the ring structure.

The sum of all components results in an event rate of 6.7 ± 0.8 events/keV/kg/day in the energy range from 1 to 1,000 keV which is in reasonably good agreement with initial measurements. About 10% of the rate is contributed by the detector stack itself. The major contributors to the background budget are the gammas from the SNOLAB cavern (~30%), the inner layer of the external lead shield (~20%) and the stainless steel of the OVC (~13%). The nuclear recoil rate is expected to be less than half an event/kg/day in the range from 1 to 50 keV.