The Cryogenic Underground Test facility (CUTE) at SNOLAB

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On behalf of the CUTE Collaboration

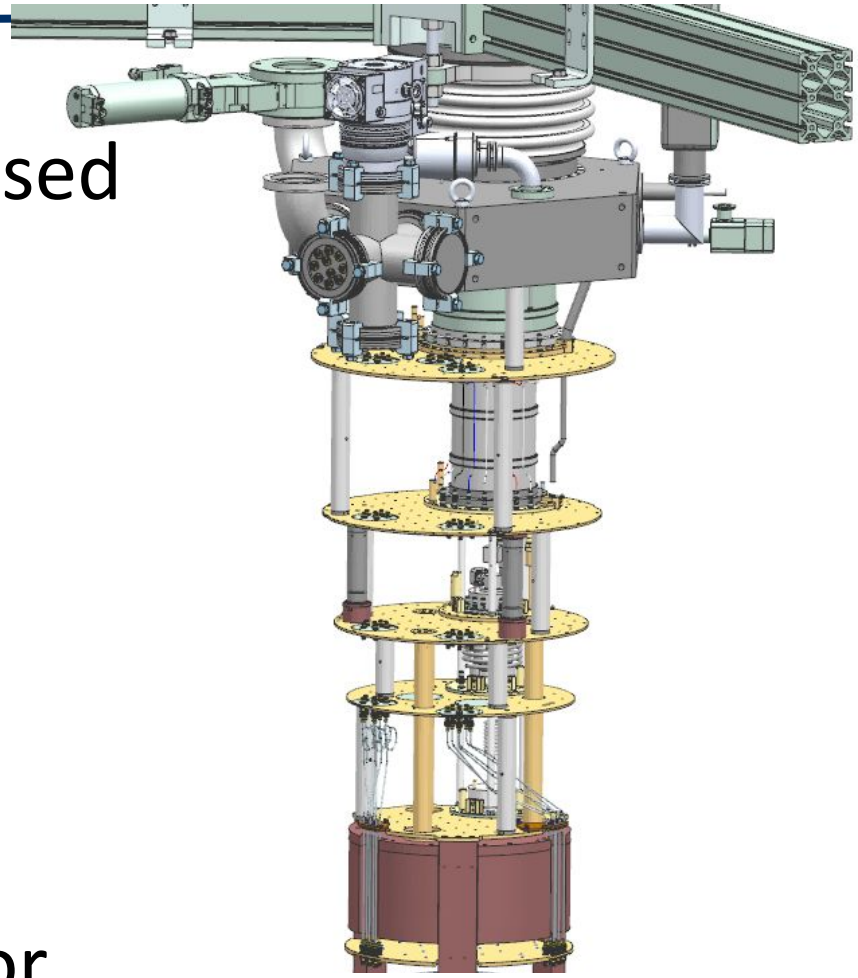
Aug. 28, 2025

Cryogenic Underground TEst facility (CUTE)

- Milli-Kelvin cryogenic technology + low background environment provides new opportunities
  - Dark matter search, neutrinoless double beta decay search, quantum sensing and computing, etc.
- CUTE@SNOLAB provides unique environment for testing and operating cryogenic devices
- Facility Paper: https://www.frontiersin.org/articles/10.3389/fphy.2023.1319879/full

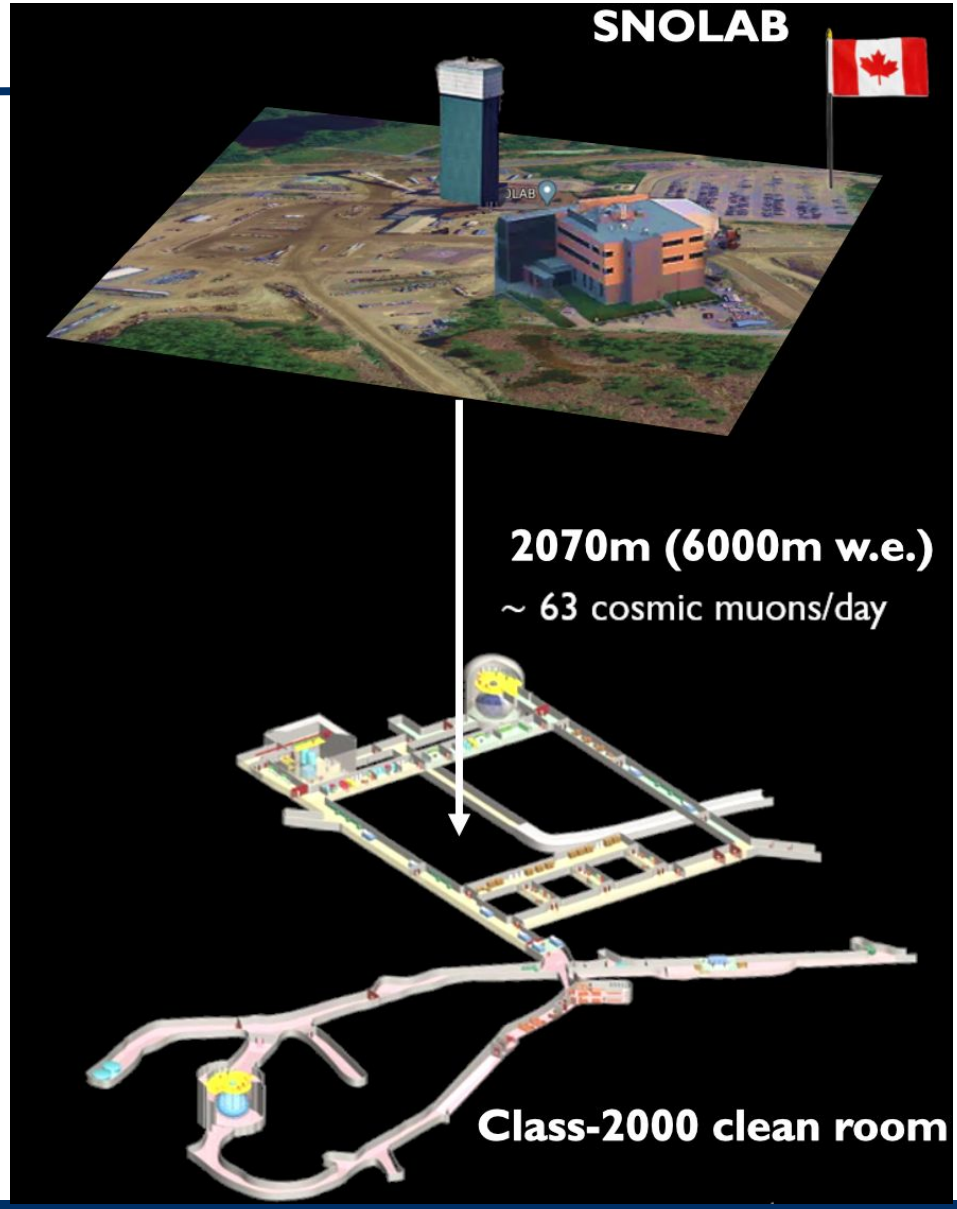
Cryogenic

- Pulsed-Tube-based Dilution fridge purchased from Cryoconcept
- Base temperature: **12 mK** with payload
- O(10 L) experimental space
- Can support up to a **20 kg** payload
- Cooldown Cycle: **1 week**
  - 3 day warm-up, 3.5 days cooldown
- Fridge can run with minimum attention for extended periods



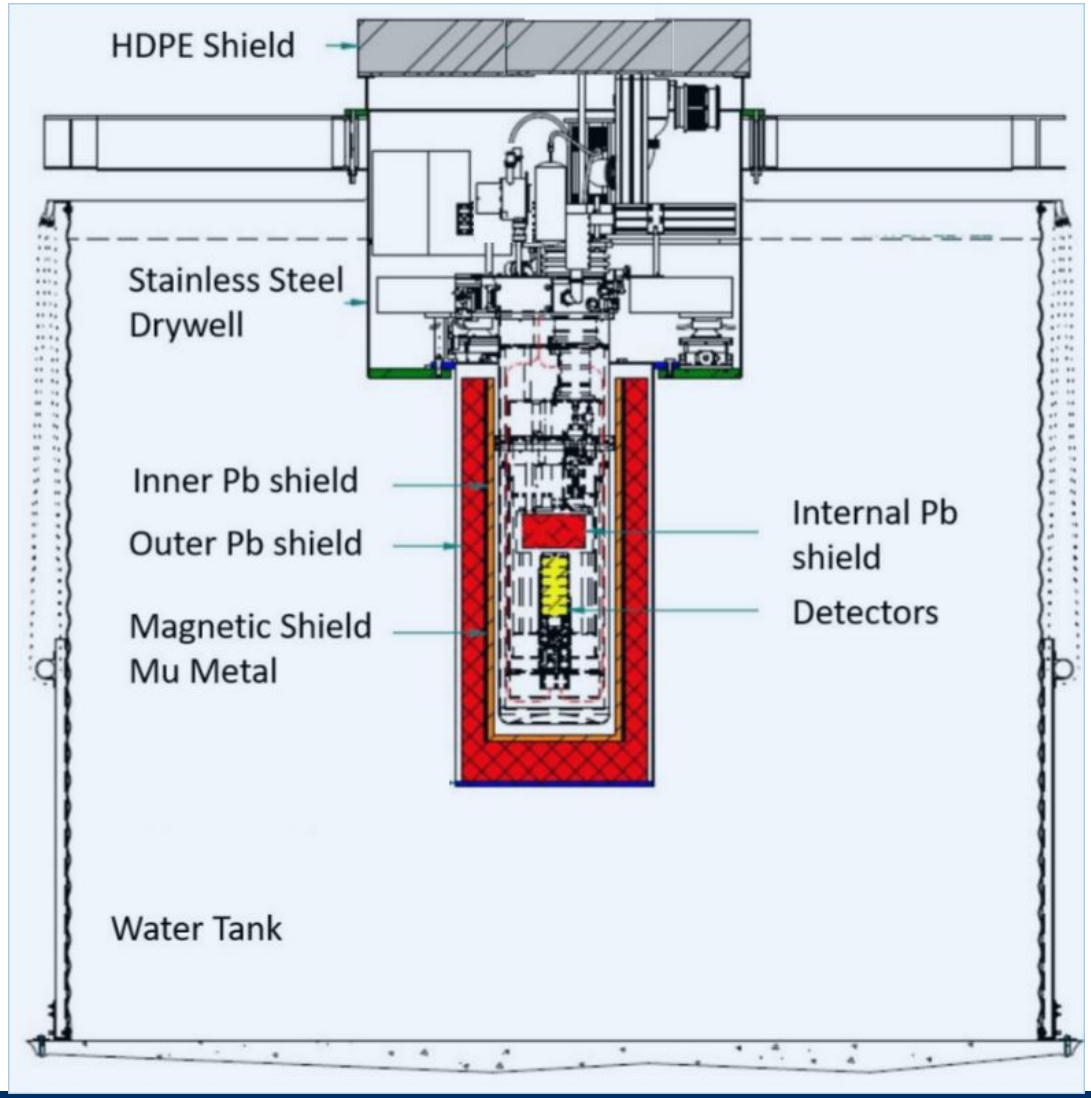
Underground Advantage

- SNOLAB is located at the active Vale-Creighton mine
- Just outside Sudbury, Ontario, Canada
- 2 km deep
- Entire lab is a class-2000 clean room
  - <2000 particle w/ >0.5µm in diameter per cubic foot
- Low muon flux
  - < 0.27 µ/(m^2 * day)
- Hosts rare event searches and low-background measurements



Underground Backgrounds

- Ambient backgrounds (gammas, neutrons and alphas) still present in SNOLAB
- Fridge inside drywell in a 3.5 m diameter water tank with 20 cm polyethylene lid for neutron shielding
- 10 cm of low-activity lead as additional gamma shield
- 15 cm internal lead “cake” for almost 4π shielding
- Low-radon air into the drywell

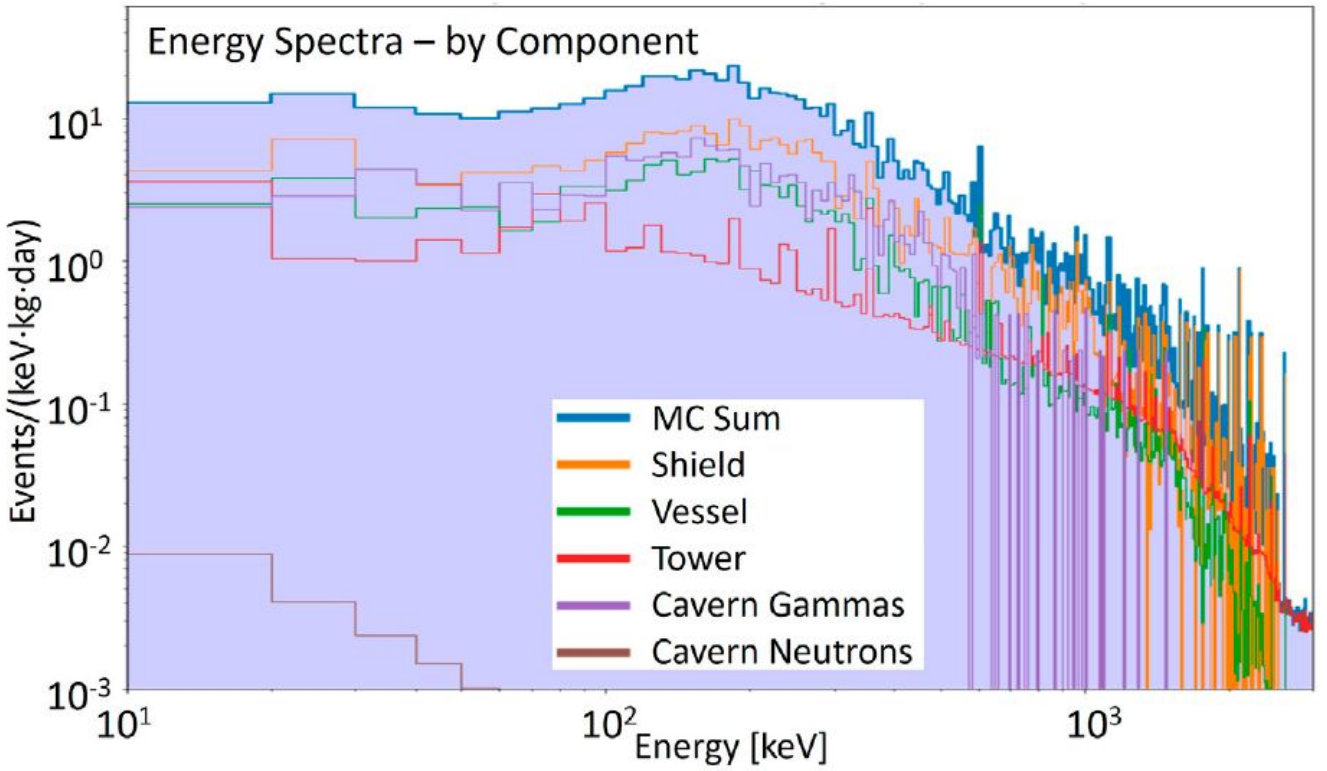


Low radon cleanroom for payload installation

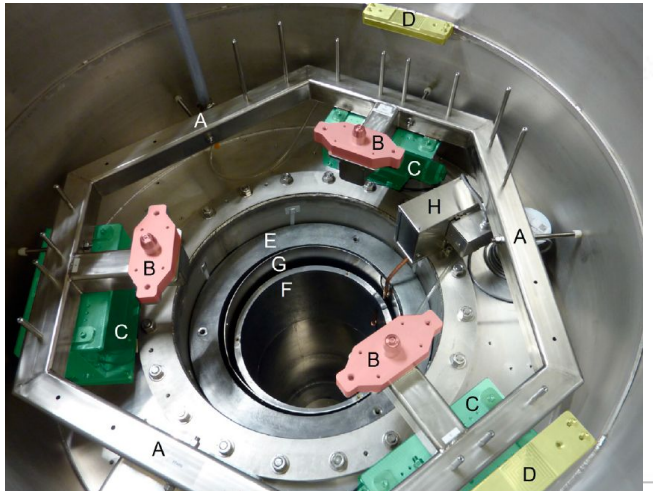
- Class 200, with Radon level < 10 Bq/m^3

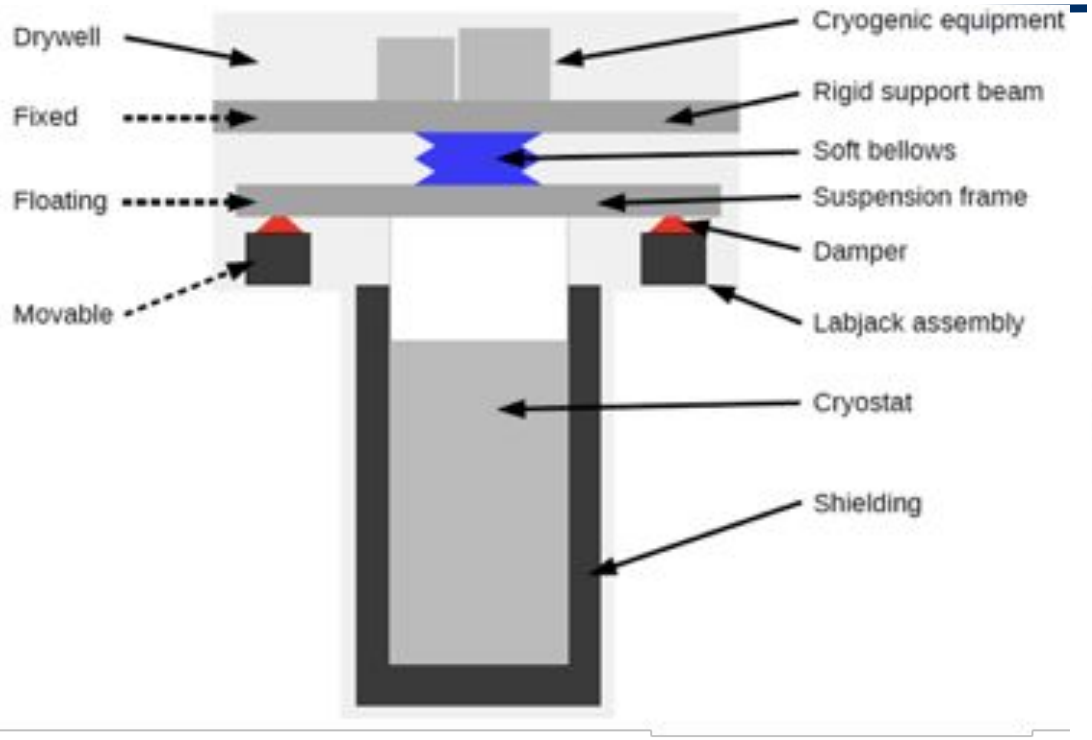
CUTE Backgrounds

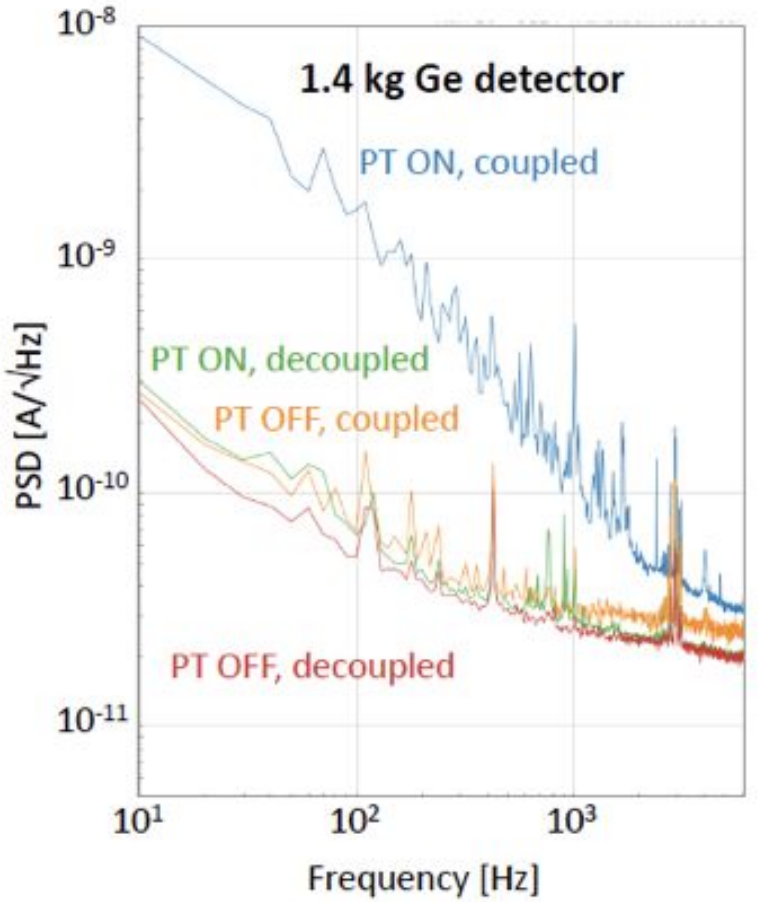
- Materials screened prior to use in CUTE
- Measured background 6.7 +/- 0.8 events/(keV*kg*day)
  - With a 600 g SuperCDMS style Ge detector
- < 0.5 event/(keV*kg*day) for nuclear recoils (simulation)
- The inner layer lead shielding (30%), SNOLAB cavern gammas (20%), OVC (13%)



Vibration



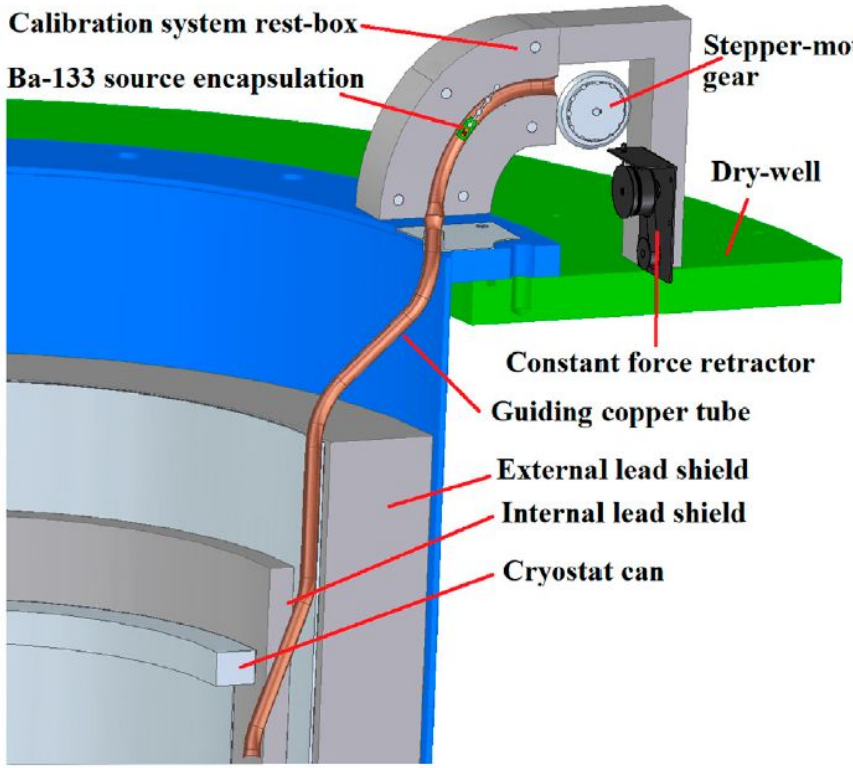




- Cryogenic devices are highly sensitive to vibrations and changing magnetic fields
- Cryostat and pulse tube are decoupled through a suspension system
- Mu-metal shielding reduces the magnetic field by a factor of 50

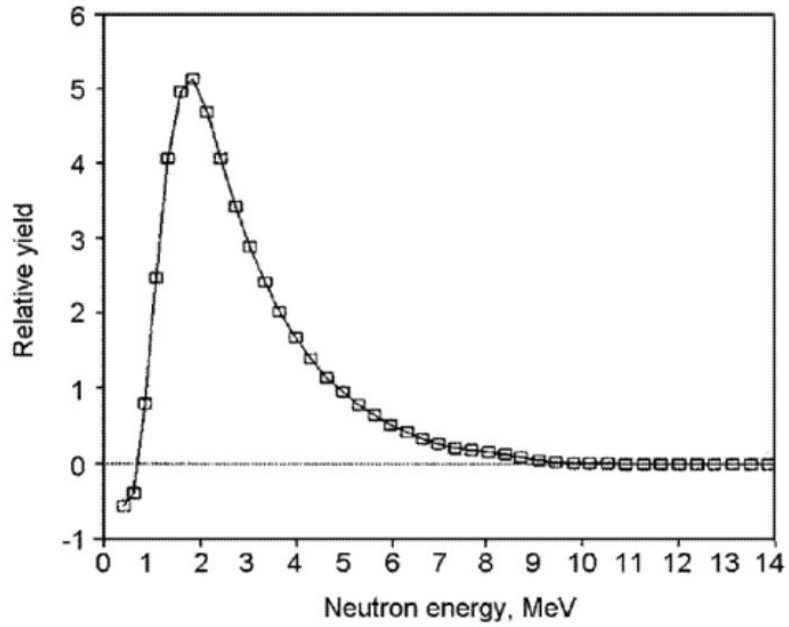
TEsting Facility: Calibration

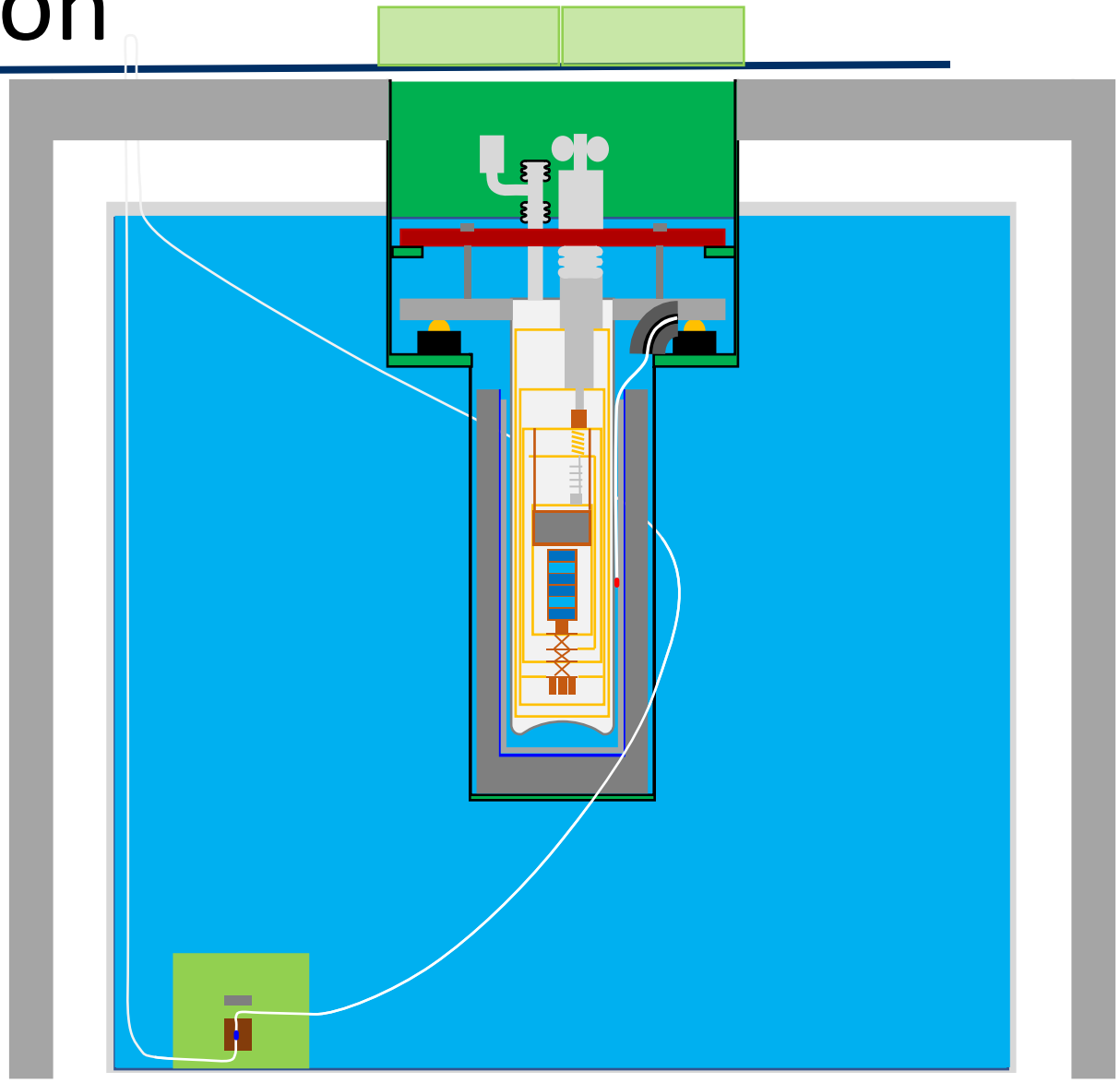
- Ba-133 calibration source (350 keV gamma, 37 kBq)
  - Can be deployed along the length of the cryostat
- Internal Fe-55 source (6 keV) is also available for low energy calibration

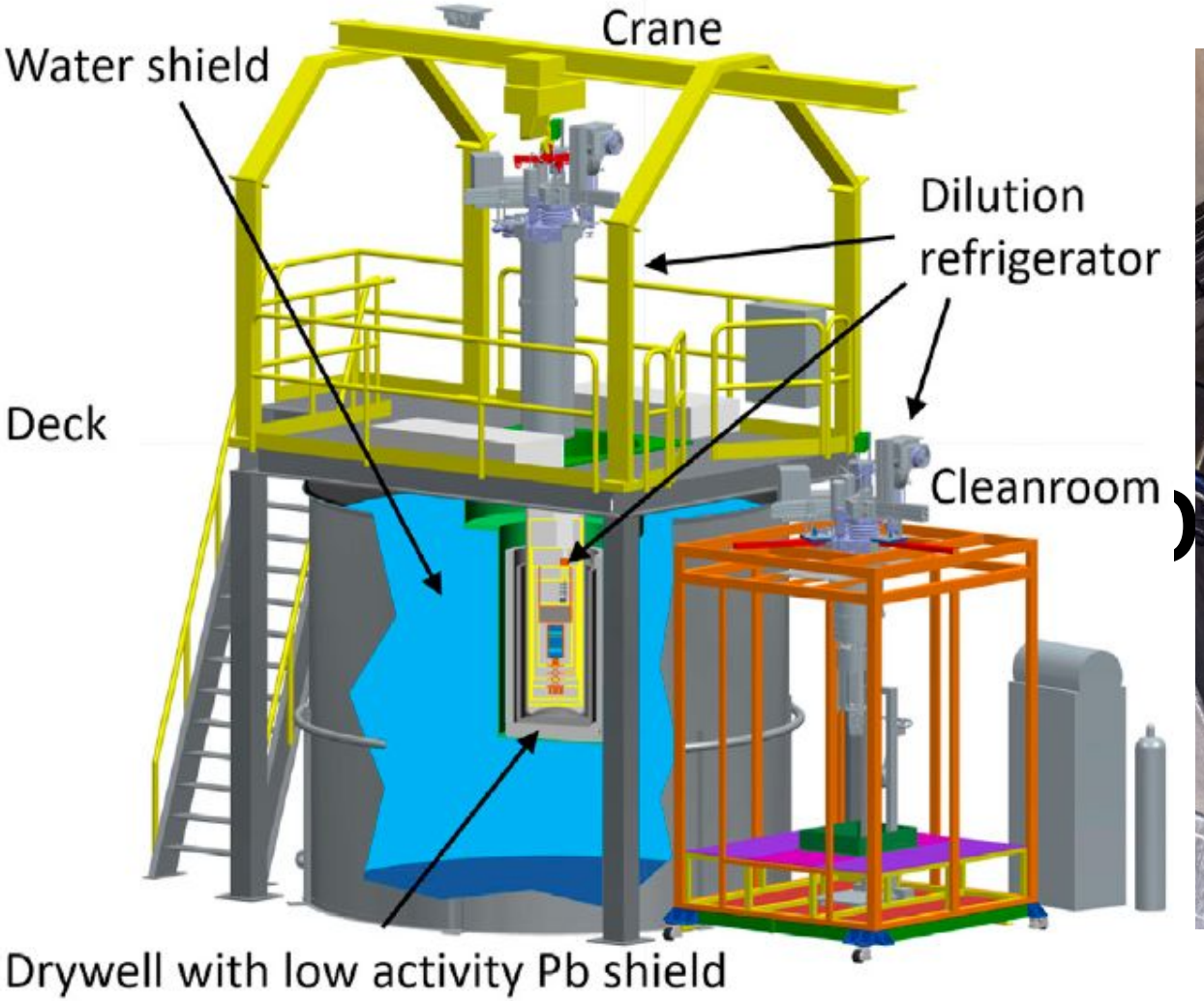


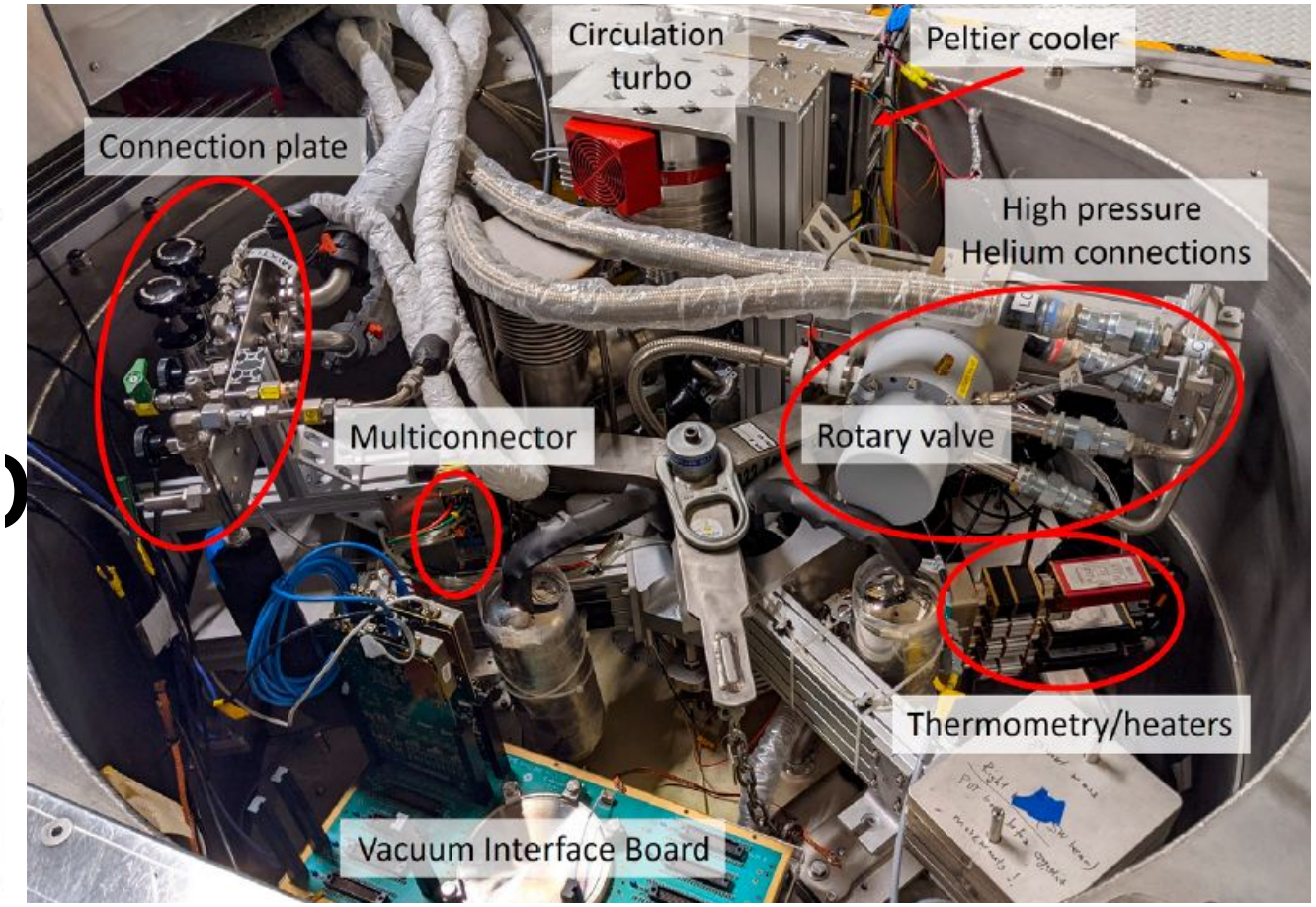
TEsting Facility: Calibration

- Cf-252 neutron source , 37.5 kBq
- Stepper motor allows motion through the water tank



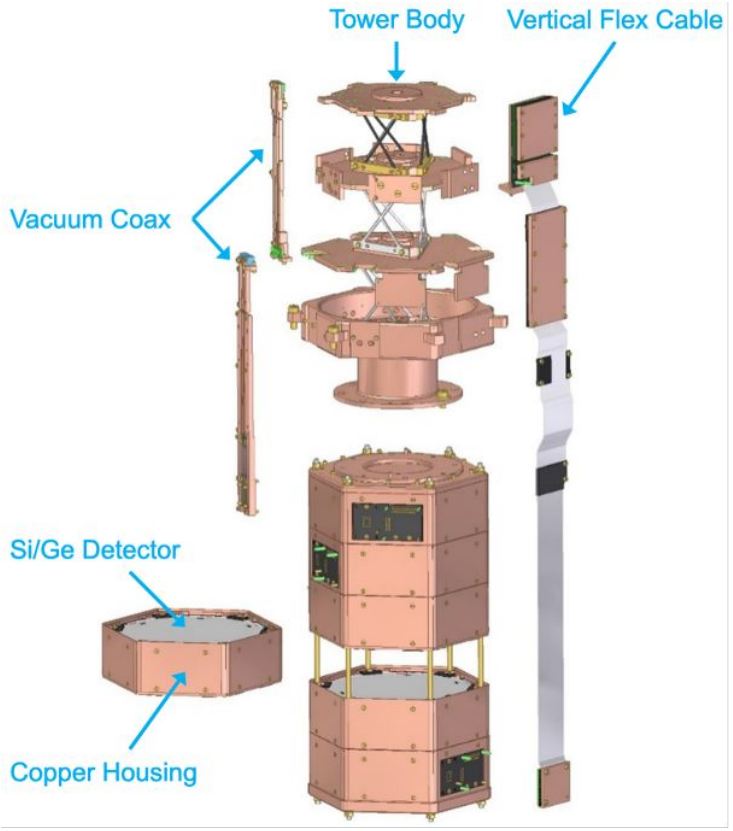


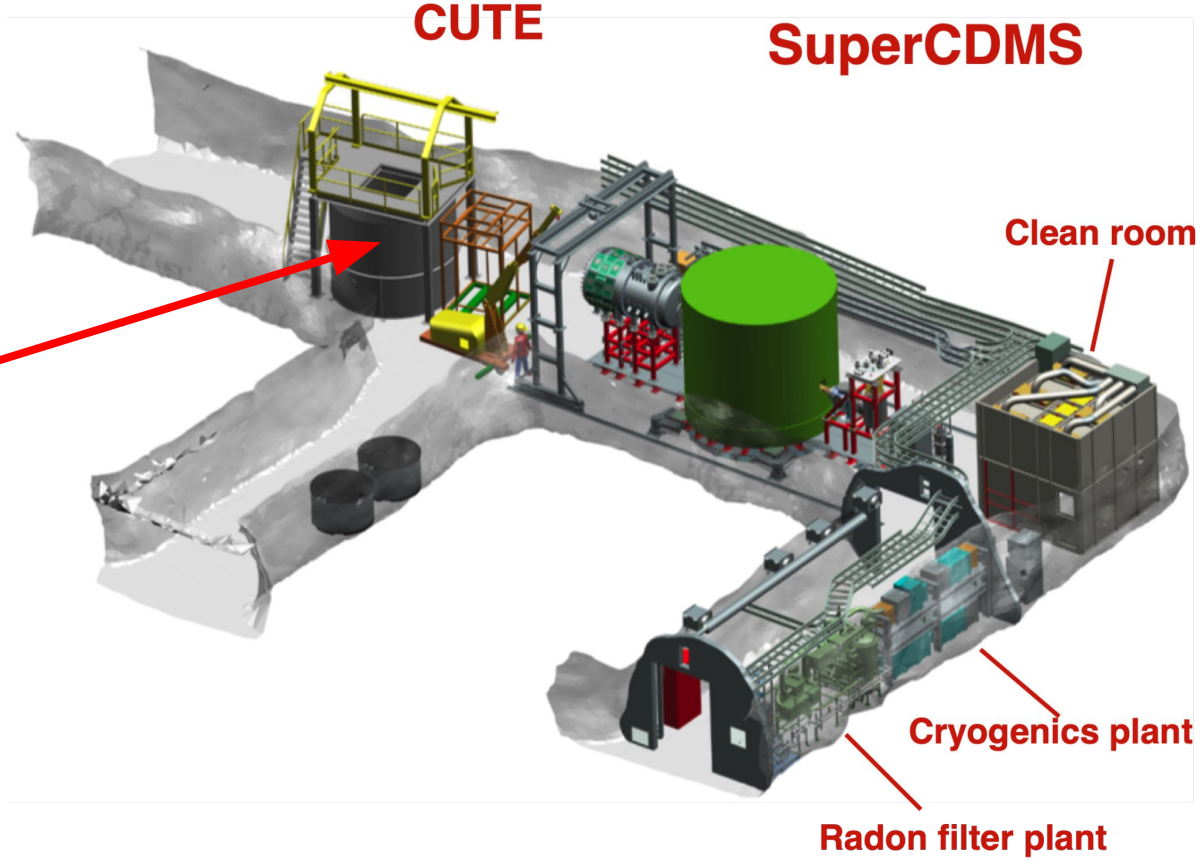

Crane
Water shield
Dilution refrigerator
Deck
Cleanroom
Drywell with low activity Pb shield


Circulation turbo
Peltier cooler
Connection plate
High pressure Helium connections
Multiconnector
Rotary valve
Thermometry/heaters
Vacuum Interface Board

CUTE Experimental Program

Completed: SuperCDMS Tower testing

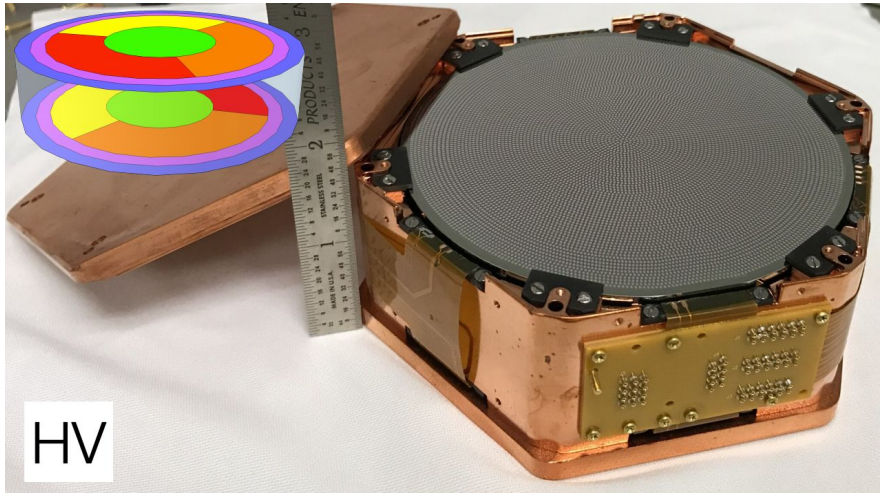


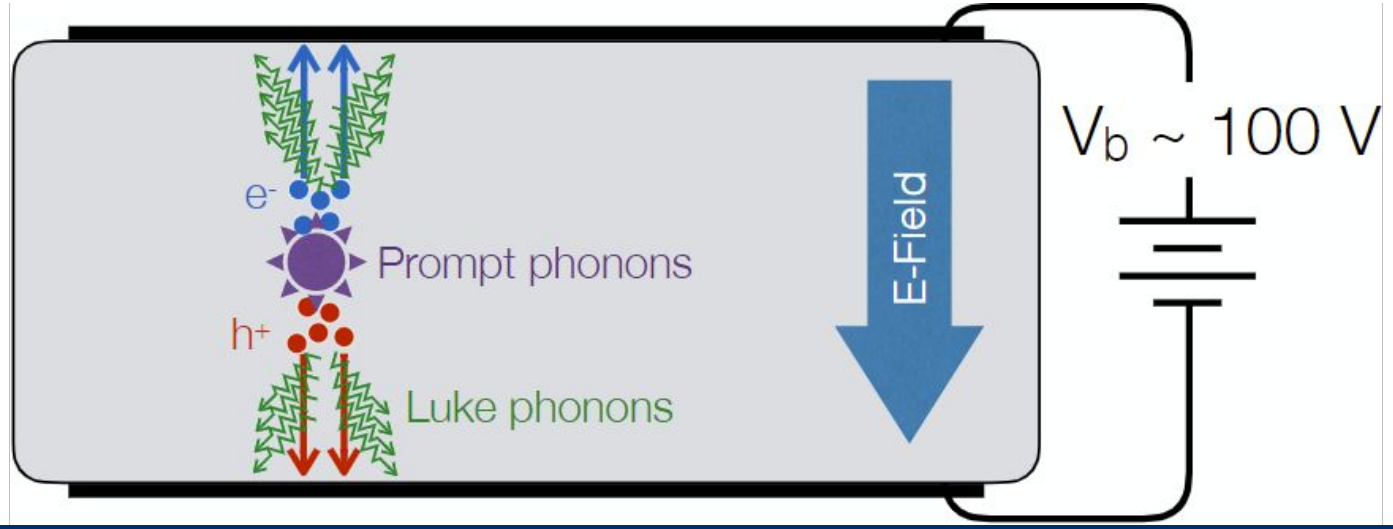


For more information about SuperCDMS, see E. Michielin's presentation on Tuesday

Why Tower Testing?

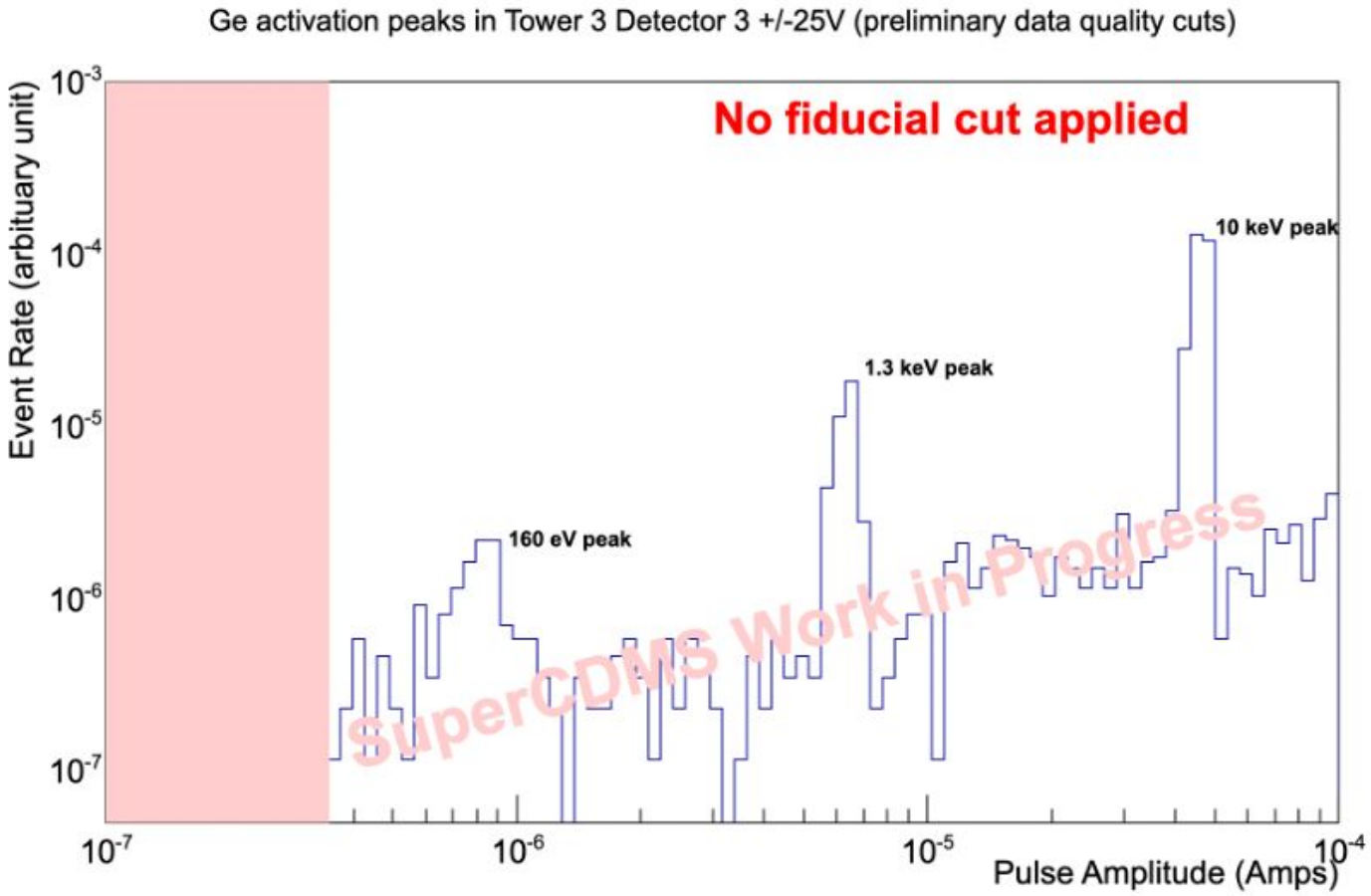
- First chance to operate these detectors in deep underground environment
- Noise performance in low background environment
- Operation of detectors with high voltage for extended periods
- Detector “neutralization” investigations
- First campaign for calibrating detectors





Ge Calibration

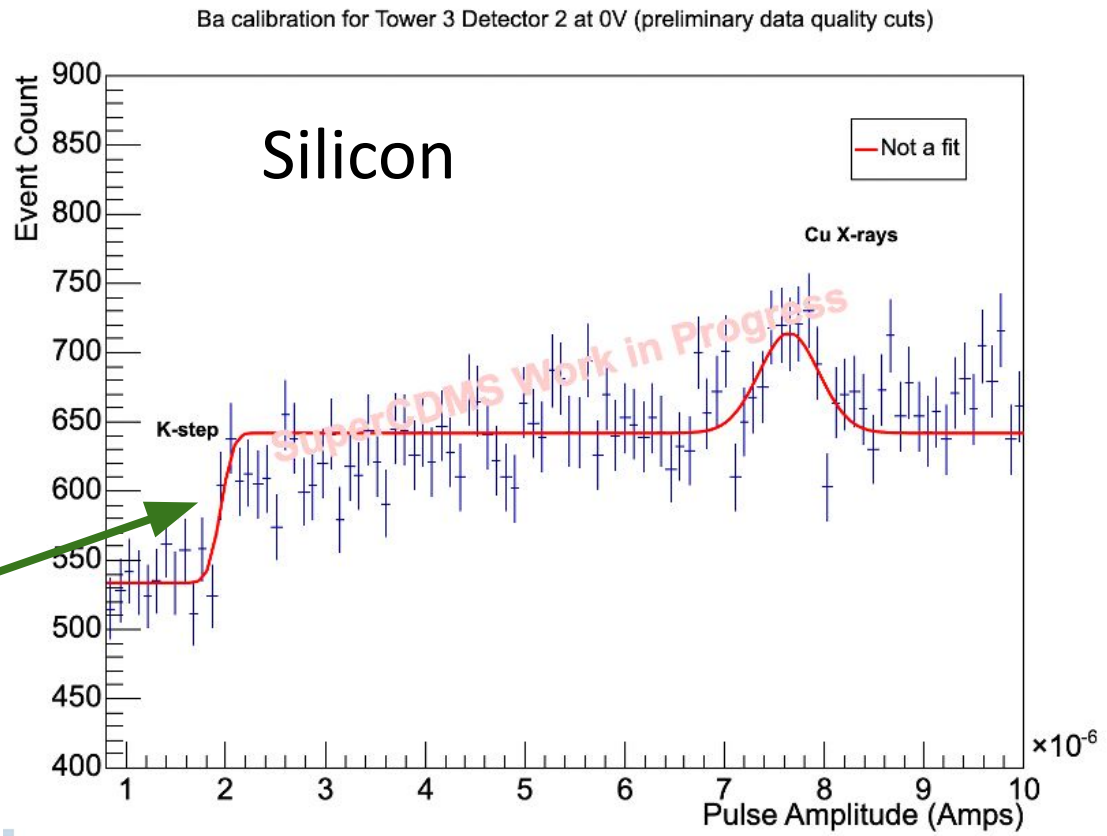
- ^{252}Cf neutron source
  - $^{70}Ge + n \rightarrow {}^{71}Ge$
- Electron-capture decay: $^{71}Ge + e \rightarrow {}^{71}Ga + \nu_e$
  - K-shell: 10.3 keV
  - L-shell: 1.3 keV
  - M-shell: 160 eV
- 3 days live-time shown here



Si Calibration

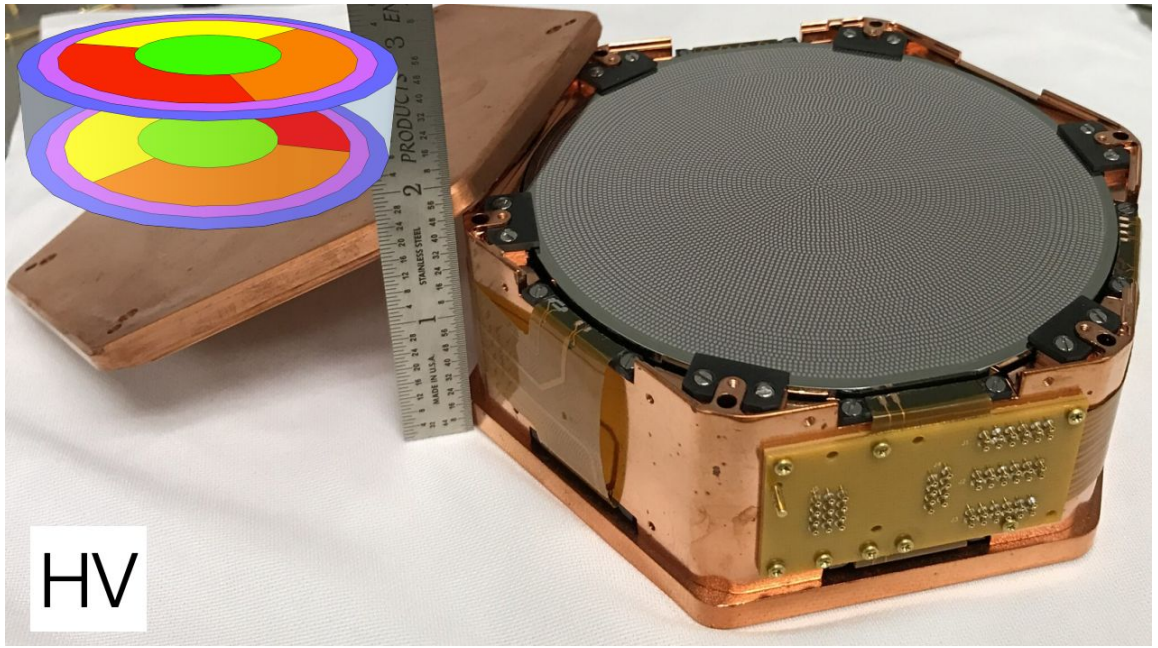
- Compton scattering with ^{133}Ba
- Scattering cross section decreases below atomic binding energies (Compton steps)
- 4 days live-time shown here
- (Red “fit” line only to guide the eye)

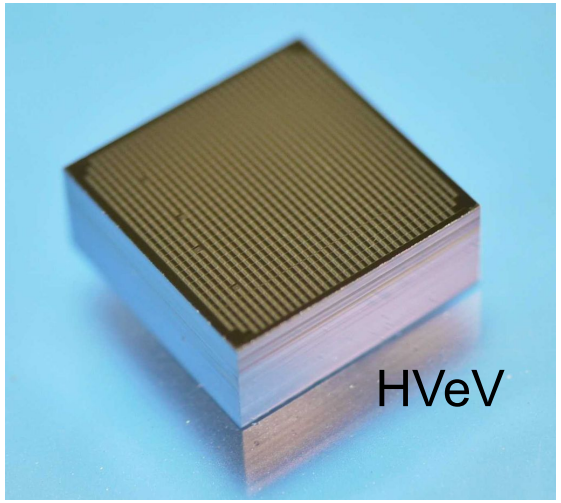
K-step, 1.8 keV



Completed: HVeV@CUTE

Gram scale eV resolution

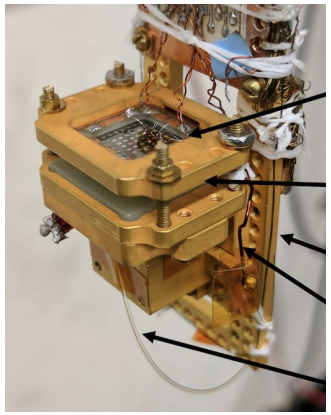




Great for

- Detailed detector response studies
- Instrumental background investigations
- Low-mass DM searches

Iterations of HVeV experiments

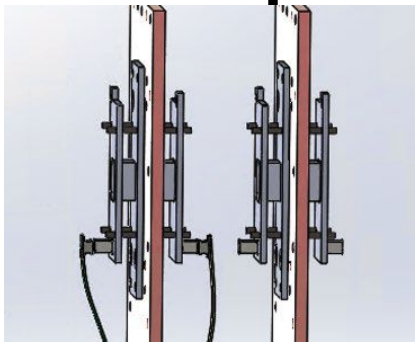


- First observation of single eh at Stanford

HVeV Run 1

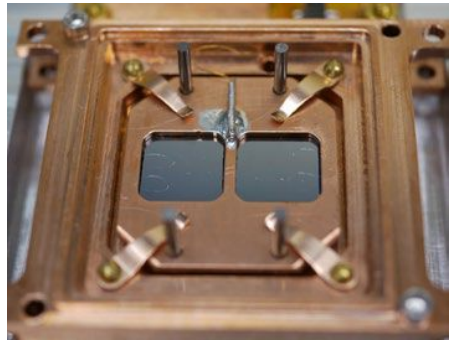
- Burst events detection and study
- Hypothesis: originated by SiO_2 in the detector holder (PCB)

HVeV Run 2



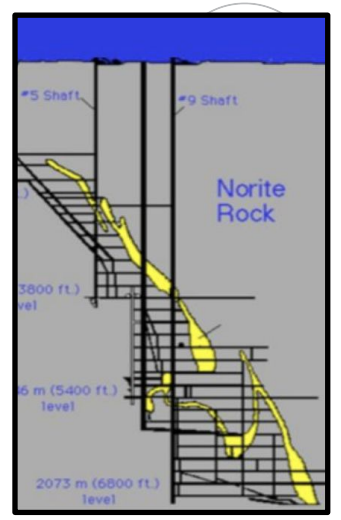
- Coincidence measurement
- Confirmed external origin of this background and its reduction with coincidence detections

HVeV Run 3



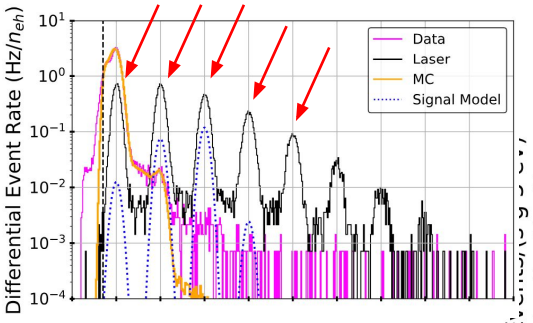
- Removed PCB from detector holder
- Elimination of quantized background above 1eh peak

HVeV Run 4

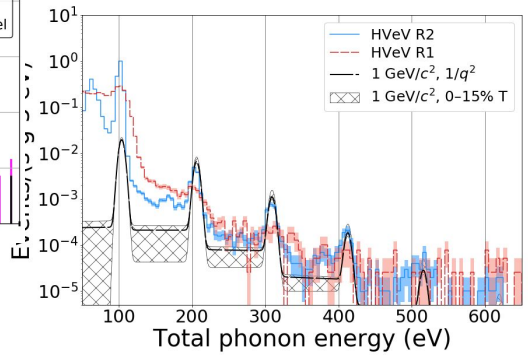


Going deep down to SNOLAB!

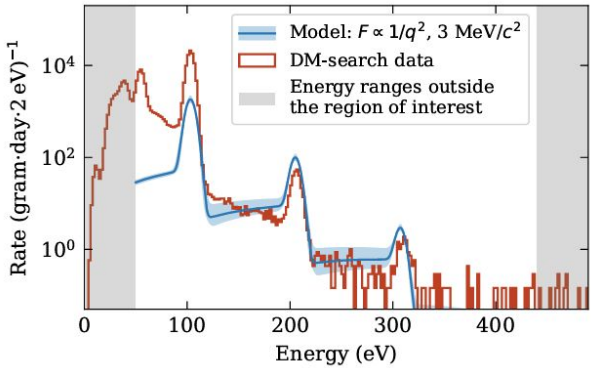
HVeV Run 5



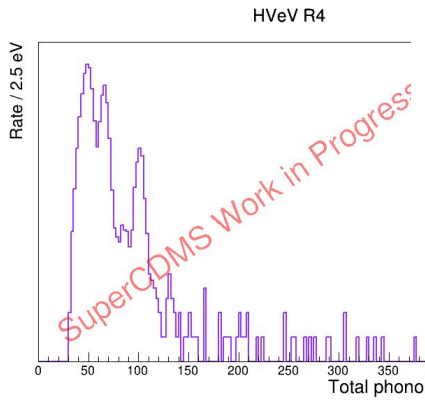
PhysRevLett.121.051301

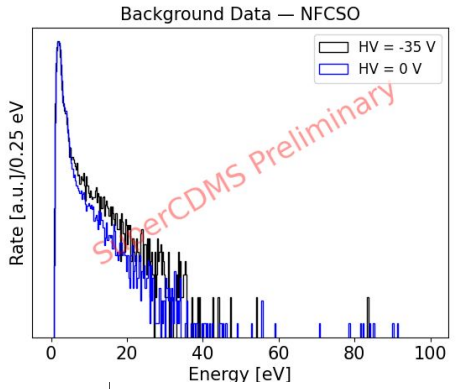


Phys. Rev. D **102**, 091101(R)



Phys. Rev. D 111, 012006





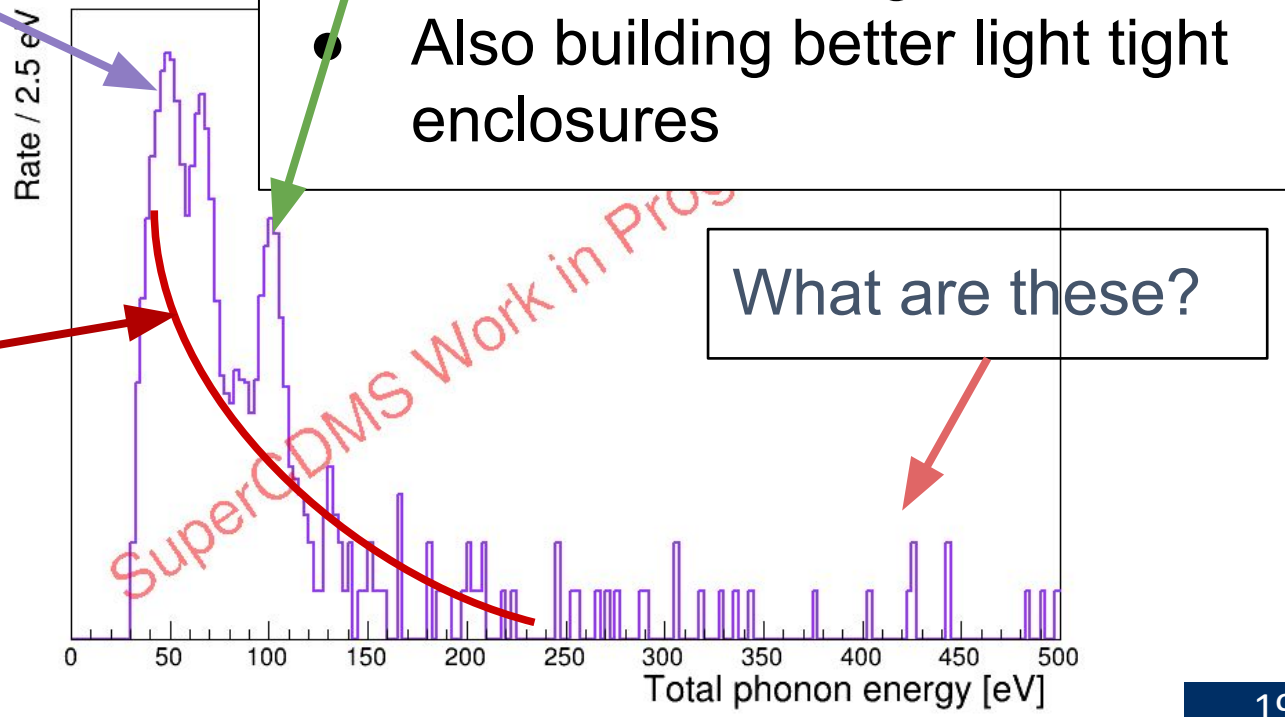
Understanding instrumental backgrounds

- Sub 1-eh peaks
- Hypothesized: from unpolished sidewalls
- Will attempt sidewall etching/polishing

- 1-eh peak
- Could be from electrode leakage, light leakage, etc.
- Attempting electrode blocking materials for mitigation
- Also building better light tight enclosures

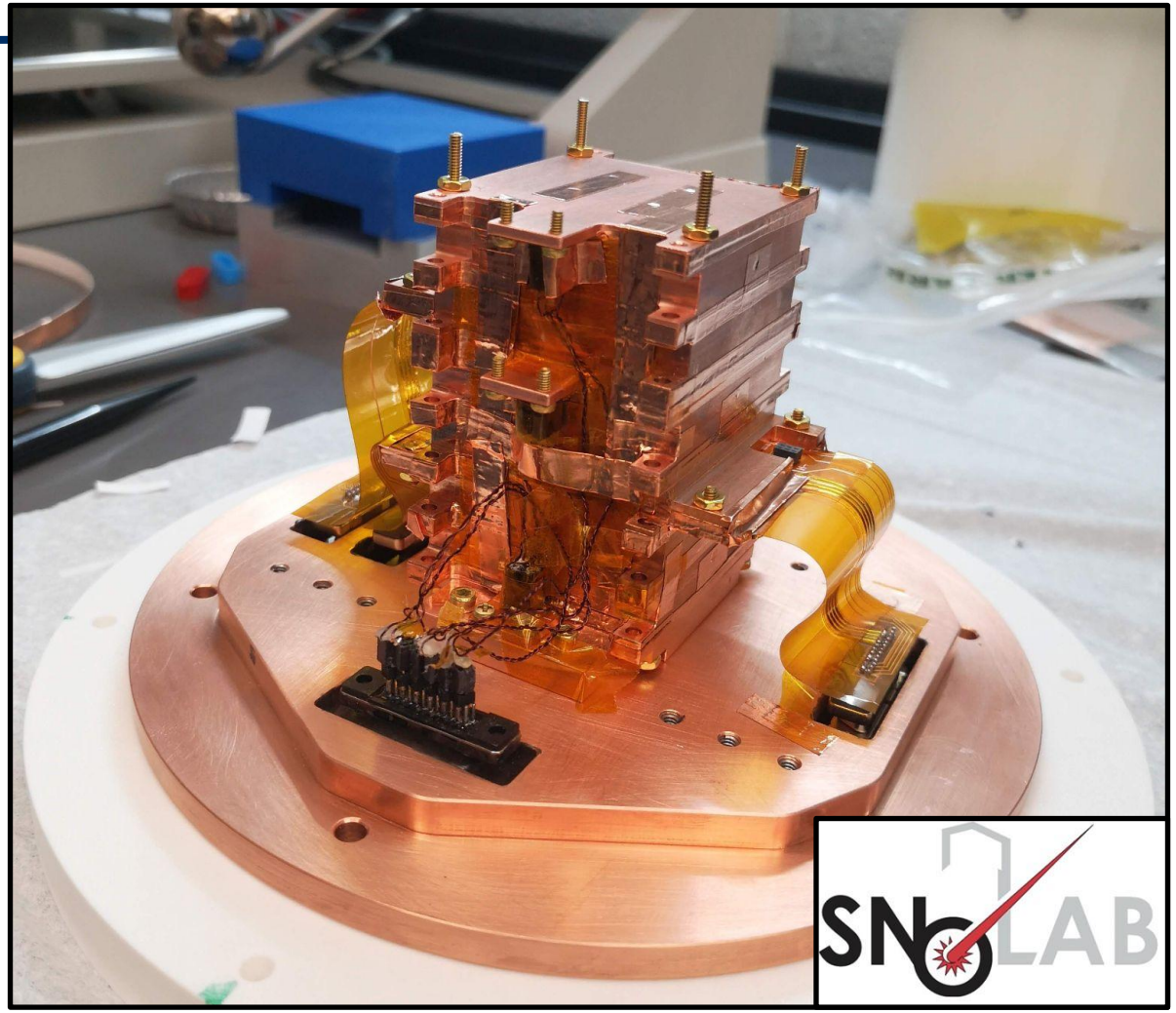
- Low energy excess
- Evidence hints at different ionization from ER and NR
  - “Heat only”
- Unpacking ER/NR/Heat Only components by operating with different voltages

Phonon energy = $E_{recoil} + n_{eh} * e * \Delta V$

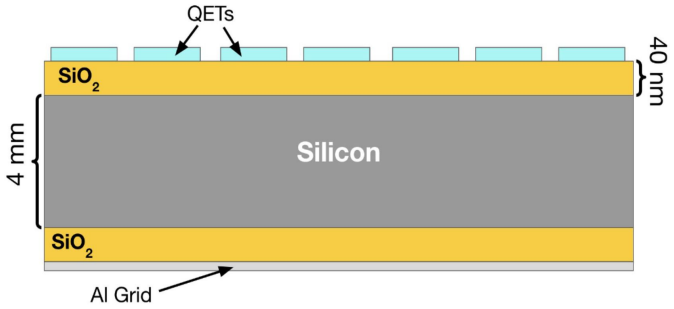


HVeV Run 5

- Payload of six HVeV detectors
- Use LEDs to calibrate
- **Primary Goal**: Study backgrounds
  - Low Energy Excess (LEE)
  - Leakage Rate
- **Secondary Goal**: DM Search

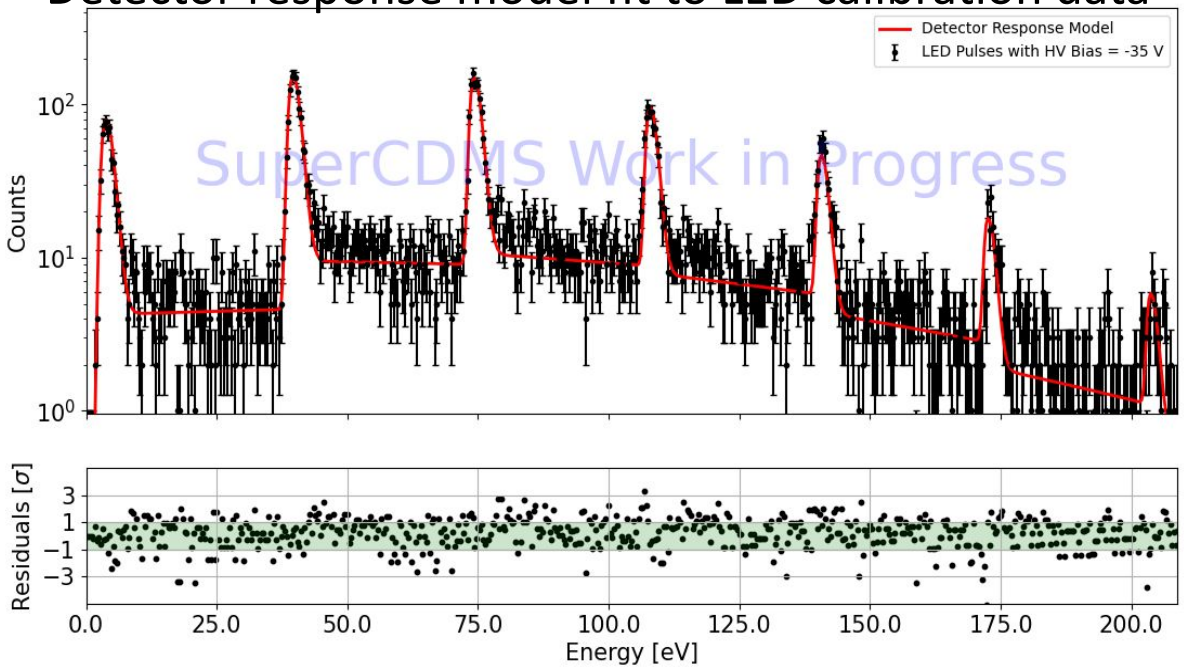


New Best Resolution for HVeV

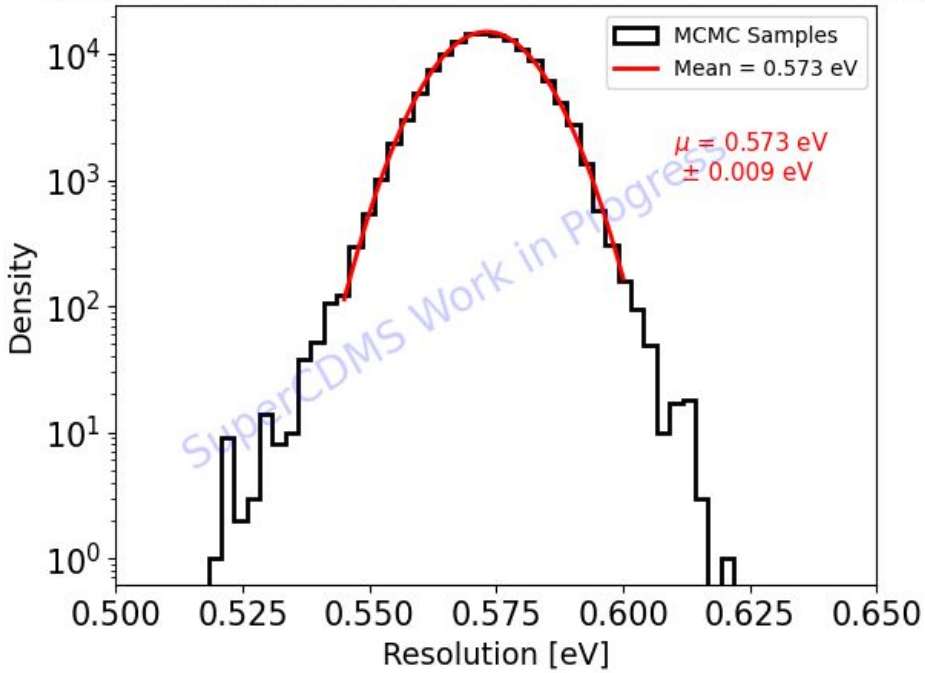


- Si detector with SiO2 buffering
- Achieved **0.57 eV baseline resolution!**

Detector response model fit to LED calibration data

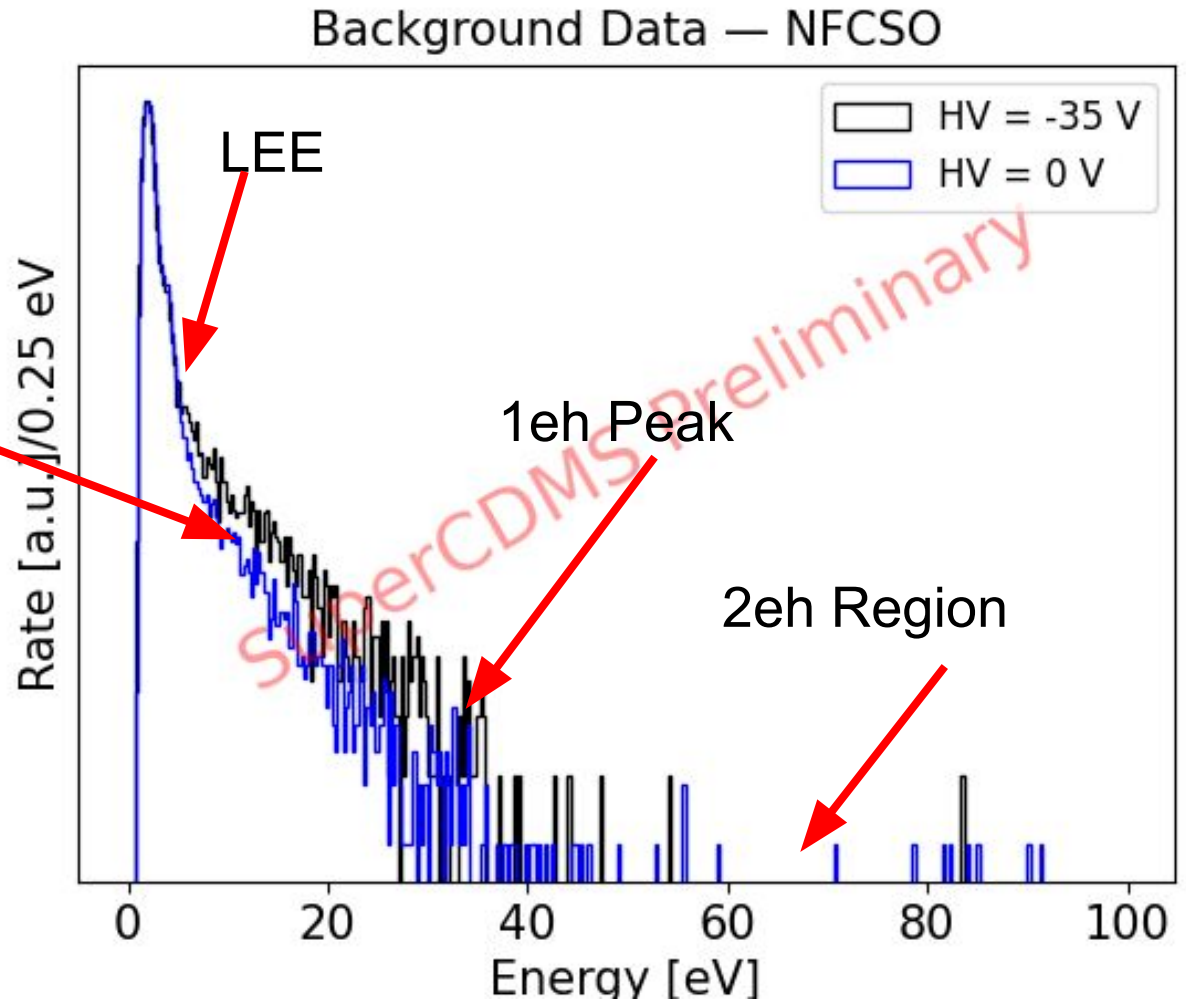


Sample of the posterior of the resolution from MCMC chain



Study of Non-ionizing Background

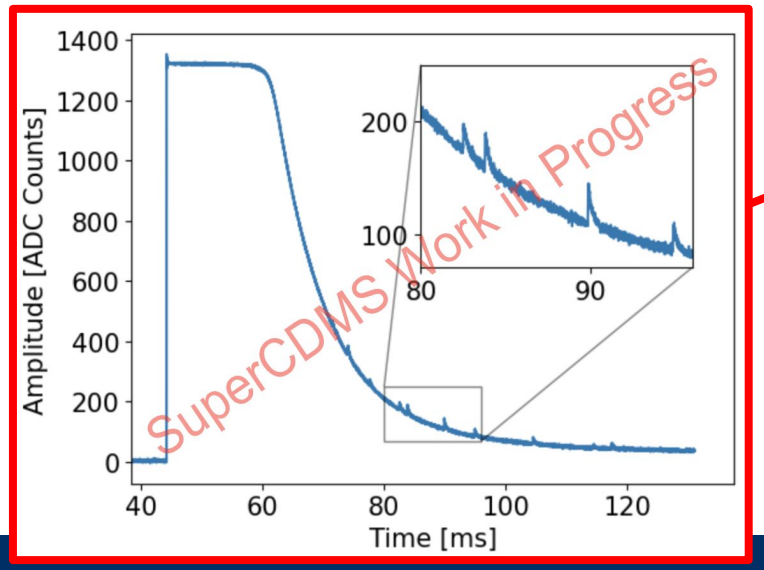
- Can use comparisons between 0V and HV data to study heat only components of the LEE
- Rate in HV data is higher in region below 1eh peak
  - Could be contamination from a particular background…
    (Next slide)

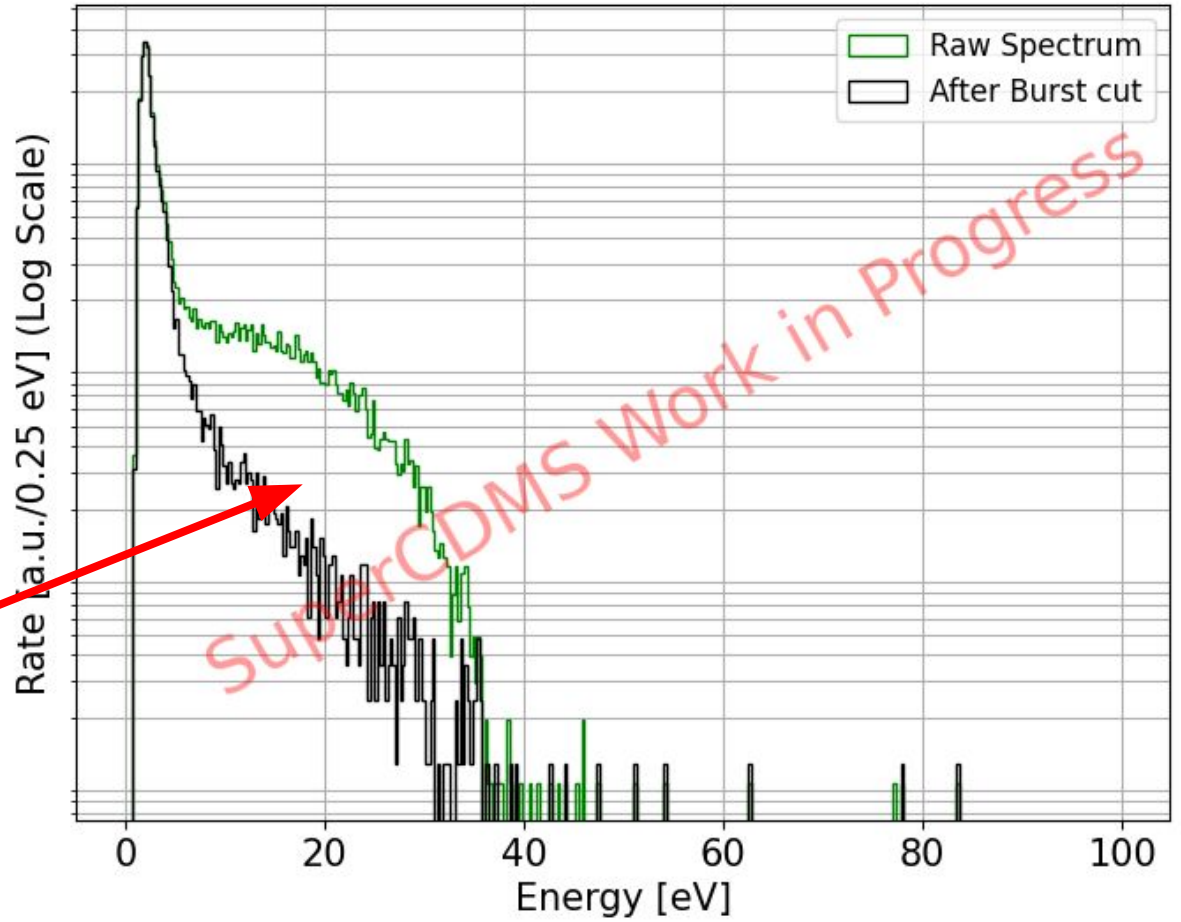


Phonon energy = E_{recoil} + n_{eh} * e * ΔV

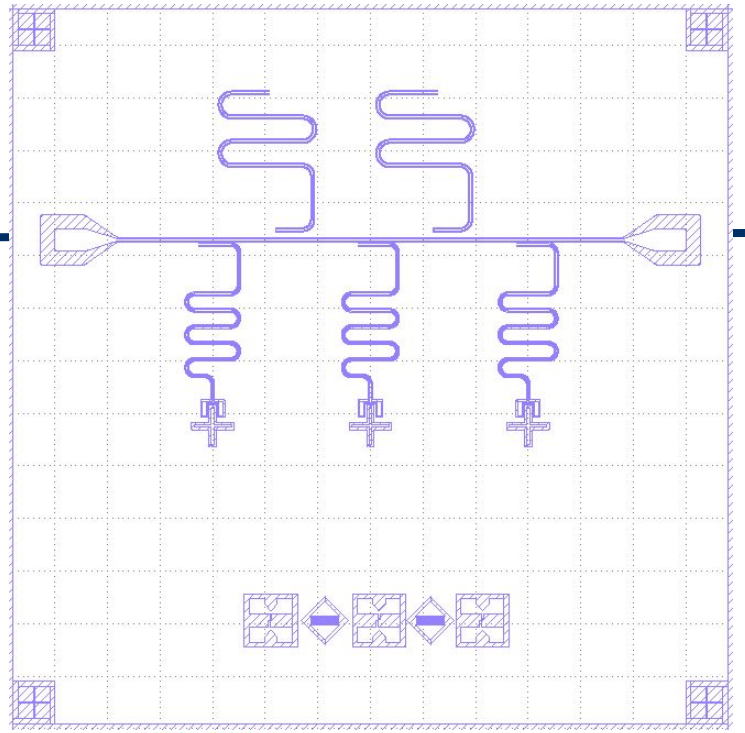
Pesky Background: “Burst Events”

- Observed “bursts” of low energy events occurring after high energy events
- **Trigger Rate can jump by a factor up to ~100 during a burst**
- Actively working on understanding then removing these events

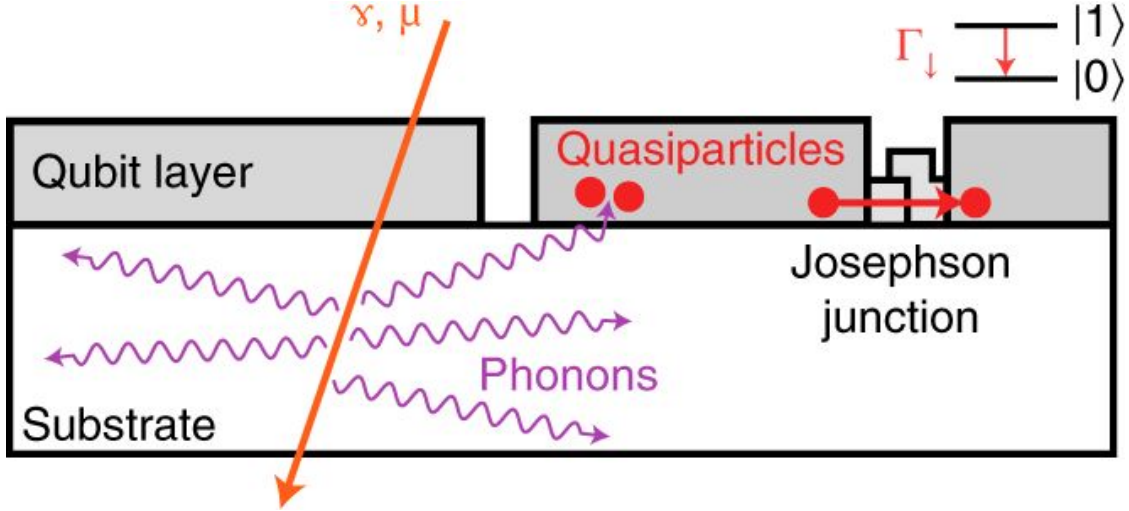




Current: QUTEbits

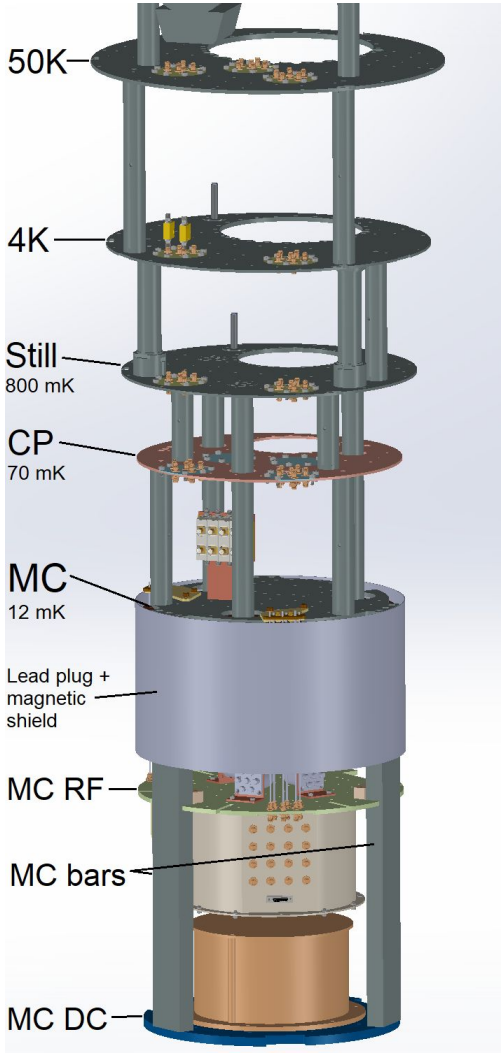


- Superconducting qubits exploit quantum superpositions to carry out complex quantum algorithms
- Coherence times limited by several sources
- Larger than expected populations of non-equilibrium quasiparticles observed (Serniak 2018)
- Ionizing radiation can contribute to this population
- First data obtained this summer
- Full sets of systematic studies planned next



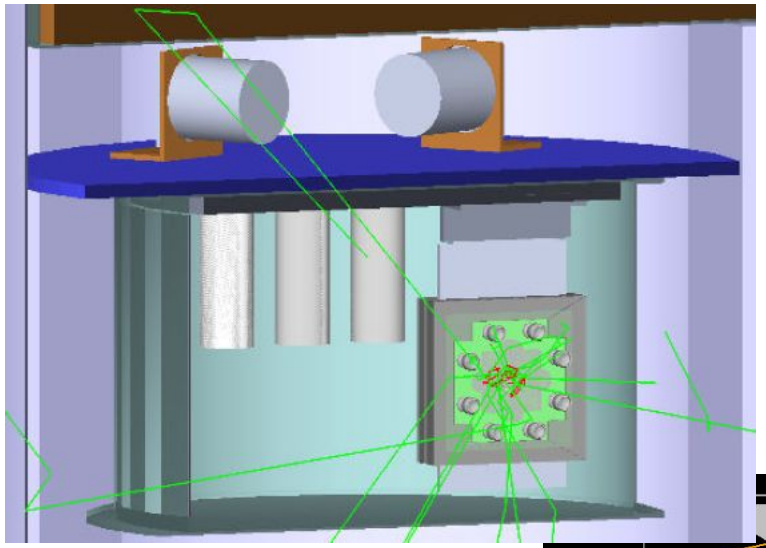
CUTE Facility Upgrades

- Facility originally supported “DC” payloads (such as transition edge sensor calorimeters)
- Upgraded facility supports up to 12 RF lines with rigid coax cables
- New sample plate and magnetic shield for qubit devices
- Can simultaneously run RF and DC payloads
- Possibilities for other RF-based experiments in the future

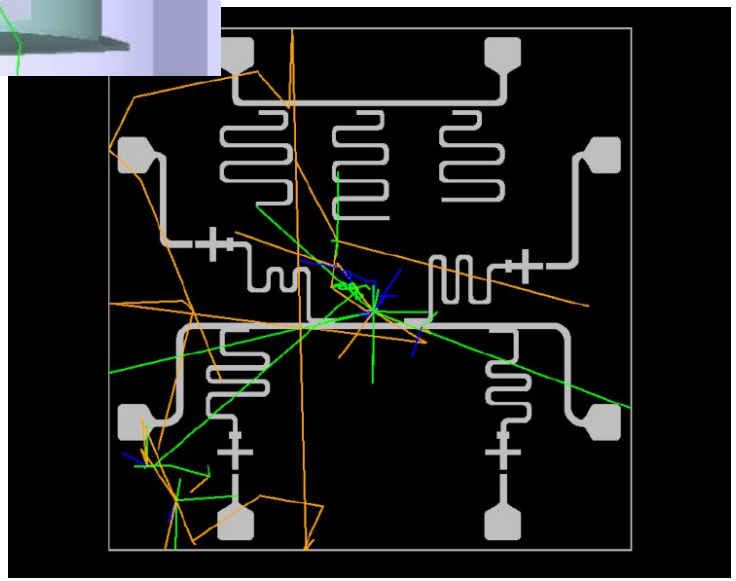


QUTEbits Simulations

- Background simulations using Geant4
- Rates informed by material assays
- Sensor response studies using G4CMP
  - First principle charge and phonon propagation simulation
  - NIMA 1055 (2023) 168473



Courtesy of S. Zatschler



Future projects: Your ideas wanted!

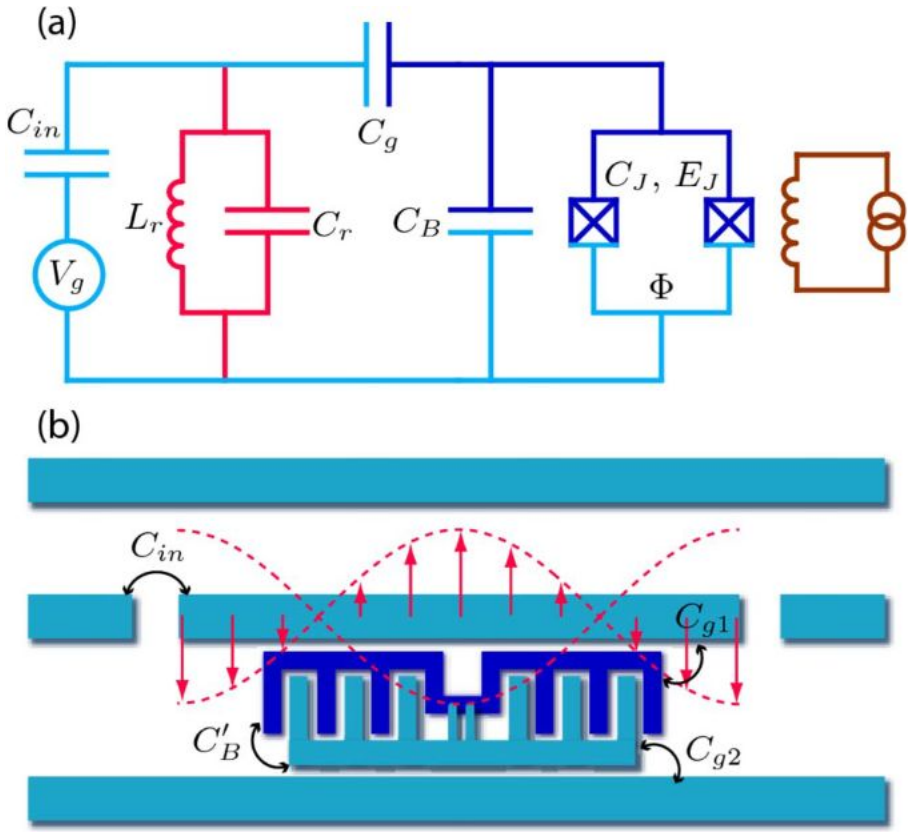
- Send proposals via e-mail to cute_proposals@snolab.ca
- Or contact SNOLAB management.

Conclusion

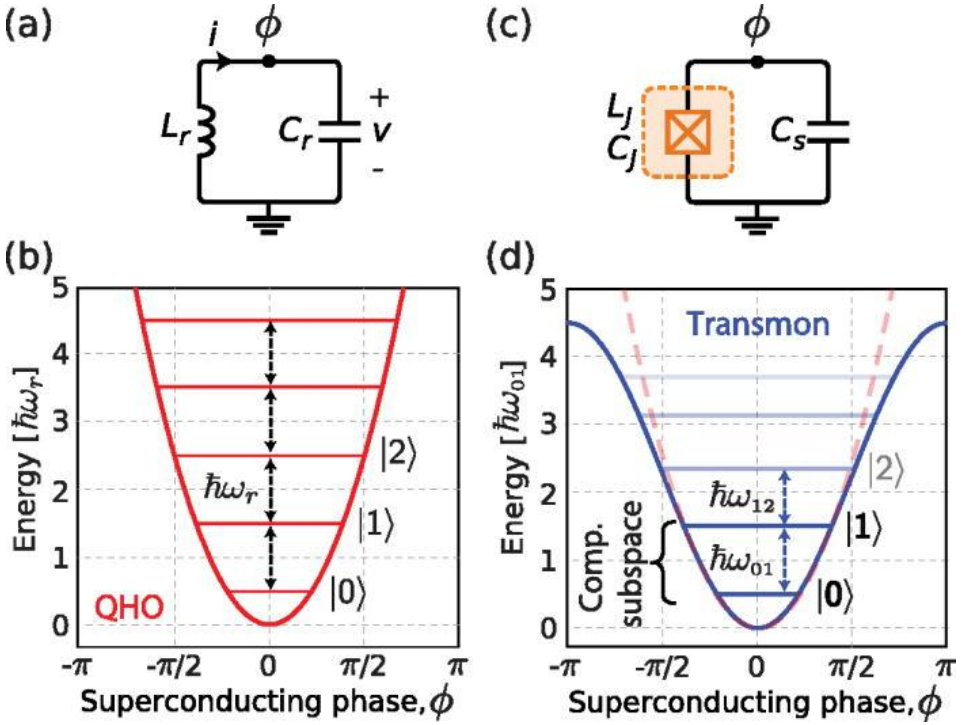
- CUTE is a SNOLAB user facility
- Provides a cryogenic low-background vibrationally isolated environment
- Successfully ran SuperCDMS tower for ~half a year
- HVeV investigates instrumental backgrounds and searches for DM
- Qubit program ongoing
- Open for future experiments

Backup Slides

Transmon Qubits



Phys. Rev. A **76**, 042319 (2007)



Appl. Phys. Rev. 6, 021318 (2019)