CUTE

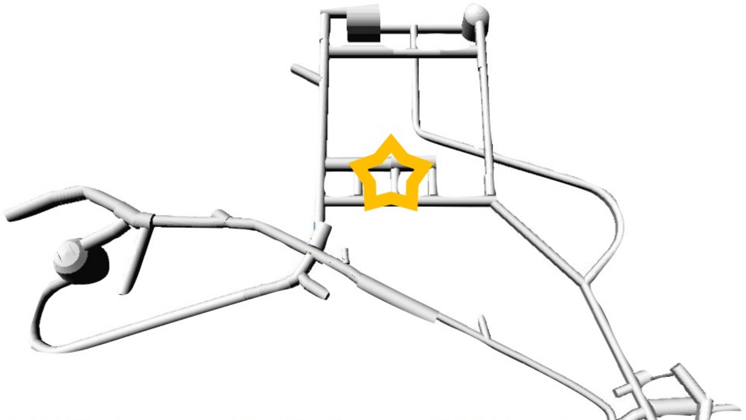
A Cryogenic Underground TEst Facility @ SNOLAB

Andrew Kubik (for the CUTE team)

GUINEAPIG

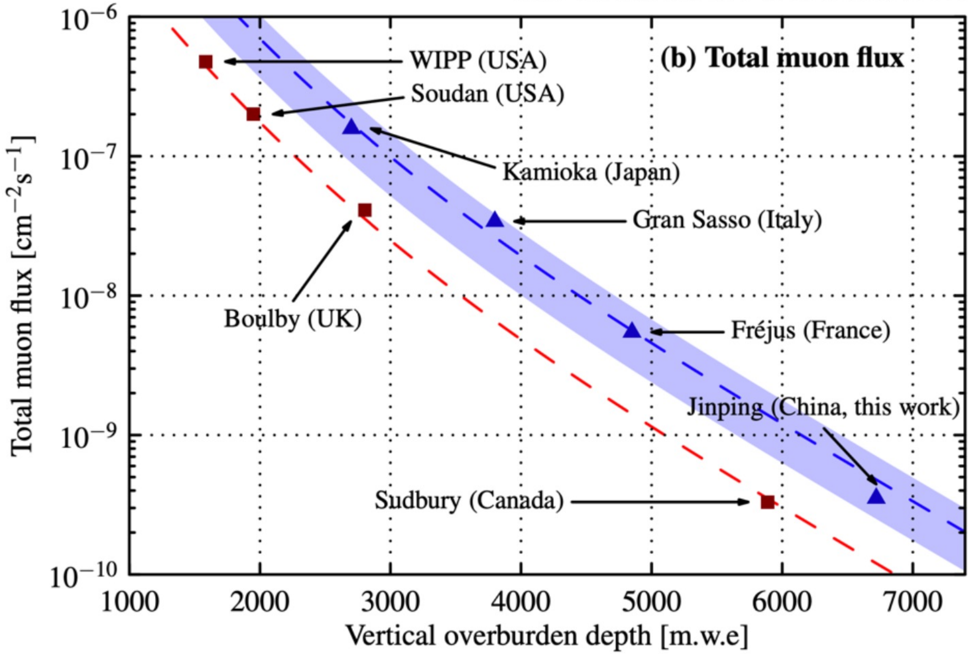
July 13, 2023

Underground



SNOLAB Underground facility layout. CUTE location

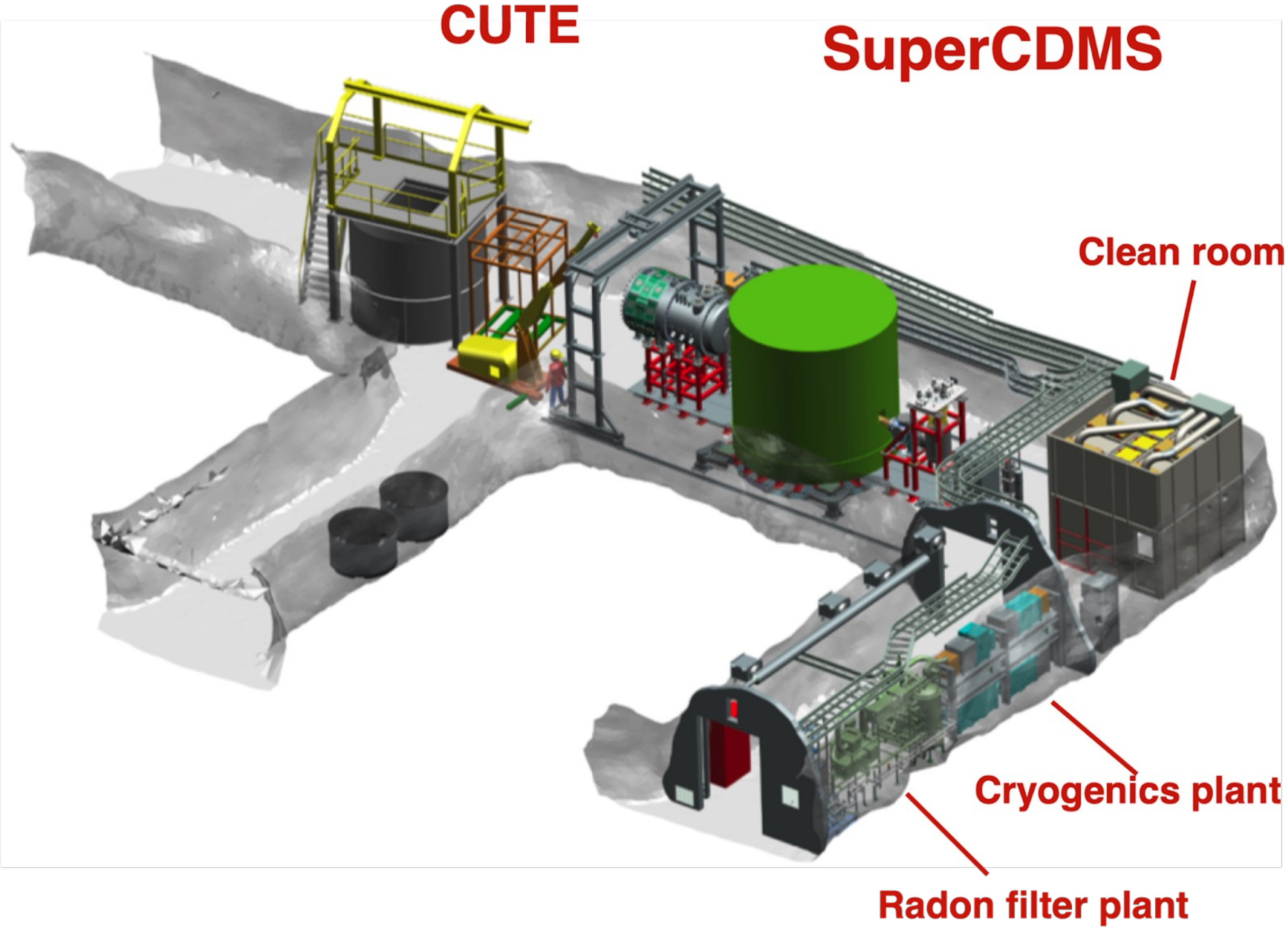
Guo et al.. arXiv:2007.15925v2



SNOLAB:

- 2 km underground
- Class 2000 clean room
- Extremely low Muon flux

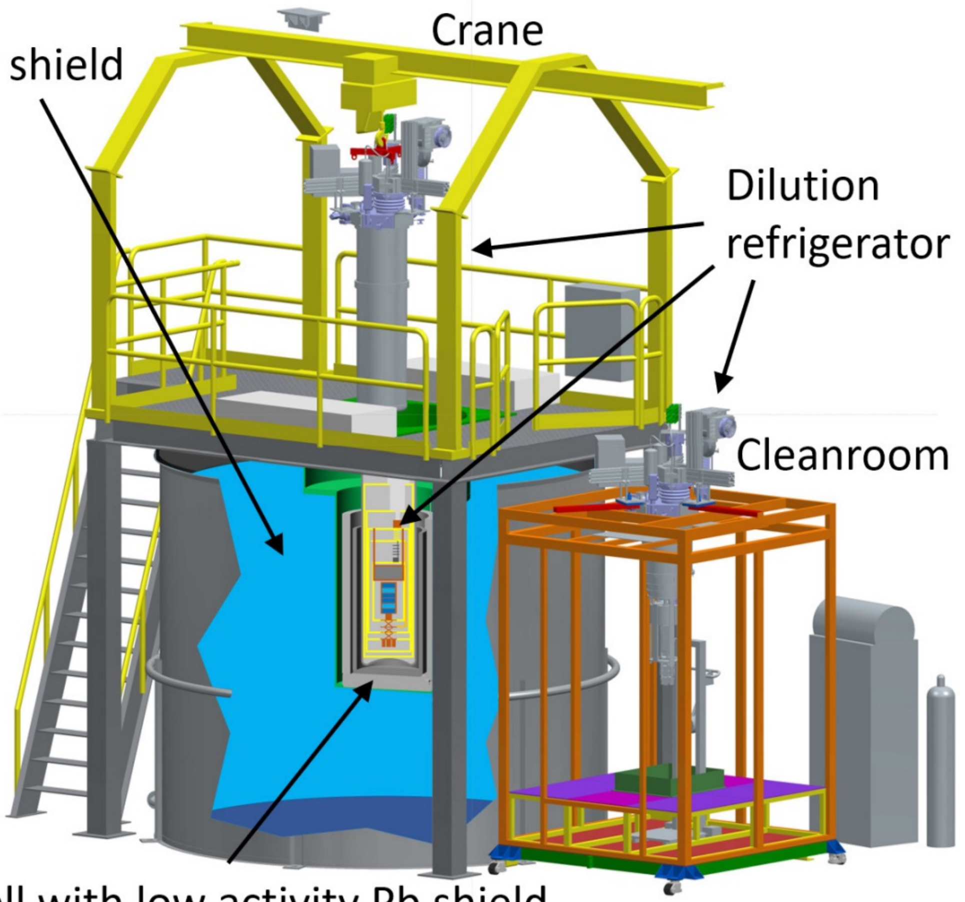
Underground



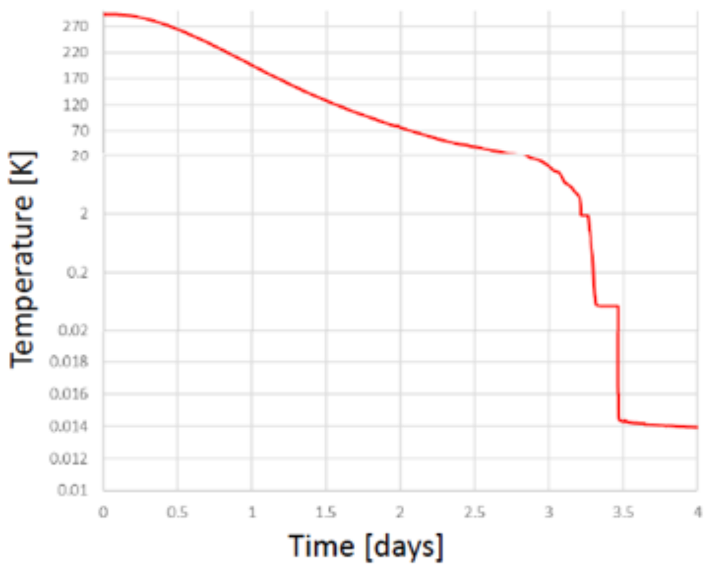
TEst Facility Overview

What the CUTE Facility can offer:

- Operational temperature as low as 12 mK
- Low overall radioactive background
- Minimal mechanical vibrations thanks to cryostat suspension system
- Low level of electromagnetic interference
- Availability of calibration sources (gamma, neutron)
- Low-radon, class 300 cleanroom to change payload
    - Typical Rn level < 15 mBq/m^3



Cryogenic



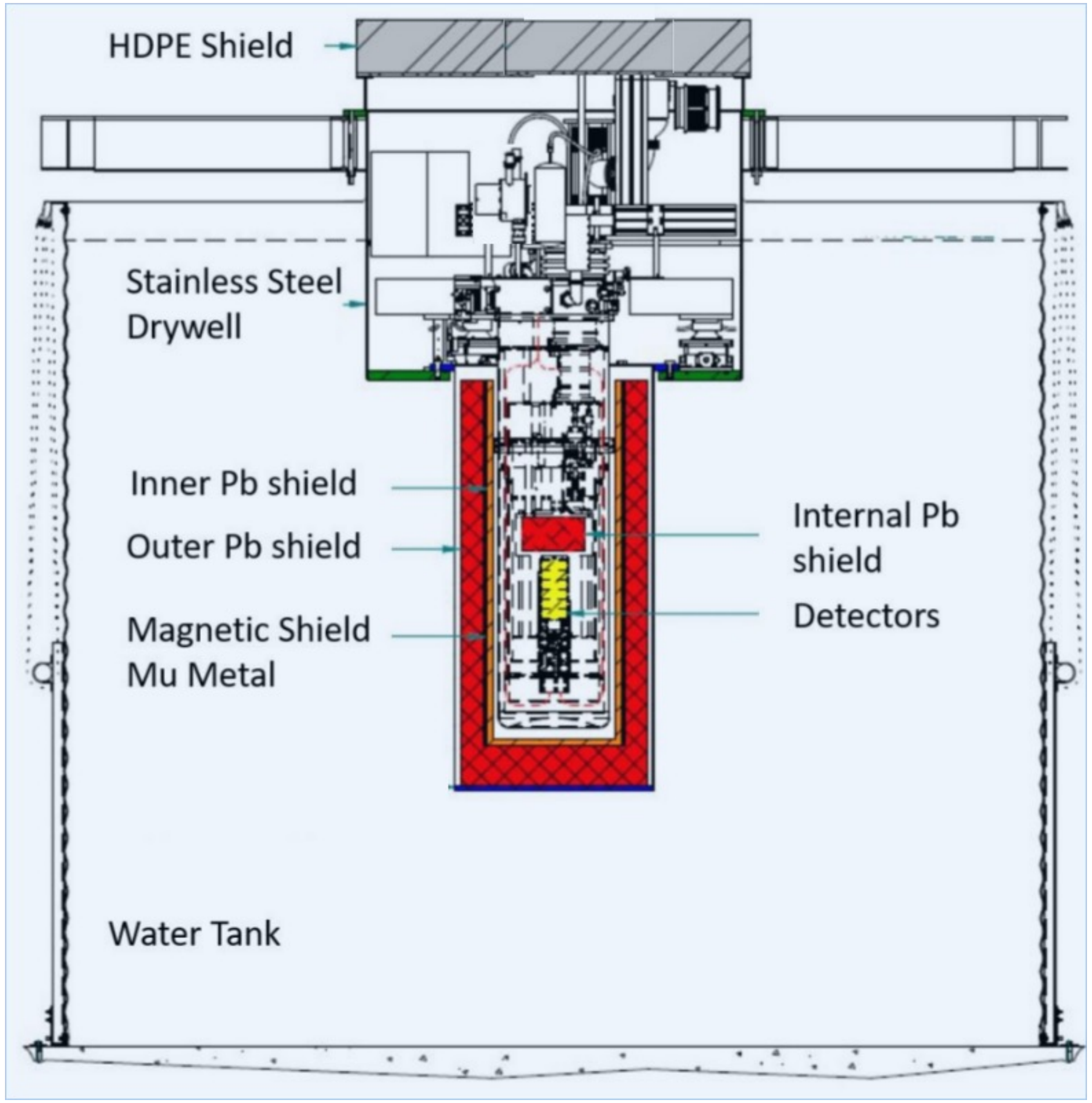
Dilution Fridge:

- Base temperature ~ 12 mK with payload
- Cooldown time ~ 3 ½ days, largely driven by ~100 kg internal Pb shielding
- Fridge can run unattended for extended periods, critical in the underground environment
  - New Liquid Nitrogen refill system allows for continuous running for ~ 2 months

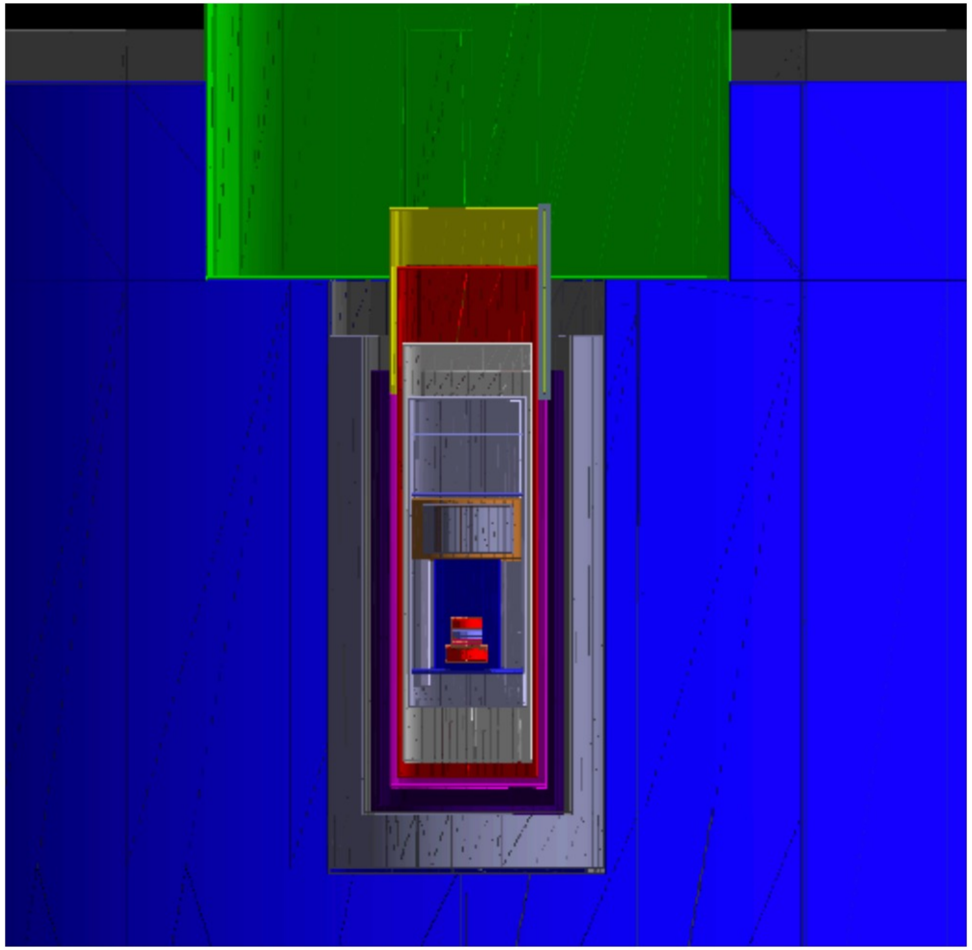
Shielding and Backgrounds

Shielding:

- ~ 10 cm low activity Lead in drywell
- Mu-metal reduces external B-field by ~x50
- ~1.5 meter of water and 20 cm Polyethylene lid
- 15 cm Lead “plug” inside of cryostat
- Active low radon air purge in drywell



Backgrounds

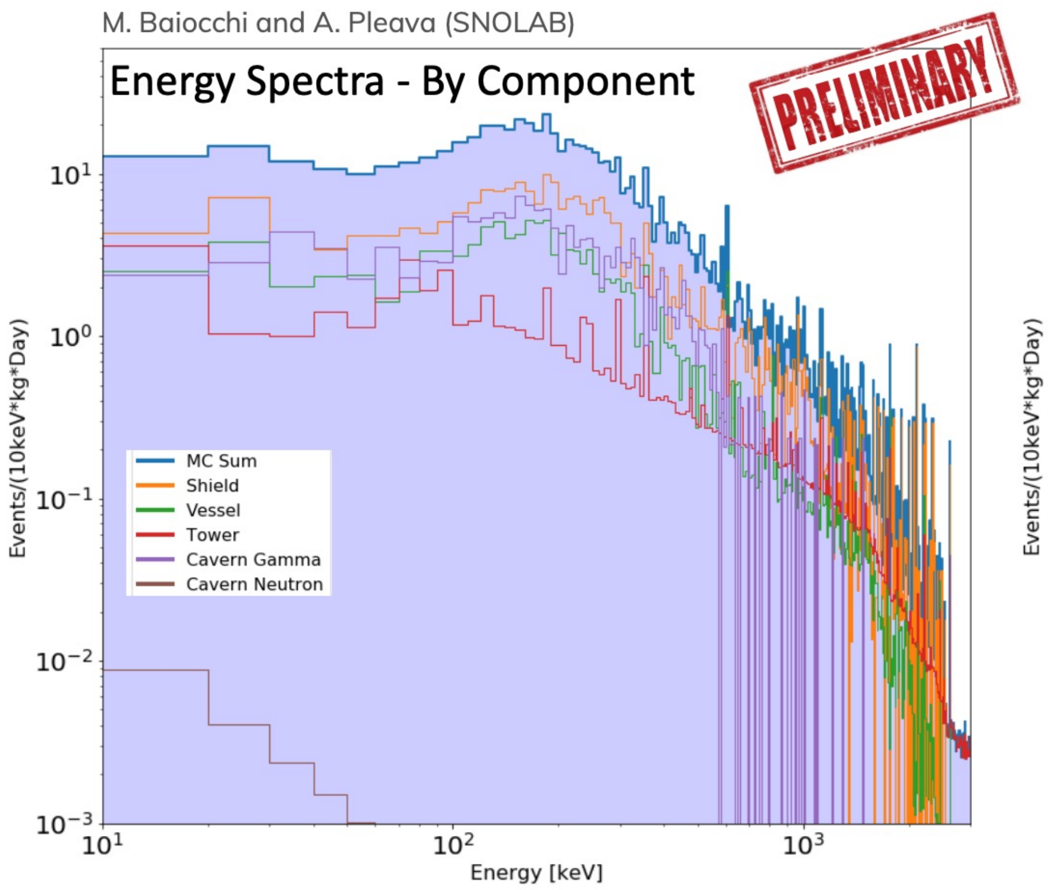

Geant4 visualization of the CUTE geometry

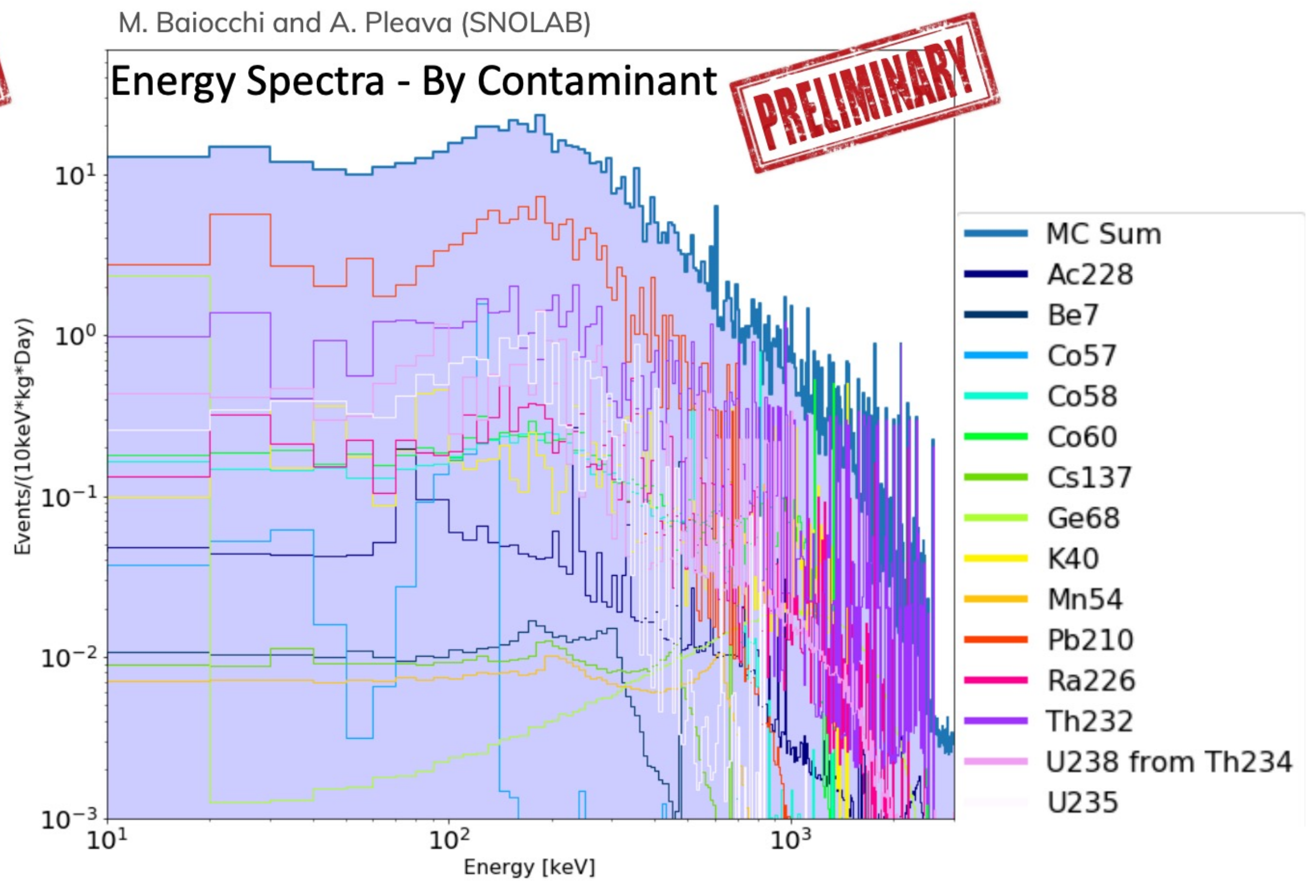
Backgrounds:

- Shielding and clean underground environment lead to low backgrounds
- All materials screened for activity using HPGe background counting facility at SNOLAB
- Create a full bill of materials in the facility
- Along with a detailed GEANT4 simulation, propagate background for each contaminate to <insert your favourite detector>
- Use Background Explore tool developed by B. Loer at PNNL to normalized contribution and generate expected event rate

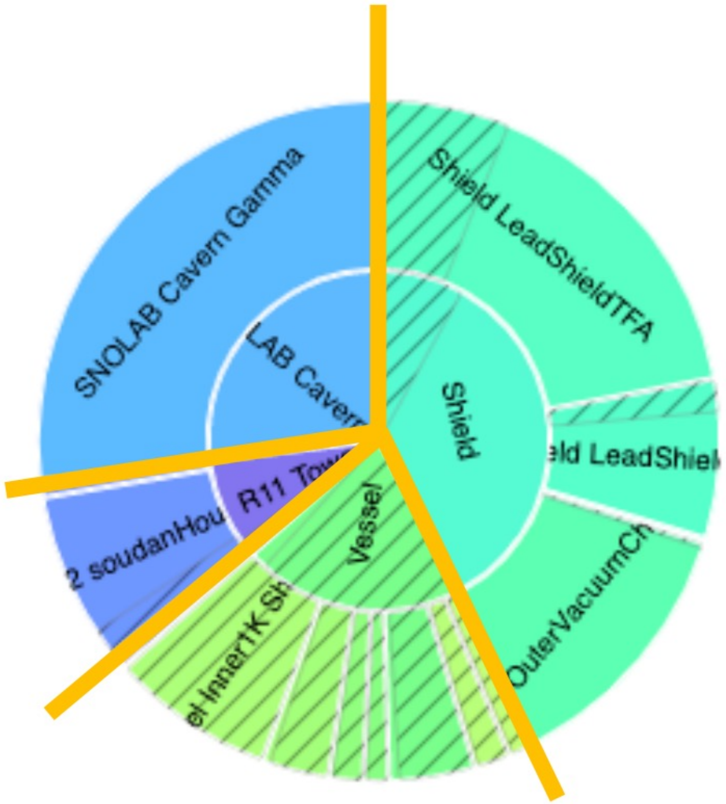
Slide courtesy S. Scorza

Background Budget

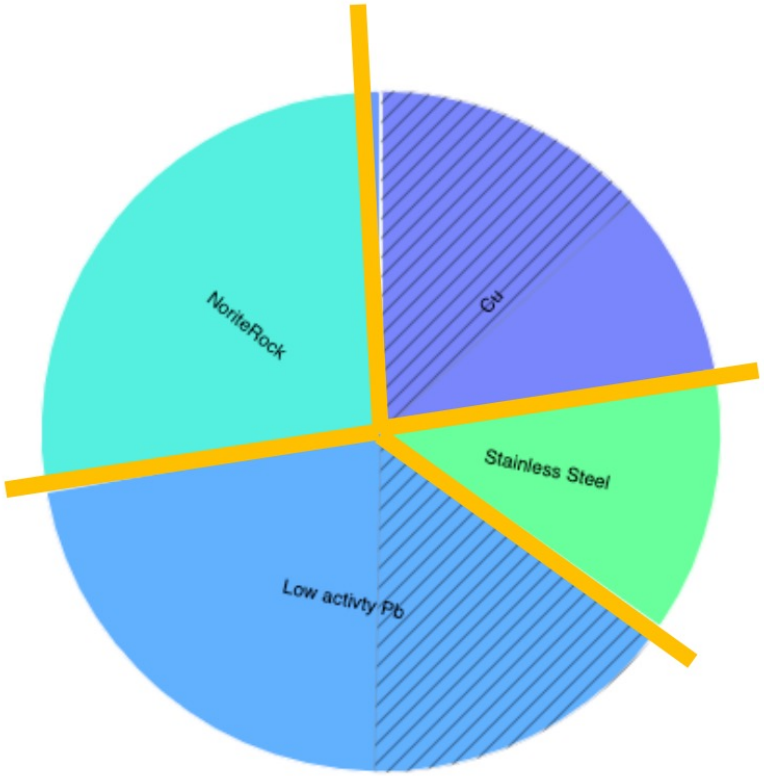




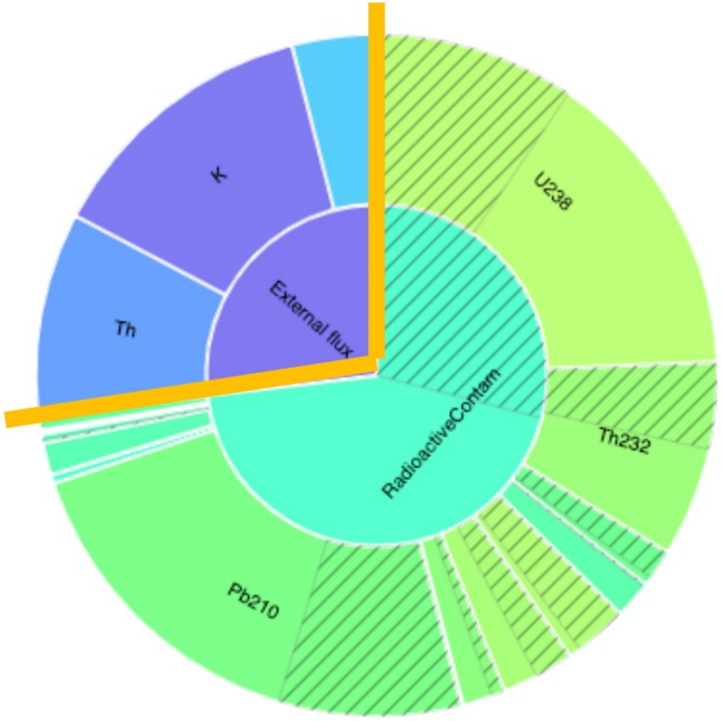
Background Budget



Component



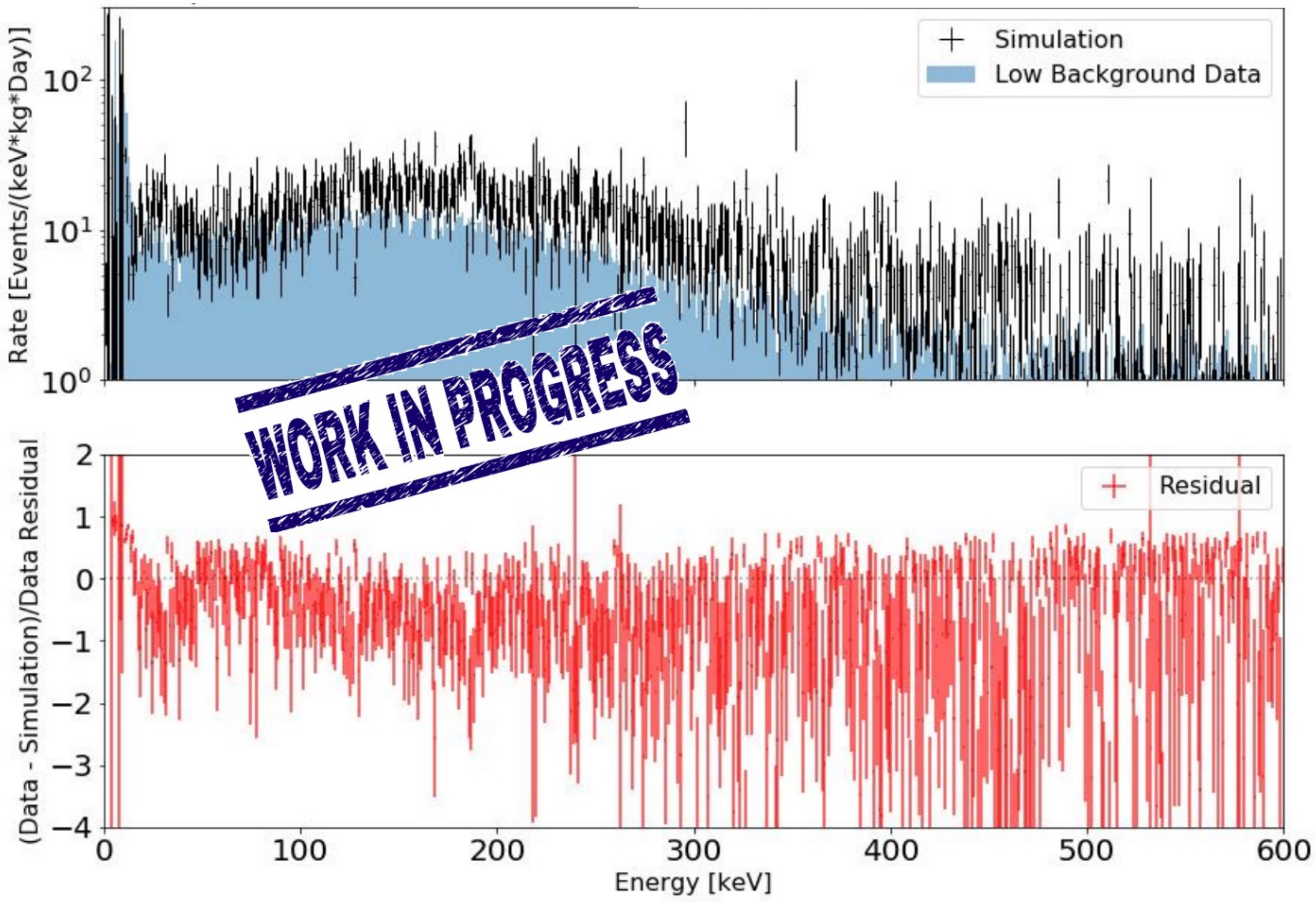
Material



Contaminant

Slide courtesy S. Scorza

M. Baiocchi and A. Pleava (SNOLAB)

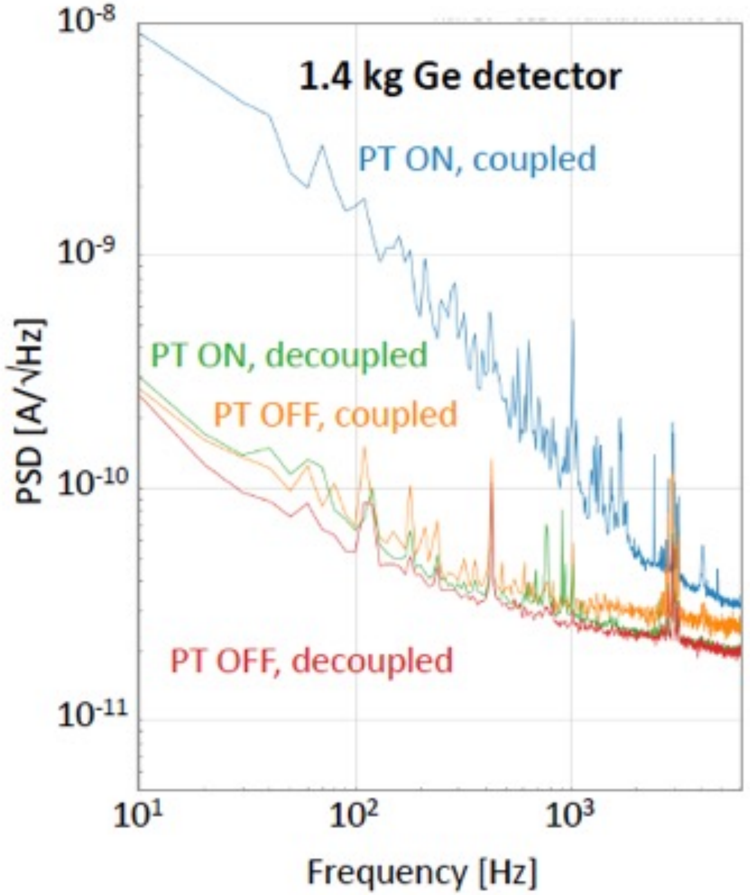


Backgrounds:

- Simulation validated with real data
- 600 g Ge detector
- Agreement is pretty good
- Suspect that remaining discrepancy may be from low counting statistics in HPGe screening
- Total rate (including the detector itself)
  - 6.2 +/- 0.7 evts/kg/keV/day [1-1000 keV]
- Rate from facility only
  - 5.6 +/- 0.6 evts/kg/keV/day [1-1000 keV]

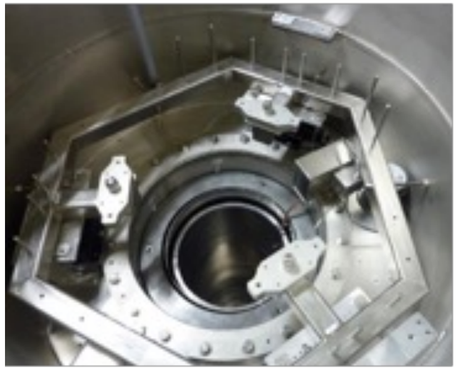
Slide courtesy S. Scorza

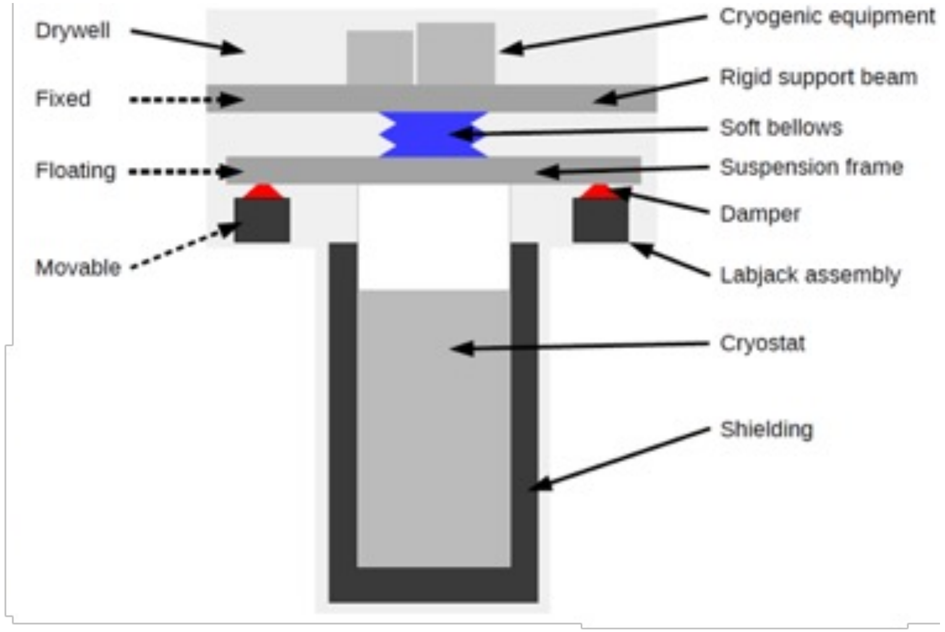
Vibrational Isolation



Vibrations:

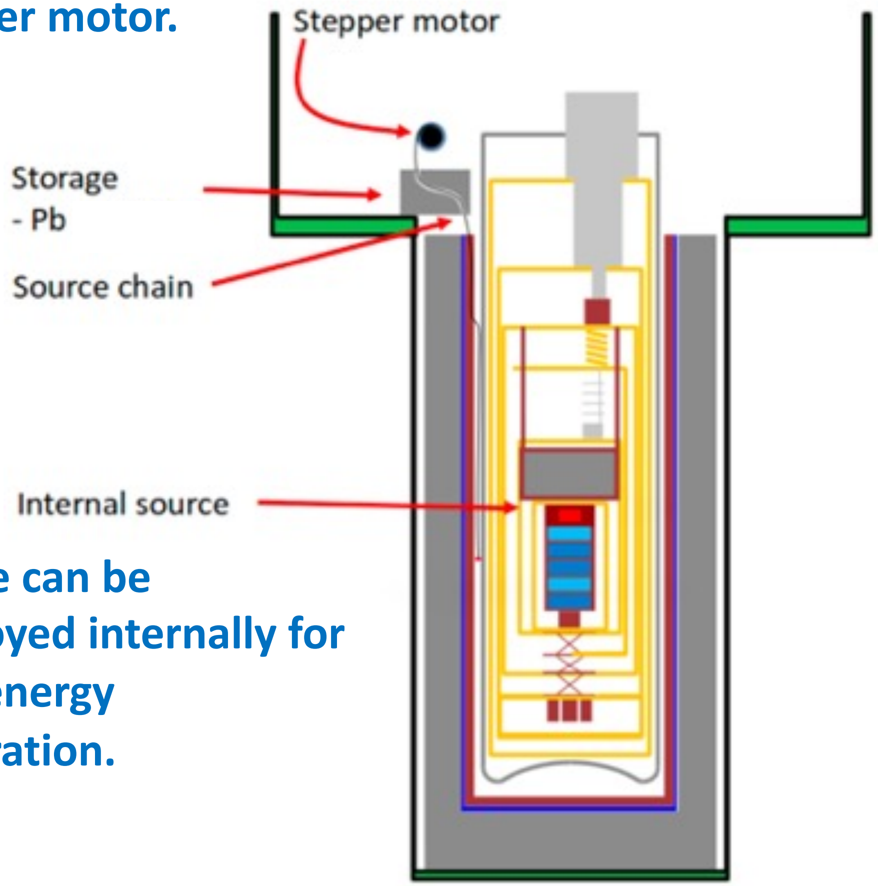
- Suspension system decouples cryostat from pulse tube and environmental vibrations coupling in through the deck.
- We can quantify the impact of vibrations with our detectors!
- Only marginal differences are seen in noise with suspension system active when we turn on and off the pulse tube cooler (one of our biggest sources of vibration)



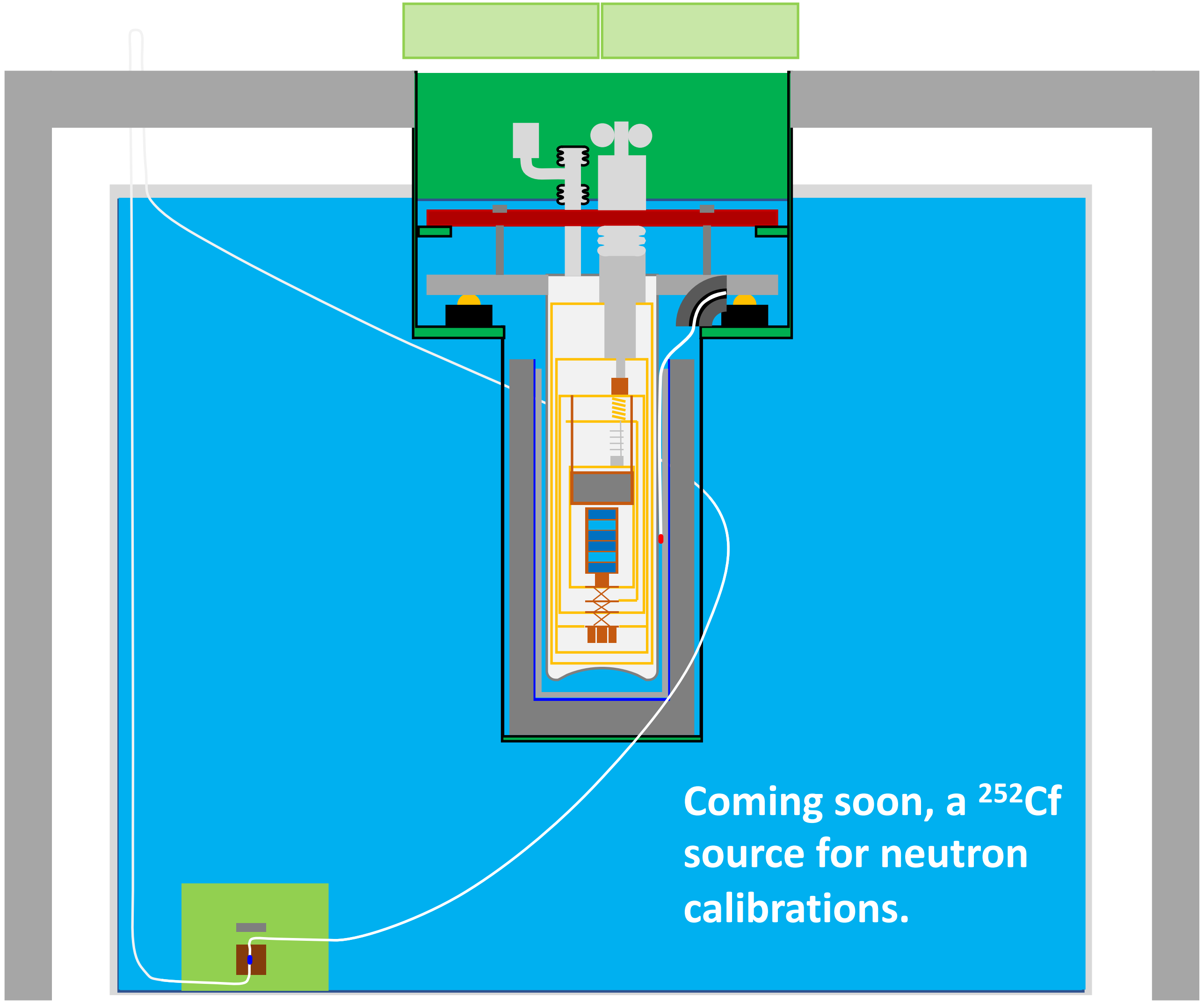


Calibration

A ^{133}Ba gamma source can be deployed into the shielding with a stepper motor.



A ^{55}Fe can be deployed internally for low-energy calibration.



Clean Room

We keep it clean:

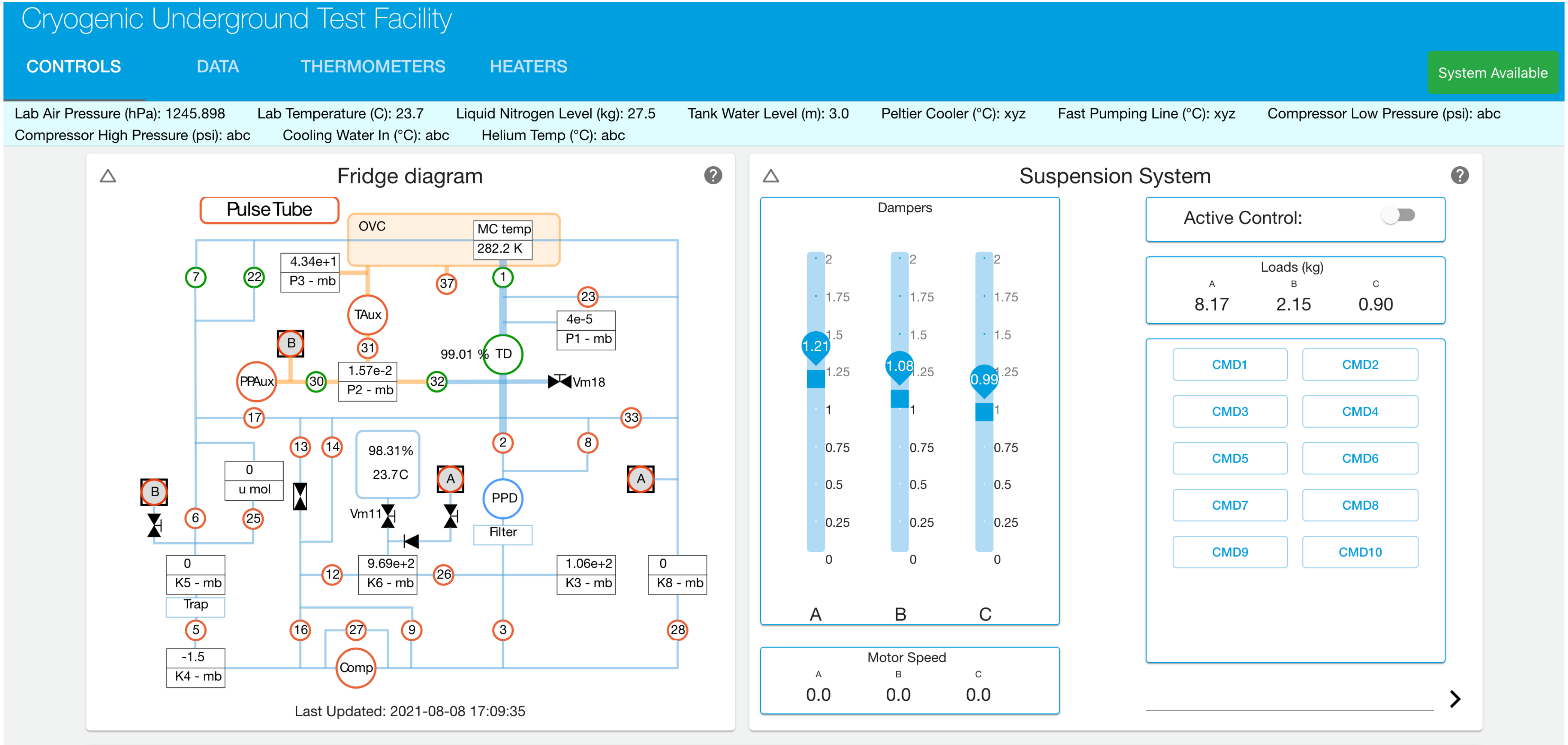
- All payload and fridge work done in our class 300 clean room (clean room inception!)
- Low radon air supplied from surface and passed through HEPA filters
- Typical radon levels < 15 Bq/m^3, but more often ~ 5 Bq/m^3 (depends on weather at surface)

Upgrade to SCDMS RRS:

- SuperCDMS Radon Reduction System recently fully commissioned and brought online
- Can supply low radon air to CUTE
  - Design allows for simultaneous operation but not yet demonstrated
- < 0.02 Bq/m^3 achieved

S. Jess & J. Gauthier

Remote Operations



CUTE Facility -- GUINEAPIG – July 13, 2023

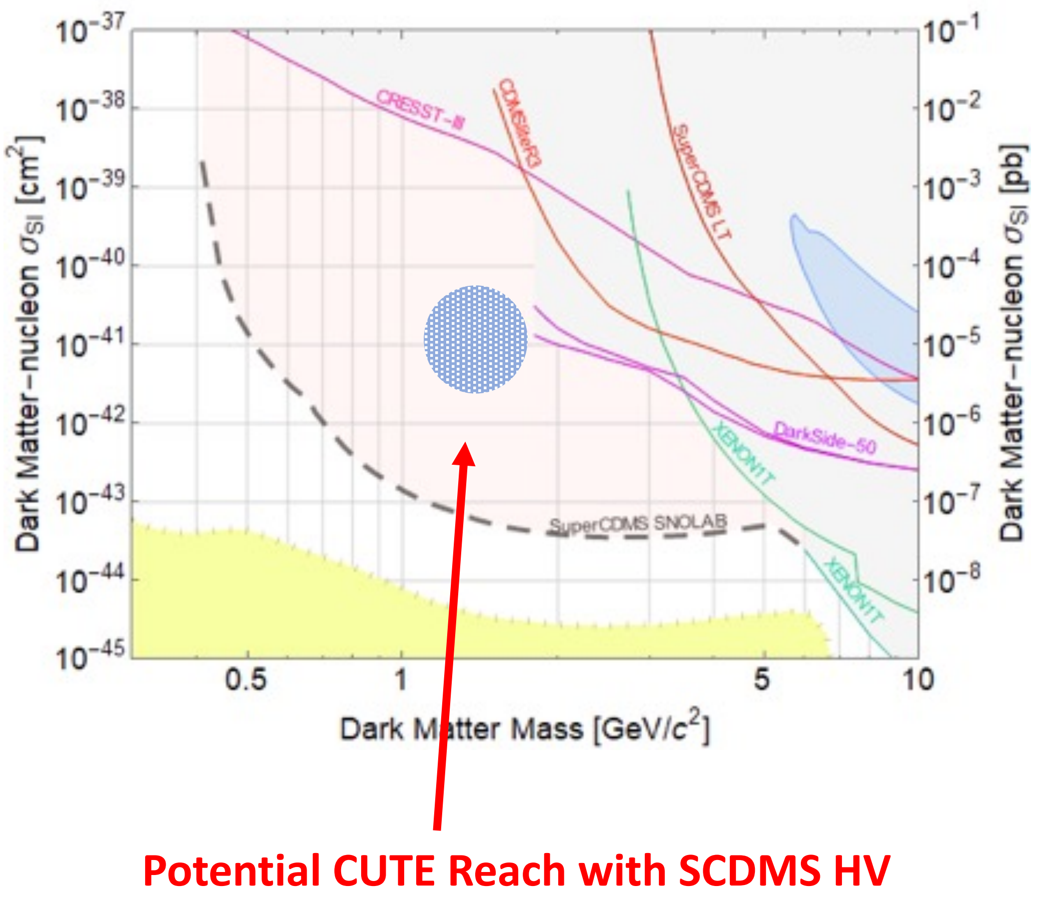
Near Term Plans

SuperCDMS Detector Testing:

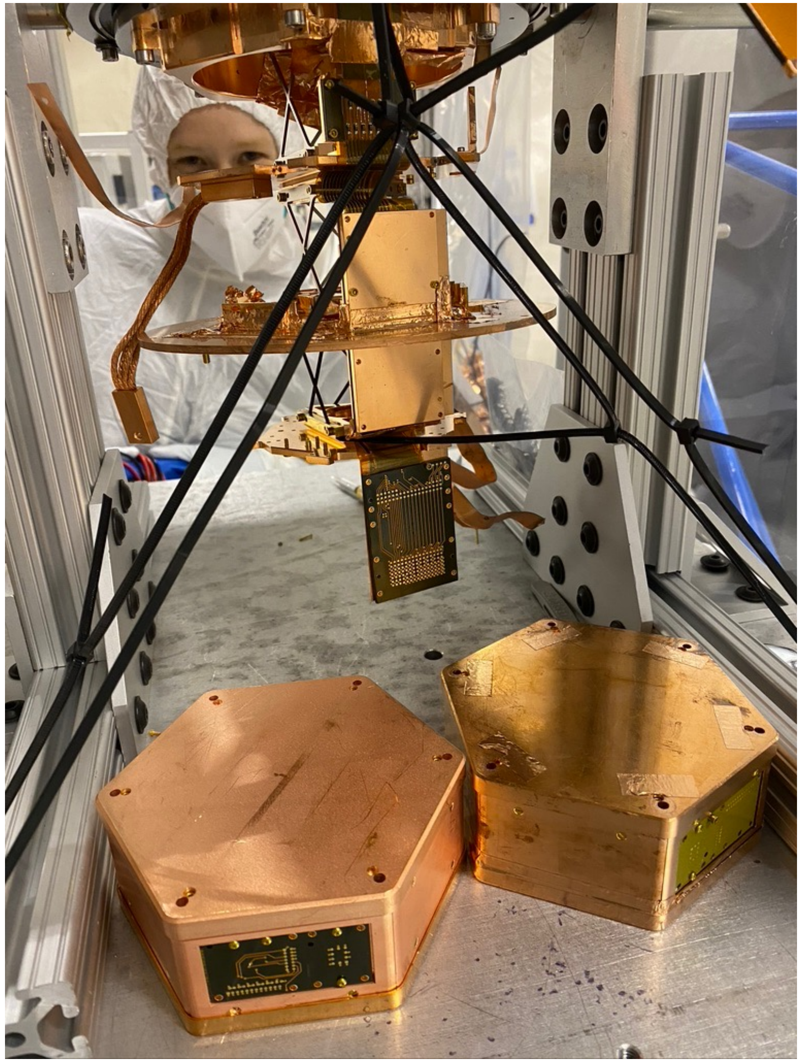
- Single SuperCDMS Ge HV (1.4 kg)
- Single SuperCDMS Si HV (~600g)
- First full "tower" of 4 Ge and 2 Si HV detectors (Fall 2023)
- First full "tower" of 4 Ge and 2 Si iZIP detectors (spring 2024)

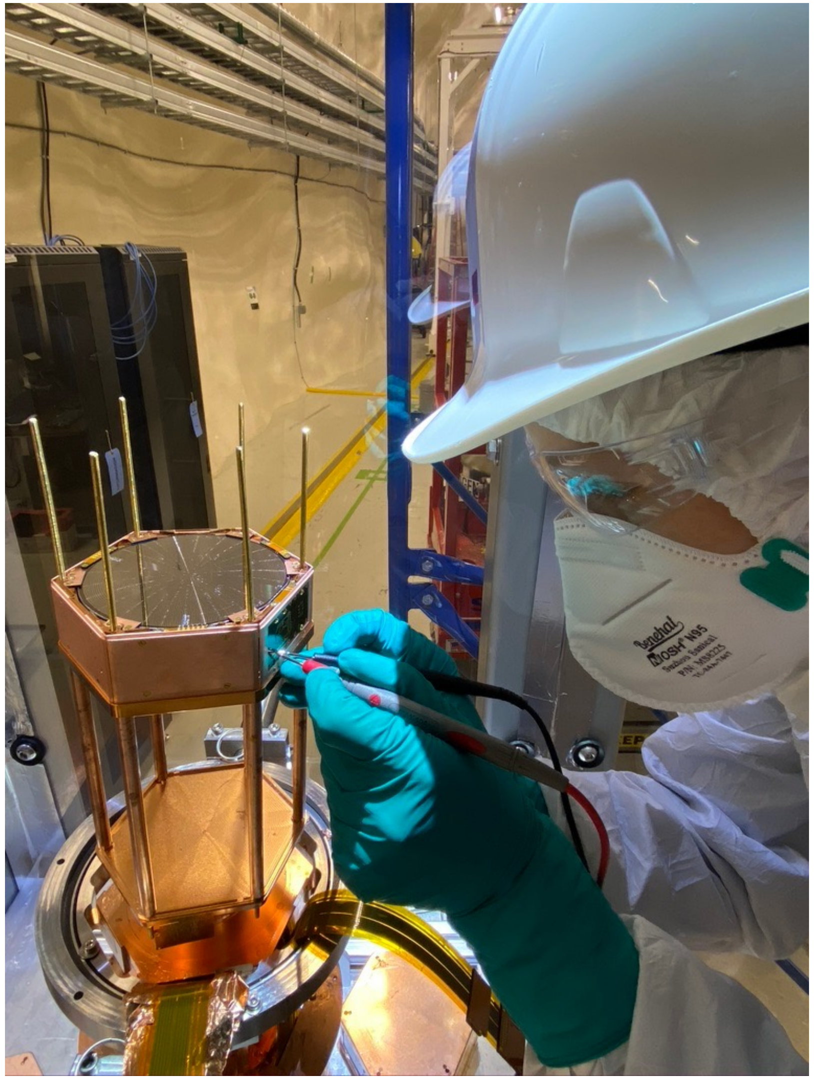
DM Searches with SuperCDMS detectors:

- Use detector payload or test devices and do some searching!
- Science with full SuperCDMS tower before SuperCDMS starts up



“Ops” Tower in CUTE





SuperCDMS Detector Testing:

- Current work
- Single SuperCDMS HV detector (Ge or Si)
- Focus on:
    - Facility performance
    - Calibration
    - Noise hunting
    - Preparing for tower data

Full Tower(s) in CUTE

<u>SuperCDMS Full Tower Test:</u>

- Towers 3 and 4 arrived at SNOLAB earlier this year
  - Tower 3: 4 Ge and 2 Si HV detectors
  - Tower 4: 4 Ge and 2 Si iZIP detectors
- Priority is testing towers for SuperCDMS, but we hope to run long enough to get physics data as well

Long Term Plans

<u>SNOLAB User Facility:</u>

- **CUTE is a SNOLAB user facility!**
- SNOLAB-maintained and continuously improved
  - Collect proposals
  - Expert committee will make recommendations, CUTE management will negotiate details
  - Work with users to implement their experiment

<u>Future Uses</u>

- **Detector testing**
  - Future DM detectors (total mass of ~ 20 kg are possible)
  - Rare event searches (such as ^{50}V rare nuclear decay search)
  - HVeV devices
  - Single photon IR sensors (Nanowire)
  - Testing effect of backgrounds on superconducting qubits
  - <insert your idea here>

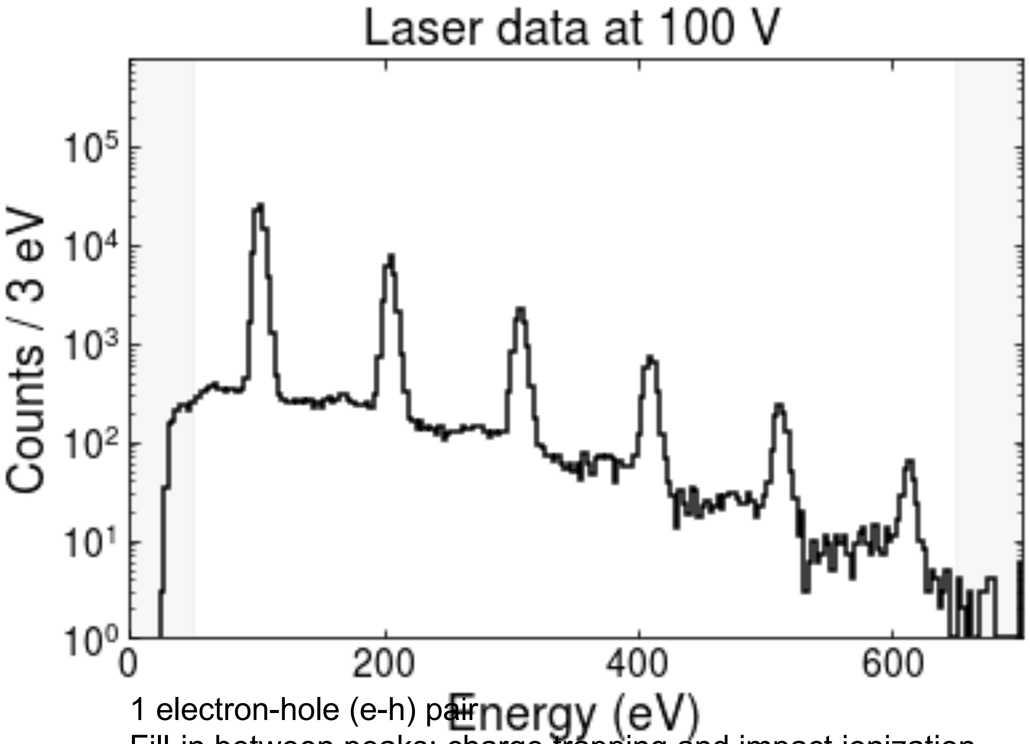
Interested?

Have a project that would benefit from running at CUTE?

Please let us know!

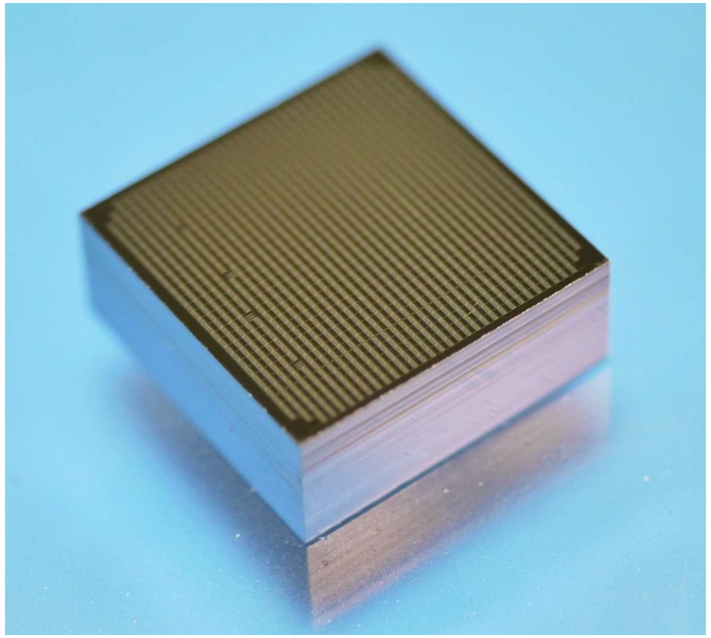
Another Facility for HVeV Operations

- **HVeV Detectors Underground**
  - **Proposal for 5 detectors**
  - **Plan for readout and installation underway**



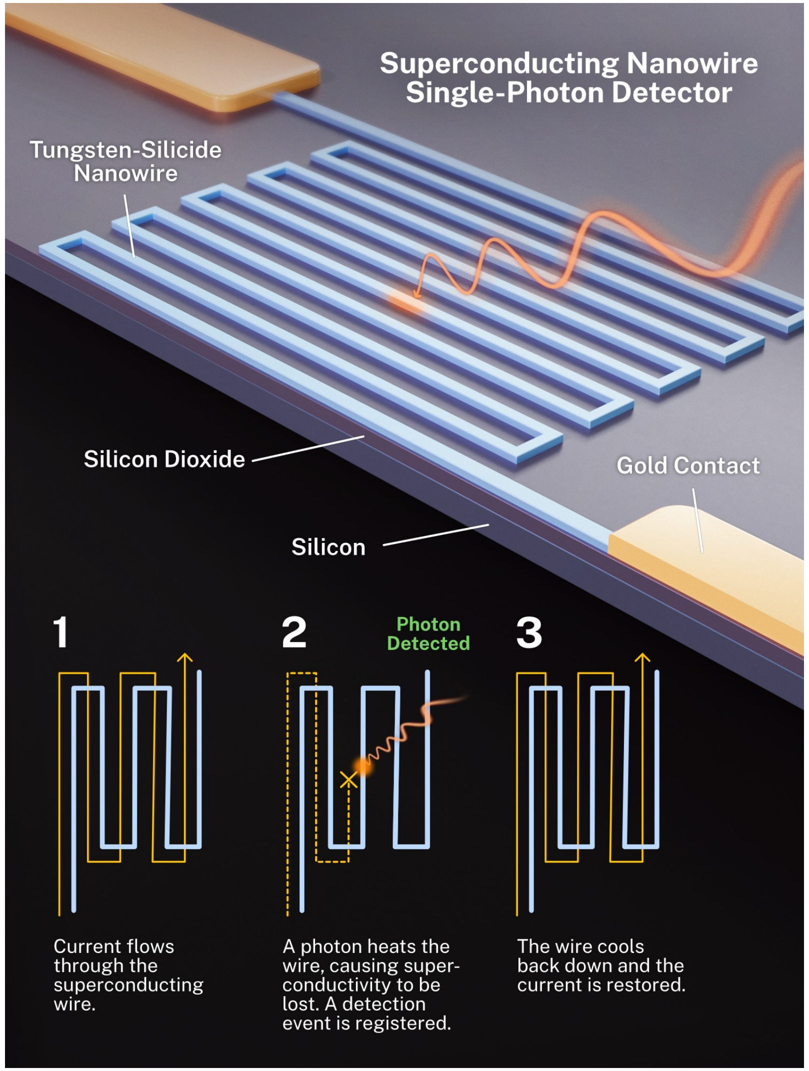
1 electron-hole (e-h) pair
Fill-in between peaks: charge trapping and impact ionization

See Ziqing's talk from yesterday!



D. W. Amaral *et al.*, Phys. Rev. D 102, 091101(R), 2020
F. Ponce, et al., Phys. Rev. D 101, 031101(R), 2020
R. Ren et al., Phys. Rev. D 104, 032010, 2021

SuperConducting Nanowires

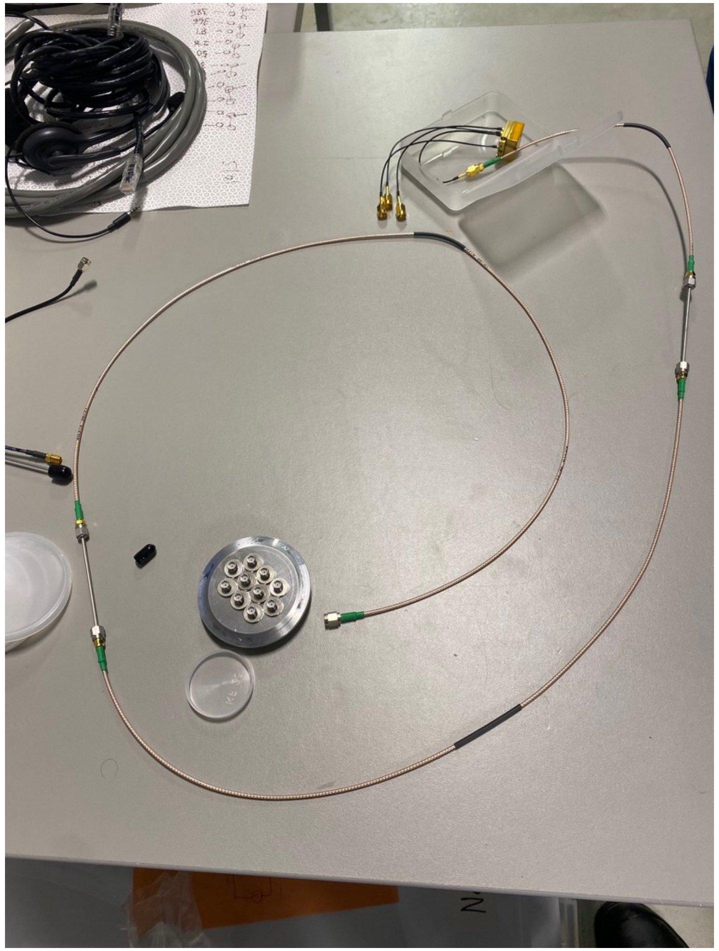


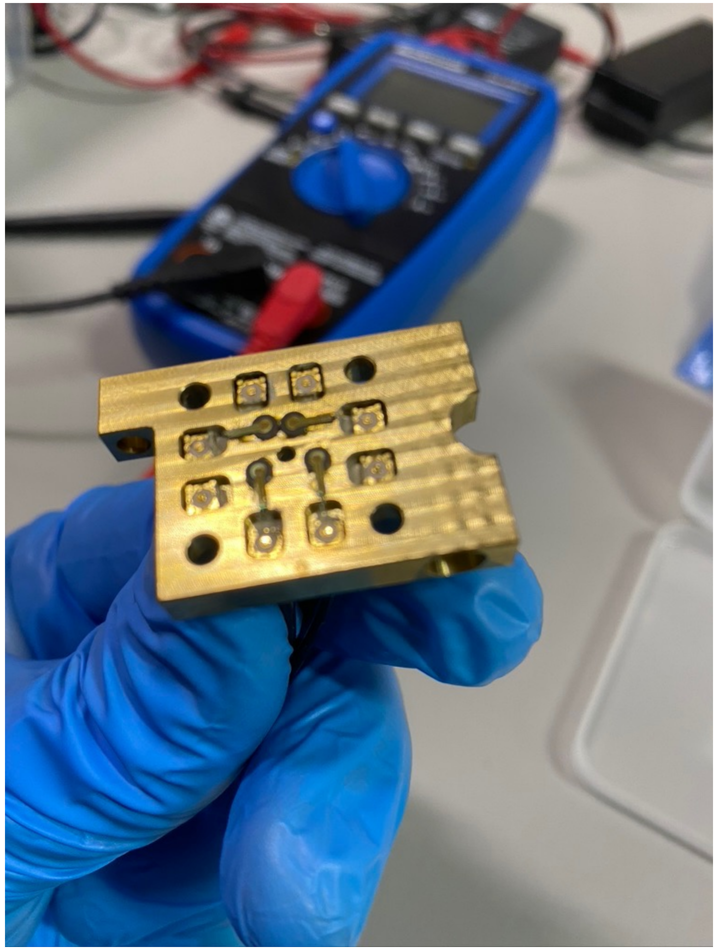
Credit: S. Kelley/NIST

<u>How do we understand the non-ionizing radiation environment in CUTE?</u>

- Increasingly important as we move to lower and lower energy threshold
- Can measure the infrared portion using SuperConducting Nanowire Single-Photon Detectors (SNSPDs)
- Sensitive to short-wave infrared photons
- Spectral information from tunable threshold
- Simple readout, low cost to set up
- Potential for DM hunting as well

Superconducting Nanowires



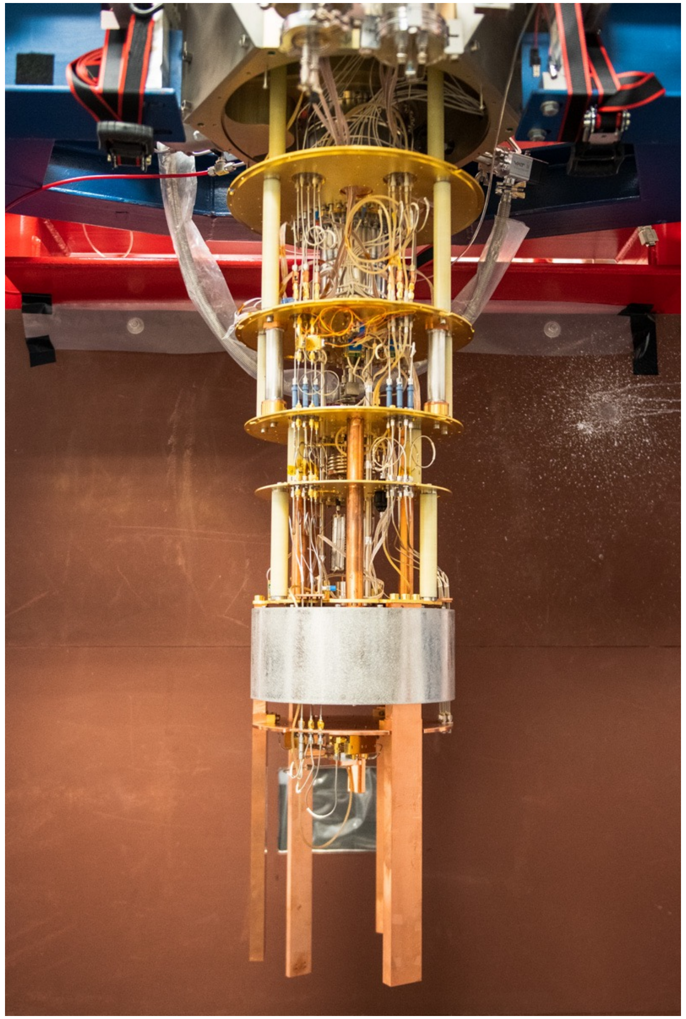


Collaboration between SNOLAB and NIST

- Proof of principle device in hand
- Can run at 1 Kelvin so testing can be in parallel with other projects
- Currently working on readout wiring, hope to test device soon

Qubits

This is NEXUS (same fridge model)
For Illustrative purposes only



Funded proposal to study Qubits in a low radiation underground environment

- Funded by US Army Research Office
- Collaboration between SNOLAB, University of Waterloo, and Chalmers University of Technology
- CUTE facility offers excellent opportunity to study ionization effects on coherence
- Will require upgrades to the CUTE fridge
- Similar upgrades for similar work on same fridge model at NEXUS (see photo)

The CUTE Team

PI	until 2020: G. Gerbier (W. Rau: Co-PI)
	since 2020: W. Rau
Project Manager	until 2017: Ph. Camus
	2018-2020: S. Nagorny
Operations Manager	until 2022: S. Scorza, A. Kubik interim
SNOLAB team	A. Kubik, J. Hall, S. Scorza (until 2022) (Research Scientists)
	J. Gauthier (until 2022) (Operations Engineer)
	R. Schleehahn (Operations Engineer)
	J.M. Olivares (Technical support)
	M. Baiocchi, A. Pleava, S. Jess, Y. Esenullah (students)
	Support from SNOLAB technical team
On-site work	J. Corbett, M. Ghaith, S. Nagorny (until 2020)
Off-site	R. Germond (slow control)
	Z. Hong (facility upgrades)
	T. Aramaki (payload)
	B. Serfass, E. Fascione, E. Michielin,
	R. Underwood, Y. Liu et al (DAQ)
	A. Mayer, S. Pandey, T. Reynolds, A. Reyes, V. Iyer, A. Pradeep, M. Al-Bakry,
	R. Bhattacharyya, S. Dharani
	P. Pakarha (2018/19, calibration)
	K. Dering, S. Crawford (design engineering, until 2019/20)

Thank You!