SuperCDMS & CUTE

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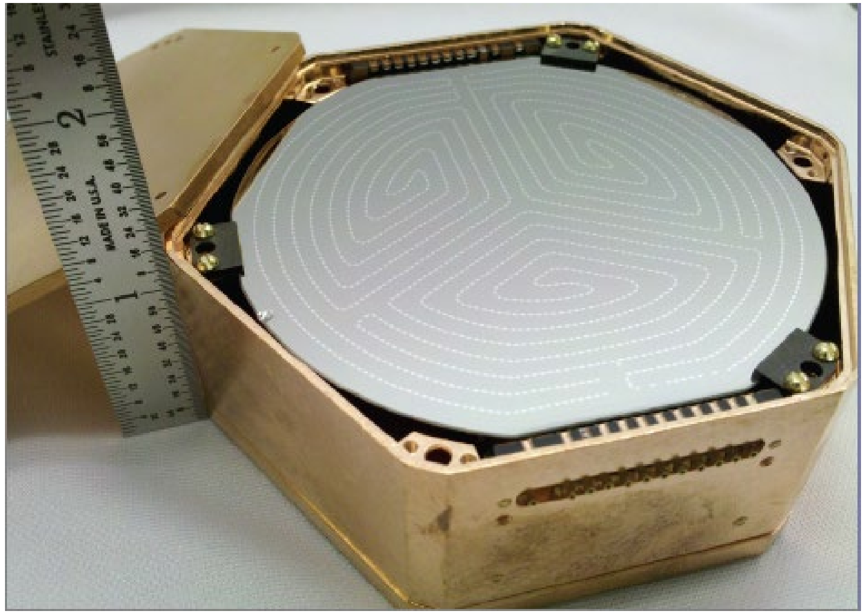
IPP Town Hall

July 15, 2020

SuperCDMS technology



Cryogenic semiconducting crystals (Ge or Si), with phonon and ionization sensors

Heat capacity ∝ T^3:
T ~ 10's of mK makes crystal heating, phonon signal easy to see

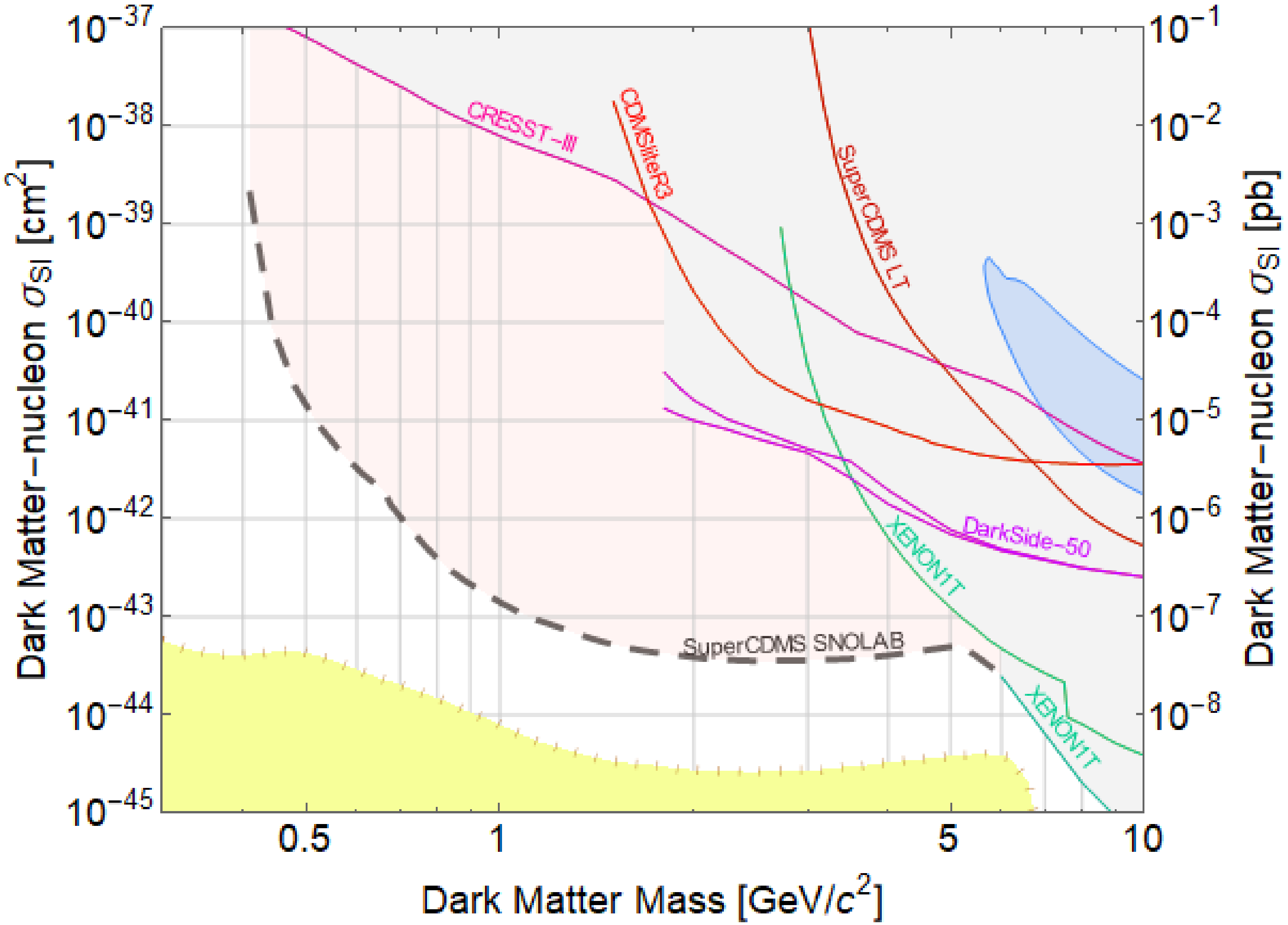
Nuclear recoils by WIMPs create phonon excitations (vibrations) in crystal. Ionization creates electron/hole pairs in crystal in proportion to energy and to yield factor *Y*:

$$N_{e/h} = \frac{YE_r}{\epsilon}$$

$$\begin{aligned} E_{phonon} &= E_r + N_{e/h} V_{bias} e \\ &= E_r \left(1 + Y \frac{V_{bias} e}{\epsilon}\right) \end{aligned}$$

SuperCDMS SNOLAB science reach

- Aims to be the world's most sensitive experiment between 0.5-5 GeV/c^2.
- Both germanium and silicon detectors (two nuclear targets), in two different configurations: 12 HV detectors (lower mass reach) and 12 iZIPs (better background rejection)
- Also sensitive to low energy electron recoils: dark photons, axion-like particles, low mass DM.



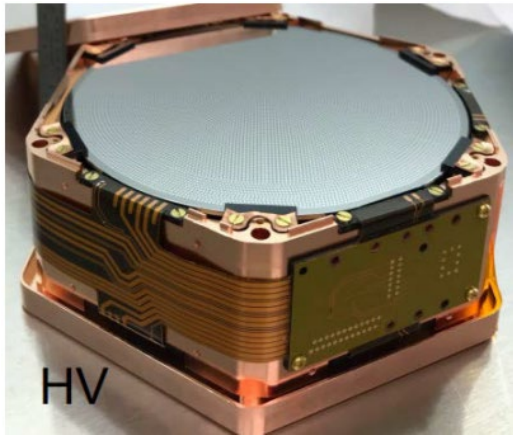
SuperCDMS SNOLAB status

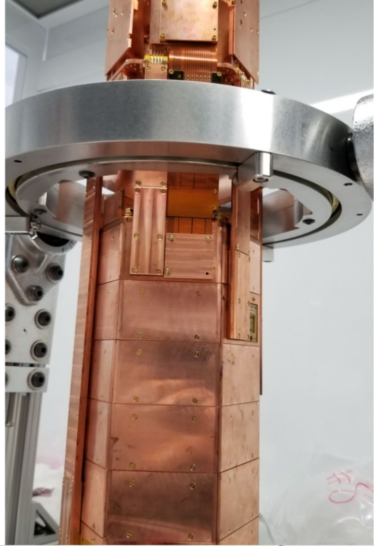
Significant systems making great progress:

- Detector fabrication ~50% complete
- Dilution fridge and most of shield delivered
- Readout electronics being manufactured now
- Significant work underground: seismic platform, crane, chilled water system

Challenges:

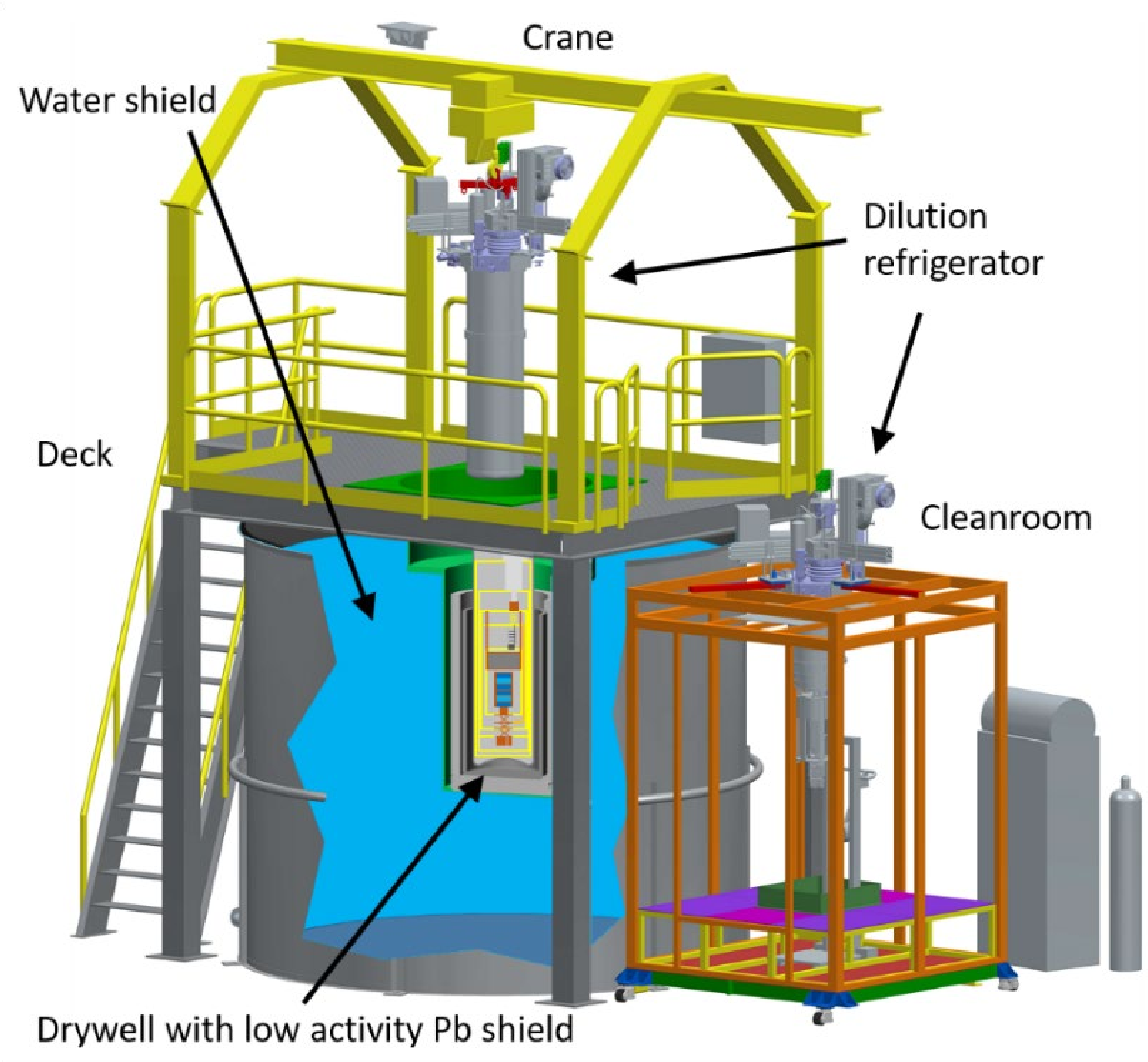
- Cost/schedule considerations have prompted redesign of cryostat: reduction in size reduces maximum payload size (unless upgraded), but no change in initial payload.
- COVID-19 work stoppages at virtually all institutions have delayed installation, pushing project completion well into 2021. Aim to complete commissioning in 2022.





CUTE

- Underground test facility at SNOLAB, capable of operating one SuperCDMS tower or individual detectors
- Operational since 2019, was taking data until March 2020.
- Platform for doing detector R&D in low background environment, and early science from SuperCDMS while project installation completes.
- Available for testing other cryogenic devices, including quantum computing, new detector designs, etc.



The Canadian group

- Members at 6 Canadian institutions make up 23% of collaboration – a rapidly growing fraction
- Nine Canadian PIs contribute 6 FTE. Two new PIs: Jeter Hall (SNOLAB), and Ziqing Hong (Toronto, starting January 2021)
- Major areas of Canadian contribution:
  - CFI funding provides 10% of capital cost: cryo, shielding, underground infrastructure
  - CUTE facility is entirely funded by Canada (Queens CERC funding)
  - Data acquisition system designed and led by UBC/TRIUMF group
  - Background characterization and screening (SNOLAB, Montréal)
  - Simulations, computing, Compute Canada (Toronto)
  - Detector characterization and testing (TRIUMF, Queens)
  - Leadership positions: chair of Collaboration Council, current and previous analysis coordinator, many working group chairs

2022-2027 outlook

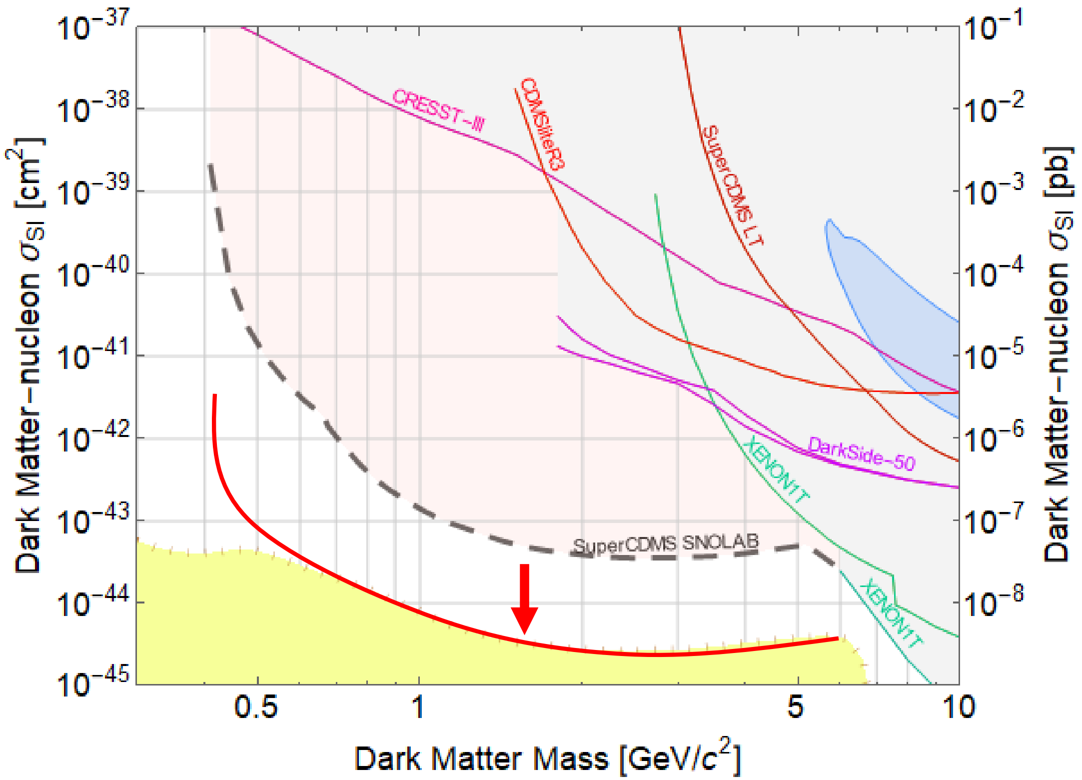
- The time period singled out by IPP corresponds nearly exactly to SuperCDMS's anticipated science run with its initial payload of 24 detectors. First science run to begin in second half of 2022.
- Current Canadian funding is ~$1.1M/yr (40% NSERC/60% MI), + SNOLAB in-kind contributions. Canada provides ~20% of total operating cost of experiment. Replacement for MI funding after CFREF ends is critical issue for the group!
- Use CUTE facility in parallel to test new detector designs, advance R&D. Could lead to upgrade proposals to be submitted in the latter half of this 5-year period.

HQP

- Anticipated Canadian group size over the 2022-2027 period:
  - 8 PIs (+ any new PI hires in Canada)
  - 8 PDFs
  - 17 grad students
  - 1 technician, based at SNOLAB and supported by CFI IOF
  - 5 undergrads
- Canadian PDFs and students have taken on significant leadership:
  - Belina von Krosigk (PDF): analysis coordinator 2018-2020, now new faculty at Hamburg
  - Emanuele Michielin (PDF): elected analysis coordinator 2020-2022
  - Richard Germond, Eleanor Fascione, Matt Wilson, (graduate students): led recent dark absorption paper (PhysRevD.101.052008)
  - Matt Wilson (graduate student): co-led new paper on low mass DM search with surface-operated single-charge sensitive detector (arXiv:2005.14067)

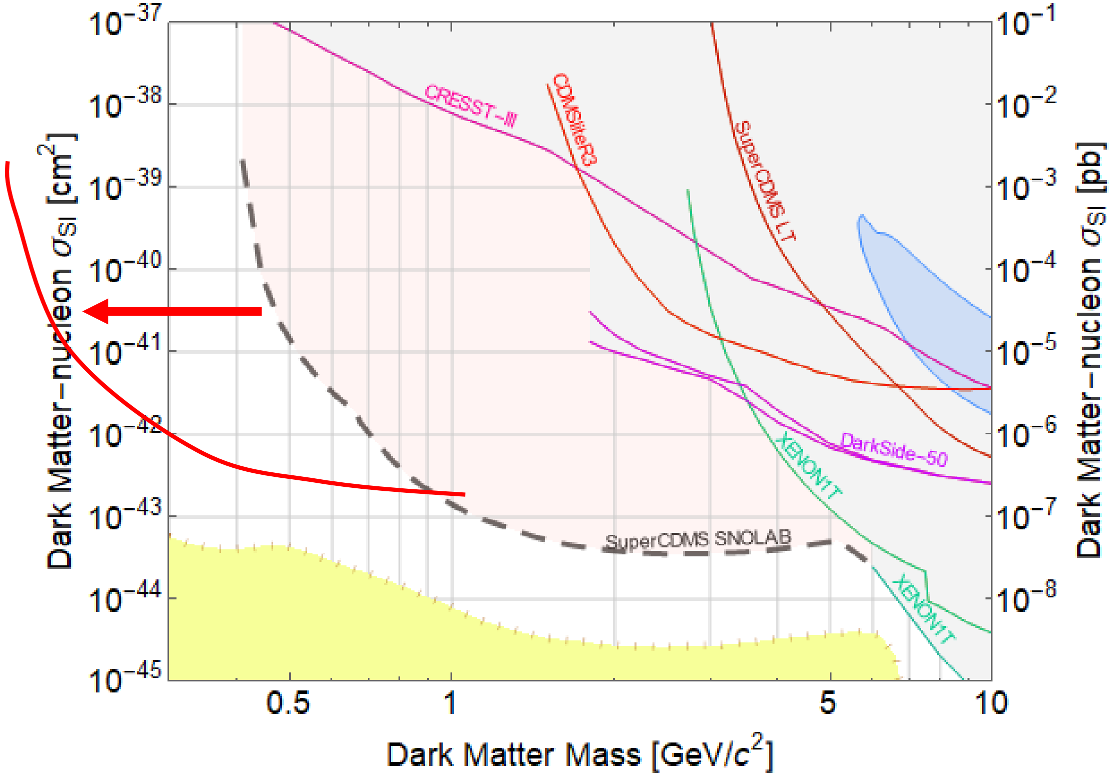
Longer term: push down in cross-section to ν floor

- Depends on reducing dominant cosmogenic backgrounds:
    - Could we make electroformed copper underground at SNOLAB?
    - Could we grow crystals and manufacture detectors underground at SNOLAB?
    - Improve detector design to have better background rejection?
    - Maybe \$3-5M total. Could be useful for entire underground science community.
- Increase detector mass:
    - Build more detectors
    - Maybe expand cryostat size, if warranted
    - Maybe another ~\$5M in detectors and infrastructure upgrades



Longer term: Pushing lower in mass

- Options for lowering energy threshold:
  - Improve resolution by lowering T_c on TES
  - Improvements in sensor design
  - Build detectors from lower-mass nuclei (e.g. diamond detectors)
- For electron recoil signatures:
  - Understand & reduce charge-transport effects in detector bulk
- Improving background rejection:
  - Good enough resolution to resolve individual electron-hole pairs could allow NR/ER rejection
  - Resolution already achieved in gram-scale test devices – can we scale up in mass?



Conclusions

- 2022-2027 science:
  - Best nuclear recoils limits in mass range from ~0.5-5 GeV/c^2
  - Limits on very low energy electron recoils: very light dark matter, dark photons, axion-like particles, etc.
  - R&D to understand backgrounds, improve resolution, push down in energy
- Future depends on what is seen in various experiments
  - Any signal from SuperCDMS or other experiments? This is critical issue for deciding on the next step!
  - Push down in xsec? Need larger mass, lower cosmogenic backgrounds …
  - Push down in mass reach? Need better energy resolution, new designs, but not a lot of target mass
- Underground fabrication of materials useful to lots of low background experiments: something for SNOLAB to consider?

Backups

Canadian PIs

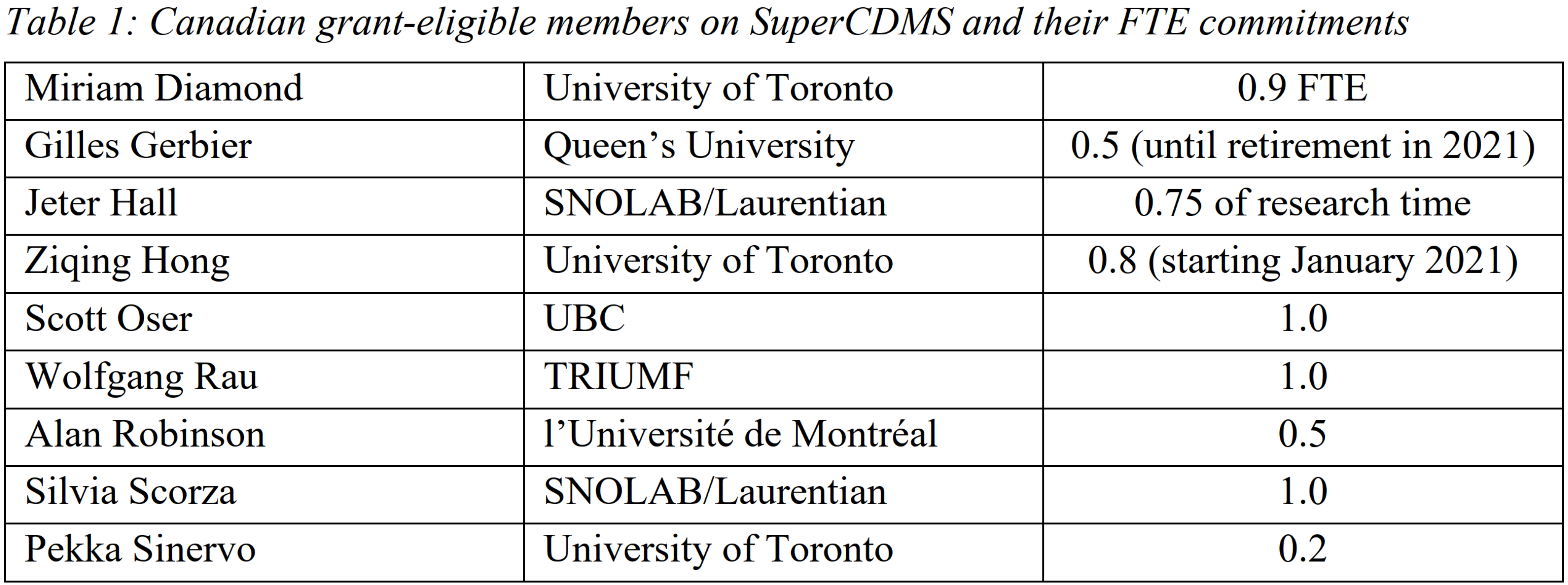


Table 1: Canadian grant-eligible members on SuperCDMS and their FTE commitments

Miriam Diamond	University of Toronto	0.9 FTE
Gilles Gerbier	Queen's University	0.5 (until retirement in 2021)
Jeter Hall	SNOLAB/Laurentian	0.75 of research time
Ziqing Hong	University of Toronto	0.8 (starting January 2021)
Scott Oser	UBC	1.0
Wolfgang Rau	TRIUMF	1.0
Alan Robinson	l'Université de Montréal	0.5
Silvia Scorza	SNOLAB/Laurentian	1.0
Pekka Sinervo	University of Toronto	0.2

Recent electron recoil results

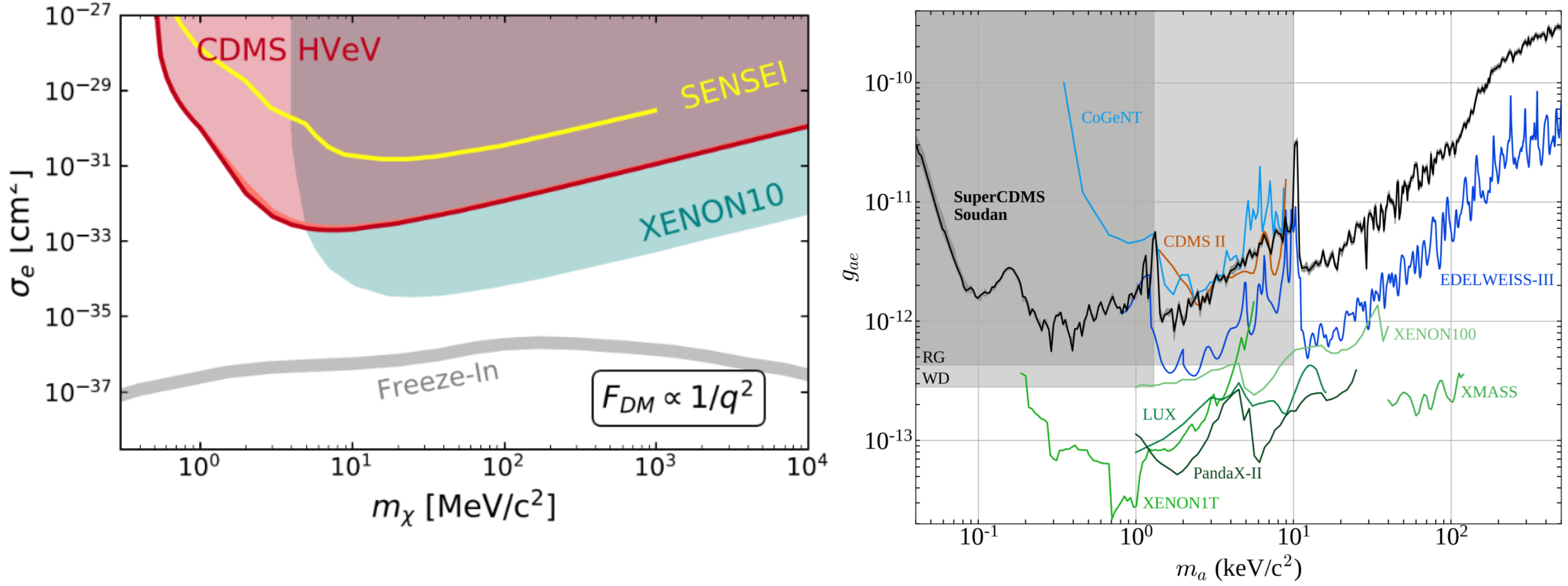


Figure 2: Left: Limits on dark matter-electron scattering, from a 0.49 gram-day exposure of a prototype HVeV detector at a surface facility and other experiments. Reductions in the radioactive and particularly in the charge leakage backgrounds are expected to improve this result considerably. Right: Limits on Axion-like Particles (ALPs) from SuperCDMS Soudan and other experiments.

EDI

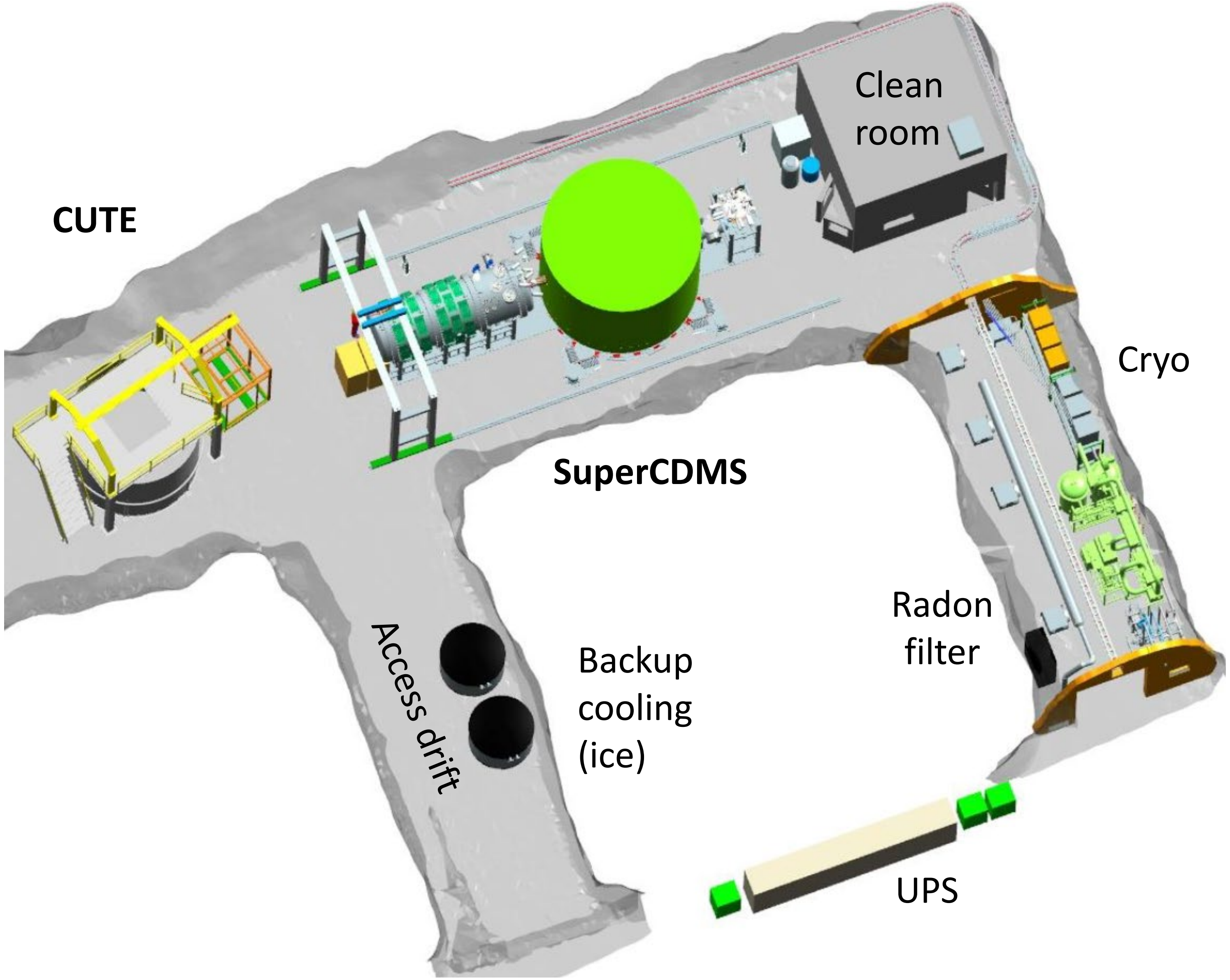
- Collaboration leadership (spokesperson + executive committee) is 60% female.
- Canadian postdocs ~40% female.
- Canadian PIs are 1/3 women or visible minority.
- Graduate students are 20% female and 20% visible minority.

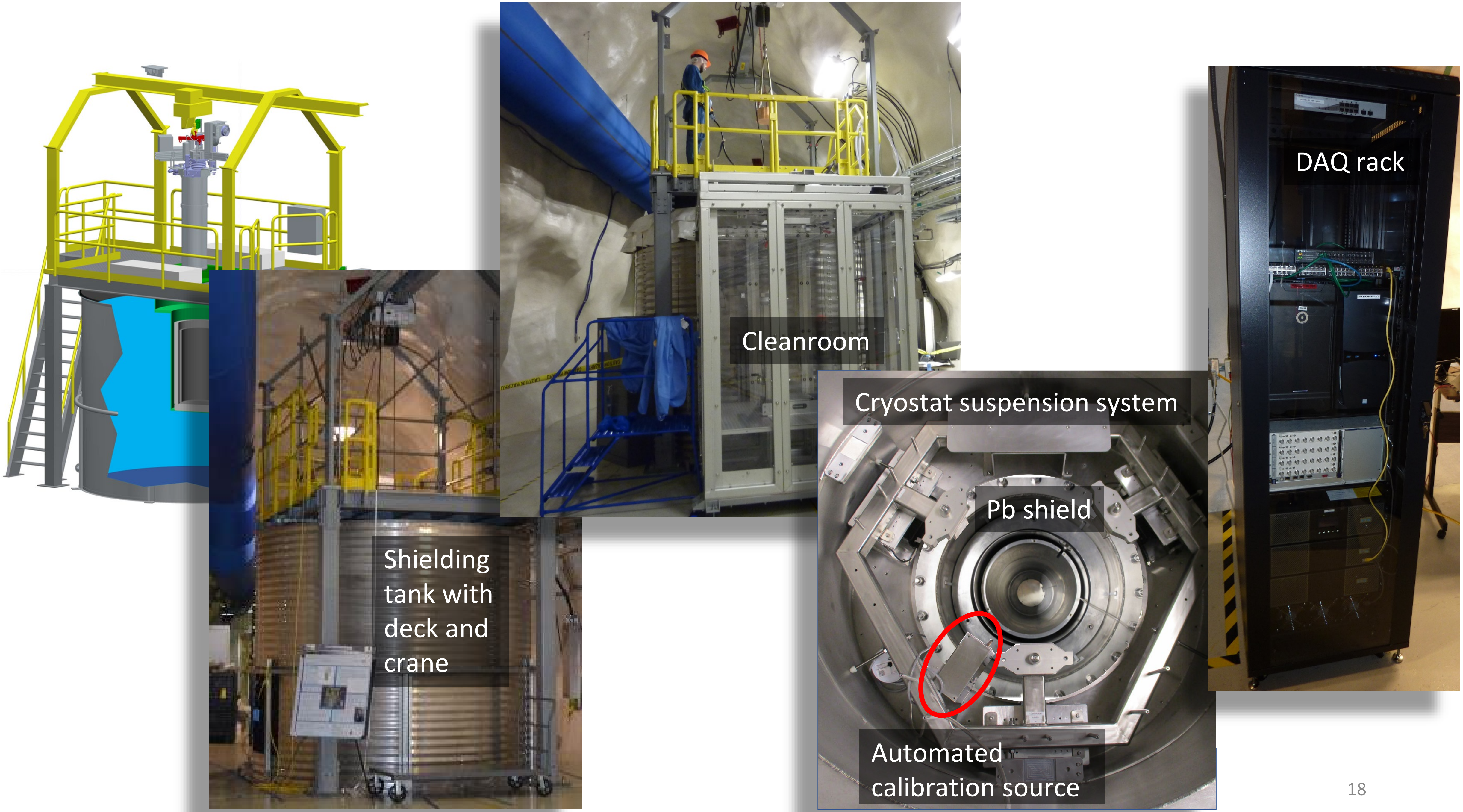
Canadian SuperCDMS group is doing above average in representation, except at graduate student level. This is an area where we should improve our position.

Outreach

- The SuperCDMS collaboration has a coordinated outreach effort, and shares outreach materials
- Social media effort: collaboration Twitter account (managed by Silvia Scorza)
- Frequent public presentations by PIs: Gilles Gerbier for Radio-Canada Découverte, Scott Oser at Vancouver’s HR MacMillan Space Centre, Alan Robinson for the JeunesExplos program, etc.
- Ongoing program to develop curriculum modules that allow students and the general public to access and work with open SuperCDMS data and learn about our science and data analysis methods.

SuperCDMS at SNOLAB

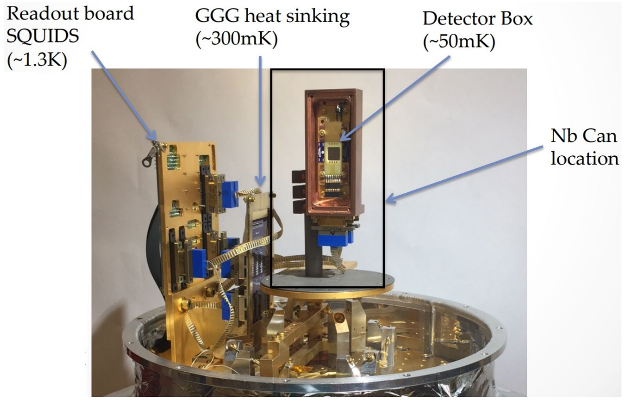


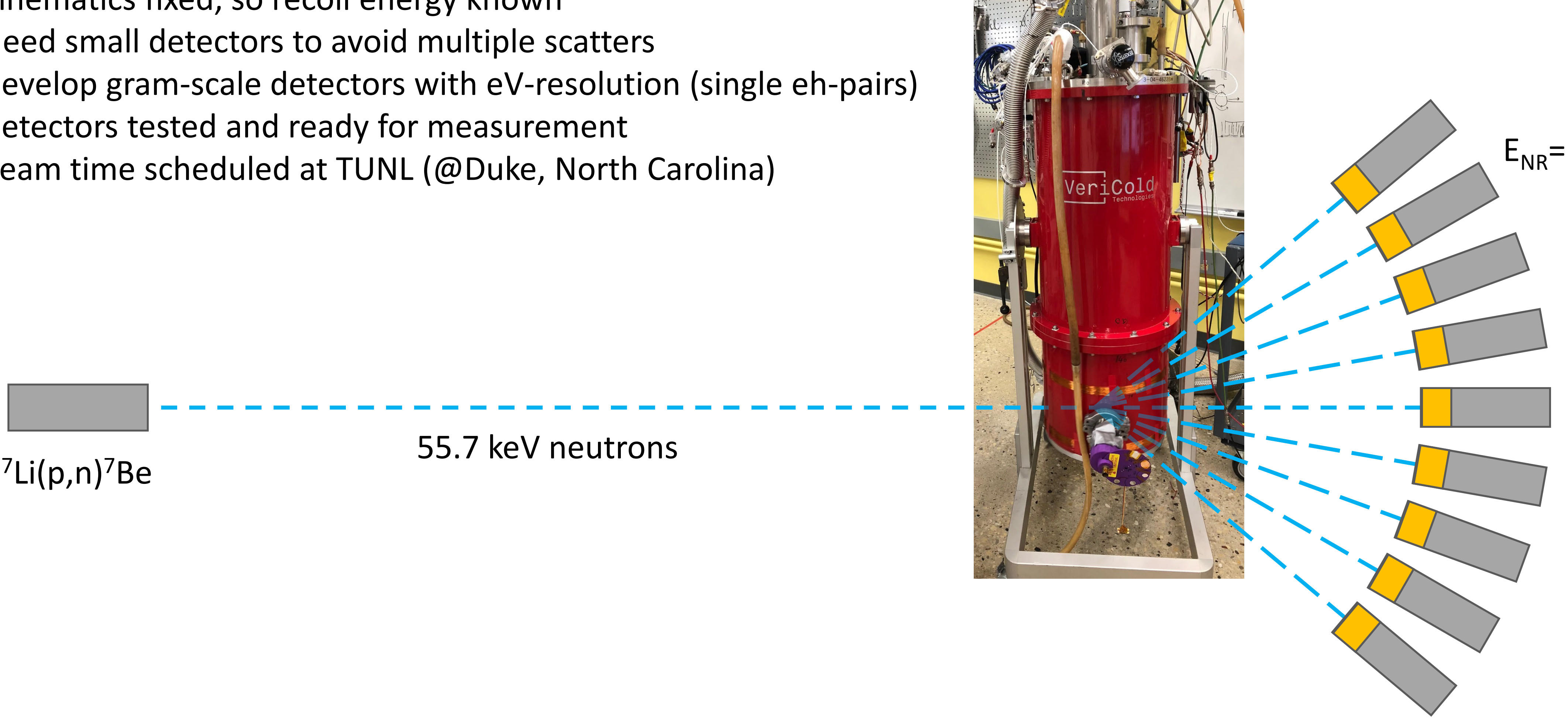

Cleanroom
DAQ rack
Cryostat suspension system
Pb shield
Shielding tank with deck and crane
Automated calibration source

Nuclear Recoil Calibration at Low Energy

Energy scale calibration with radioactive sources → electron recoils
But need nuclear recoil energy scale, in particular: ionization efficiency

- Use pulsed low-energy neutron beam
- Measure recoils response together with scattered neutrons
- Kinematics fixed, so recoil energy known
- Need small detectors to avoid multiple scatters
- Develop gram-scale detectors with eV-resolution (single eh-pairs)
- Detectors tested and ready for measurement
- Beam time scheduled at TUNL (@Duke, North Carolina)





Caltech

C2N

NIST

Pacific Northwest NATIONAL LABORATORY

SLAC

SOUTH DAKOTA SCHOOL OF MINES & TECHNOLOGY

SNOLAB

UBC

Cal

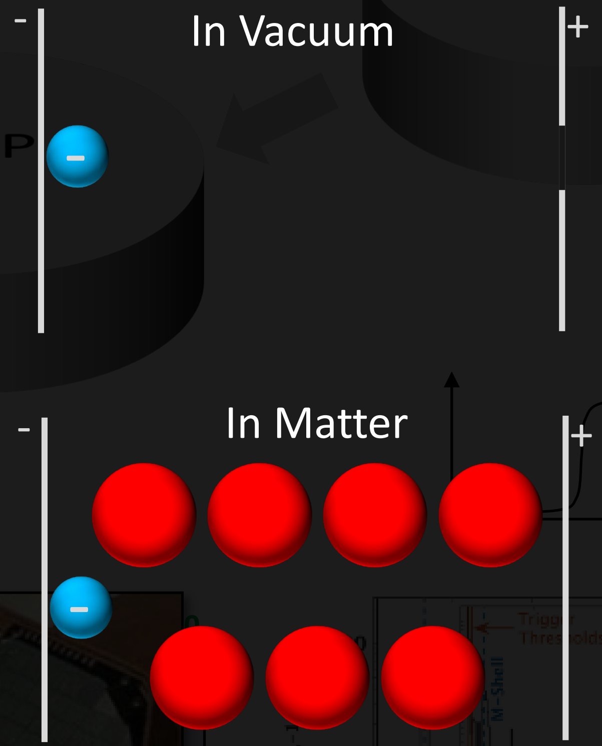
UF

UNIVERSITY OF SOUTH DAKOTA

NSF

NISER

Neganov-Luke Effect



Electron gains kinetic energy
(E = q · V → 1 *e*V for 1 V potential)

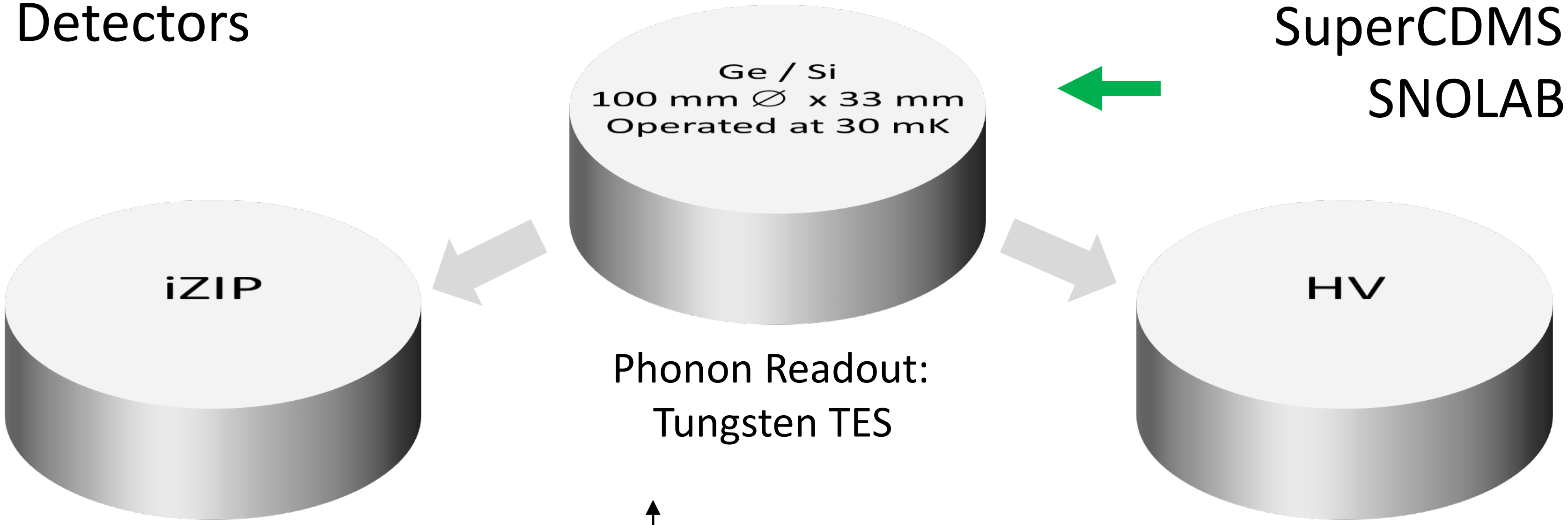
Deposited energy in crystal lattice:
Neganov-Luke phonons

∝ V, # charges

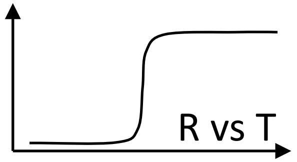
- Luke phonons mix charge and phonon signal → reduced discrimination
- Apply high voltage → large final phonon signal, measures charge!!
- ER much more amplified than NR
  → gain in threshold; dilute background from ER

Detectors

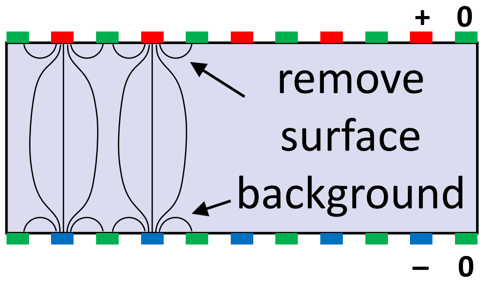
SuperCDMS
SNOLAB



Phonon Readout:
Tungsten TES

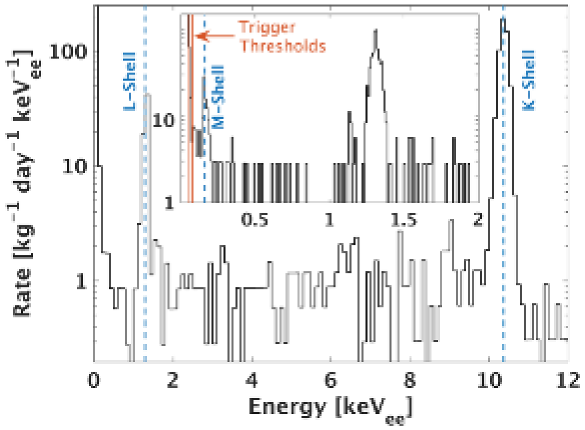


Add: charge readout (few V)
Background discrimination
Threshold < 1 keV

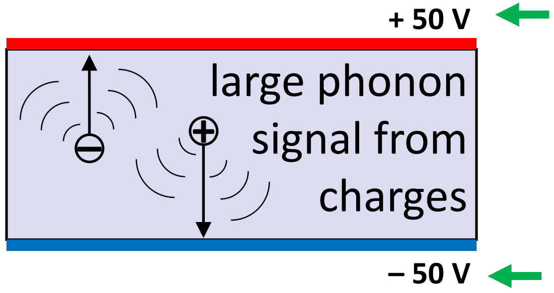


remove
surface
background

< 1 background event for
whole exposure



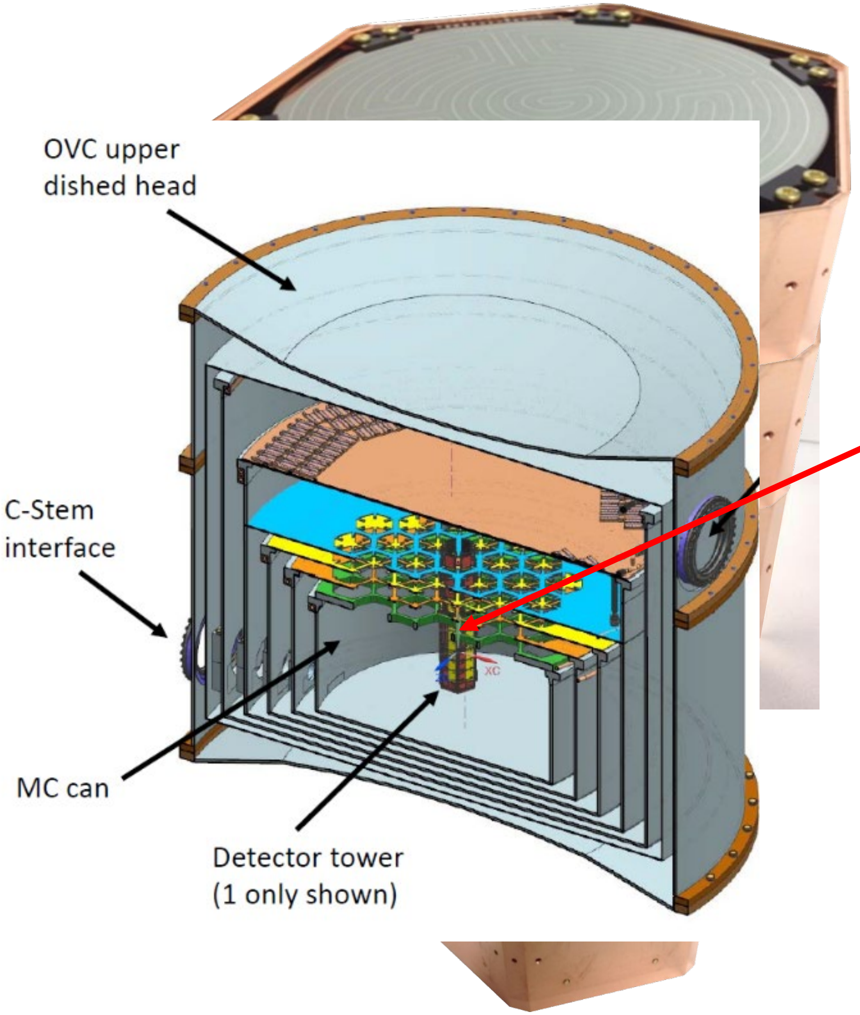
Add: high voltage (~100 V)
Phonons from drifting charges
Threshold < 0.1 keV (phonon)



large phonon
signal from
charges

effective threshold: few
(or one) electron-hole pairs

Implementation (SNOLAB setup)



6 detectors
→ 1 tower

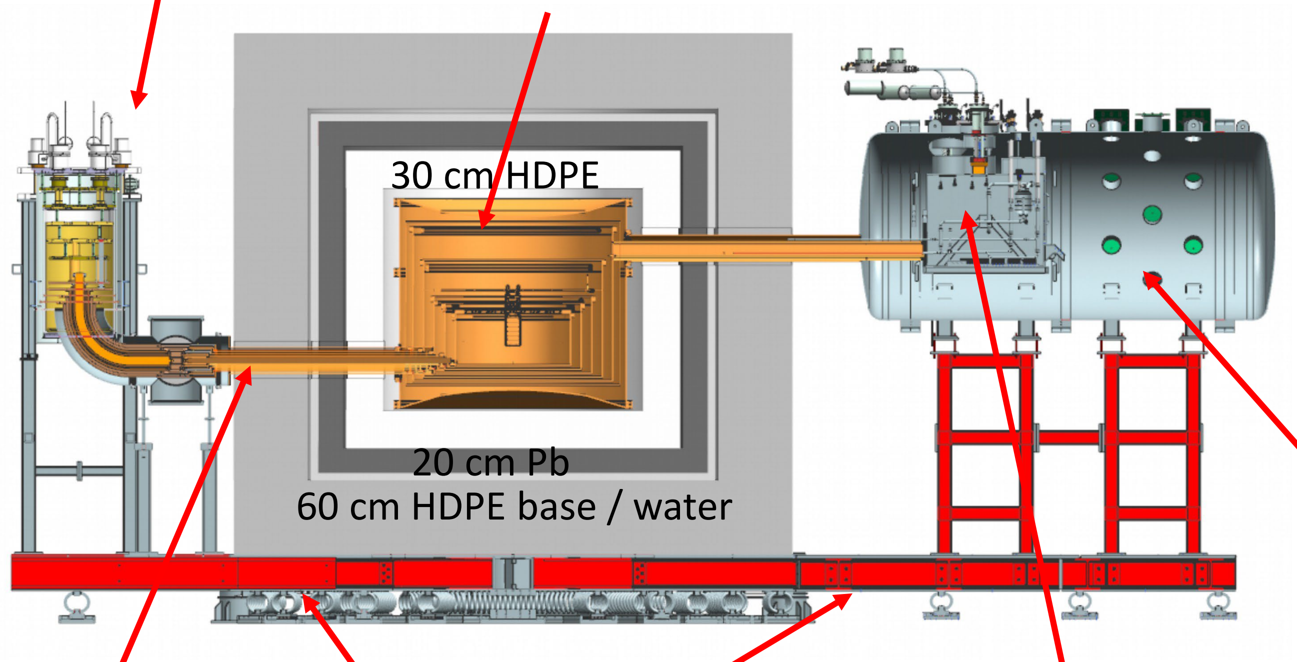
Implementation (SNOLAB setup)

Fridge to provide
<15 mK at the detector

Detector volume
(space for up to 7 “towers”)

Initial Payload:
2 HV towers (4 Ge/2Si)
1 Ge iZIP tower
1 Ge/Si iZIP tower (4/2)

6 detectors
→ 1 tower



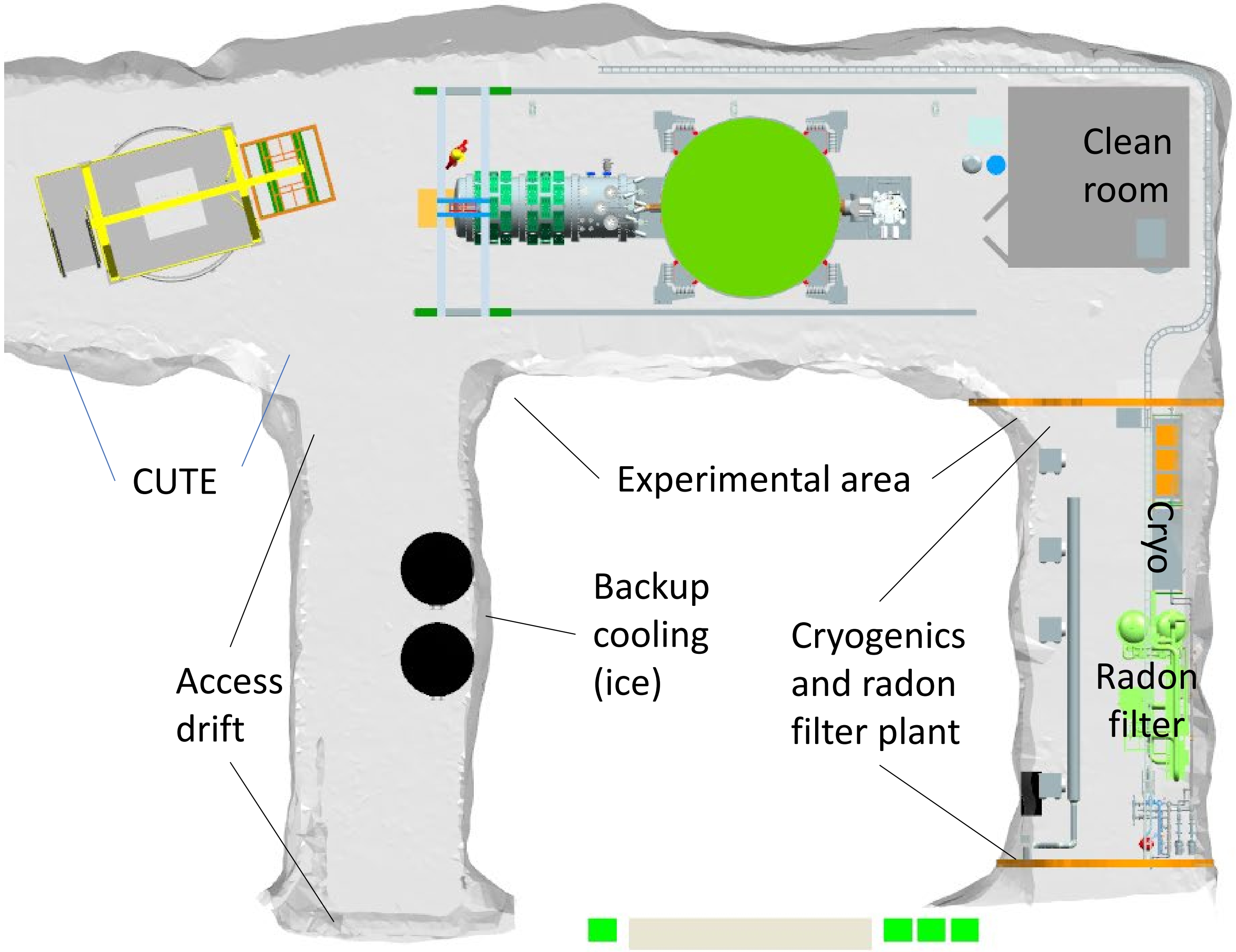
Signal vacuum
feedthroughs

Cold finger

Mounted on spring-loaded
platform (seismic isolation)

Additional cooling
(70 K/4 K)

SNOLAB



Clean room

CUTE

Experimental area

Cryo

Backup cooling (ice)

Cryogenics and radon filter plant

Radon filter

Access drift

Mass ranges and Methods

Traditional:	“background free”	≳ 10 GeV
Low Threshold (LT)	limited discrimination	~ 3 – 30 GeV
HV / CDMSlite	no discrimination (Luke)	~0.3 – 10 GeV
Electron recoil		~0.5MeV – 10 GeV
Absorption	Dark Photons, ALPs	~1 eV – 300 keV