SuperCDMS Overview and Status

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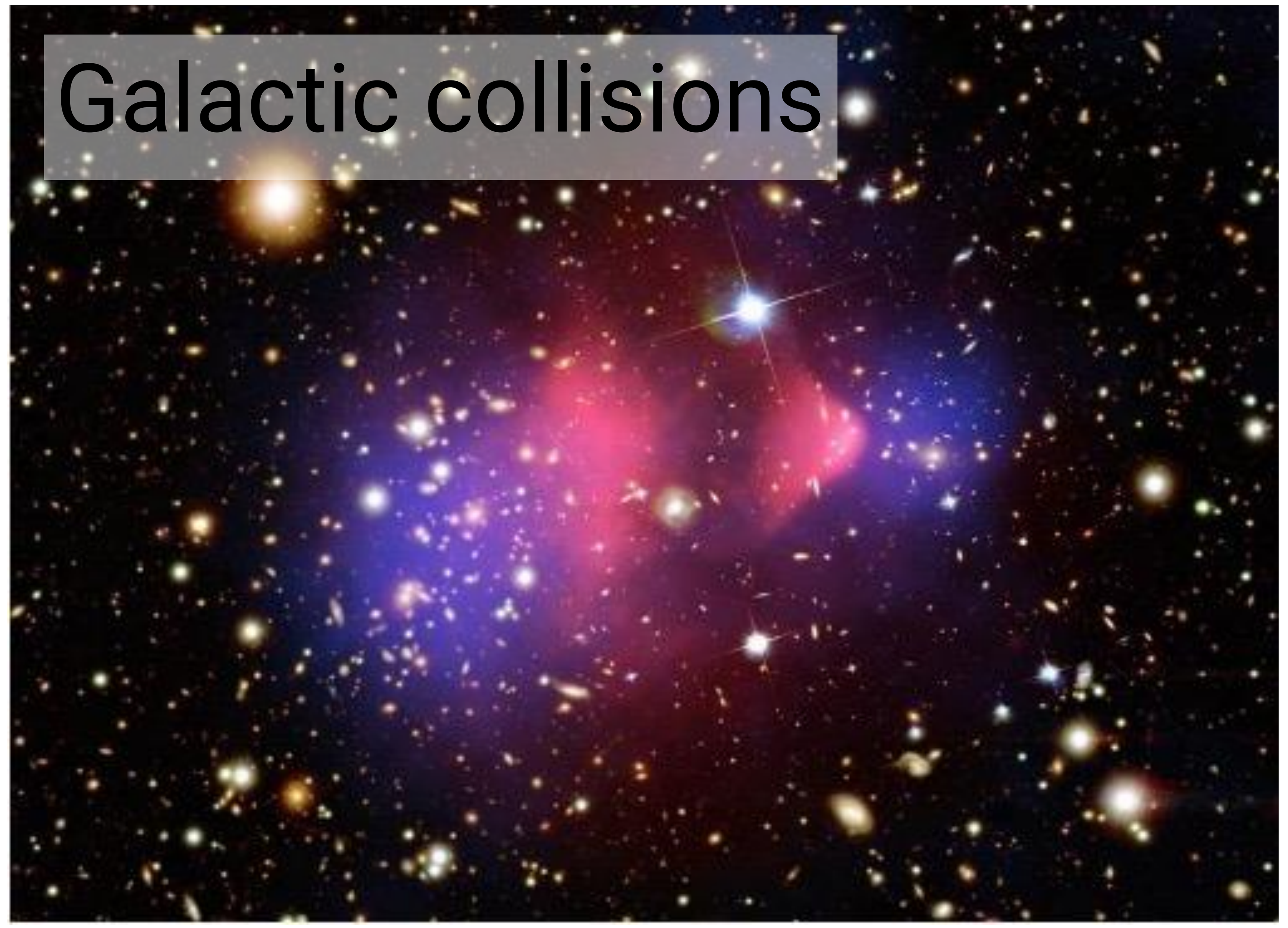
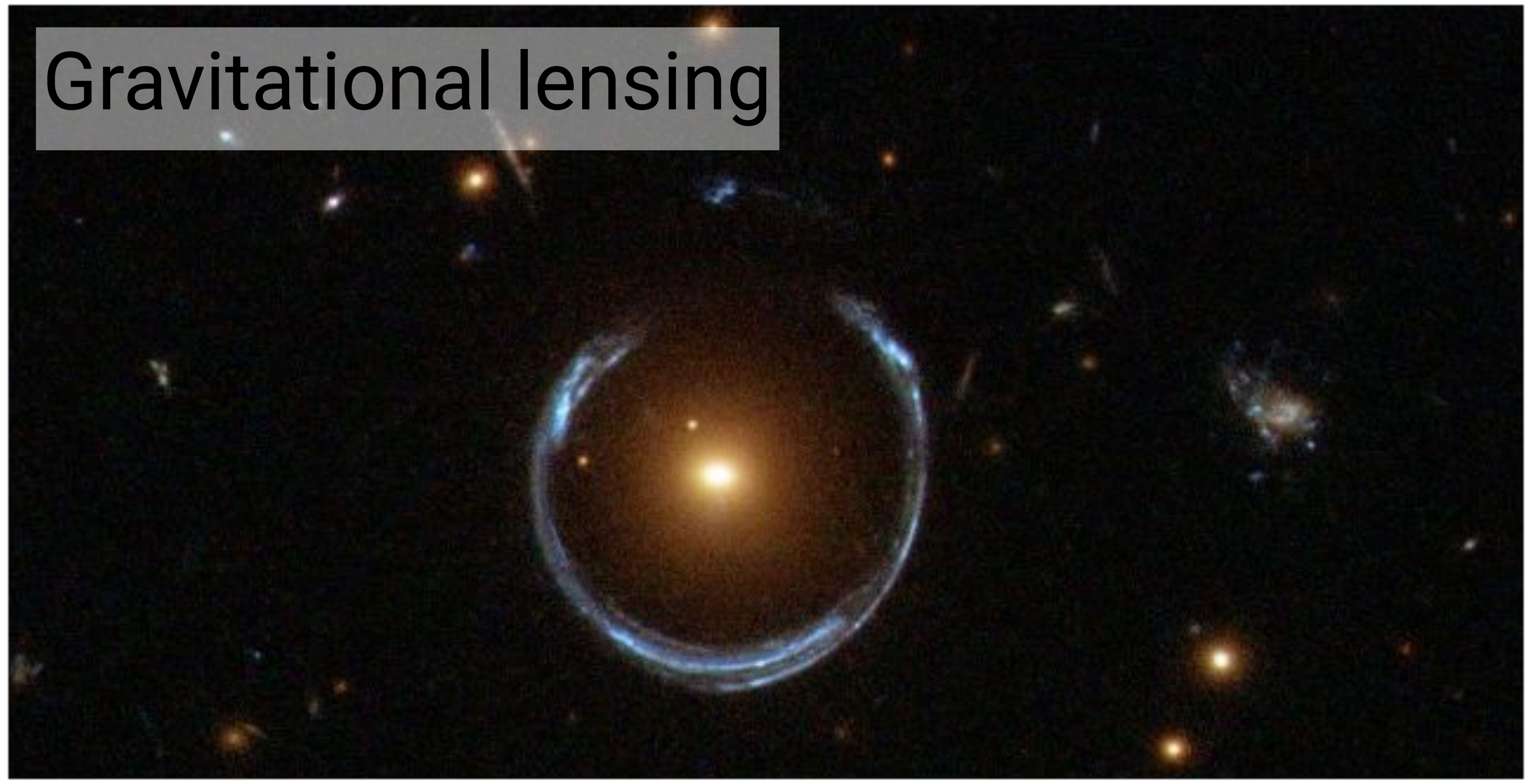
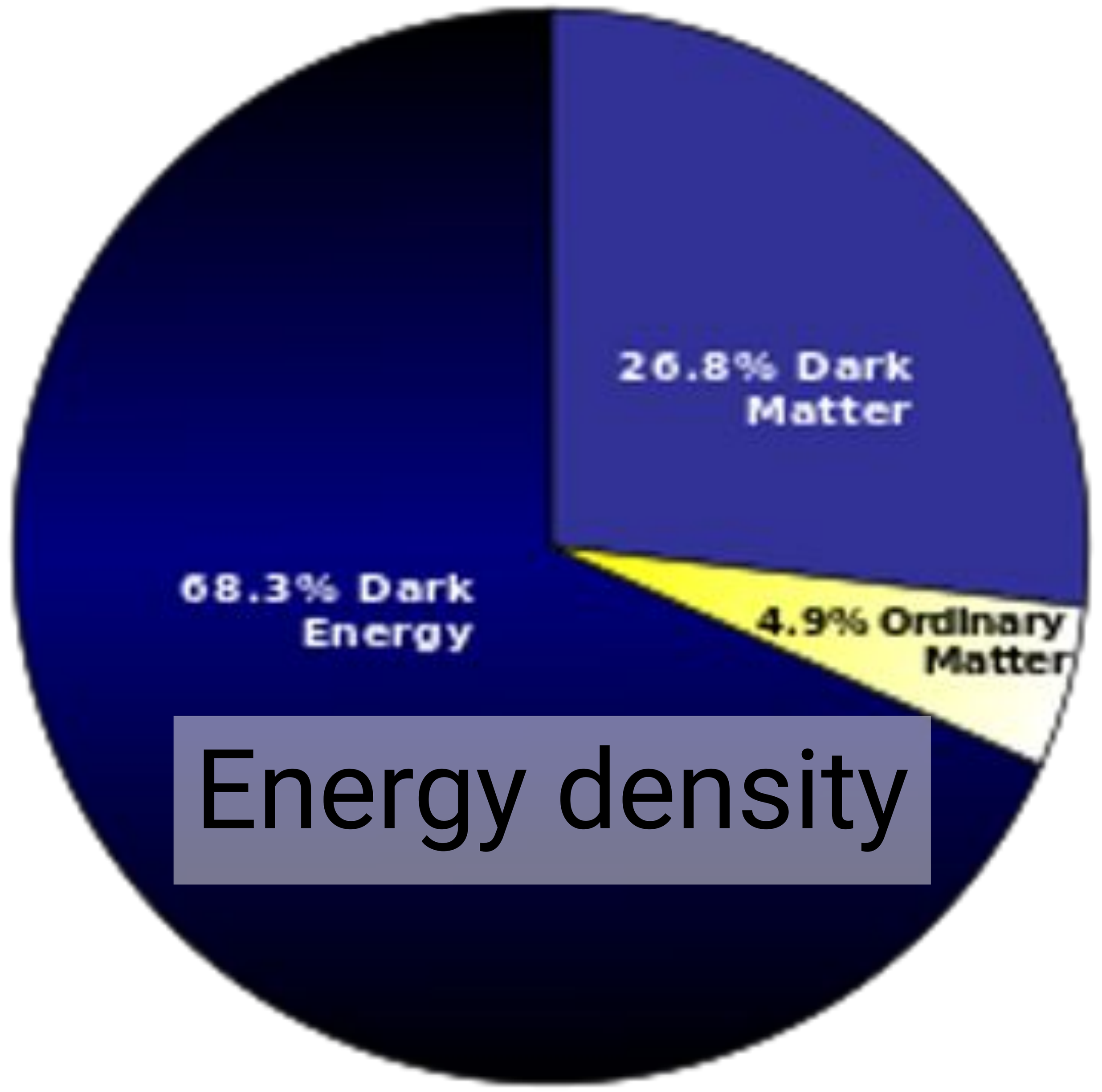
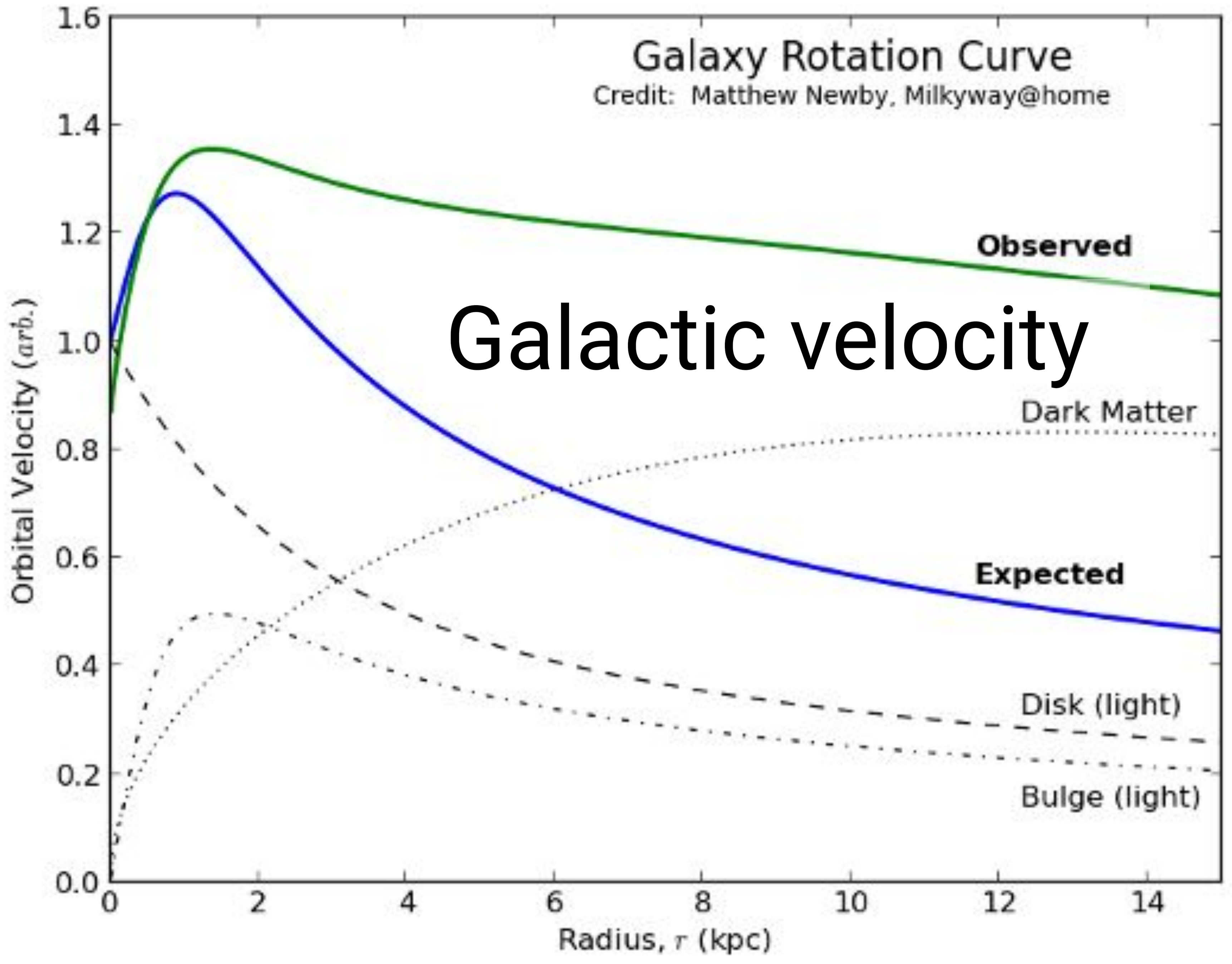
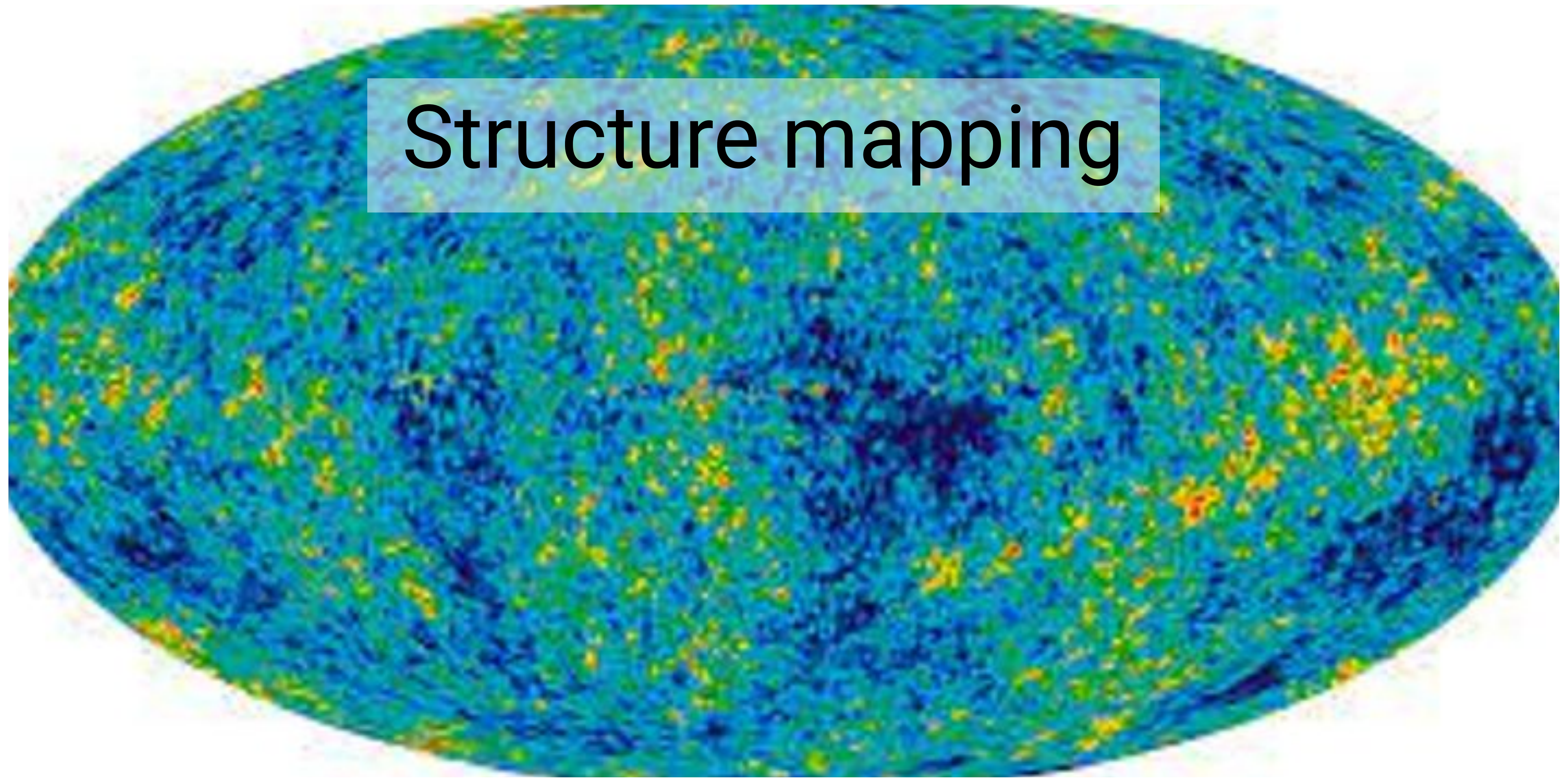
Dark Matter

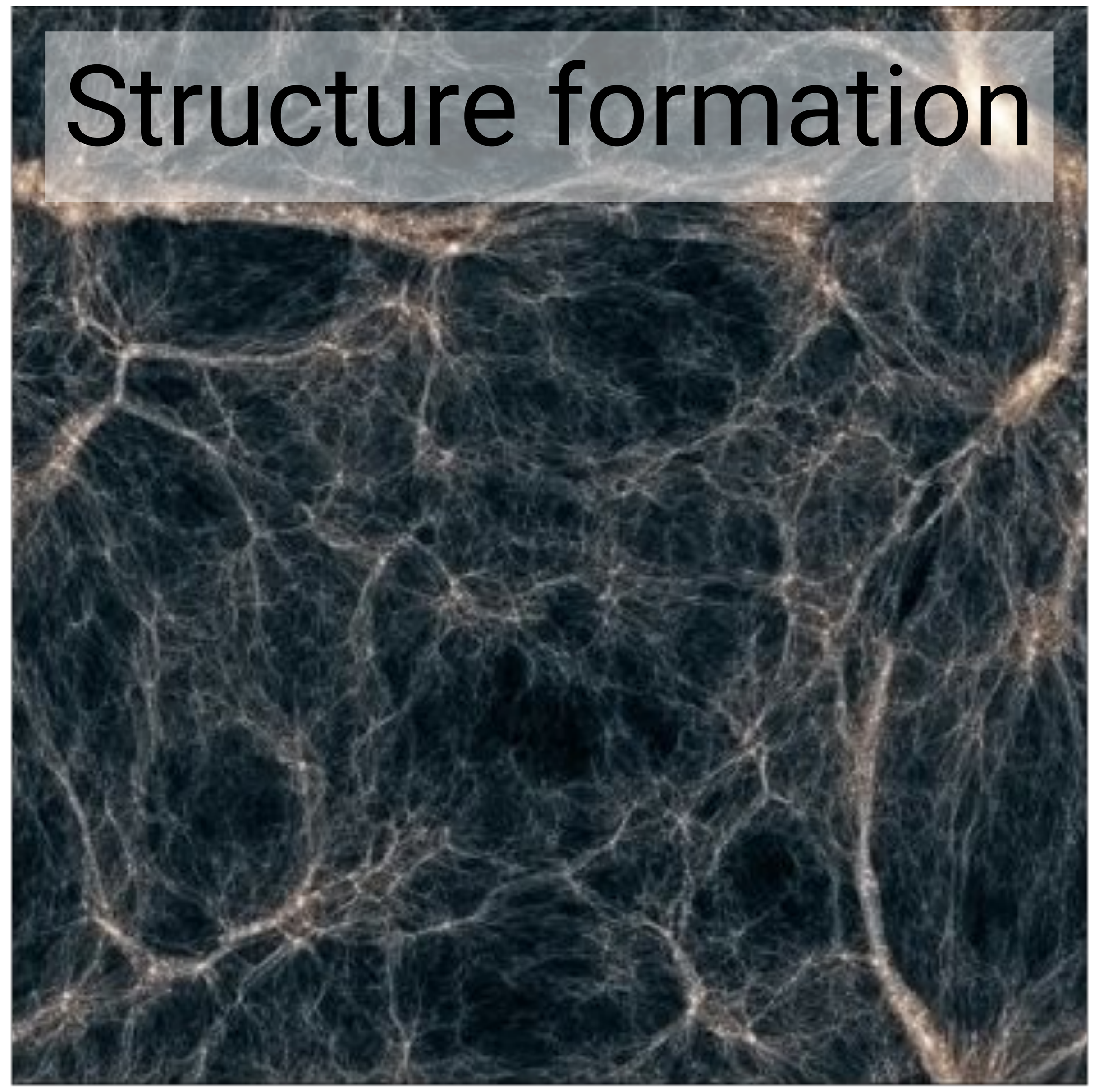

Galactic collisions


Gravitational lensing


26.8% Dark Matter
68.3% Dark Energy
4.9% Ordinary Matter
Energy density


Galaxy Rotation Curve
Credit: Matthew Newby, Milkyway@home
Observed
Galactic velocity
Dark Matter
Expected
Disk (light)
Bulge (light)
Orbital Velocity (arb.)
Radius, r (kpc)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
0
2
4
6
8
10
12
14


Structure mapping


Structure formation

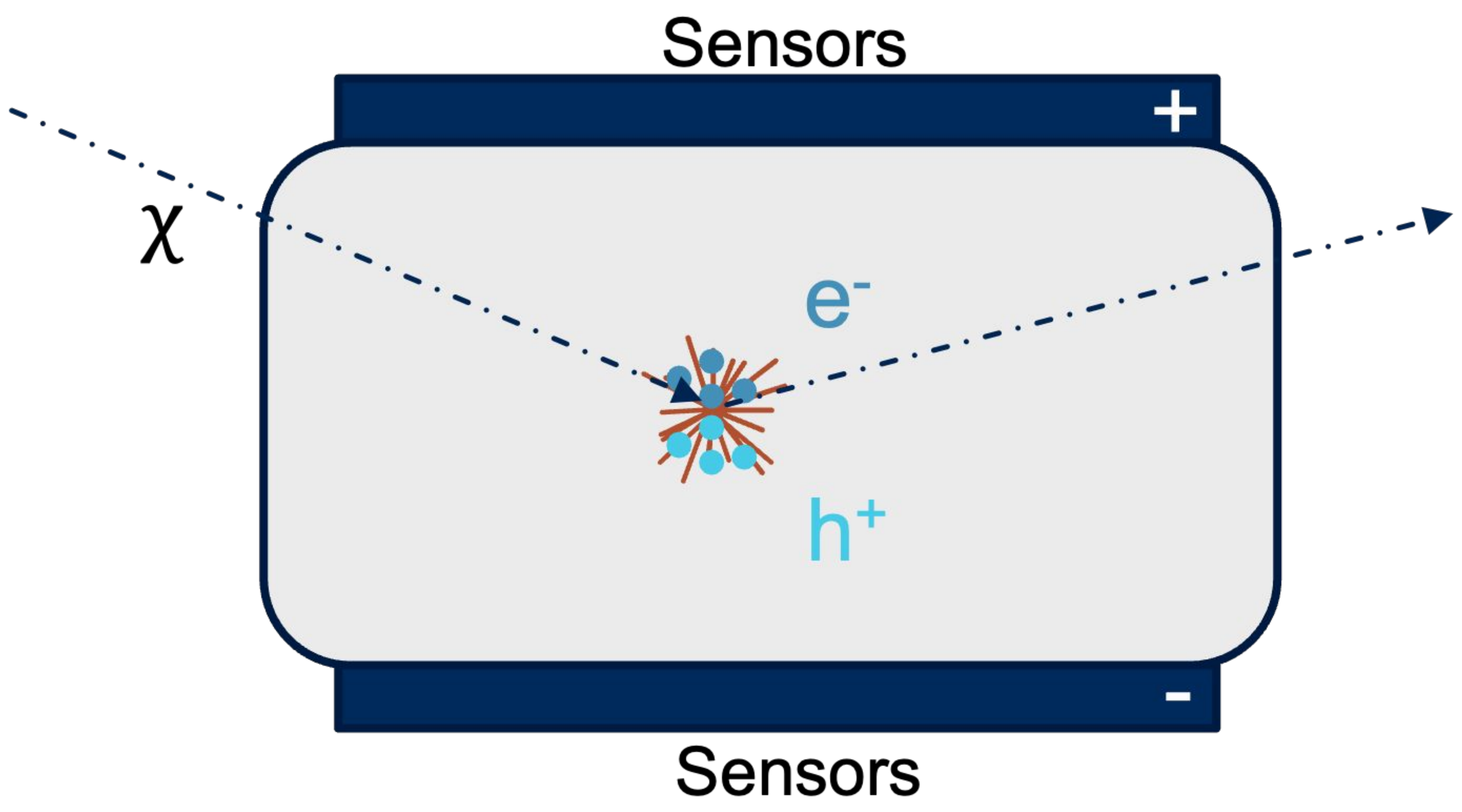
Dark Matter

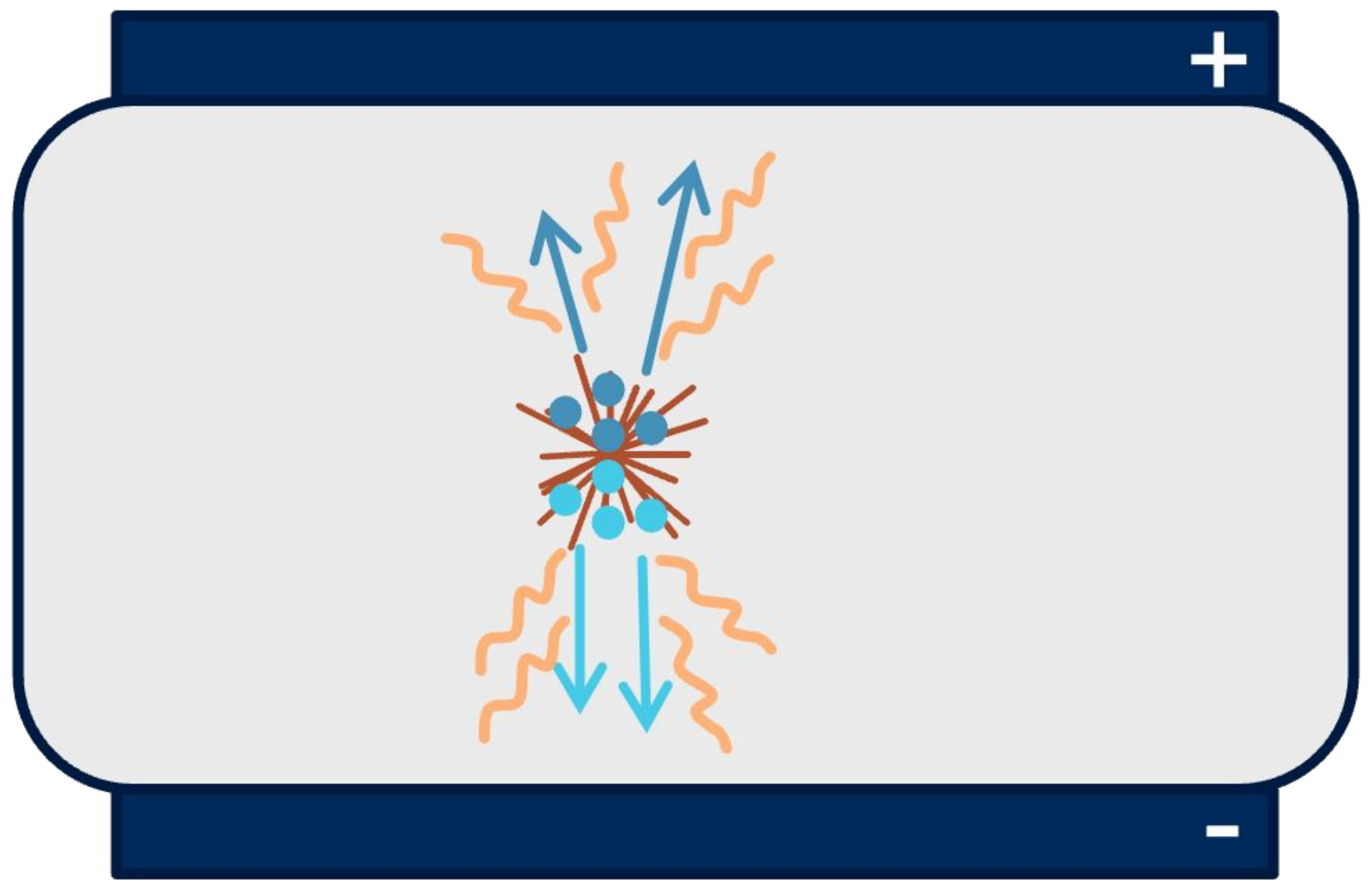
We're pretty sure it's out there, but where to look…
Lots of well motivated theories and experimental techniques

Dark Matter + SuperCDMS

Where and how we're looking

Detector Concepts





- DM scatters in crystal and produces recoil in lattice
- Energy deposition produces two observables:
  - Electron-hole pairs
  - Prompt and Neganov-Trofimov-Luke (NTL) phonons
- Charges drifted with electric field to sensors for collection of signals
  - Interleaved electrodes for ionisation
  - QETs for athermal phonons
- Combine these in different ways depending on what we want:
  - Low energy threshold: HV
  - NR/ER discrimination: iZIP

HV detectors

Key concept: use NTL effect to reduce energy threshold.

- NTL effect: drifting electron-hole pairs across potential produces phonons:

$$E_t = E_R + n_{eh}eV$$

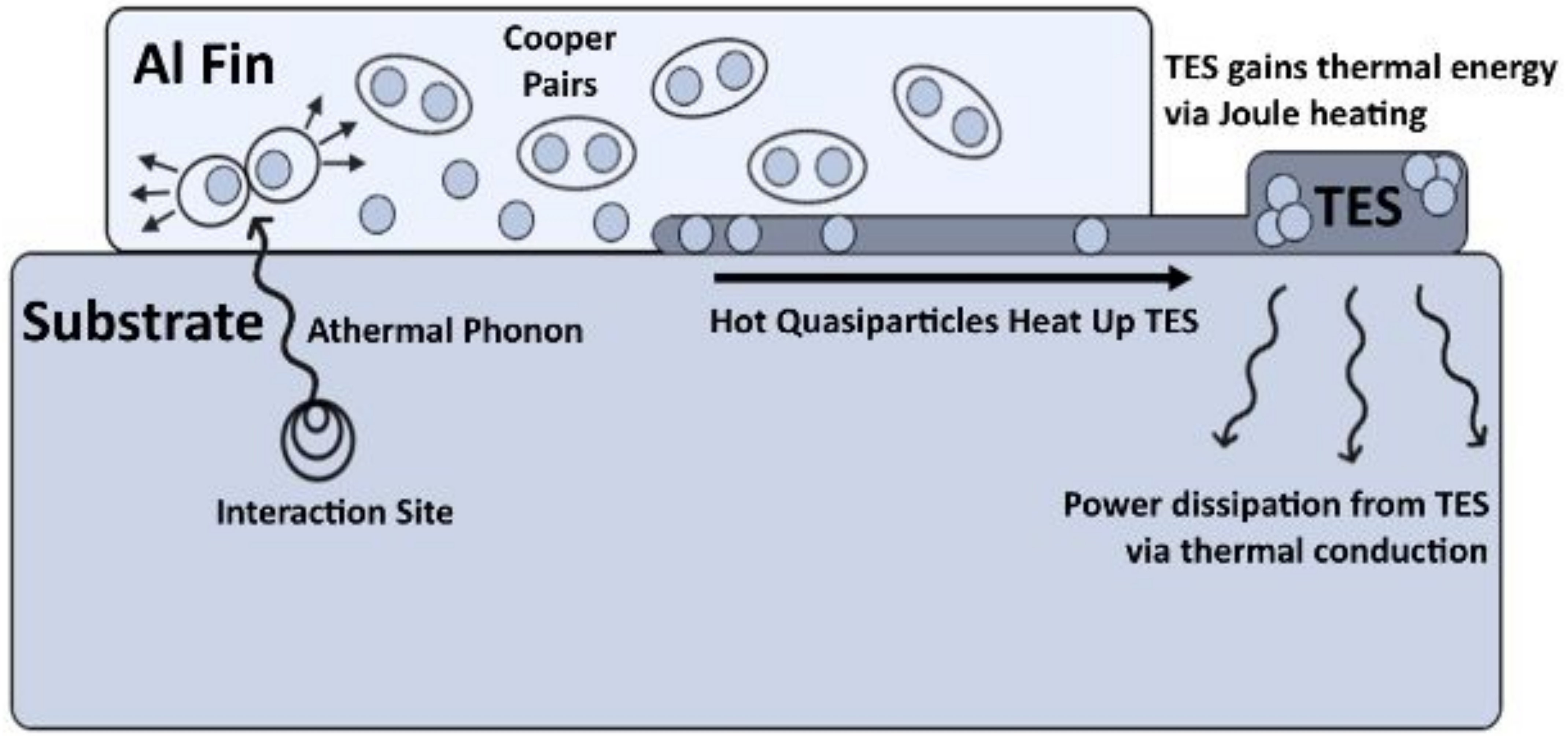
Total phonon energy

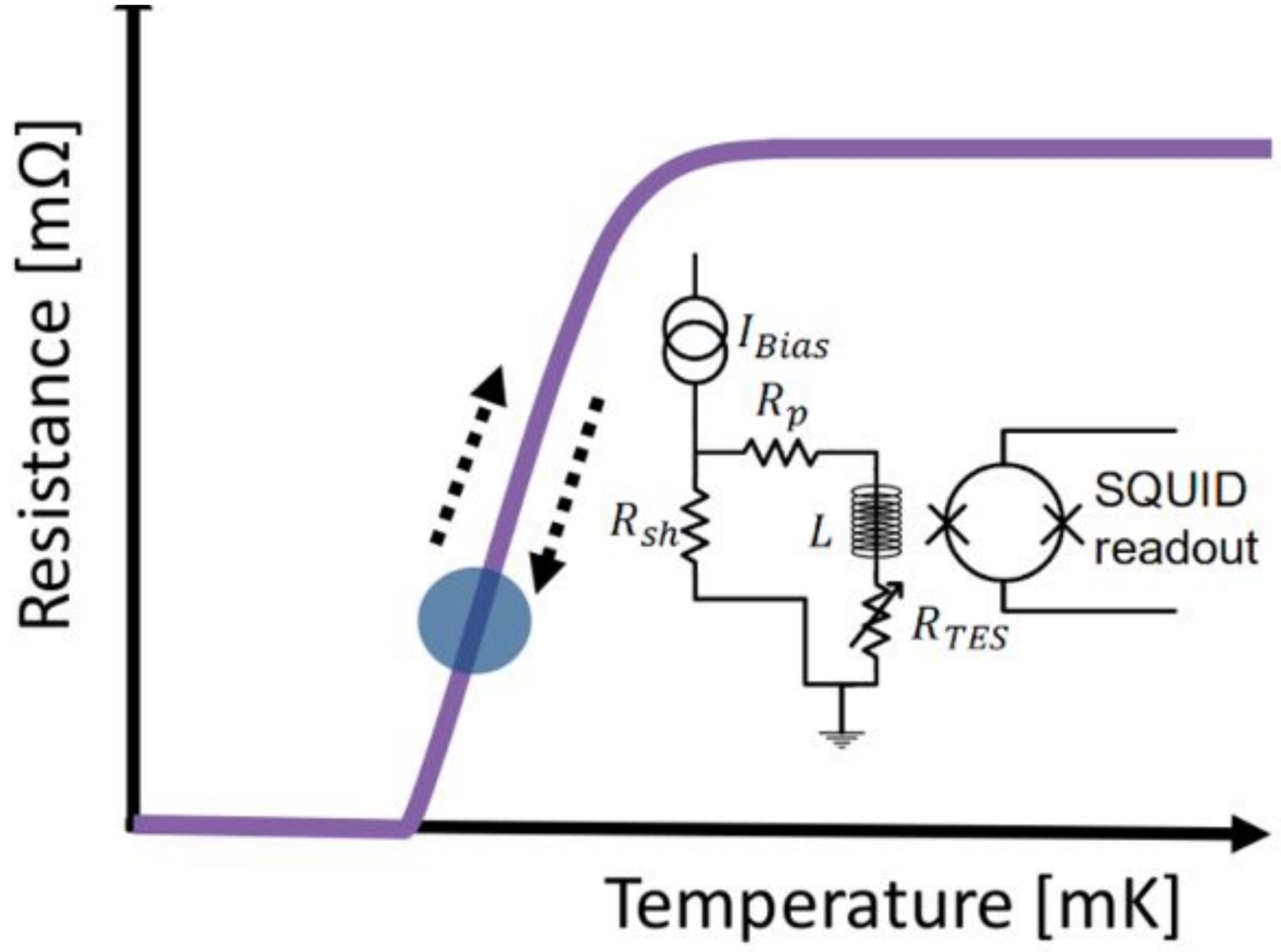
Initial recoil energy

Number of eh pairs

Potential difference

- Increased potential ⇒ increased total energy for the same recoil
- Phonons detected using TES at ~50% bias point
- 12 total channels across each HV detector





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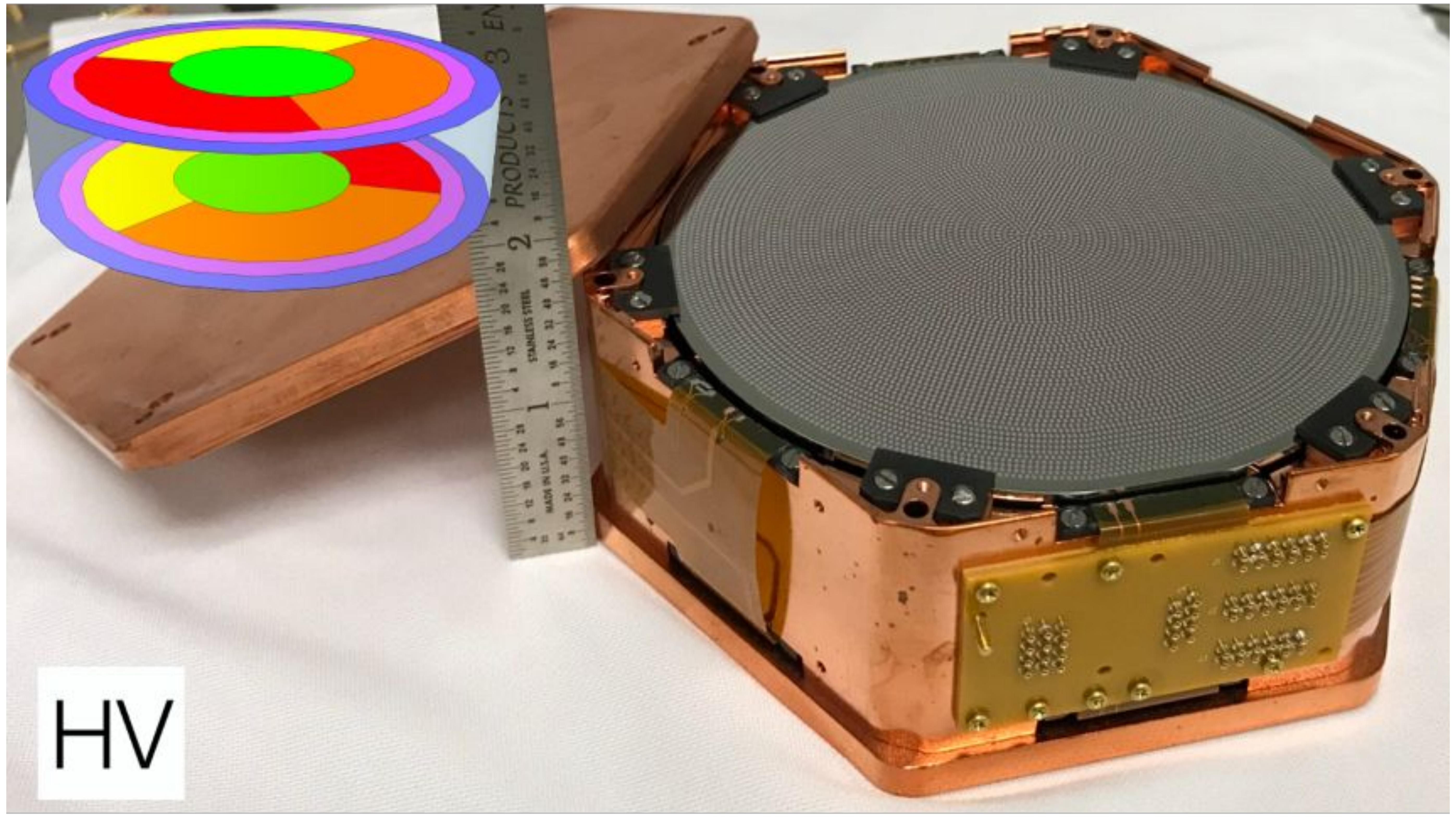


R. Agnese *et al.* Phys. Rev. D **95**, 082002

iZIP detectors

Key concept: use charge and phonon signals for electron (ER) and nuclear (NR) recoil discrimination.

- Amount of charge generated depends on <u>ionisation yield</u> of interaction:

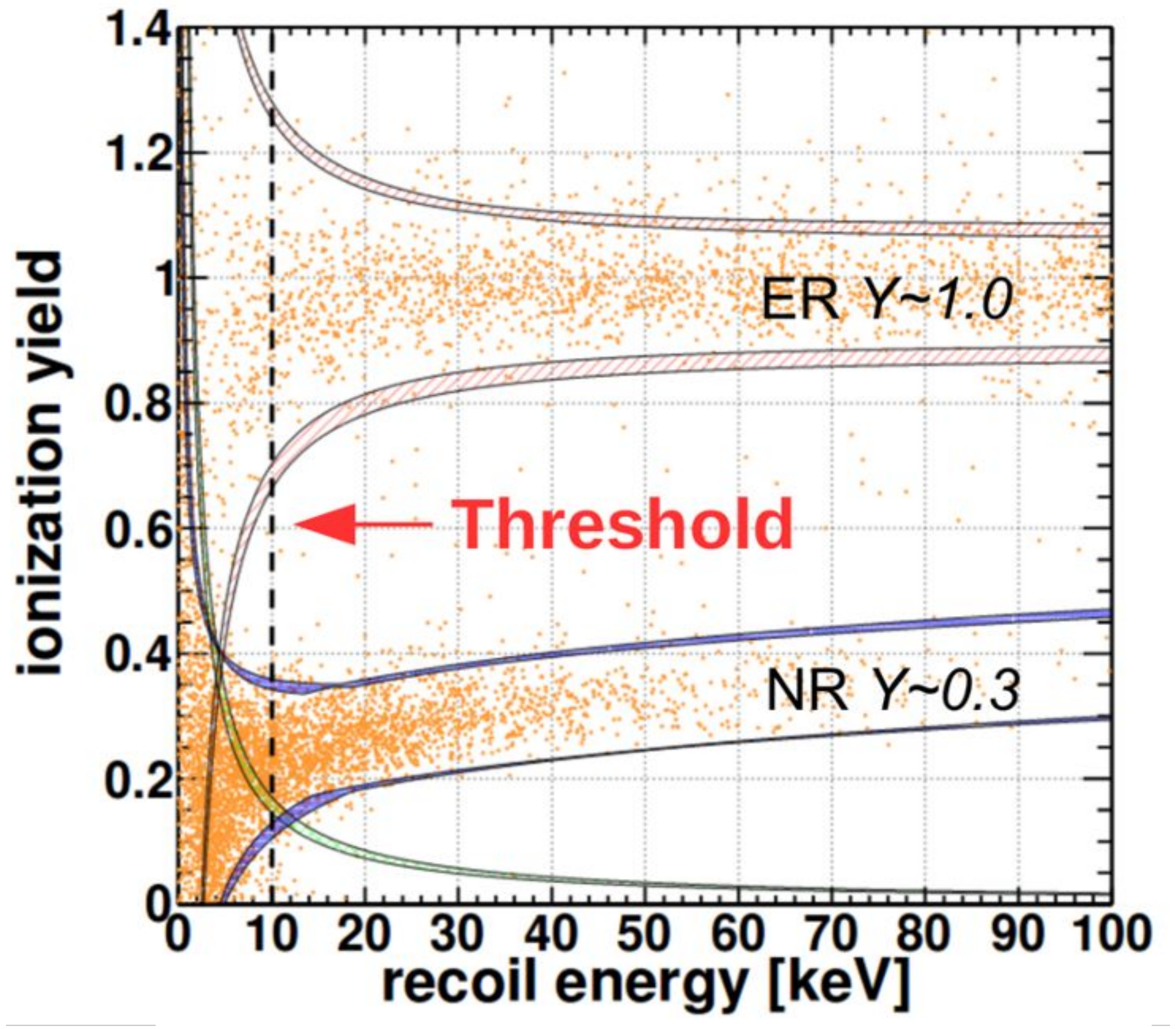
$$n_{eh} = \frac{y(E_R)}{\epsilon_{eh}} E_R$$

Number of charge pairs

Energy to produce single pair

Initial recoil energy

- Ionisation for ER is 1, for NR<1. Comparing the ratio of this to phonons gives discriminant metric
- Charge detected using electrodes on crystal as part of HEMTs (charge amplifier circuit)
- 4 charge channels, 12 phonon channels for each detector



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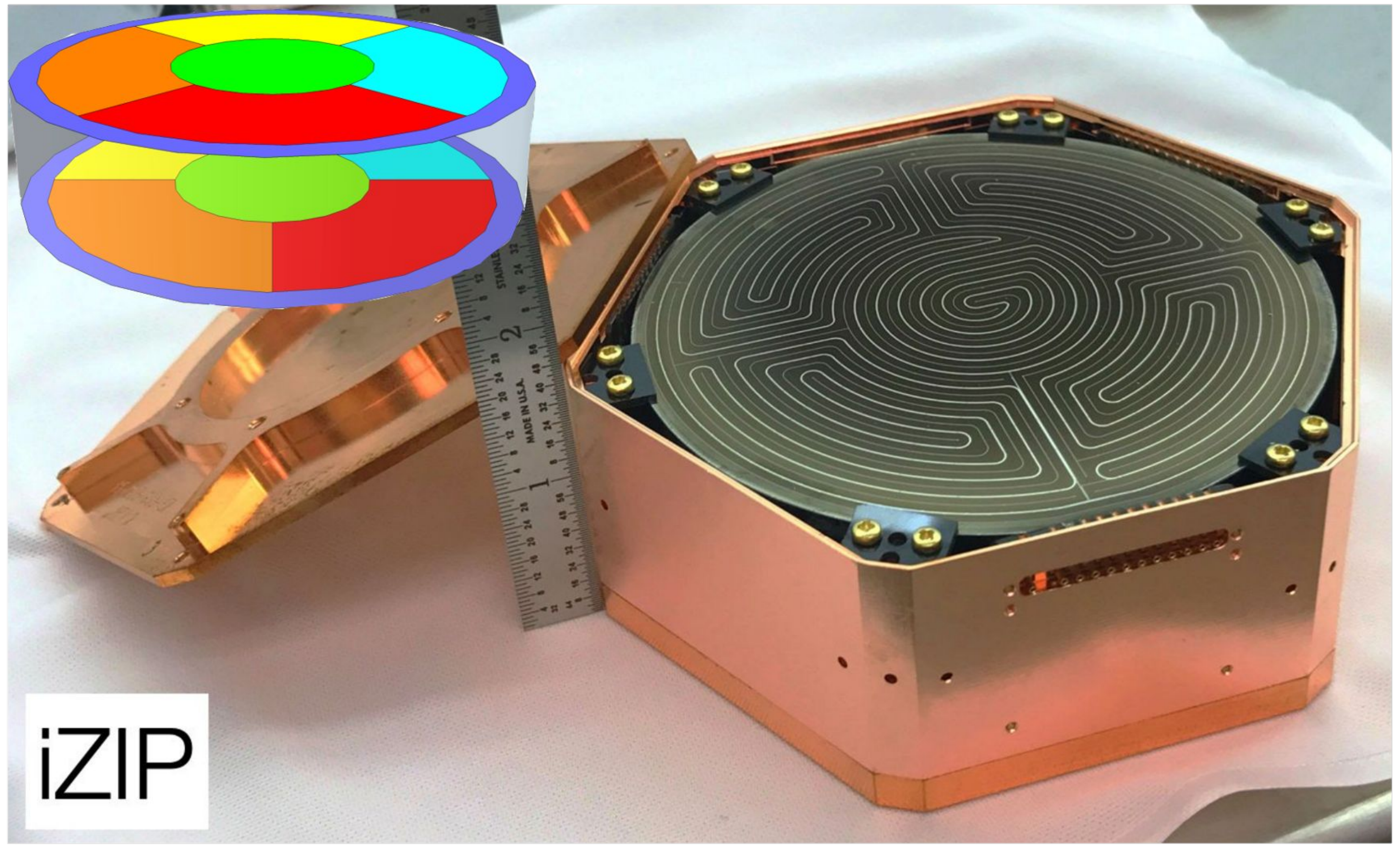
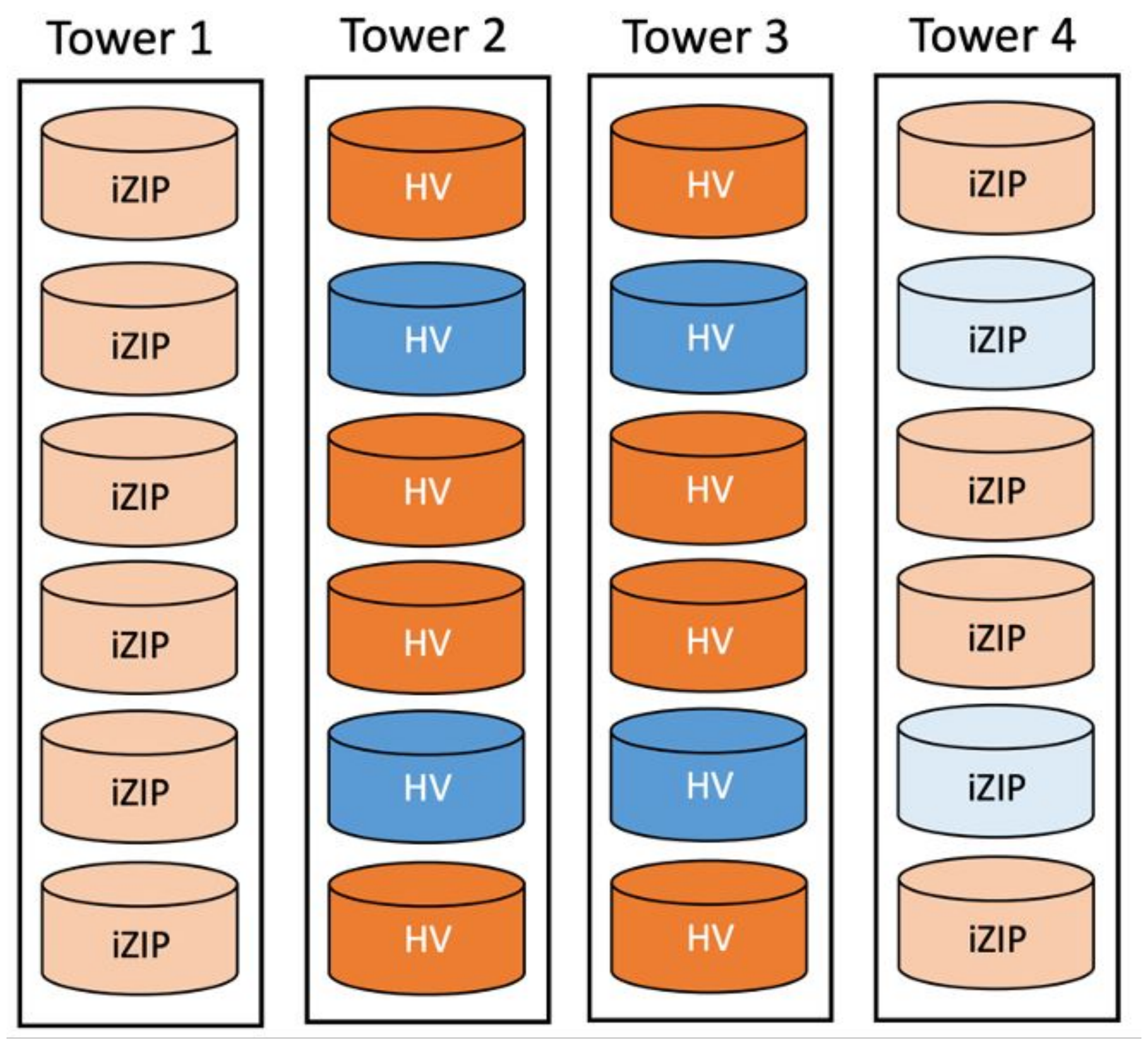
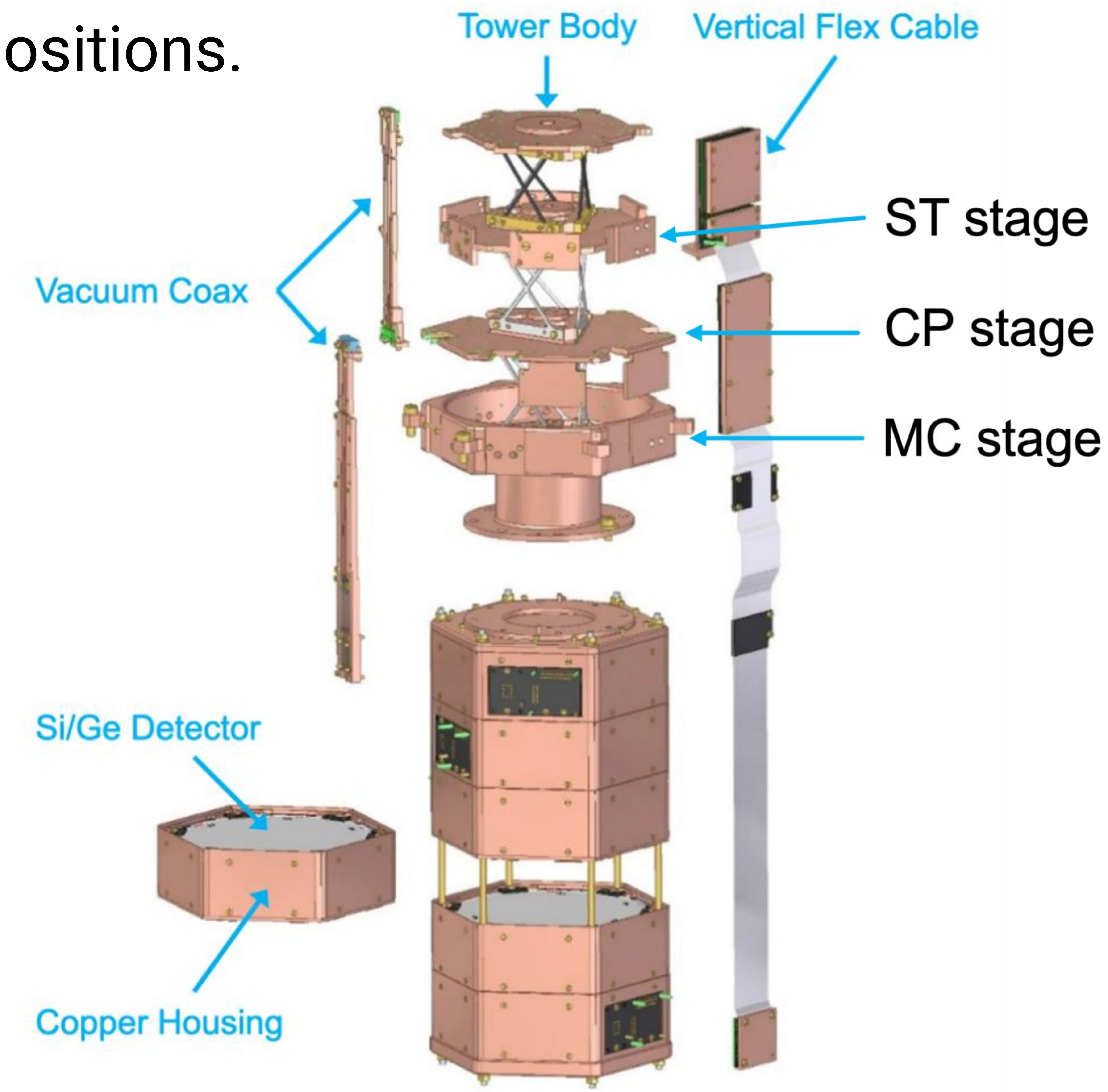


SuperCDMS

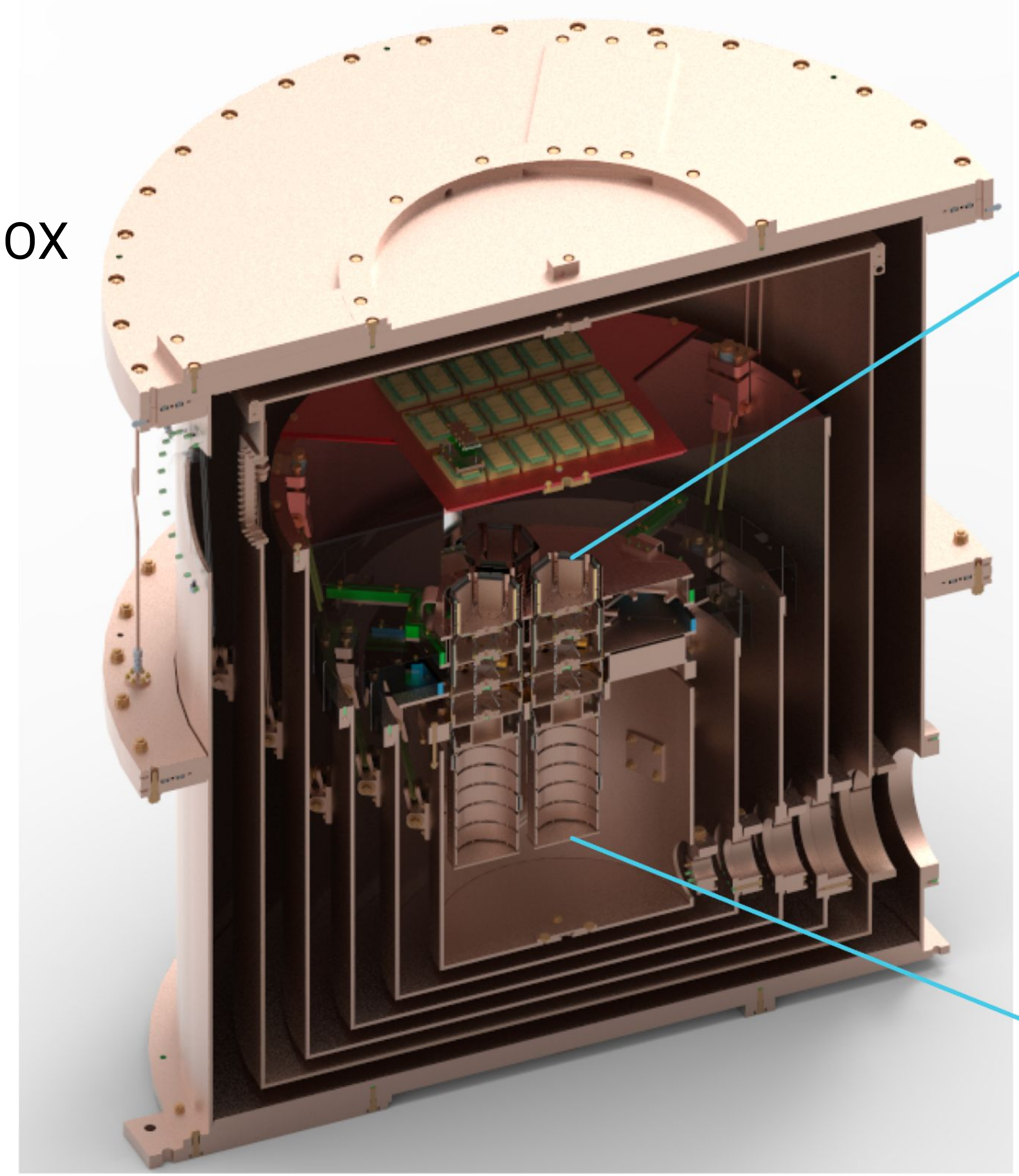
Detectors organised into 4 towers with layouts designed based on detector type and shielding/veto for different positions.
Orange ⇒ Ge, blue ⇒ Si





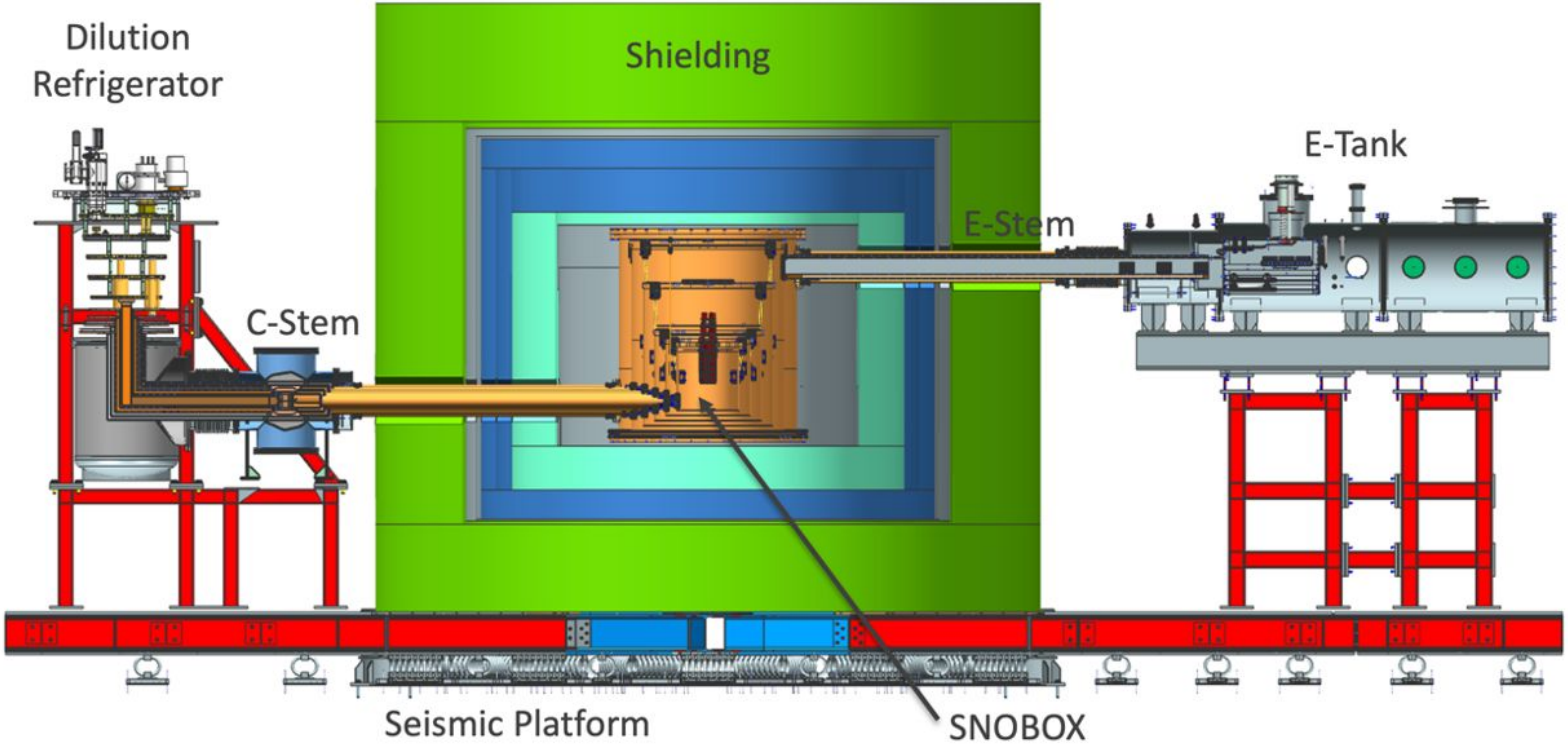
SuperCDMS

Towers placed in SNOBOX
- 6 cans forming giant dilution fridge:
  - OVC – Room temp
  - SH – <50 K
  - LH – <5 K
  - ST – 1 K
  - CP – <230 mK
  - MC – <30 mK



Detectors assembled in 4 towers, thermally coupled to each of the fridge stages

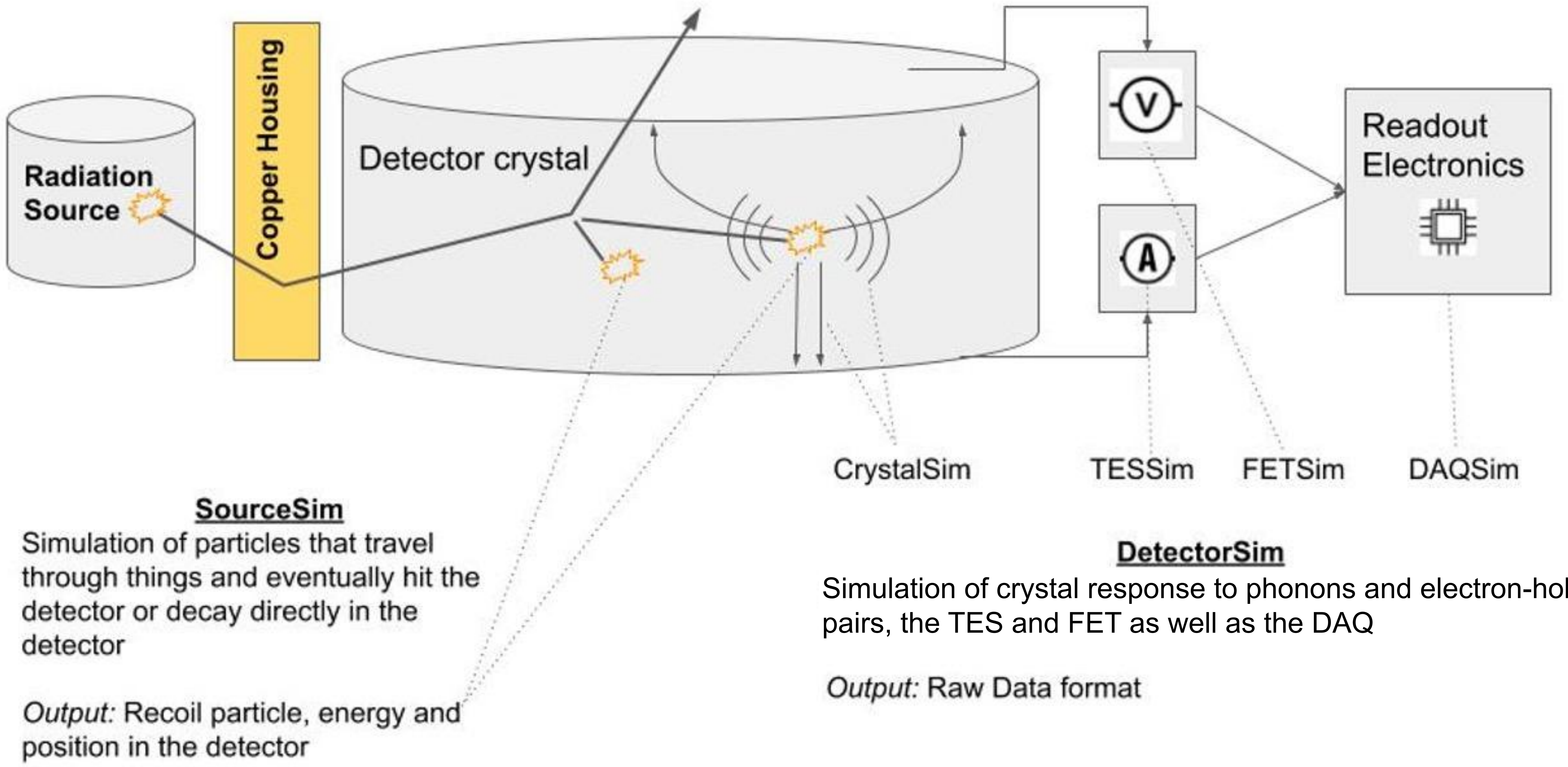
SuperCDMS



Located 2 km underground at SNOLAB

Simulation Program

GEANT4 based framework (G4CMP) that captures detector geometry and response, allowing matching to data and prototyping of analysis



Background studies

https://github.com/bloer/bgexplorer-demo
R. Agnese *et al.* Phys. Rev. D **95**, 082002

Detailed bookkeeping done using eTraveller and BGExplorer:

- 329 components catalogued
- 32 sources considered
- Tracking of location for cosmogenic and radon exposure

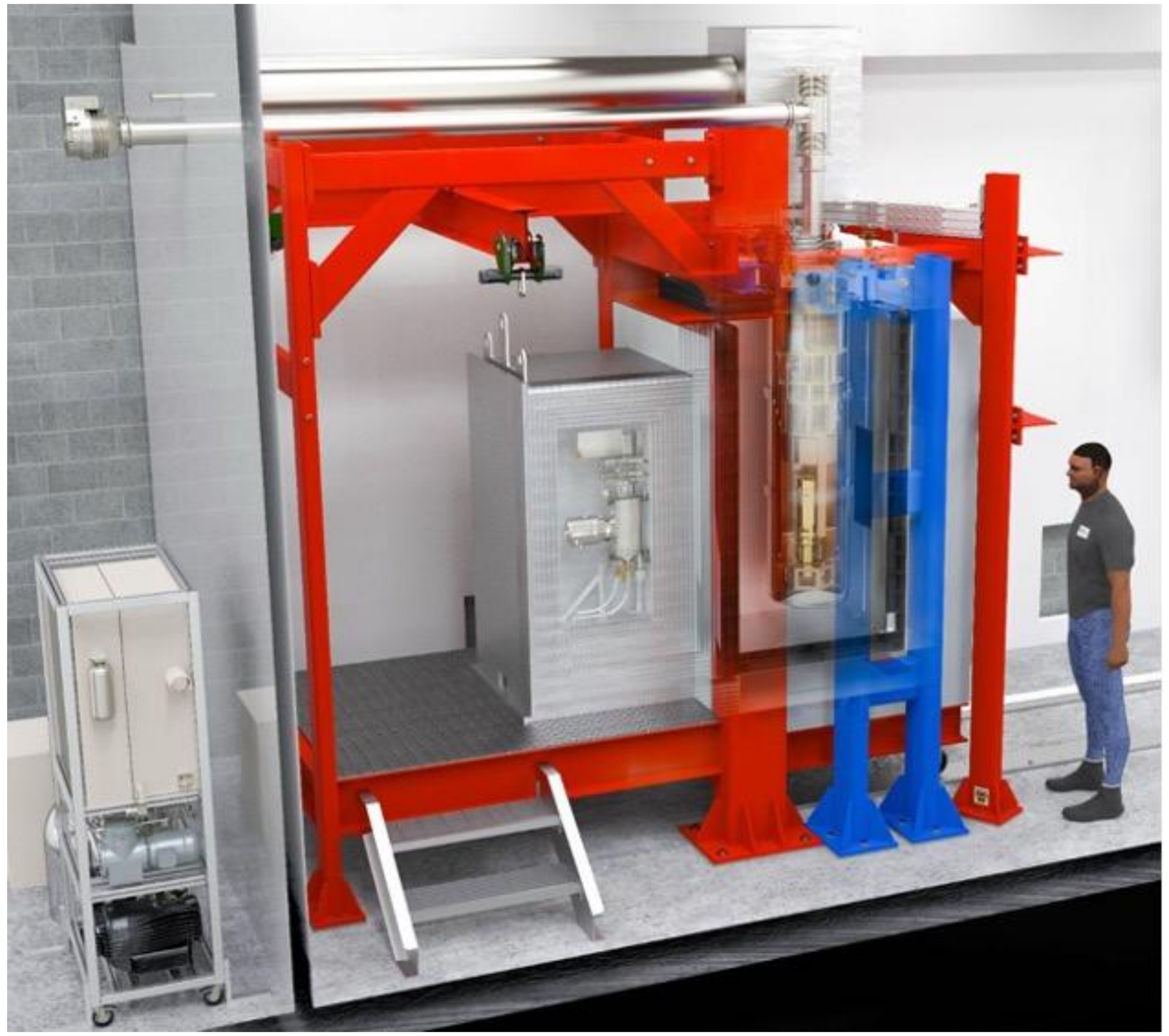
Challenge now is to turn this information into a background model suitable for analysis

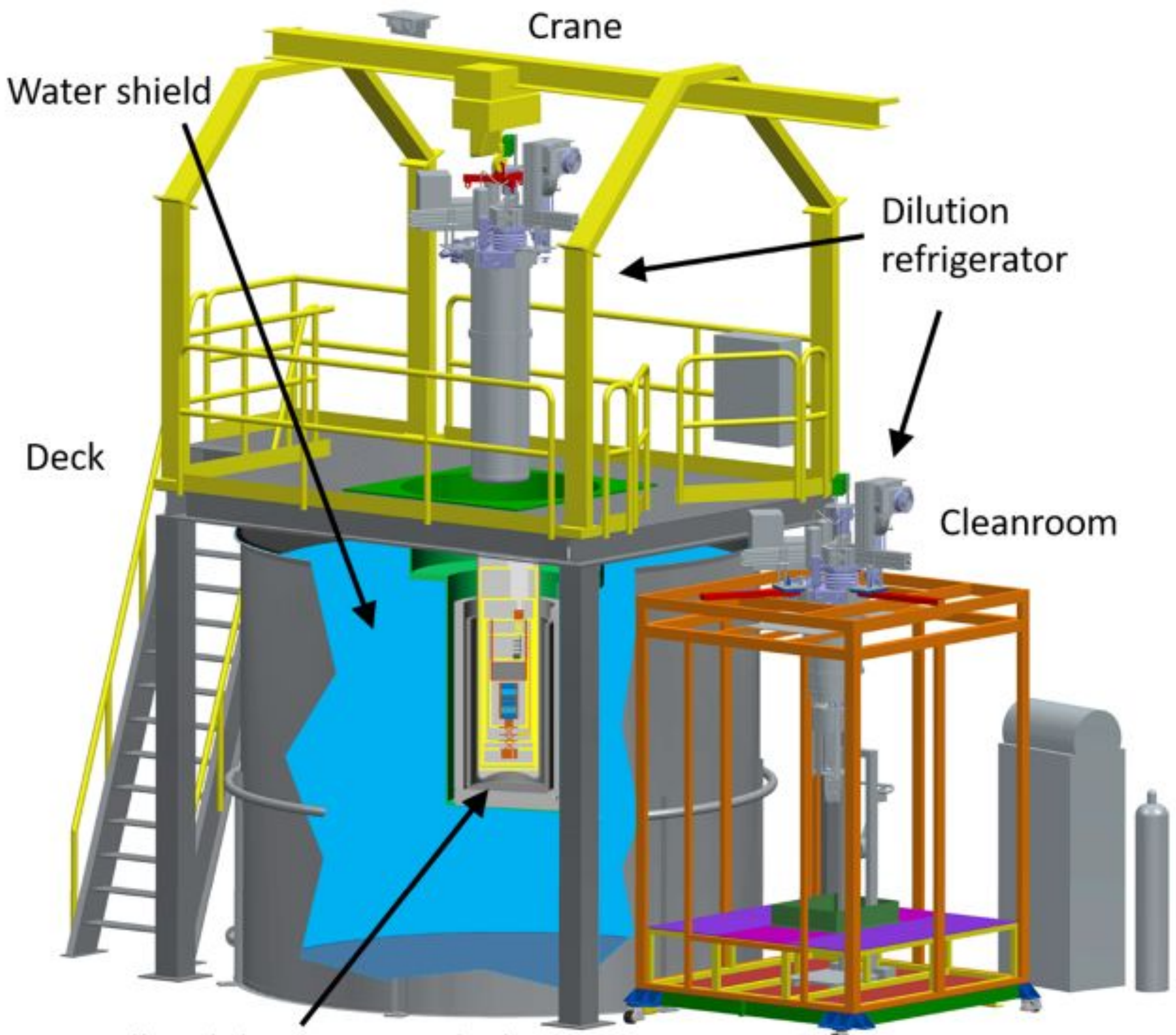
No detector response or analysis cuts applied. Raw spectra only

Test Facilities

~100 m underground at Fermilab
Used for HVeV studies

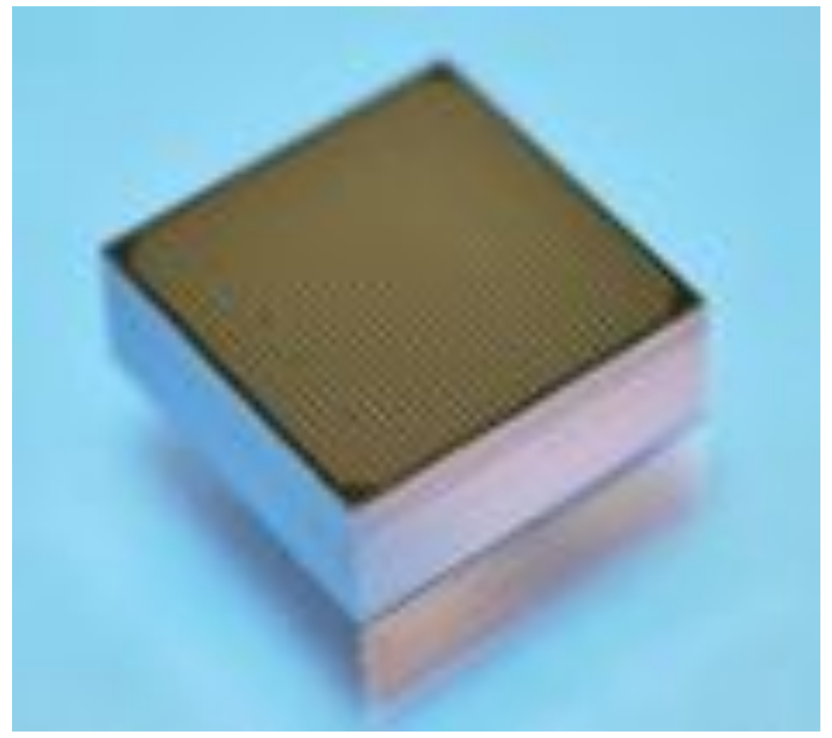
~2 km underground at SNOLAB
Used for HVeV studies, pathfinders, detector characterisation





HVeV @ NEXUS

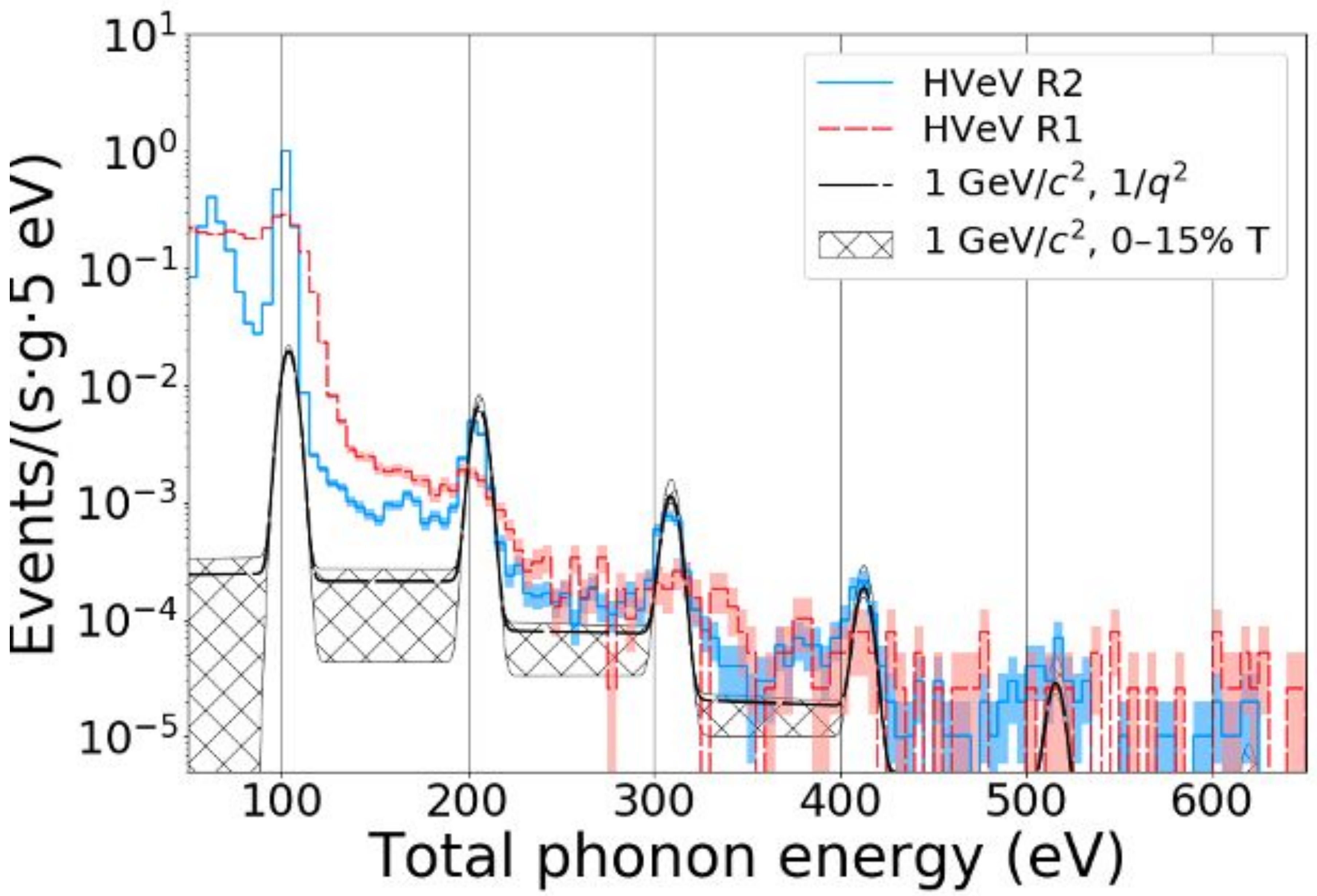
- Gram scale versions of SuperCDMS HV with eV resolution
- Opportunity to test sensor limits, calibration processes, resolution and more
- Clear improvement demonstrated over iterations, especially at low energy
- Currently taking data in CUTE

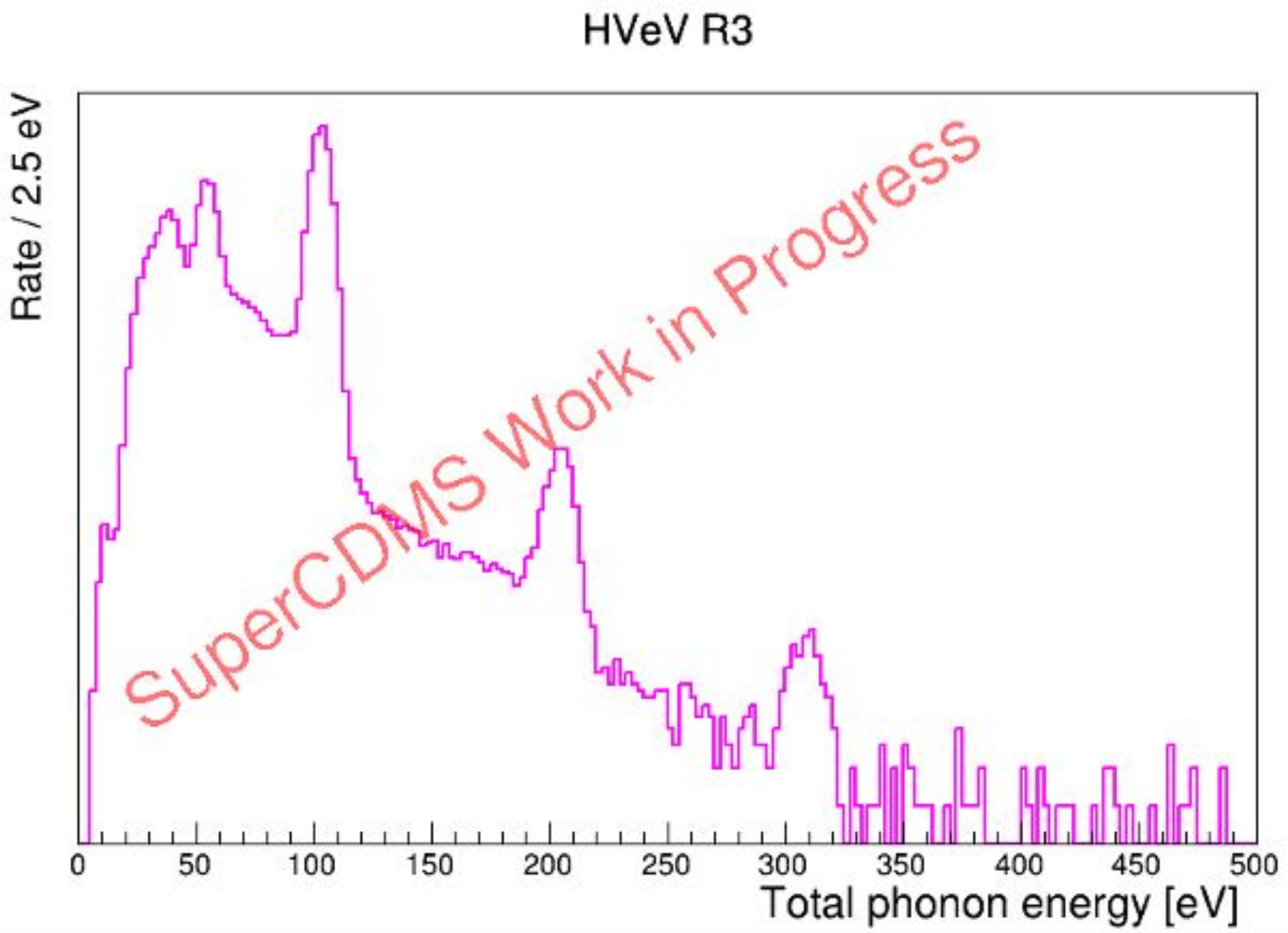


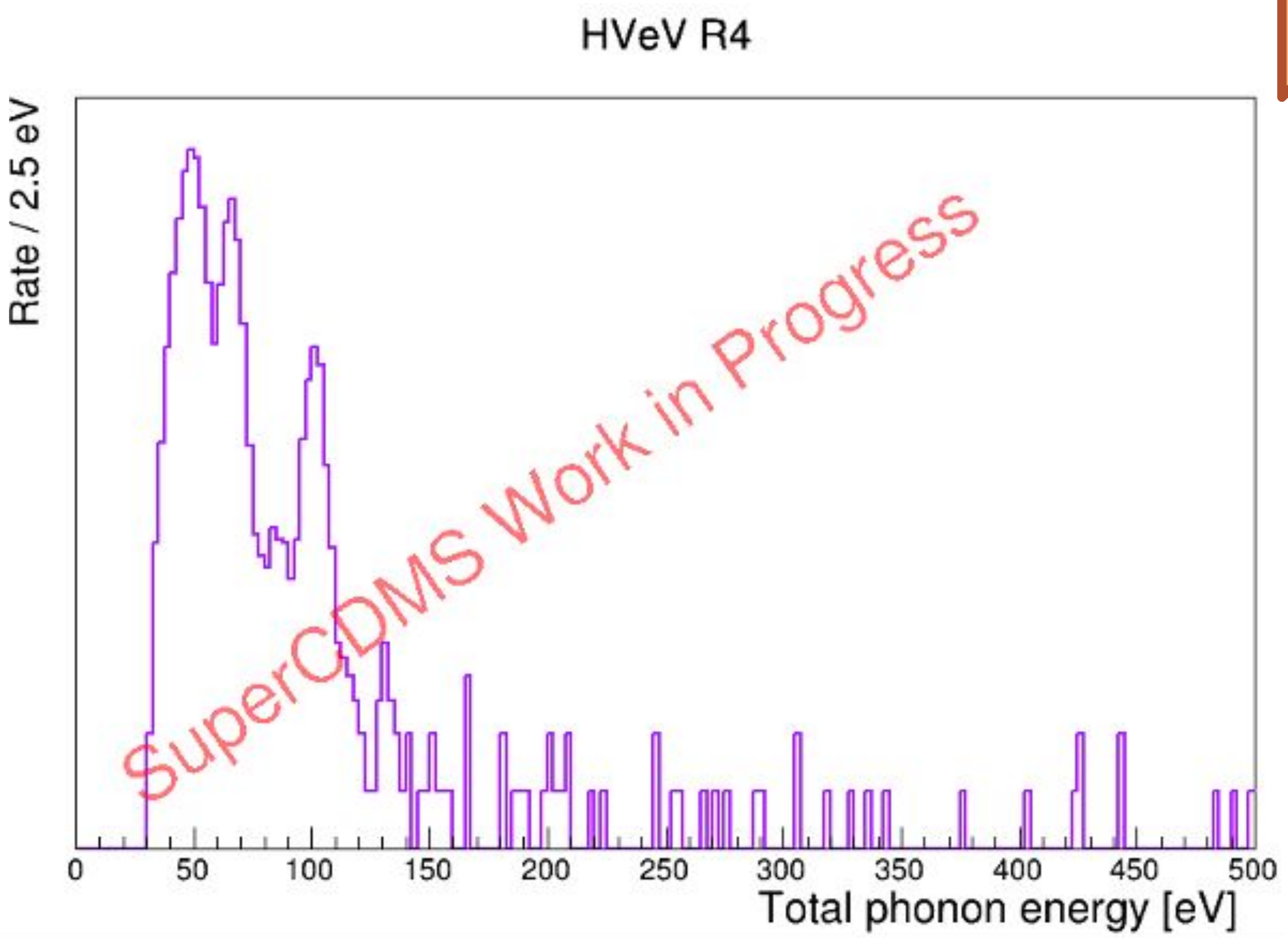
Runs 1&2: backgrounds from external

Run 3: employed coincident detectors

Run 4: found and eliminated source



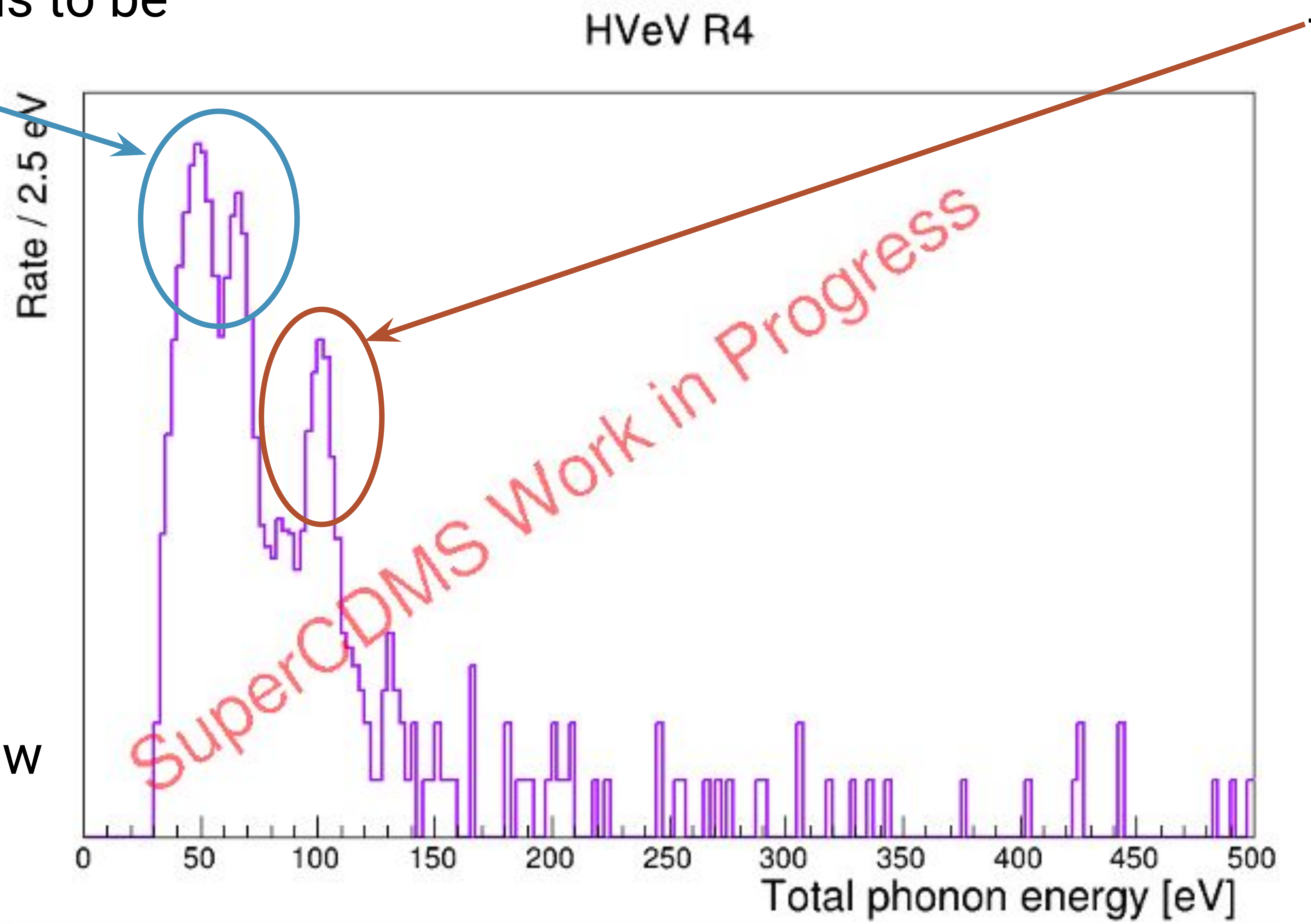




HVeV open questions

Why are there sub 1 eh peaks?
Detector imperfections to be improved?

Pronounced 1 eh peak - do we have light leakage?



See an increase at low energies - why?
Further investigation planned at CUTE

How can we calibrate Si detectors?

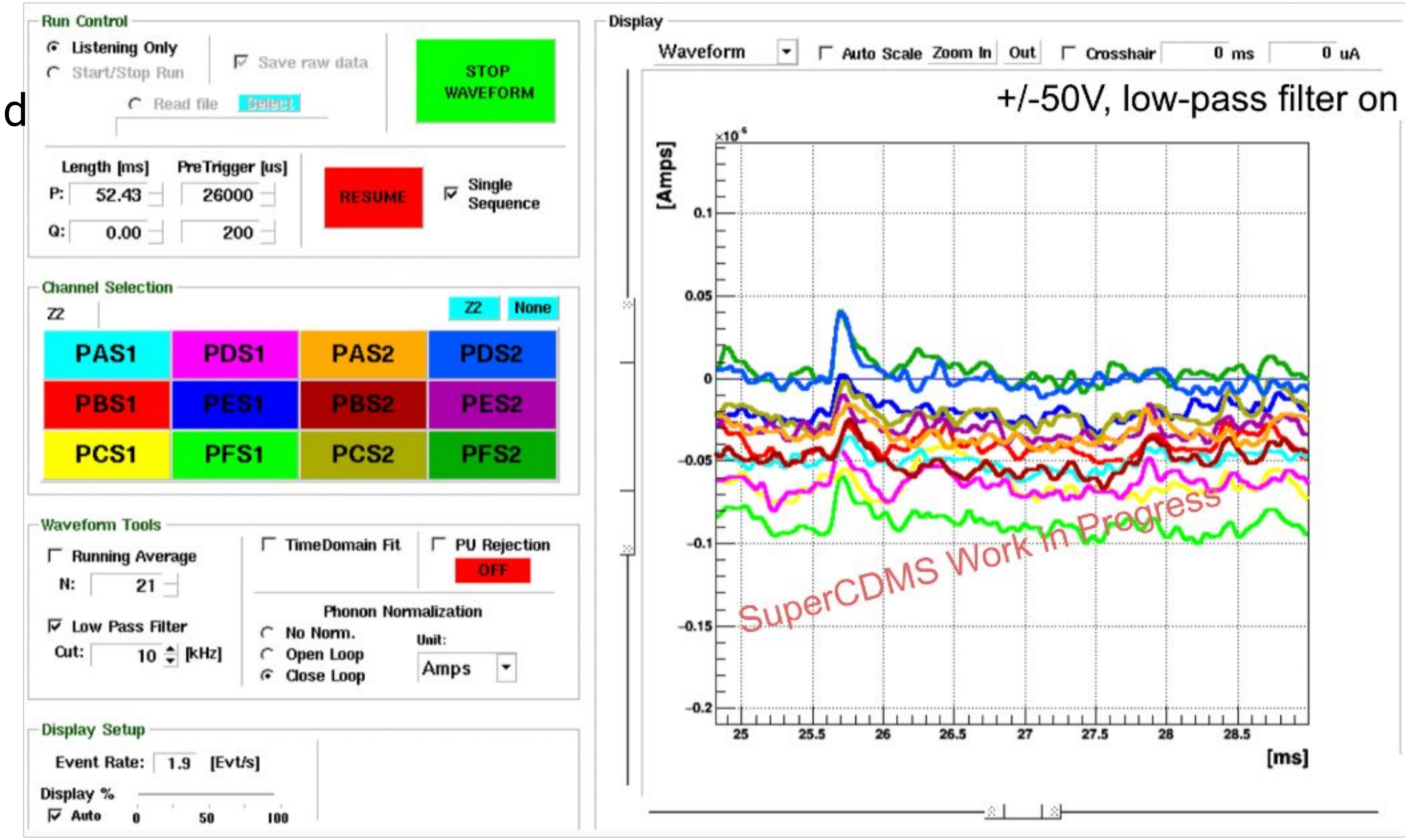
CUTE Tower Testing

Tower 3 installed in CUTE in Nov 2023:

- First time detectors operated underground
- First chance to calibrate detectors
- First HV application
- Development of operating procedures
- Training of new operators

Highlights:

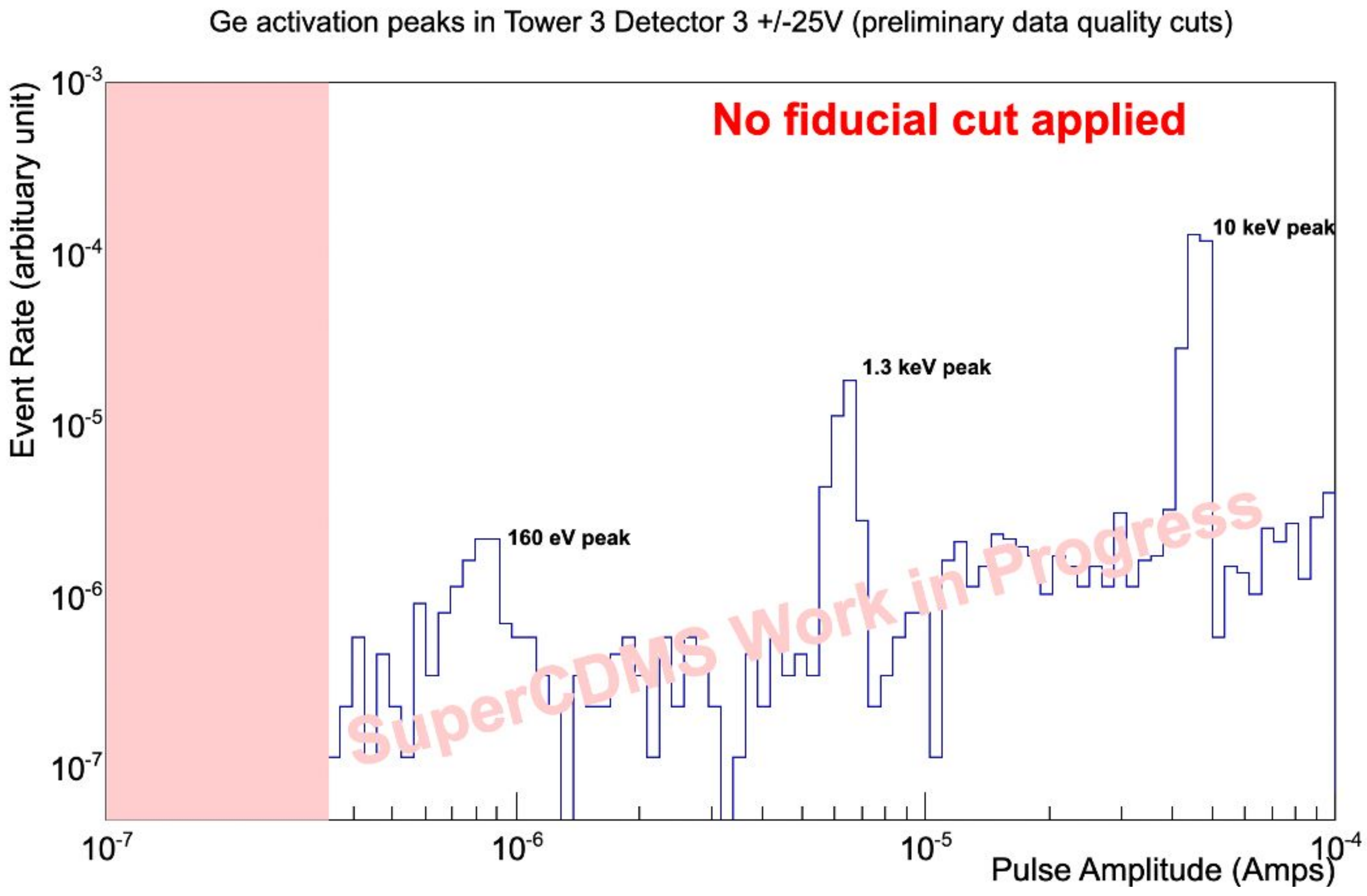
- 151 day run (4 thermal cycles)
- 400 detector days of data
- 2 months of calibration data
- 2 weeks of low background data



CUTE Tower Testing: Ge calibration

Low energy calibration of Ge can be done with activation peaks

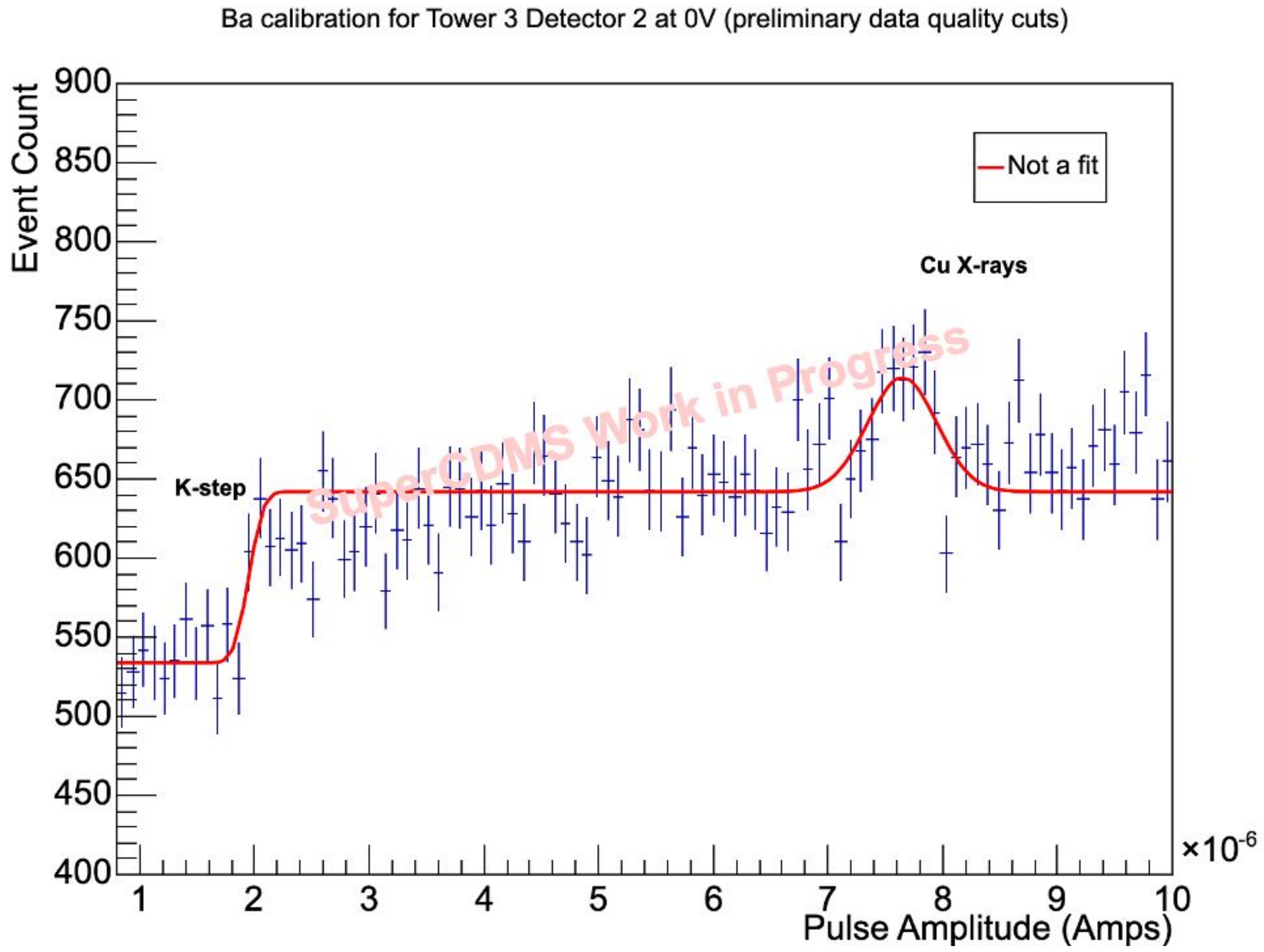
- Irradiating Ge with neutrons produces ^{71}Ge
- Undergoes electron capture producing lines at:
  - 160 eV
  - 1.3 keV
  - 10 keV
- ~90 hrs of data taken in Dec 2023



CUTE Tower Testing: Si calibration

Low energy calibration of silicon is difficult. One proposal: Compton steps

- Scattering below binding energy of electrons decreases interaction rate
- Expect to see step features at these values:
  - 1.84 keV (K step)
  - 150 eV (L_1 step)
  - 100 eV (L_2 step)
- ~90 hrs of ^{133}Ba data taken to test viability



Coming up…

Installation

- All detectors are currently underground
- Fridge installed and tested
- SNOBOX components being shipped over and cleaned
- Shield wall partially constructed
- E tank prepped for install
- Low radon cleanroom shown to be working

Software

- Simulation geometry updated for ‘as built’ experiment
- Continued development of G4CMP and detector response
- Analysis pipeline and processing taking learnings from CUTE tower run

Analysis

- Background modelling underway for PLR sensitivity
- Ongoing analysis of CUTE calibration and science data
- HVeV studies ongoing to understand calibration and low energy excess
- ERDM and NRDM modelling tools under development

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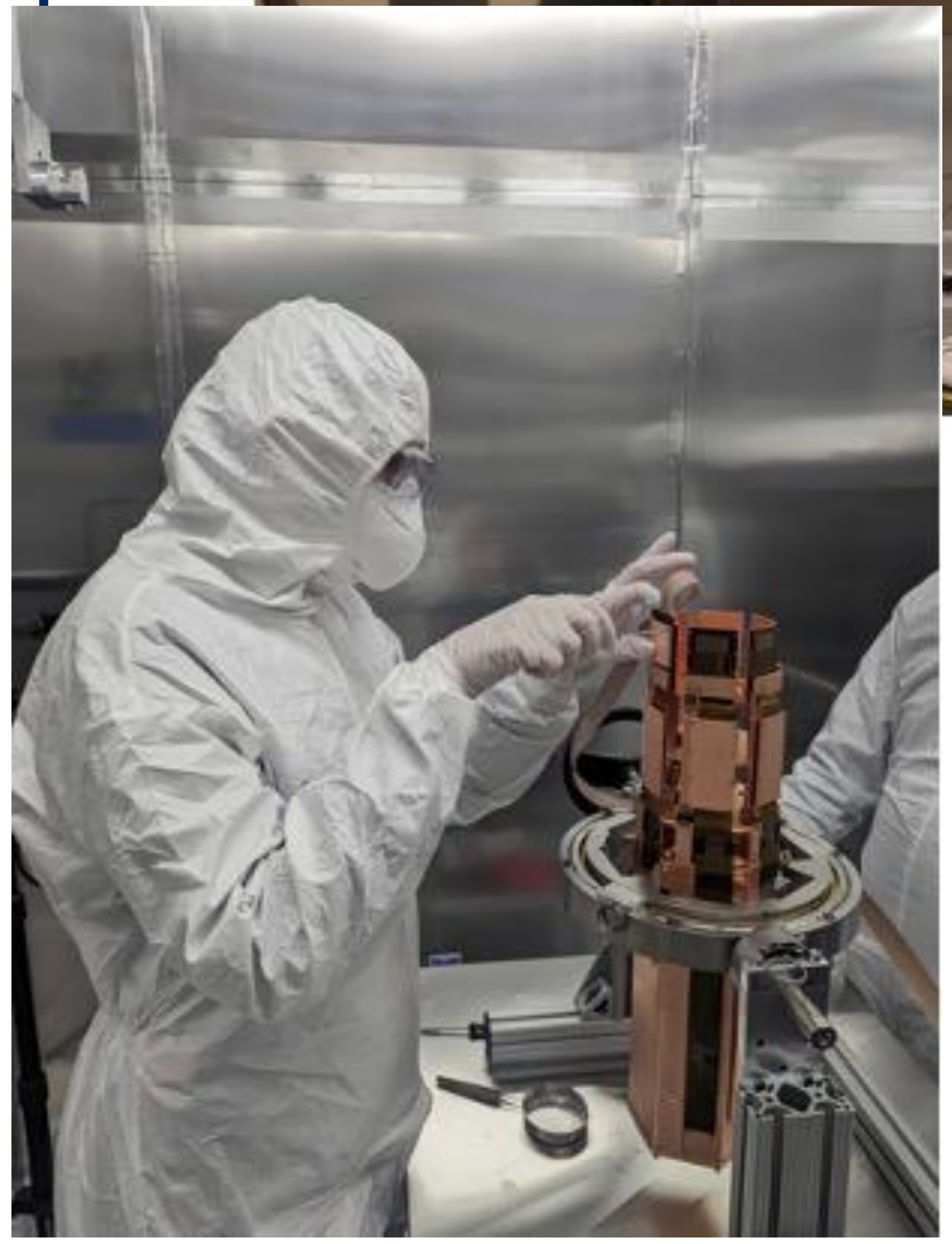
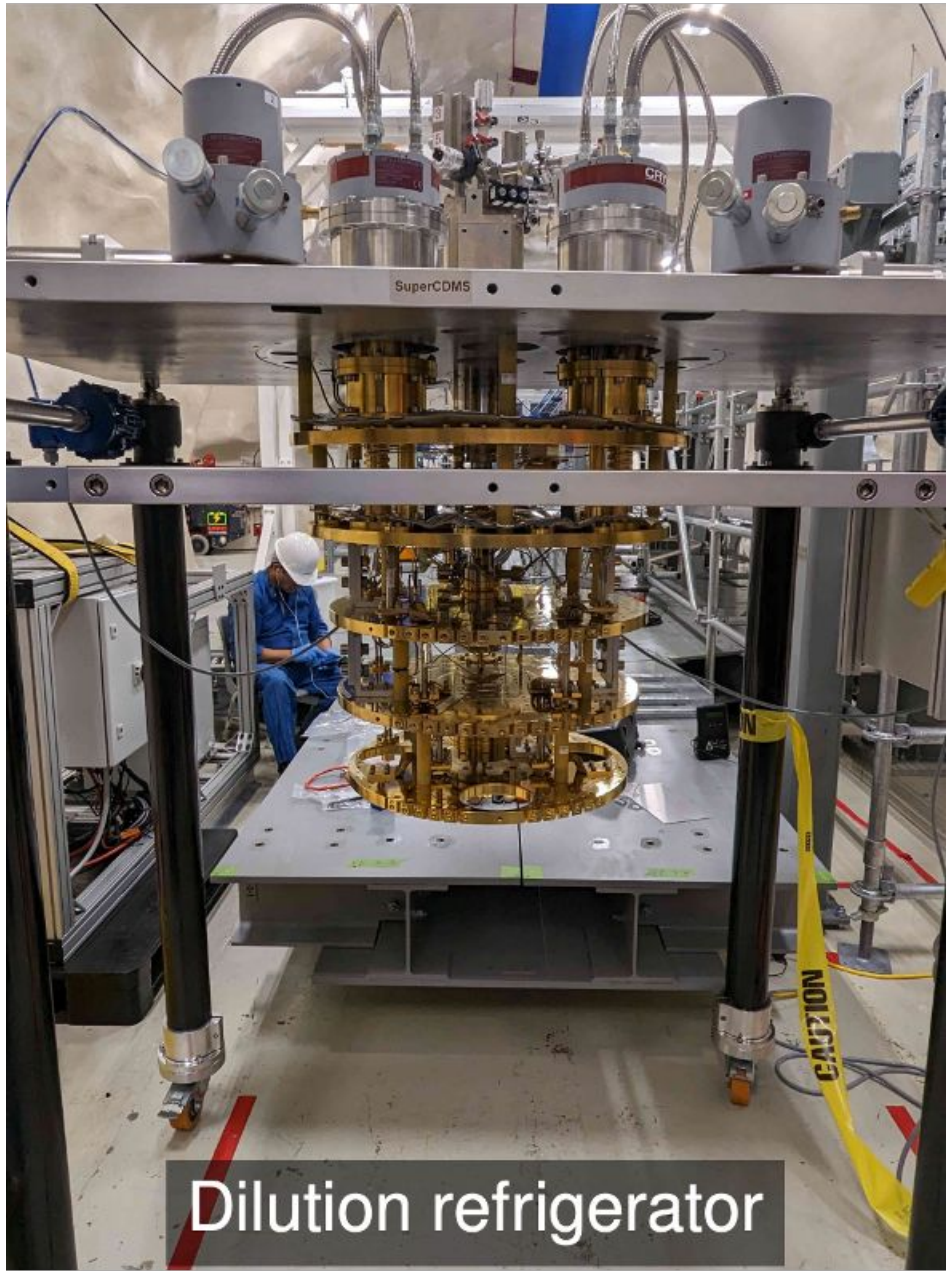


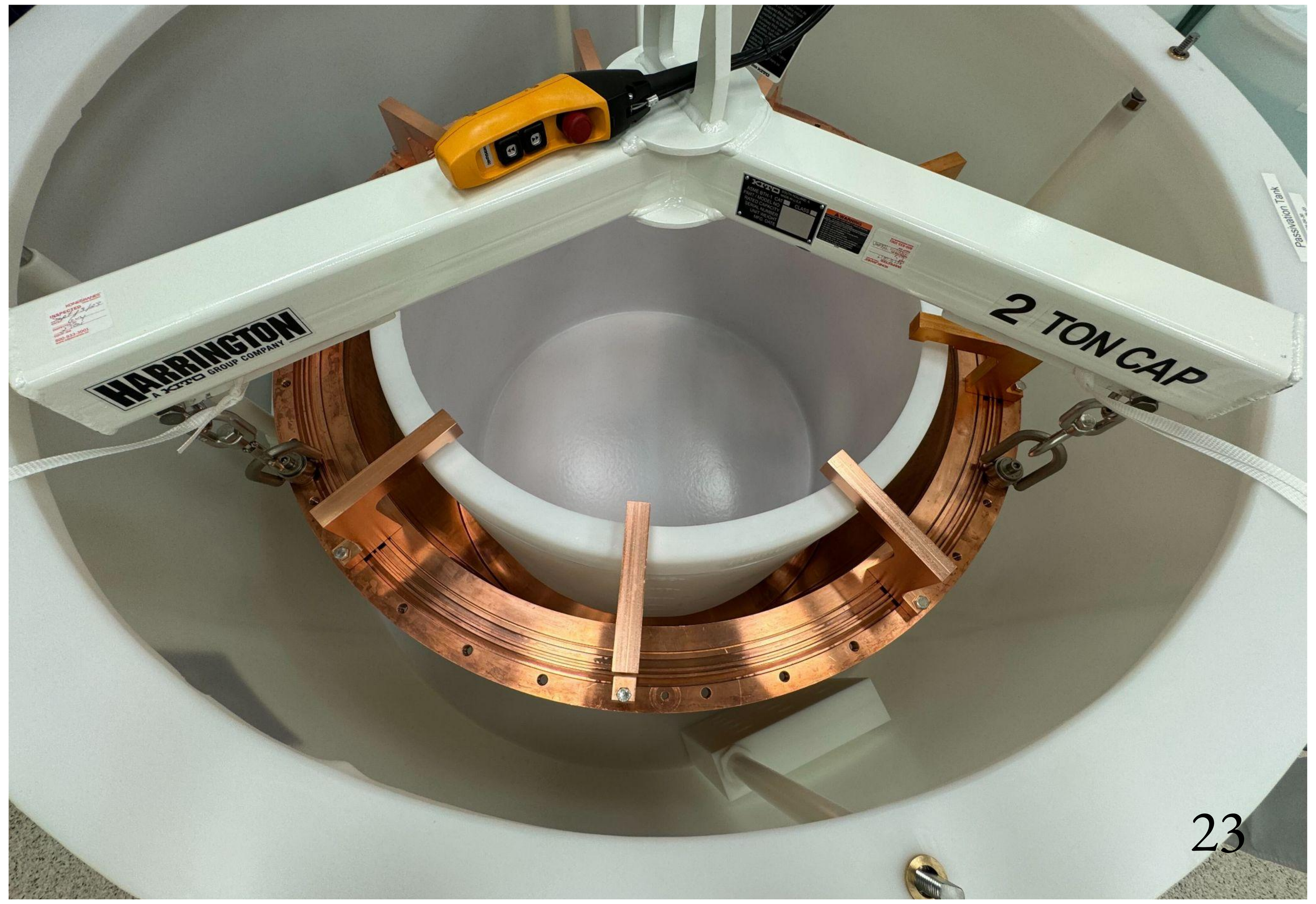
Installation activities



Dilution refrigerator

1/3 of shield constructed

OVC cleaning



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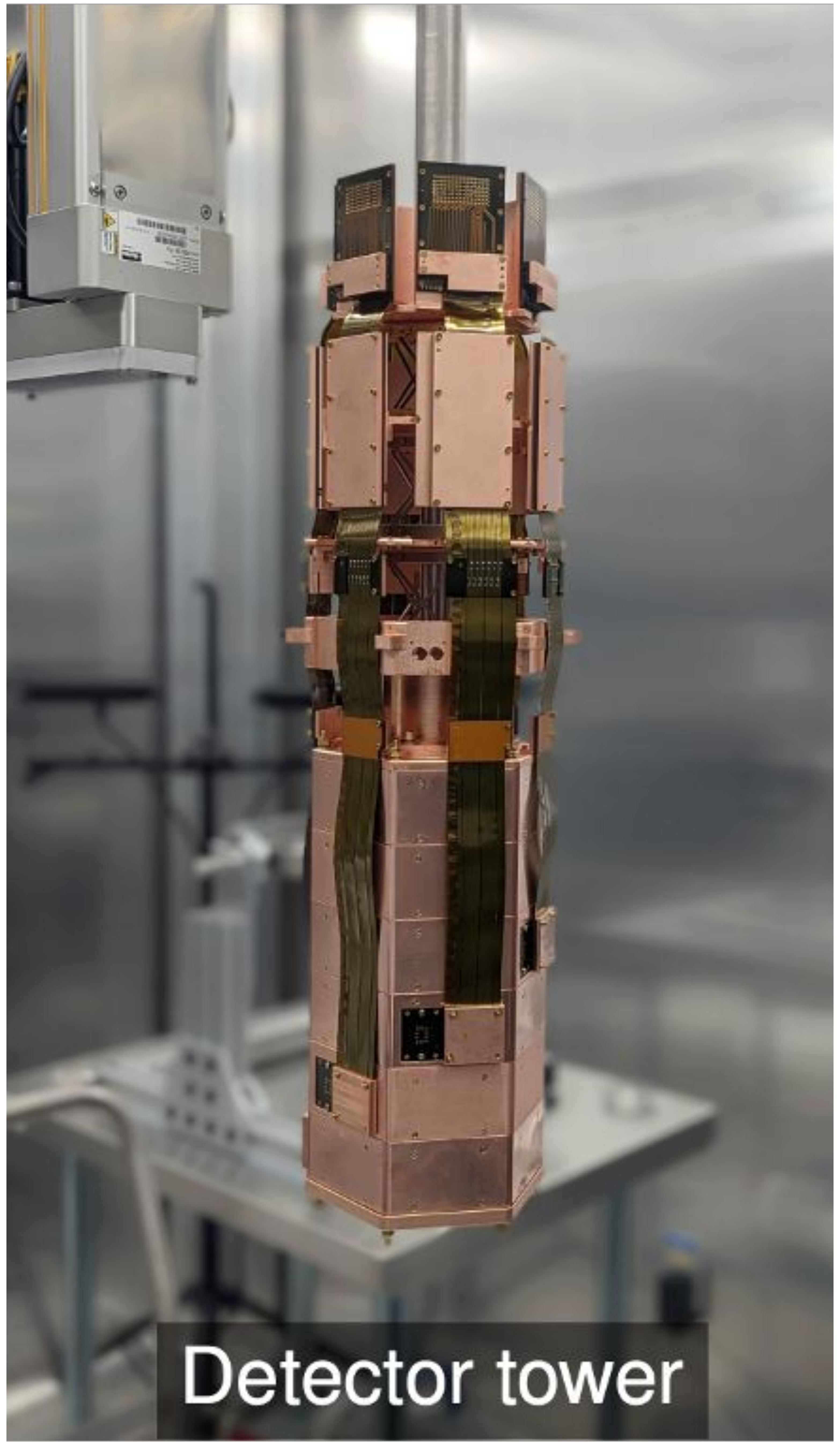
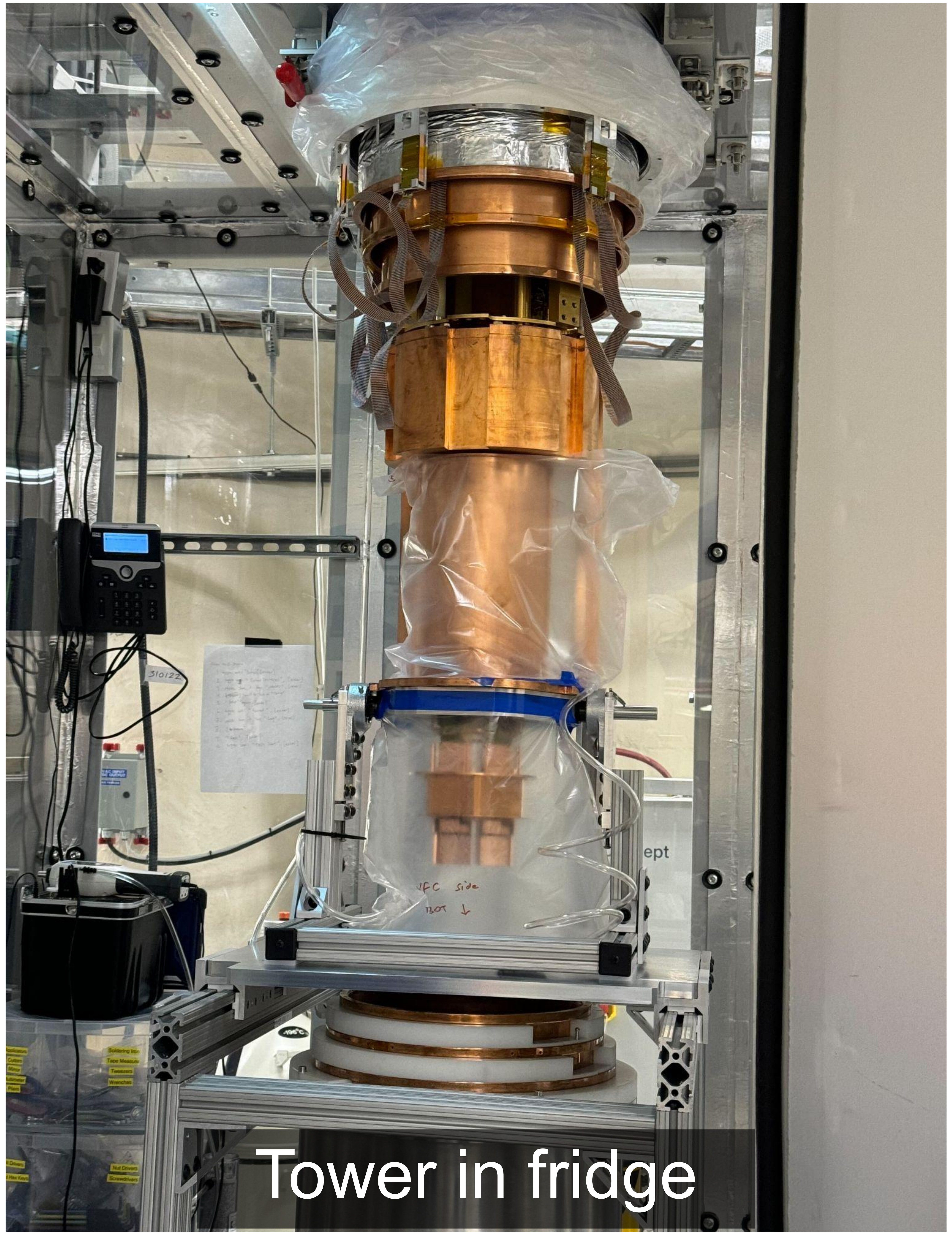
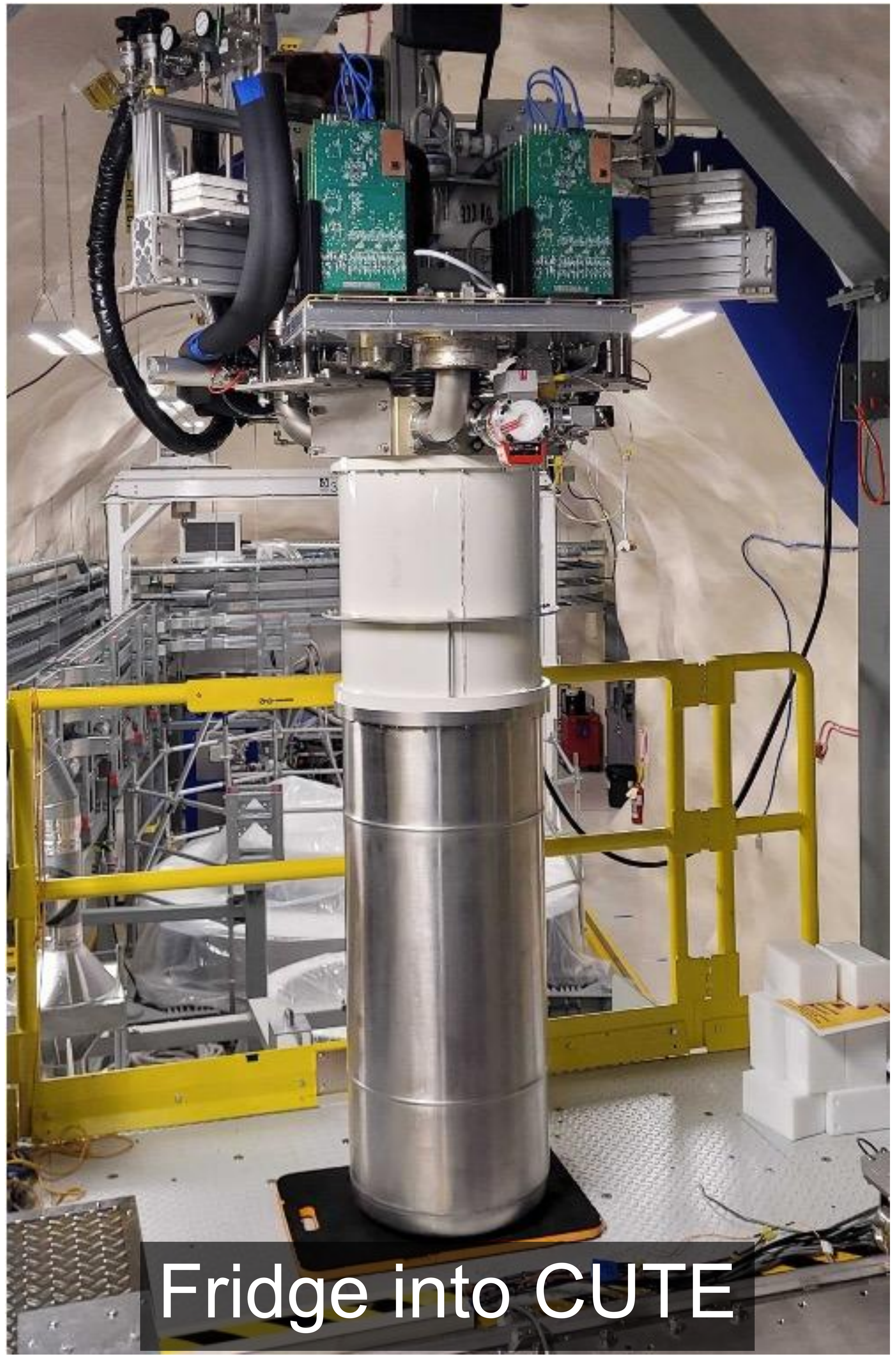
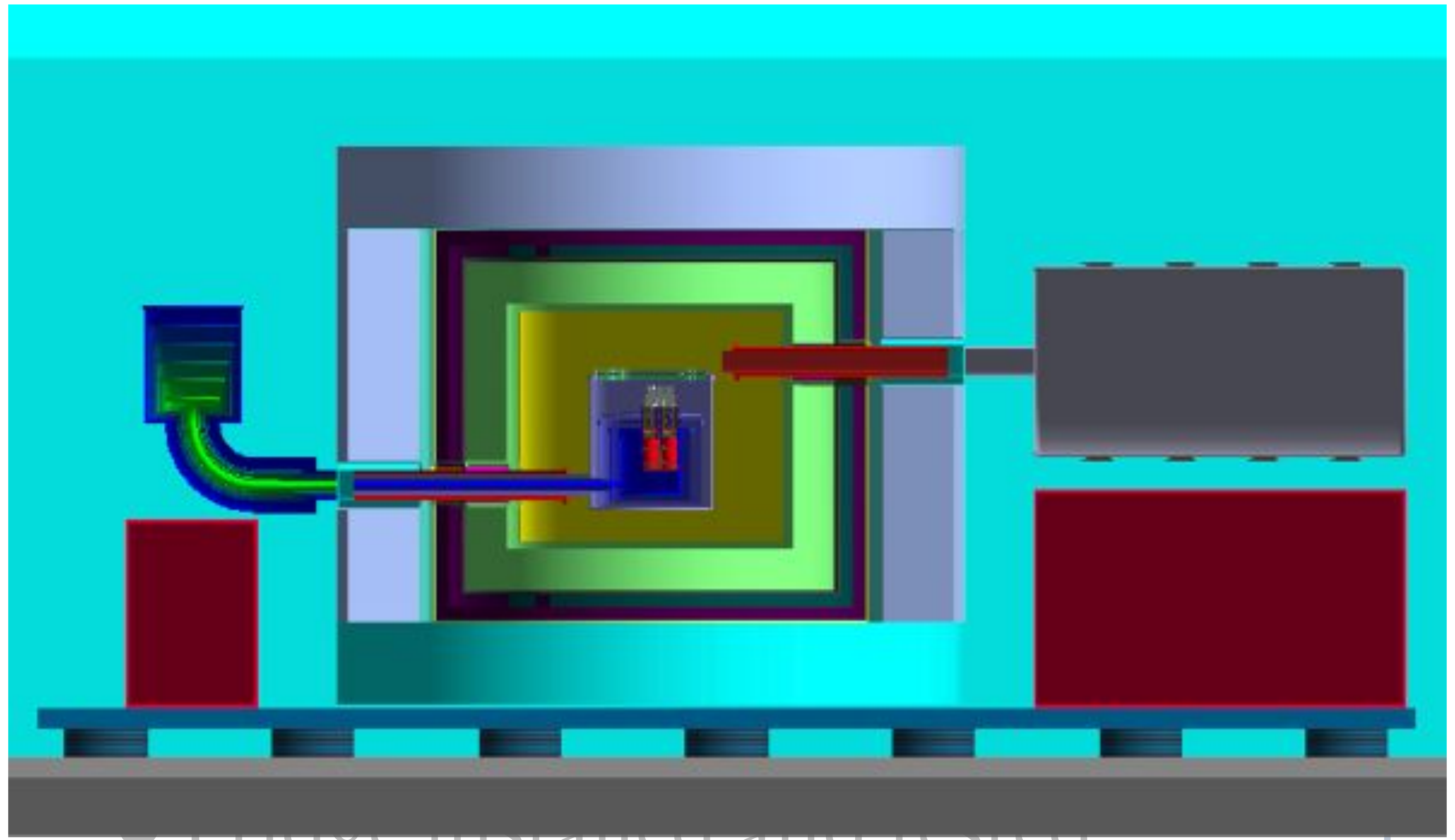
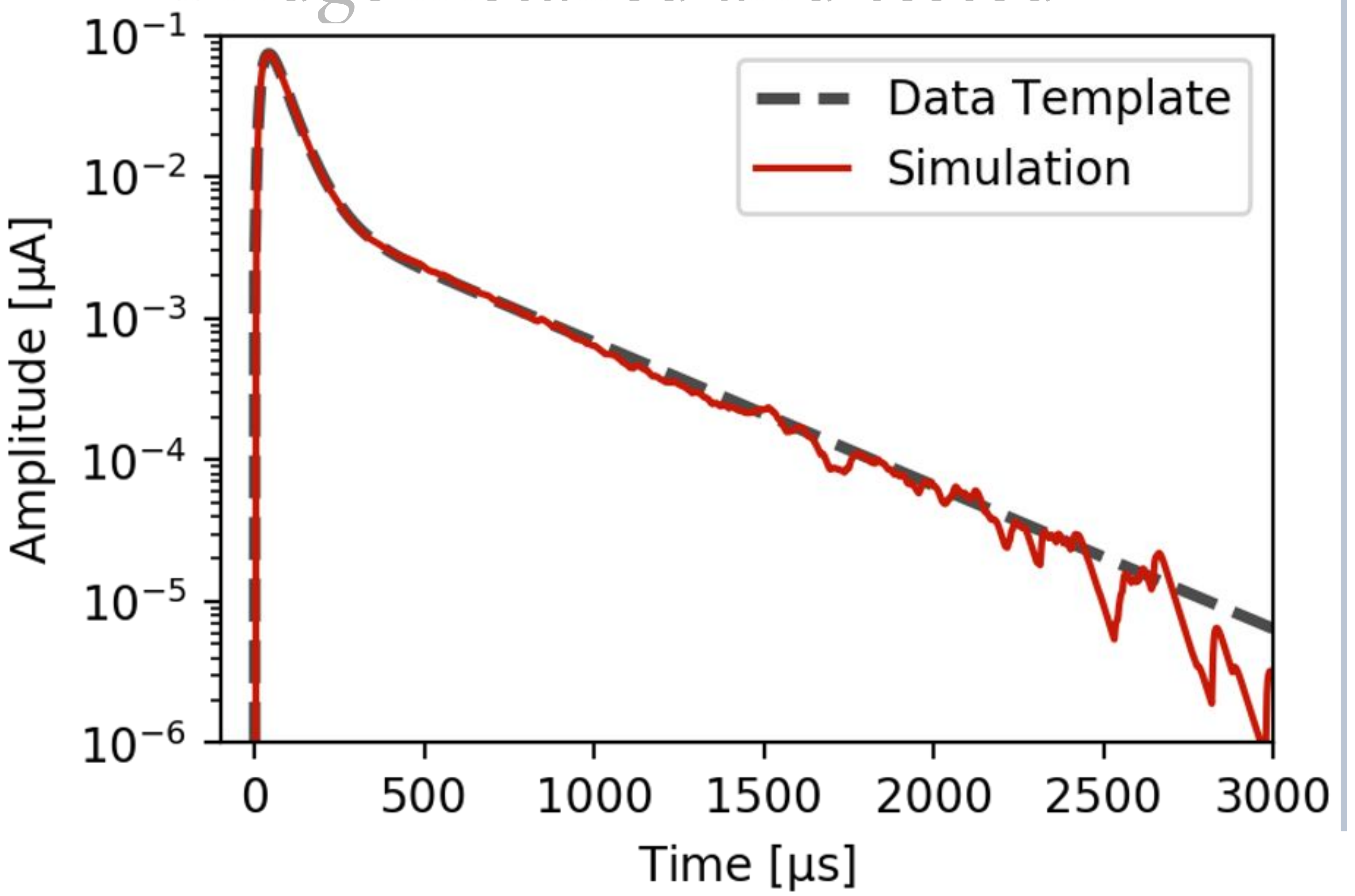

Detector tower


Tower in fridge


Fridge into CUTE

Coming up…





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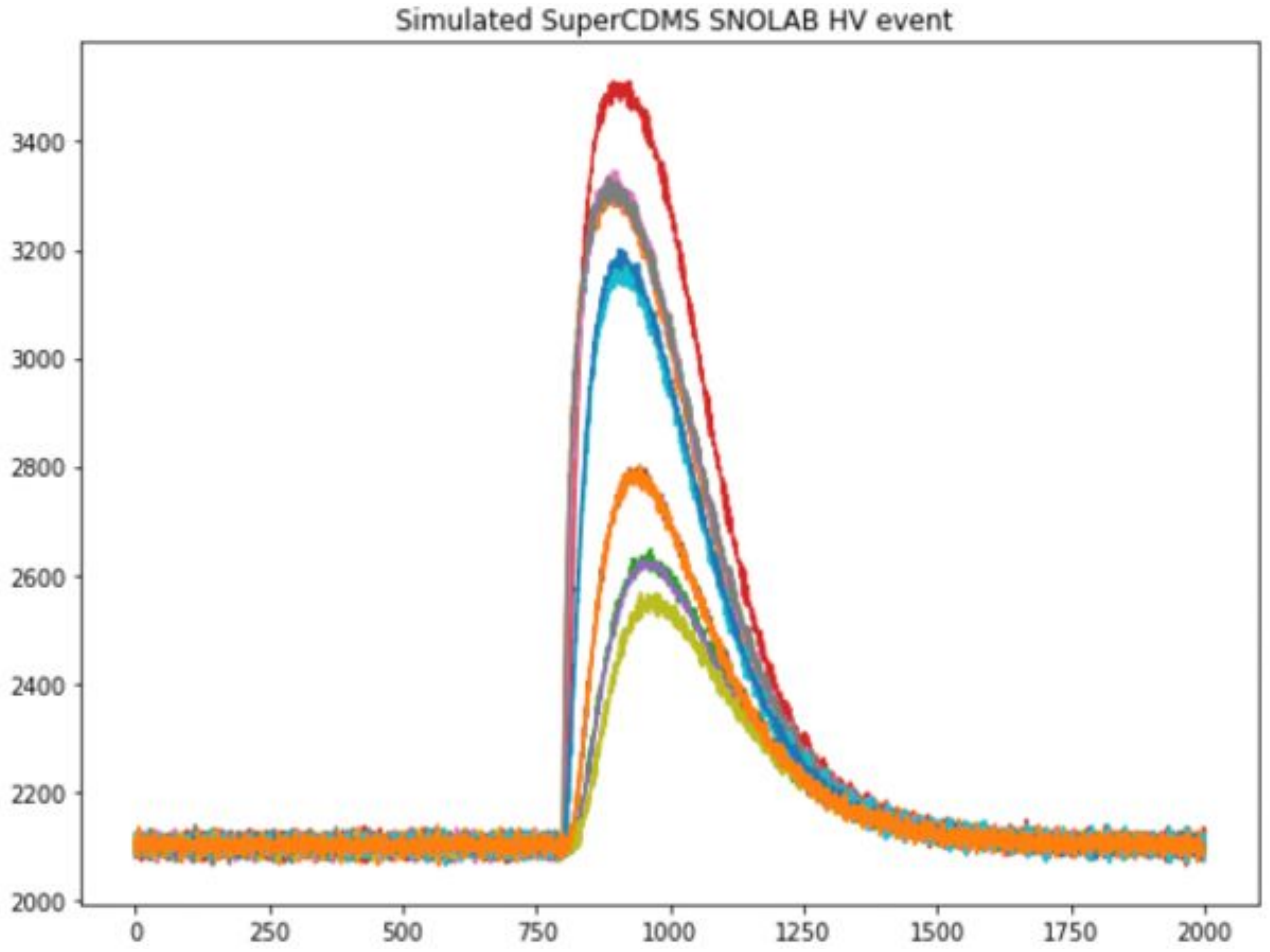

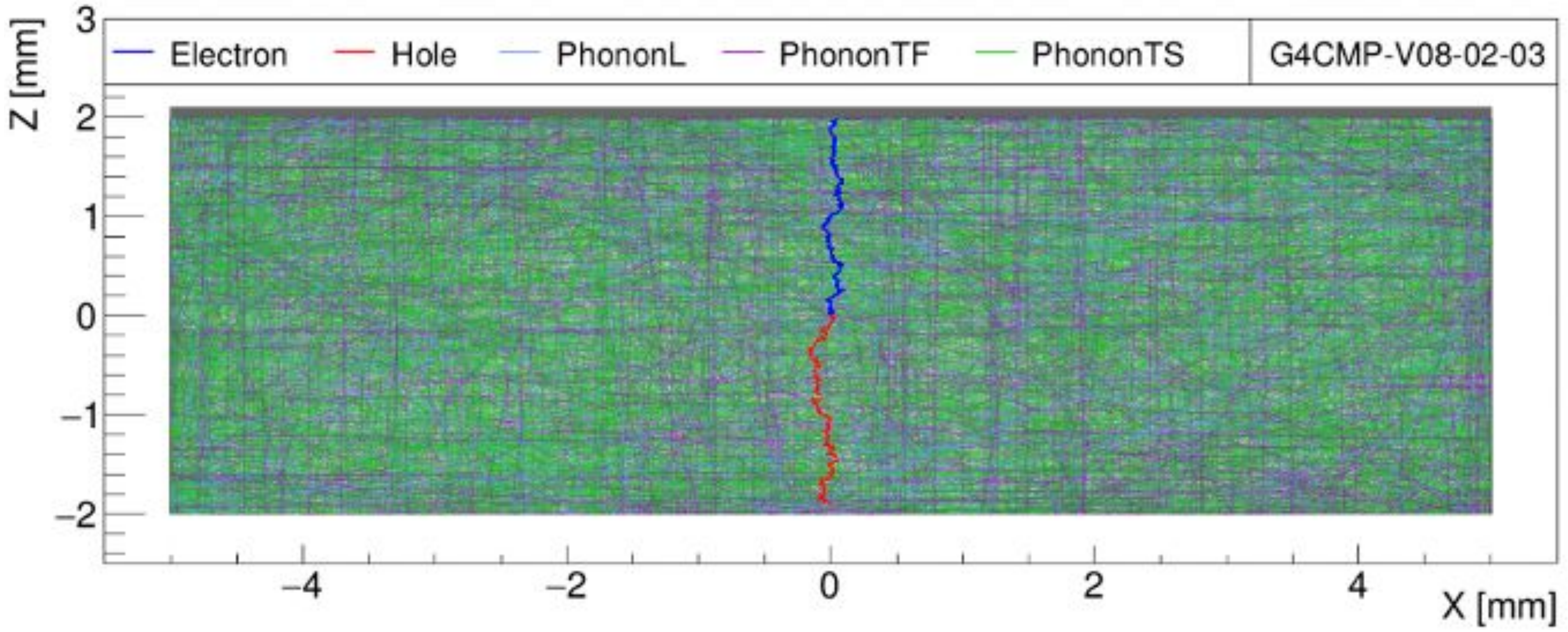

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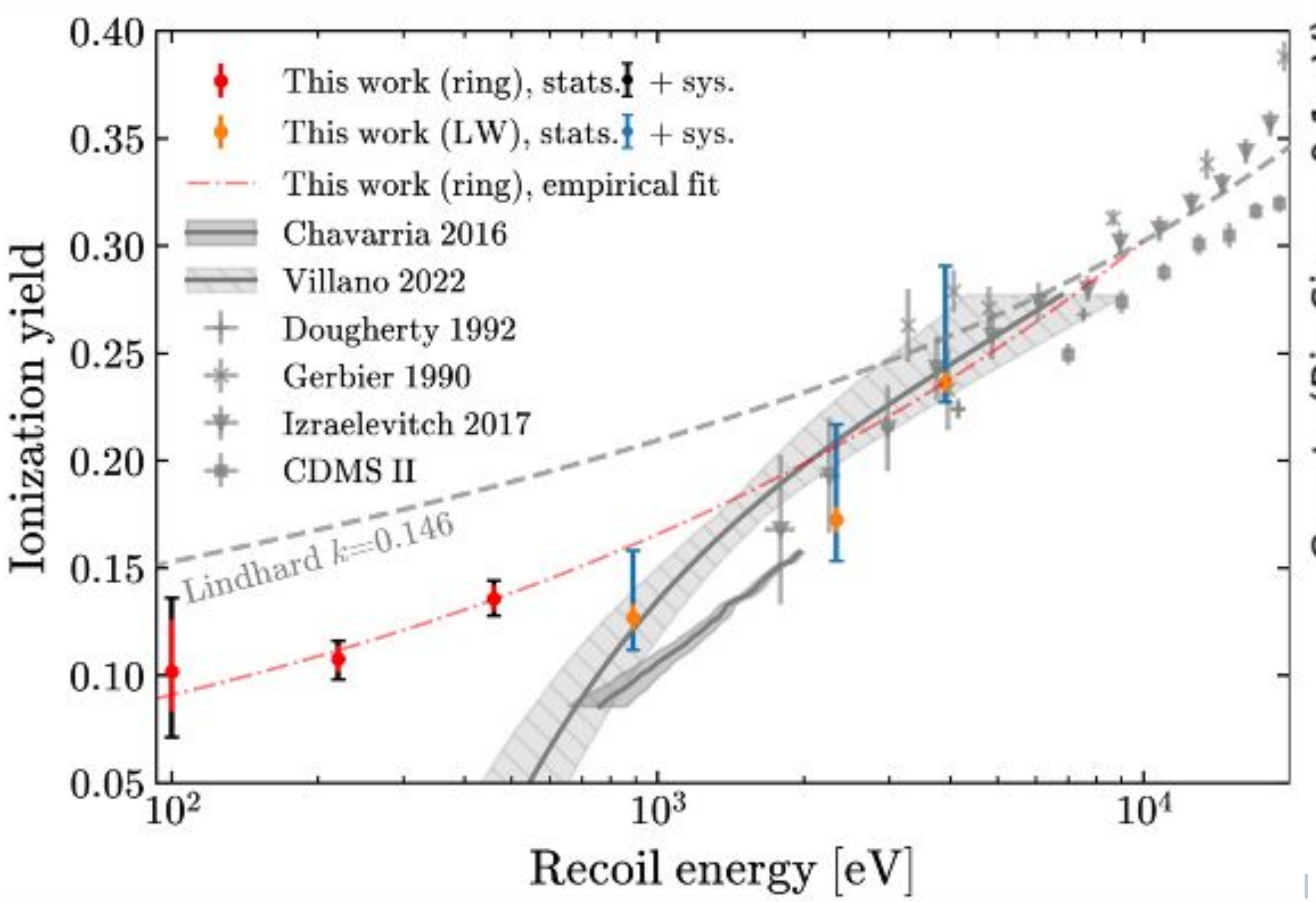

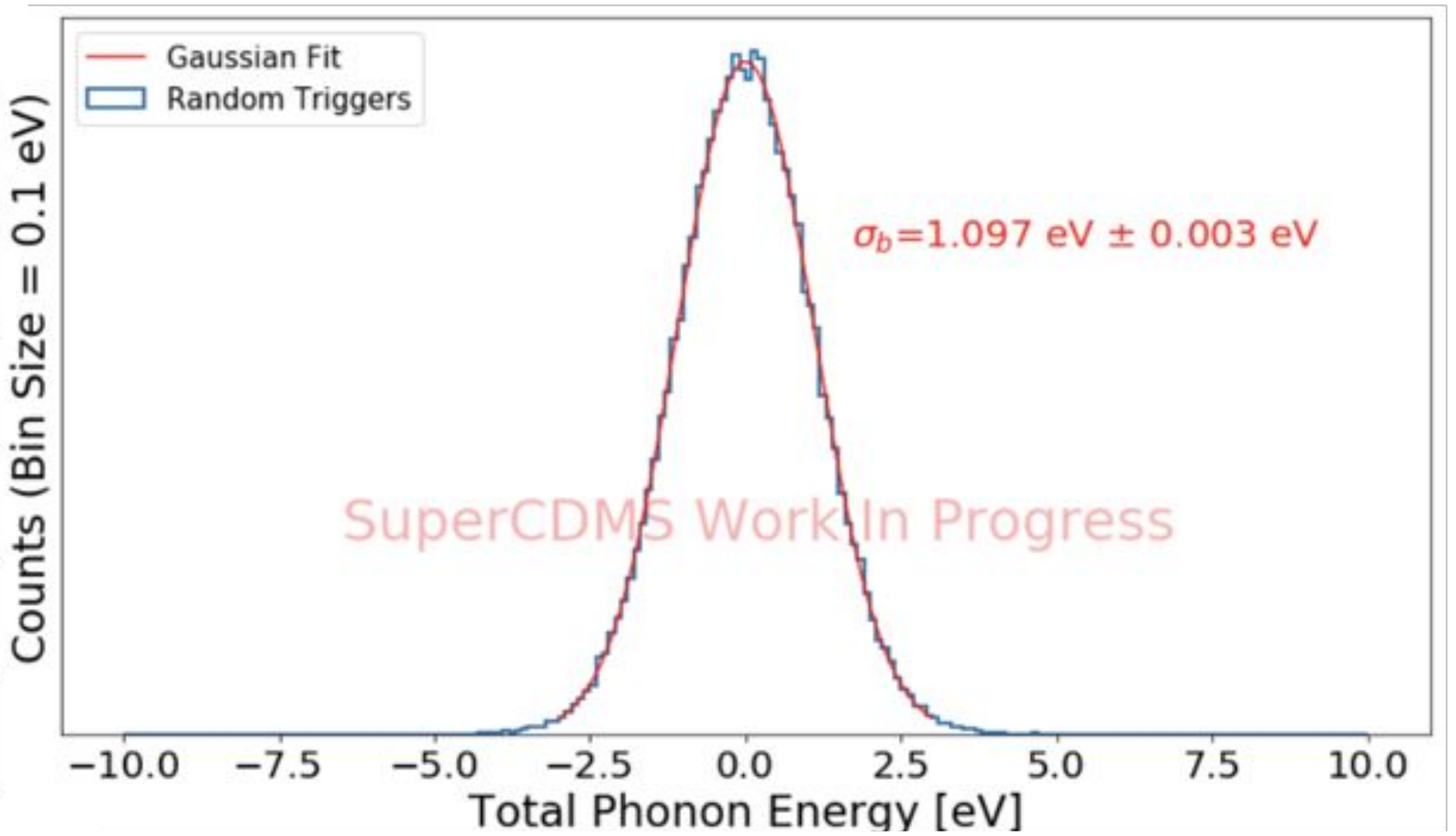

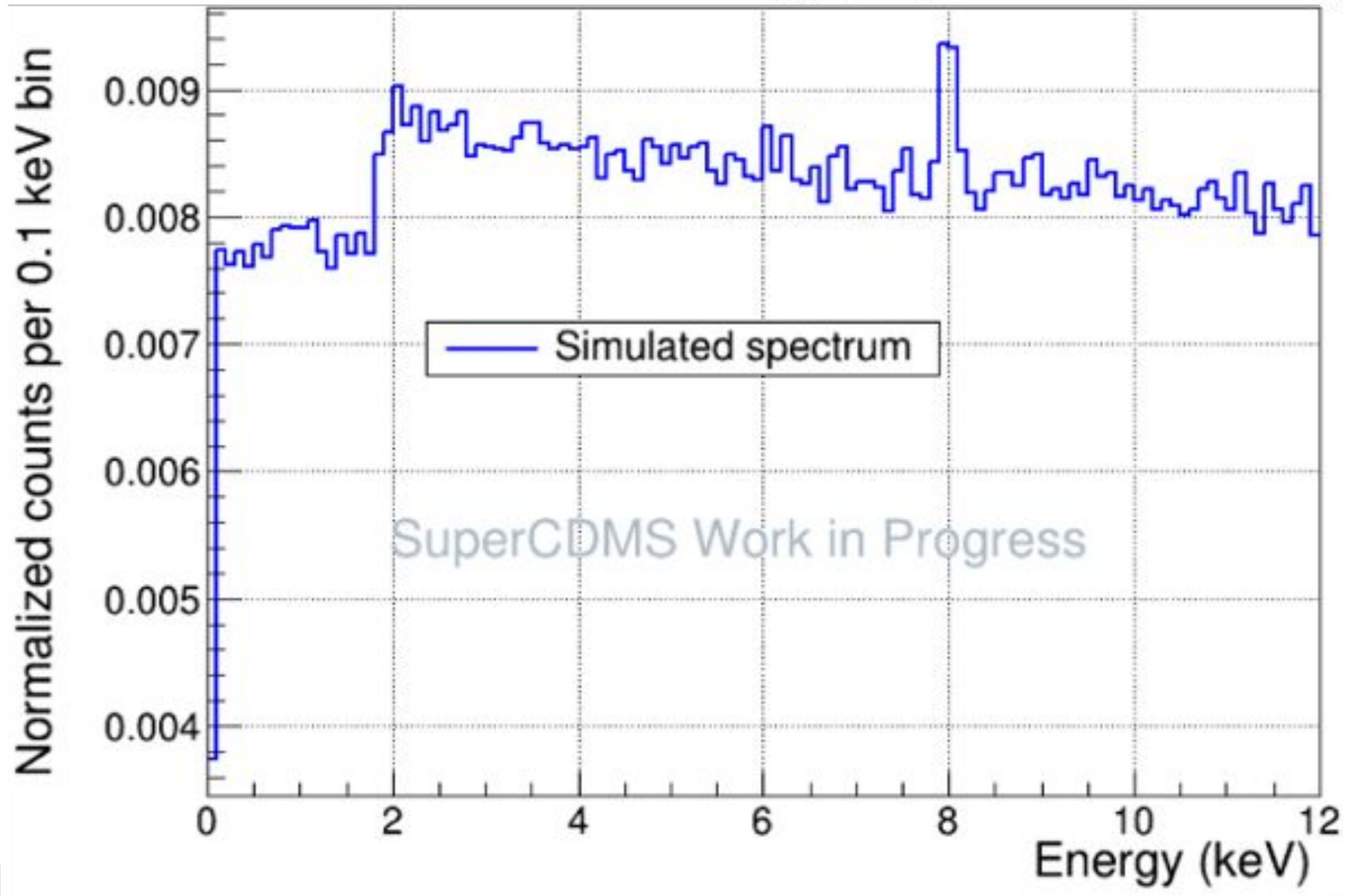

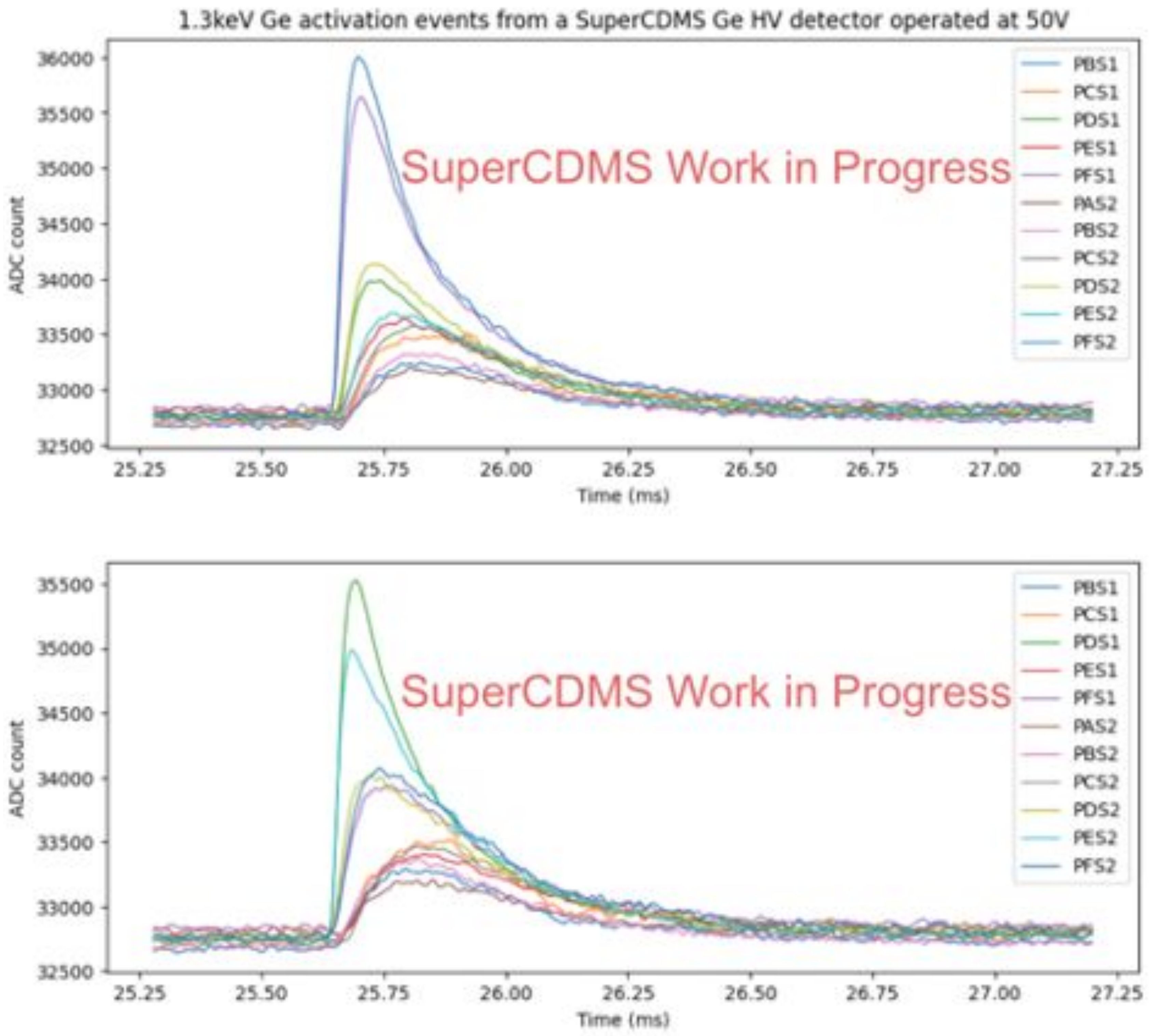

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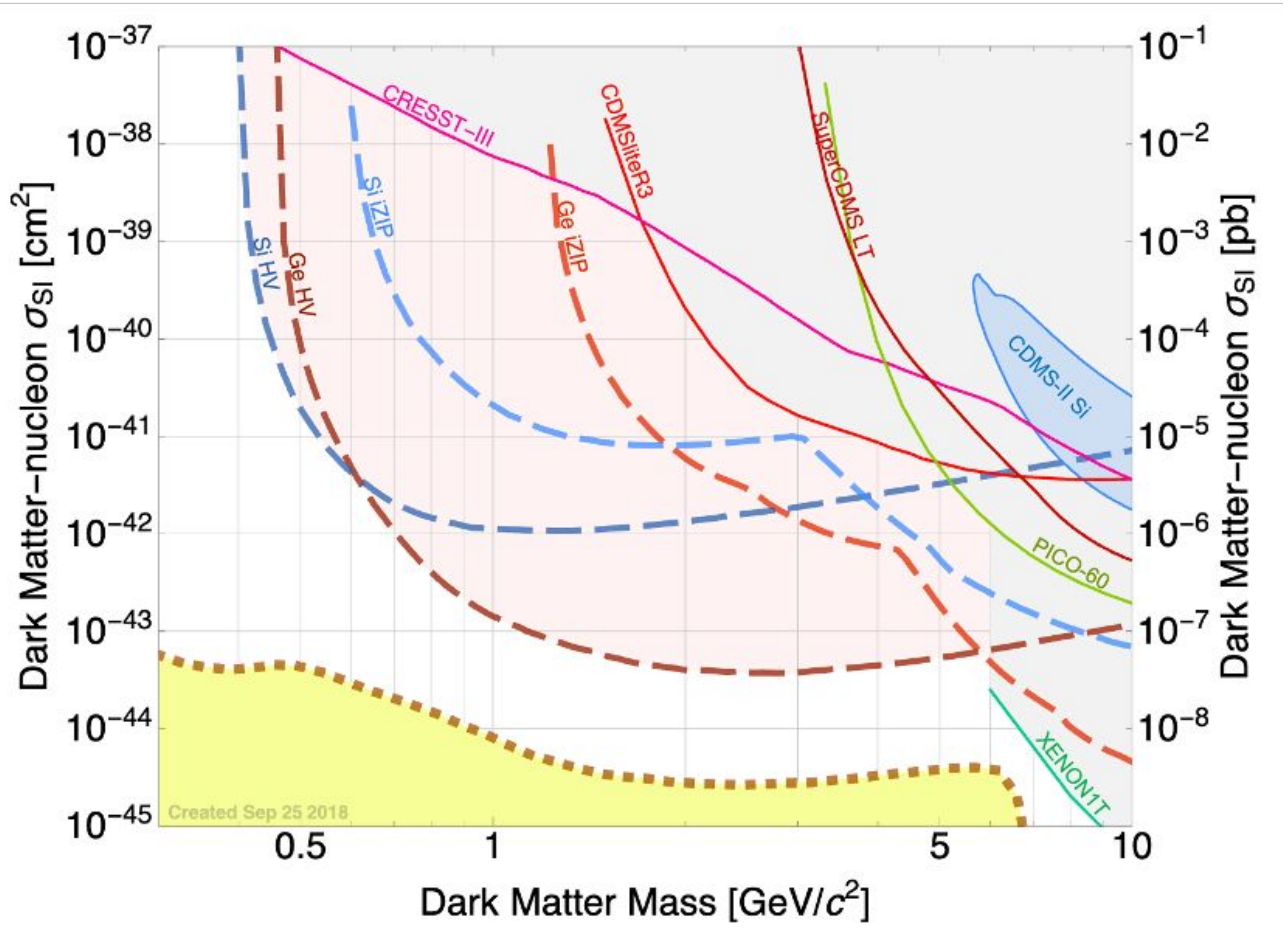
Summary

- SuperCDMS is well suited for low mass DM due to
  - Multiple targets
  - Dual, complementary detector technologies
  - Sensitivity to a range of different DM models
- SNOLAB commissioning is well underway
- Exciting results expected soon from our test facilities (NEXUS and CUTE)
  - Successfully demonstrated operation of HV detectors in low background environment
  - Testbed for calibration processes and simulation program
  - Will help prepare the collaboration for ‘first dark’

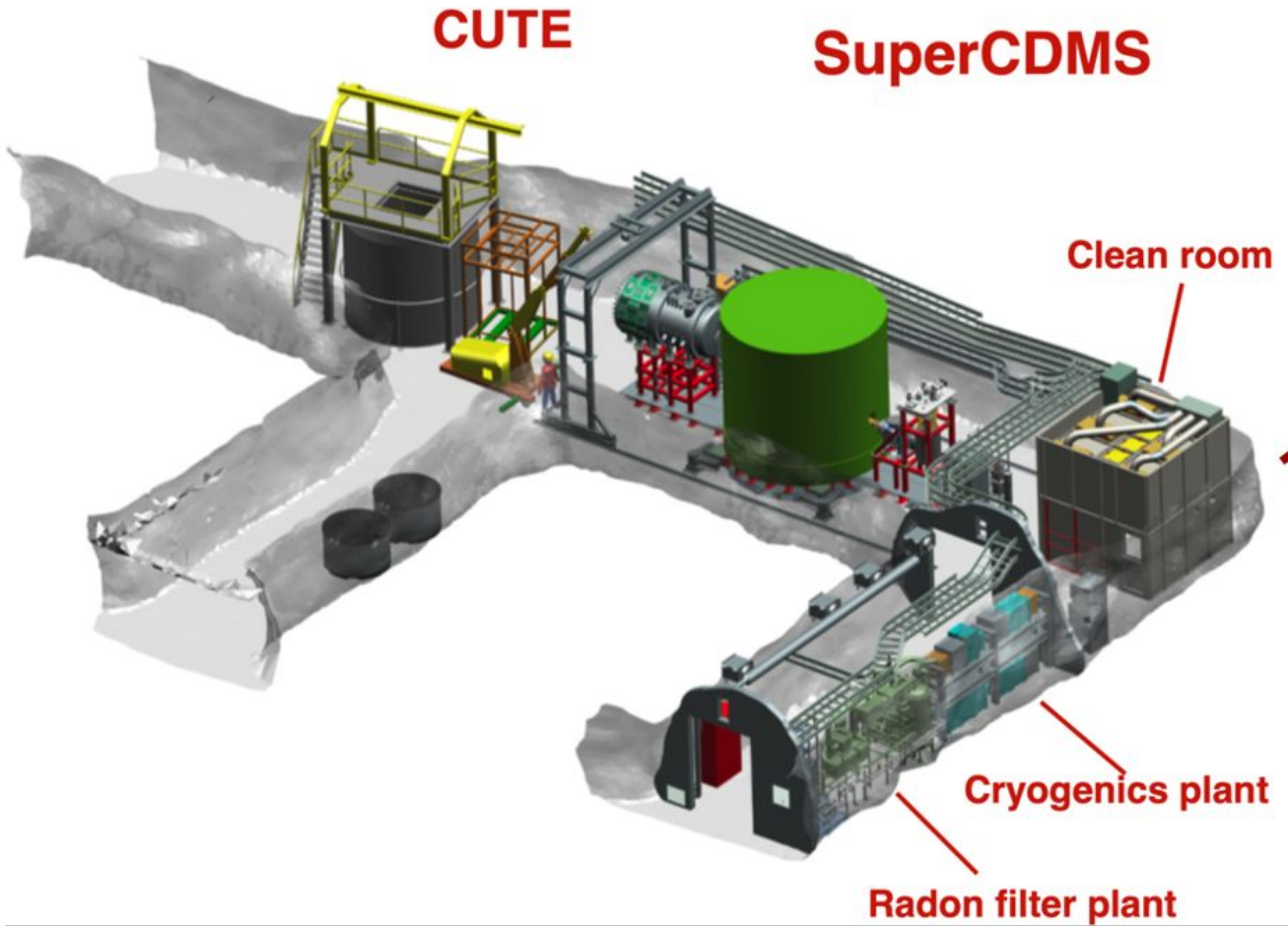


Acknowledgements

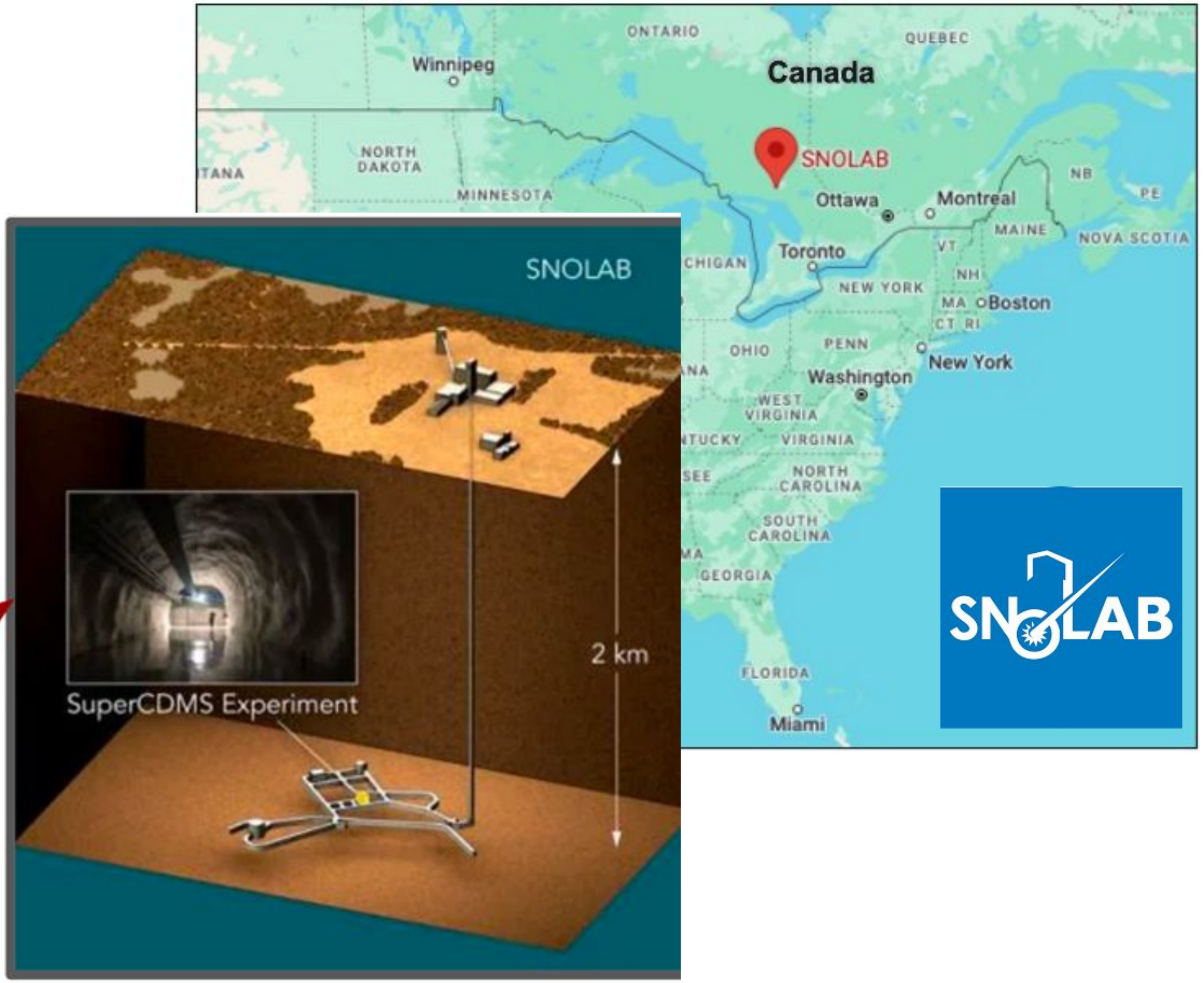
@SuperCDMS supercdms.slac.stanford.edu

Back up slides

SNOLAB



CUTE
SuperCDMS
Clean room
Cryogenics plant
Radon filter plant



SNOLAB
2 km
SuperCDMS Experiment
ONTARIO
QUEBEC
Winnipeg
Canada
NORTH DAKOTA
MINNESOTA
SNOLAB
Ottawa
Montreal
NB
PE
MAINE
NOVA SCOTIA
Toronto
VT
NH
NEW YORK
MA
Boston
CT
RI
OHIO
PENN
New York
Washington
WEST VIRGINIA
VIRGINIA
NORTH CAROLINA
SOUTH CAROLINA
GEORGIA
FLORIDA
Miami
SNOLAB

SuperCDMS search methods

- "Traditional" Nuclear Recoil: Full discrimination, ≳ 5 GeV
- Low Threshold NR: Limited discrimination, ≳ 1 GeV
- HV Detector: HV, no discrimination, ~0.3 – 10 GeV
- Migdal & Bremsstrahlung: no discrimination, ~0.01 – 10 GeV
- Electron recoil: HV, no discrimination, ~0.5 MeV – 10 GeV
- Absorption (Dark Photons, ALPs): HV, no discrimination, ~1 eV – 500 keV (“peak search”)