# The SuperCDMS Experiment at SNOLAB

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Astroparticle Symposium 2025
2025/11/04

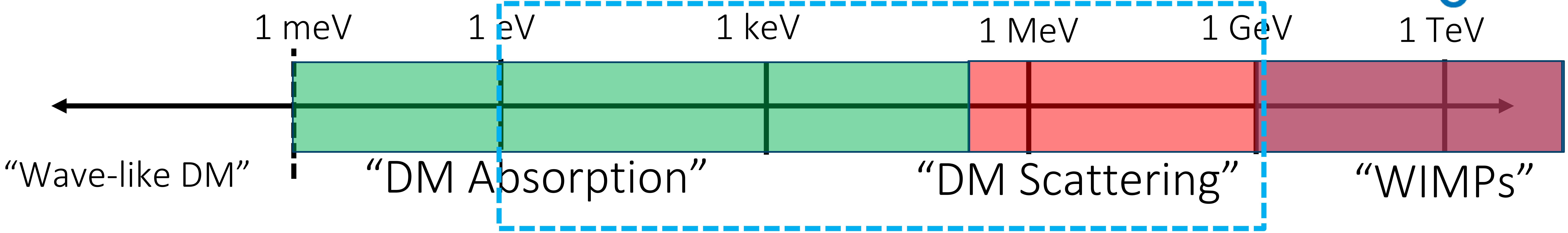
# Outline

- SuperCDMS at SNOLAB
- HVeV program

# SuperCDMS Collaboration

(+100 members, 27 institutions)

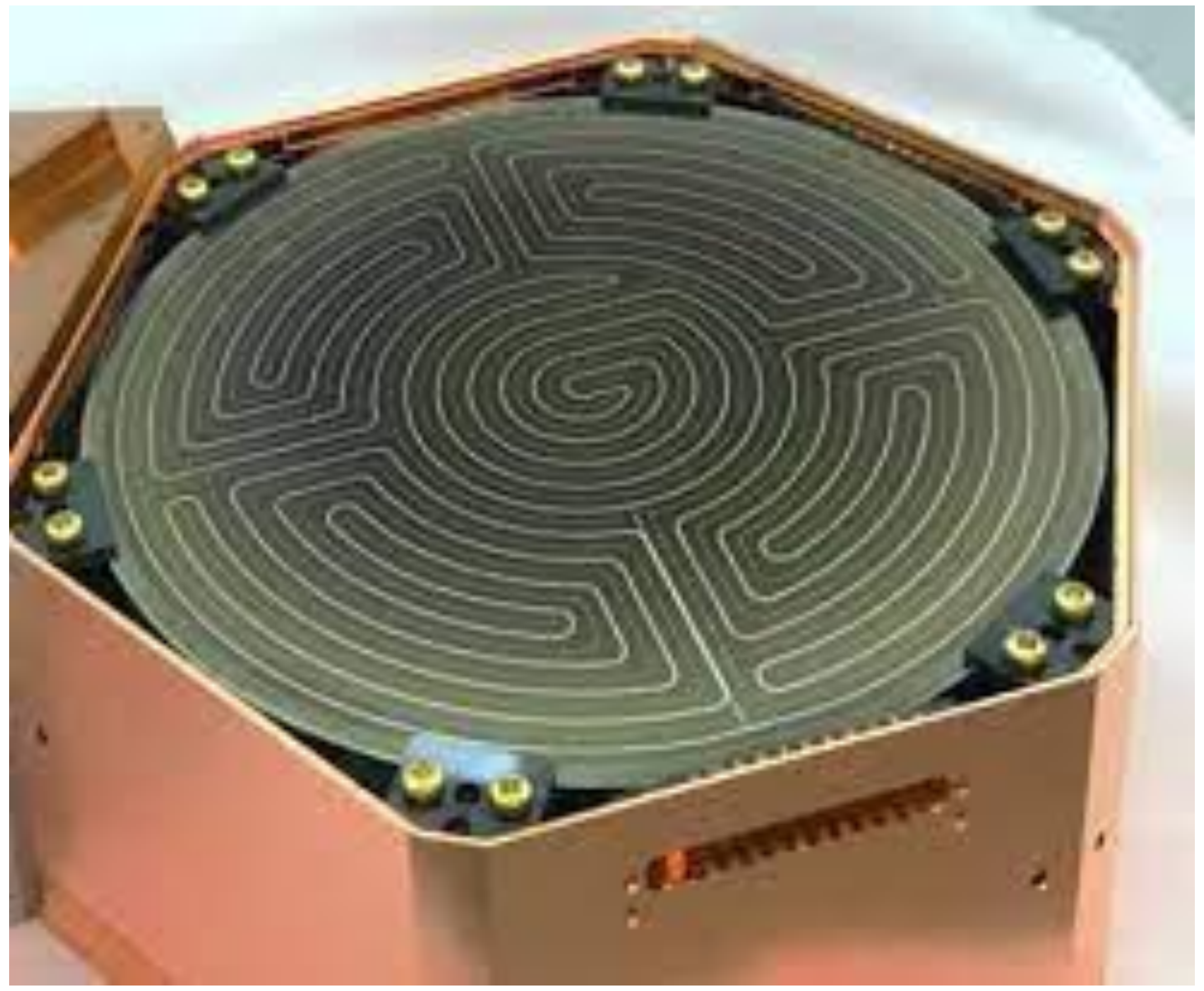
# SuperCDMS Objectives



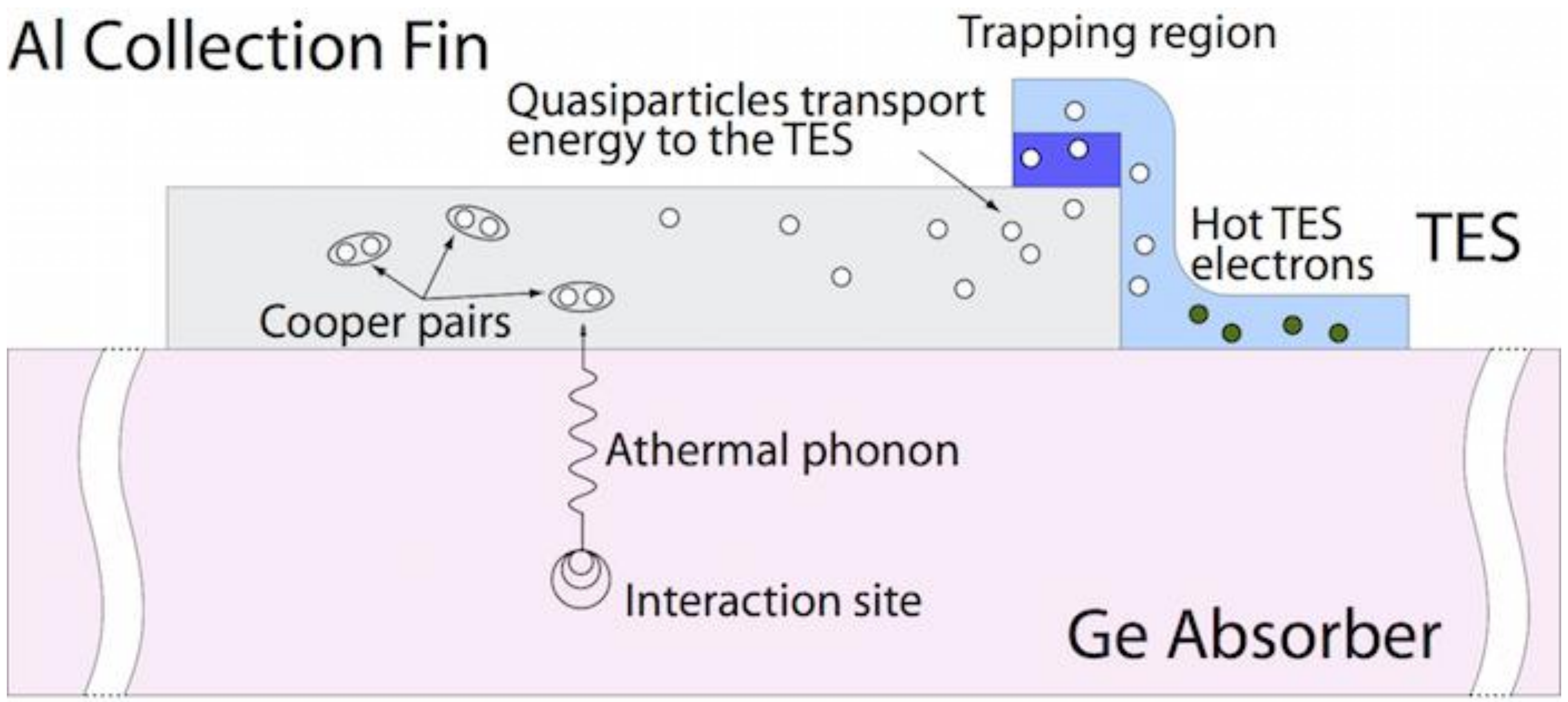

- Nucleon coupling: 0.05 – 5 GeV/$c^2$
- Dark photon-coupled light dark matter: 1 – 100 MeV/$c^2$
- Dark photon absorption : 1 – 100 eV/ $c^2$
- Axion-like particles absorption: 1 – 100 eV/ $c^2$

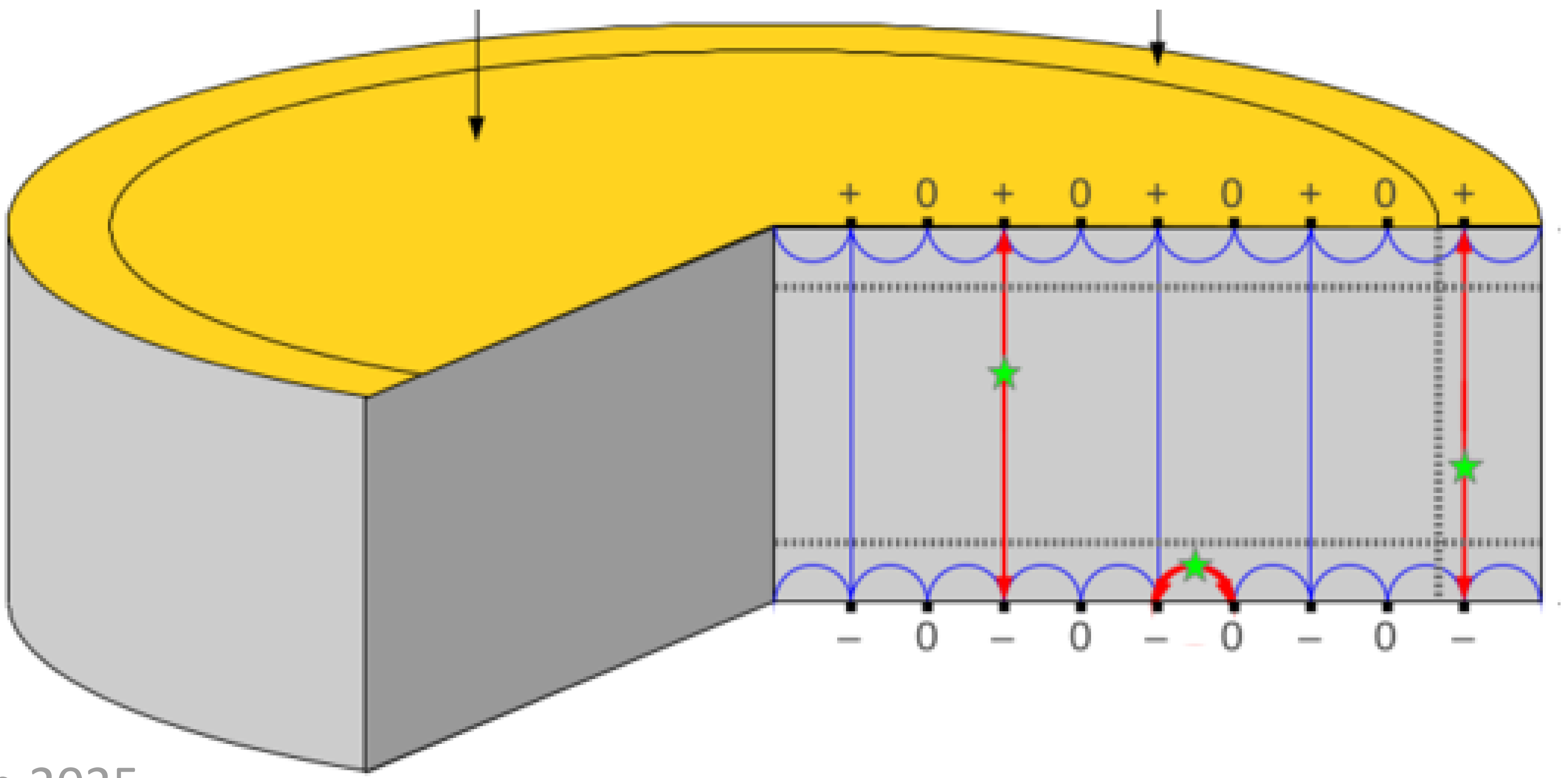

Adapted From: https://indico.cern.ch/event/1188759/contributions/5044015/

# SuperCDMS Detectors

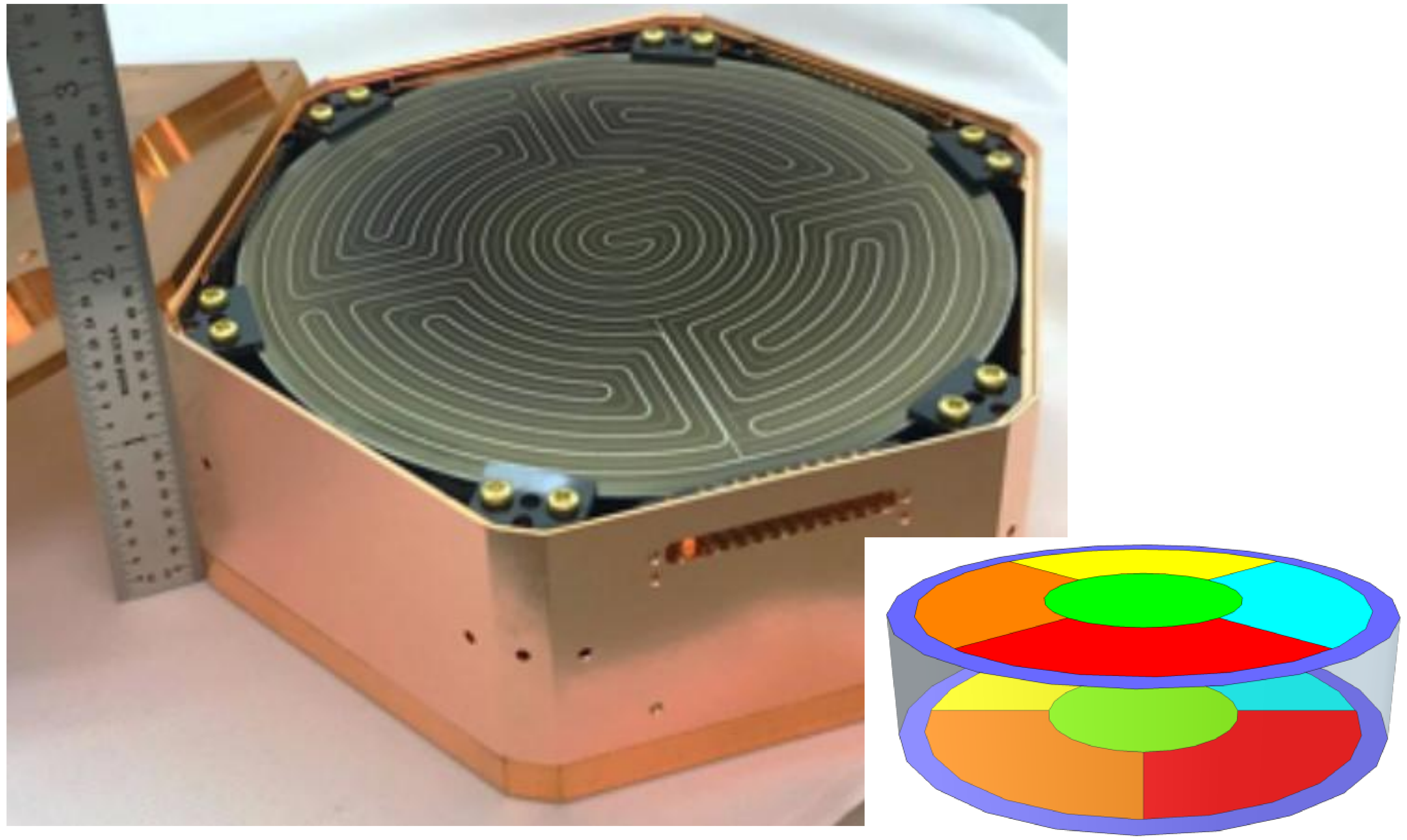


- Upgrade from CDMS and SuperCDMS Soudan (bigger and higher purity)
- Si(0.6 kg)/Ge (1.4 kg) cryogenic detectors
- Measure of **heat (phonon)** and **ionization**
- Heat is measured through Quasi-particle trap assisted electrothermal Feedback Transition Edge sensors (TES)
- Charge is measured through interleaved electrodes

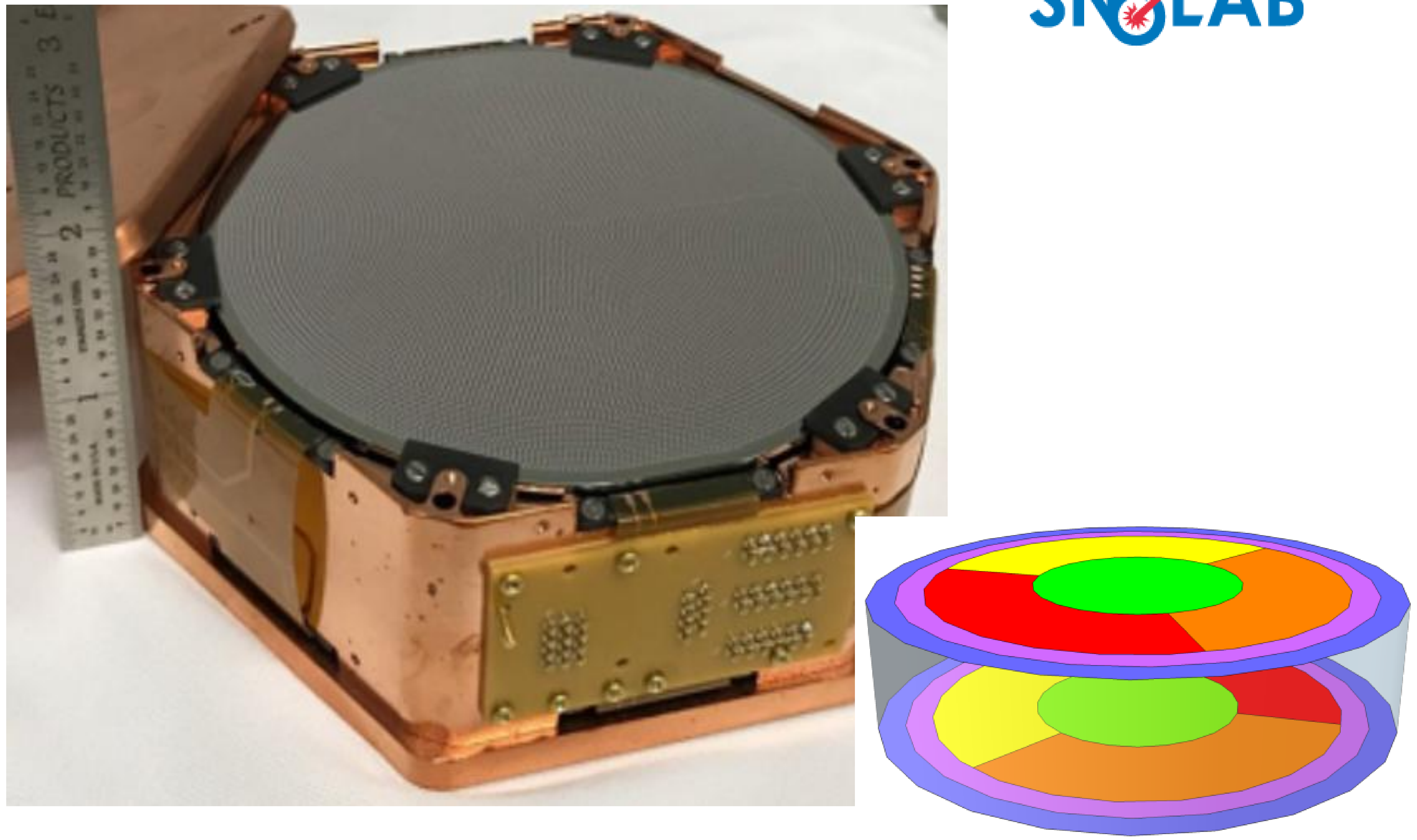


# iZIP and HV SuperCDMS Detectors



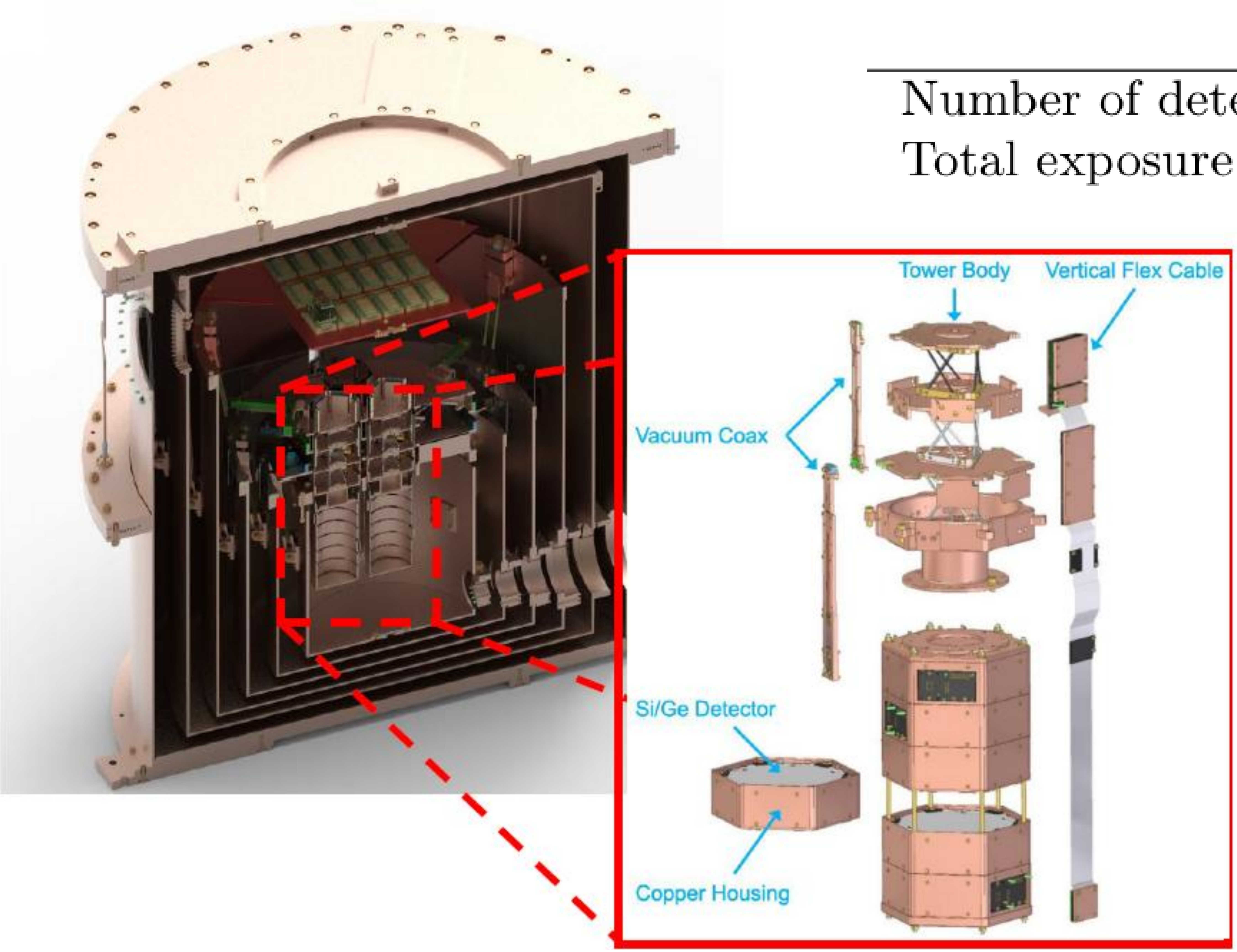
- **iZIP** (interleaved Z-sensitive Ionization and Phonon detector)
- 12 phonon, 4 charge channels
- Phonon and ionization channel allow for particle discrimination ER vs. NR

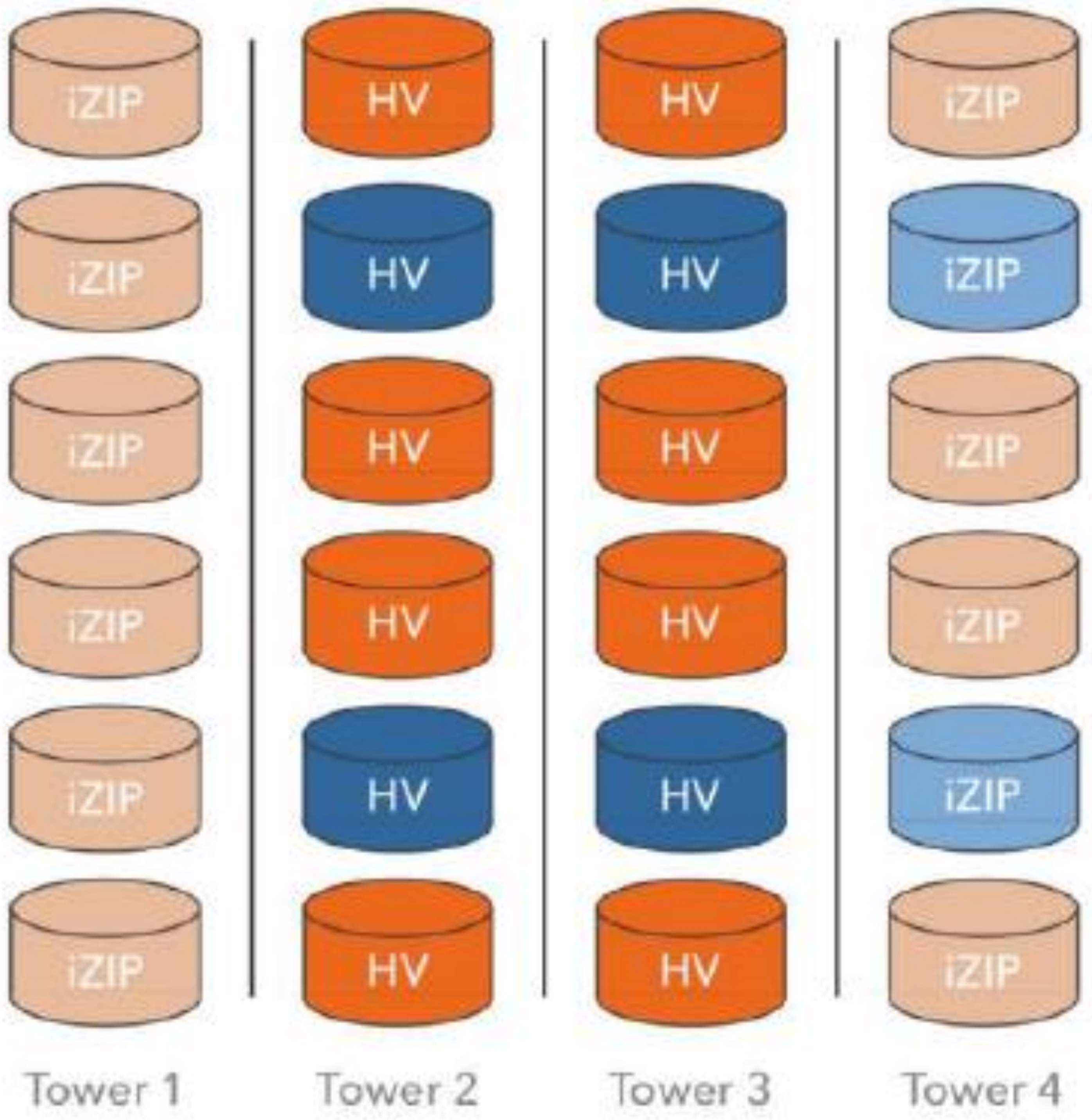


- **HV** (High Voltage detector)
- 12 phonon channels
- 100 V across the detector to exploit the Neganov-Trofimov-Luke **(NTL)** Effect

# iZIP and HV SuperCDMS Detectors

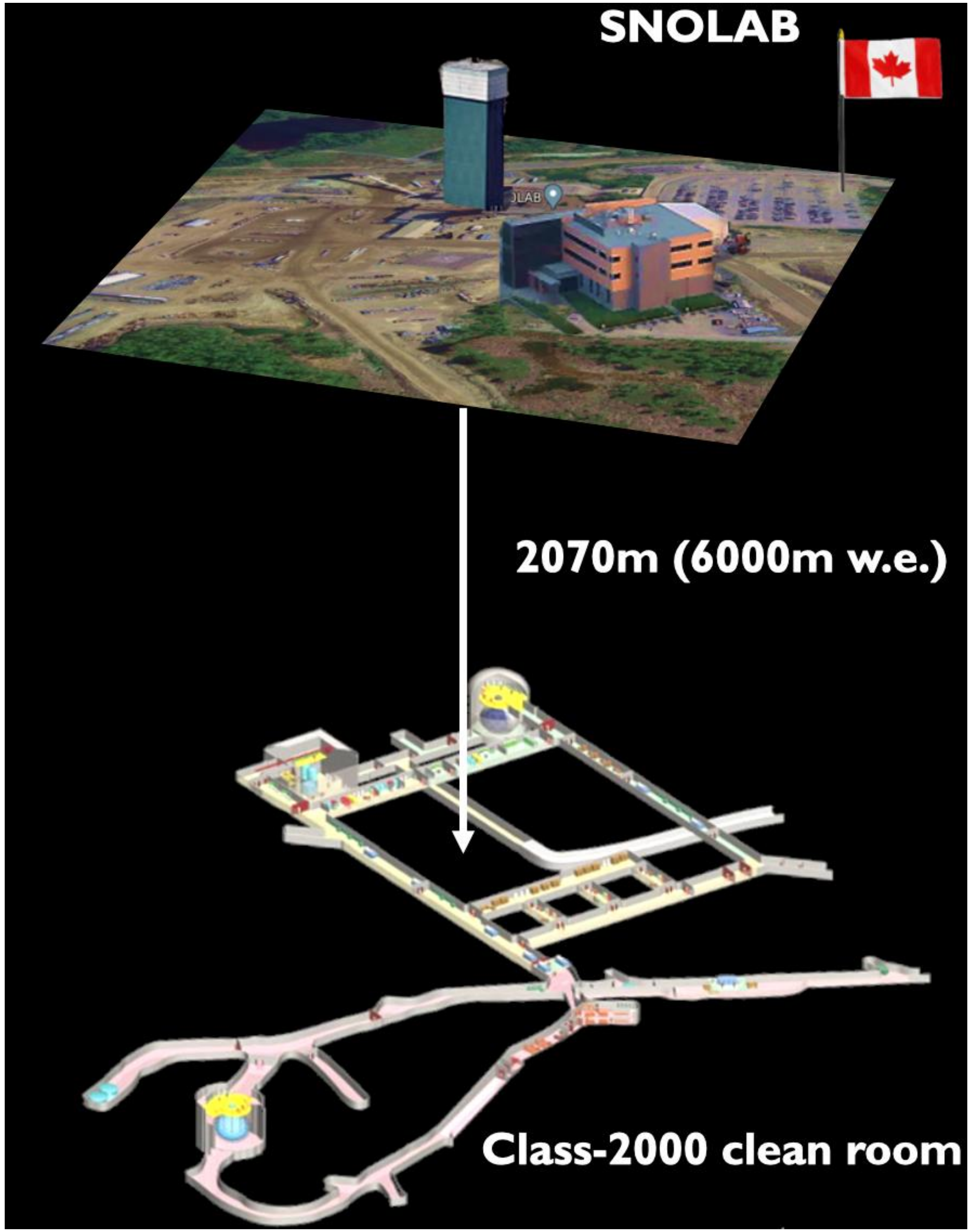
| | iZIP | | HV | |
|---|---|---|---|---|
| | Ge | Si | Ge | Si |
| Number of detectors | 10 | 2 | 8 | 4 |
| Total exposure [kg·yr] | 45 | 3.9 | 36 | 7.8 |



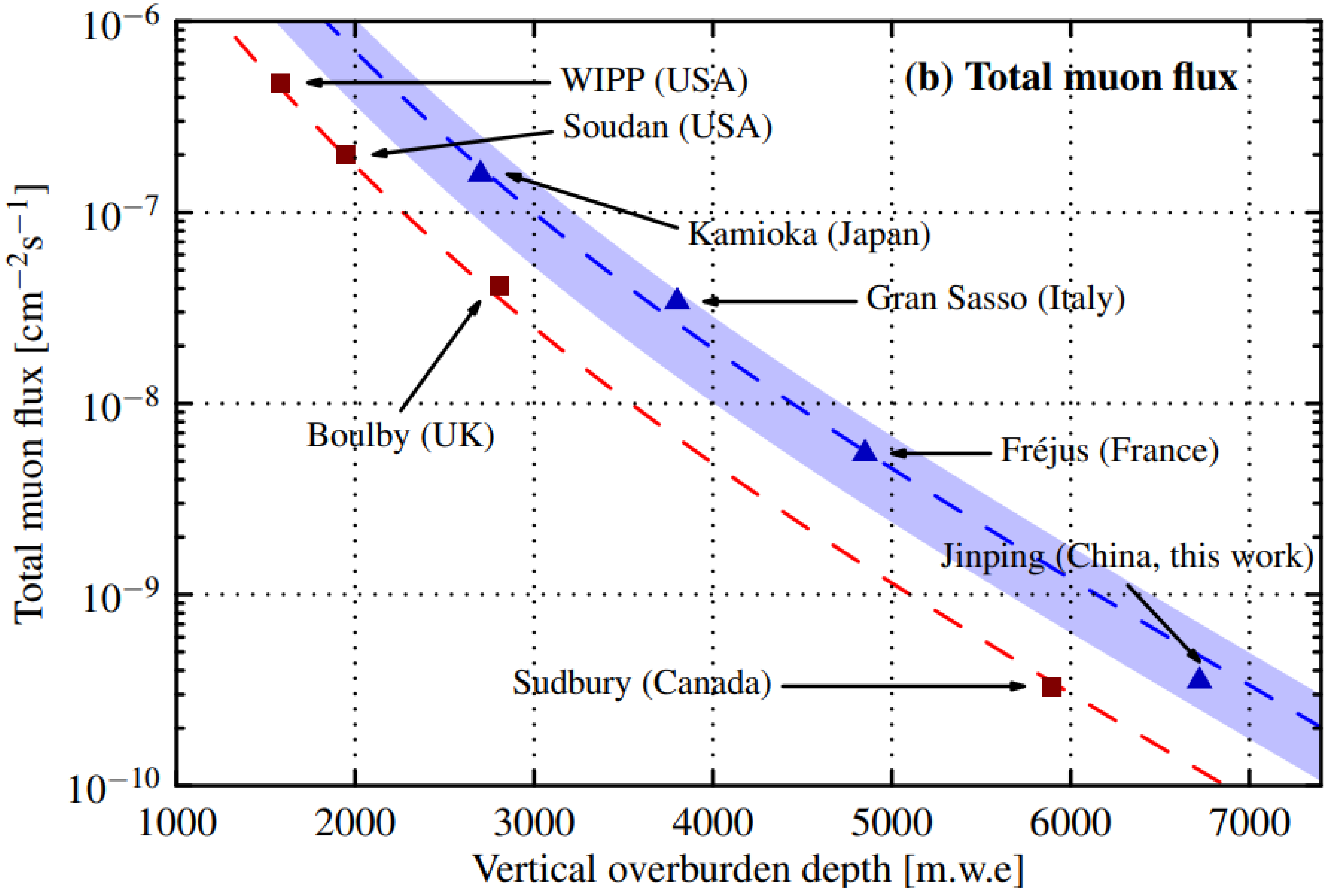



# SNOLAB

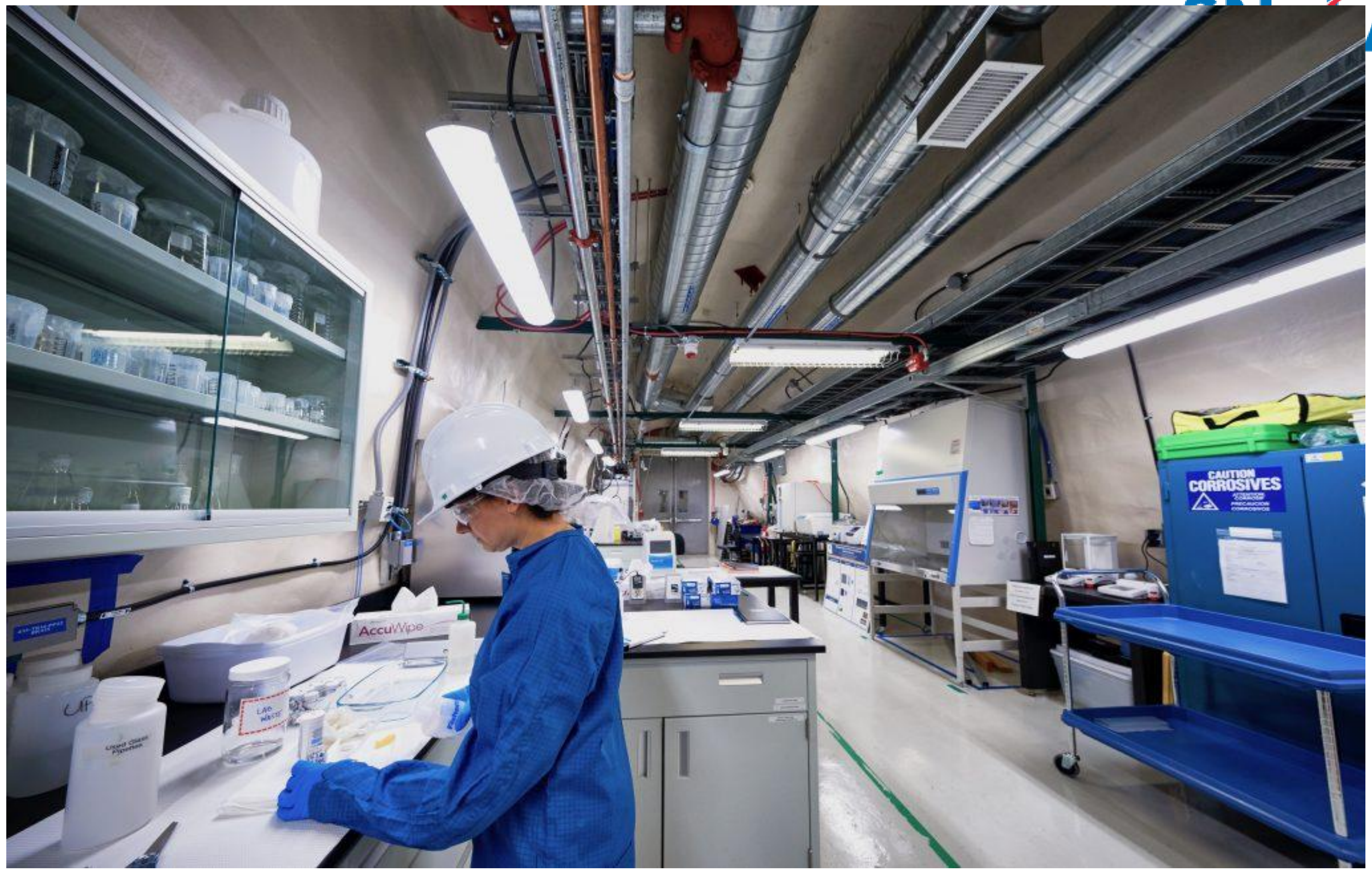
- SNOLAB is located at the Vale-Creighton mine just outside Sudbury
- On the traditional territory of the Robinson-Huron Treaty of 1850
- It is 2 km deep and operates as a class-2000 clean room
- Host to numerous particle physics experiments



# Advantage at SNOLAB




https://arxiv.org/pdf/2007.15925.pdf

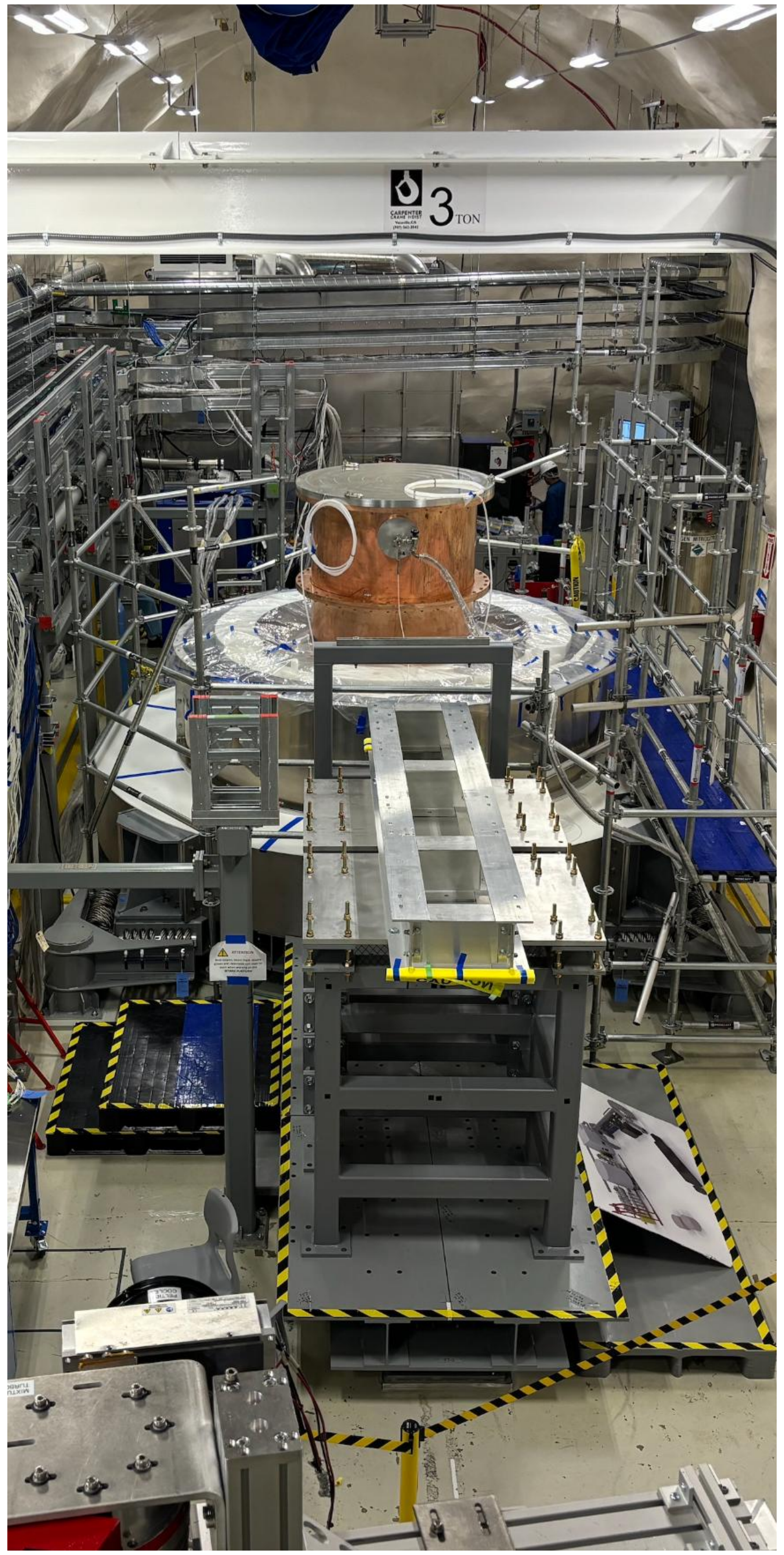



- One of the lowest muon flux in the world
- Class-2000 clean-room
- <2000 particle >0.5µm in diameter per cubic feet
- SuperCDMS additionally employs a class-100 cleanroom

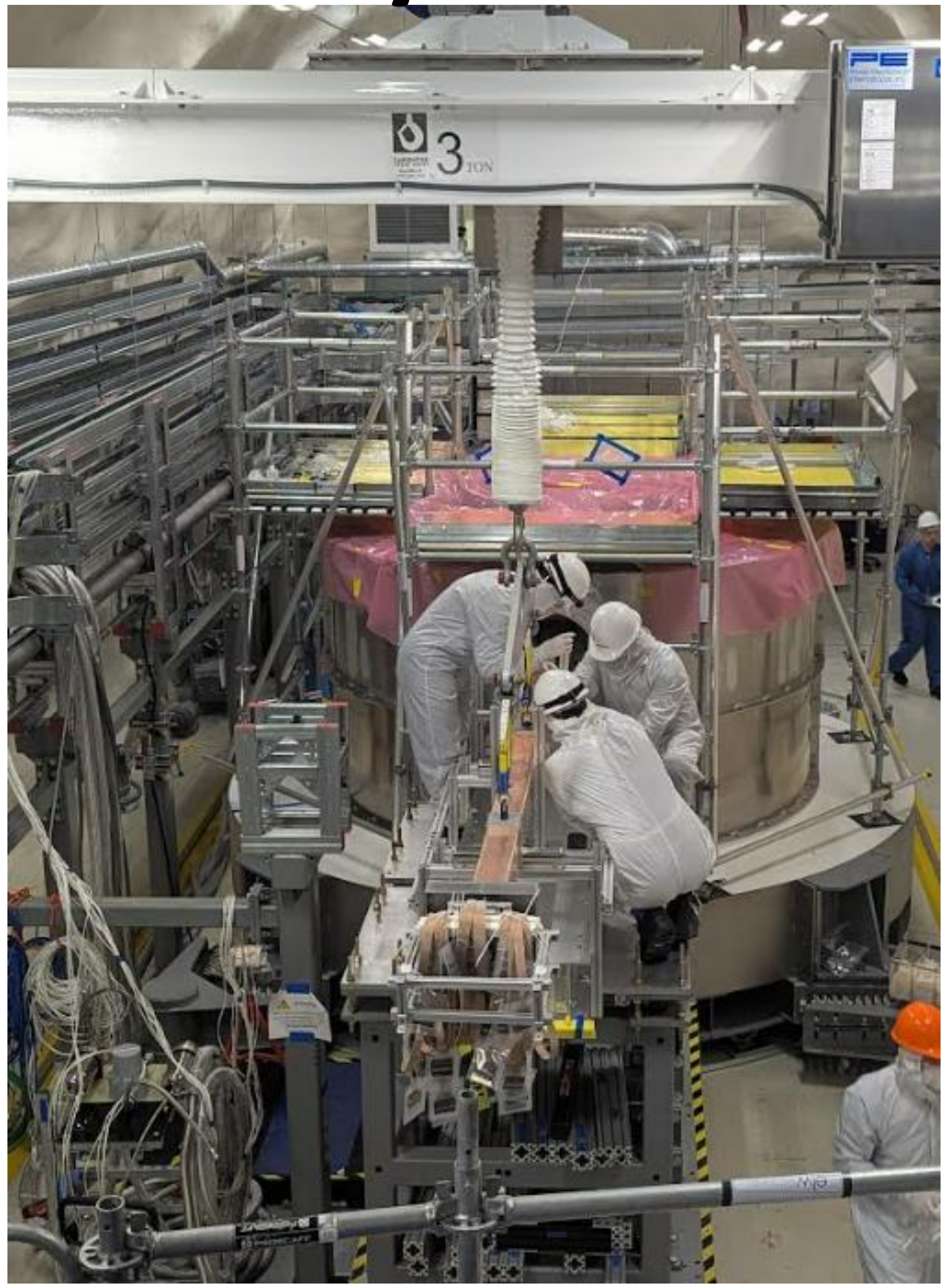
# Current Construction

2022

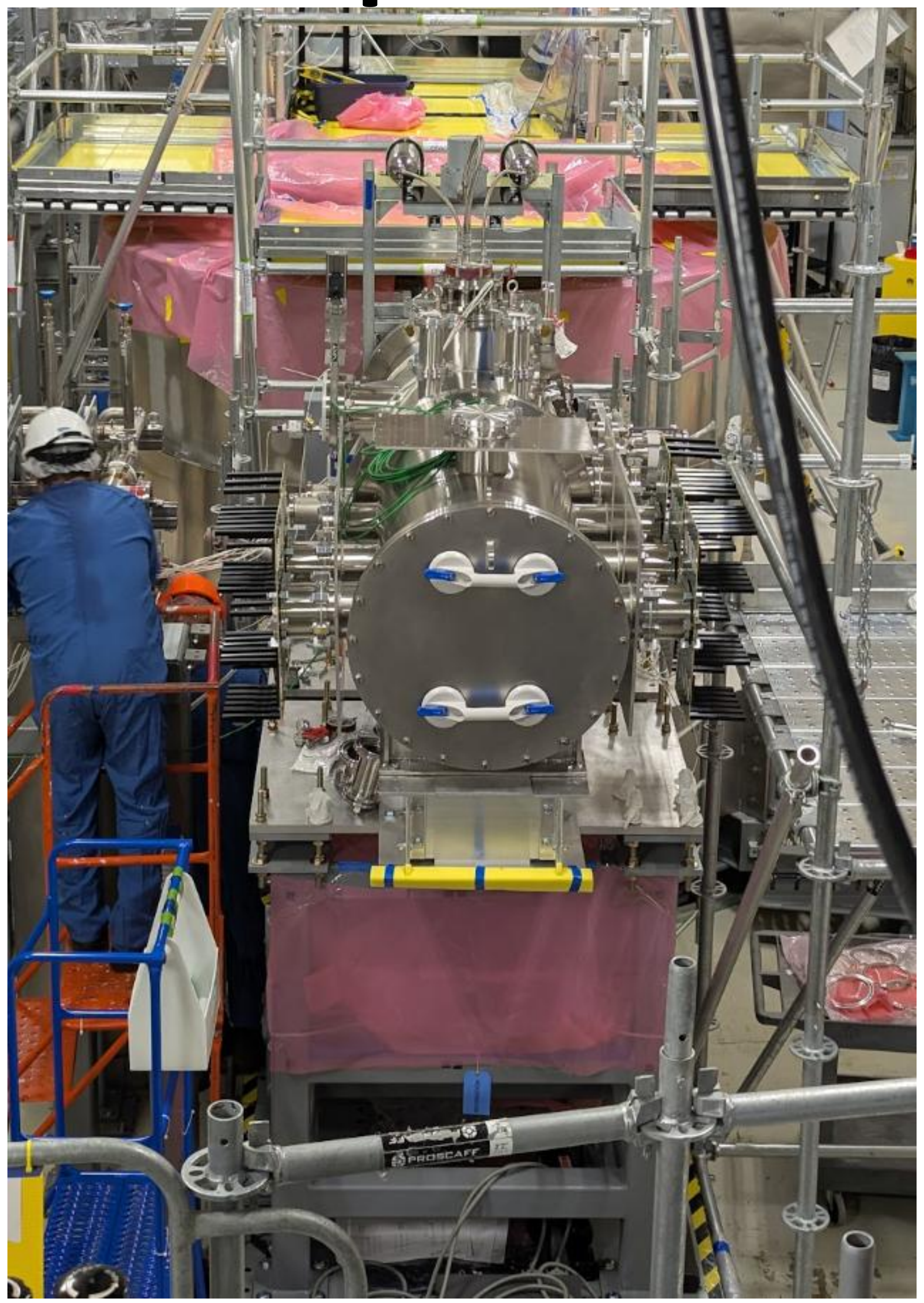
2024




May 2025

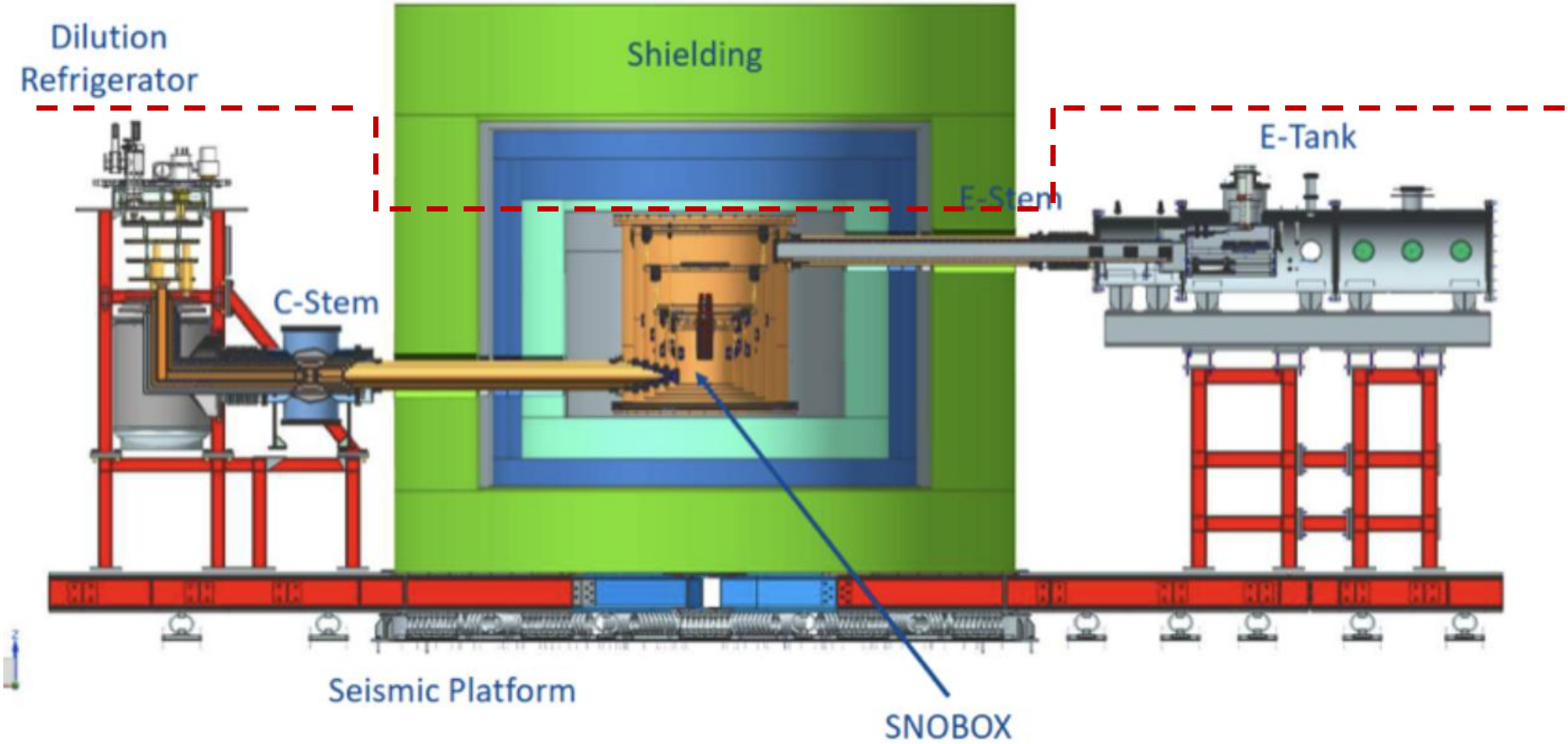



Sept. 2025

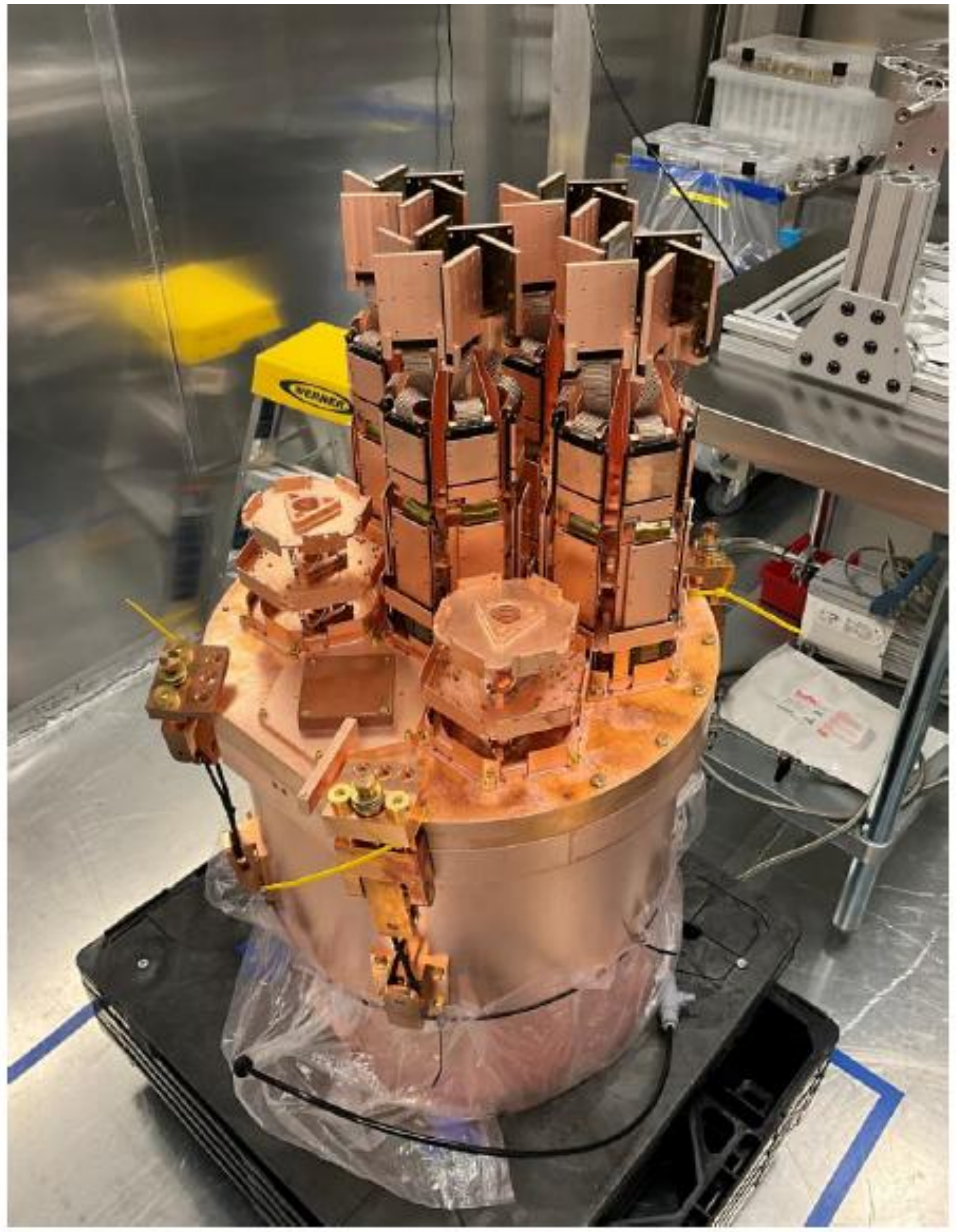


First cooldown and commissioning to begin this, Winter!!!

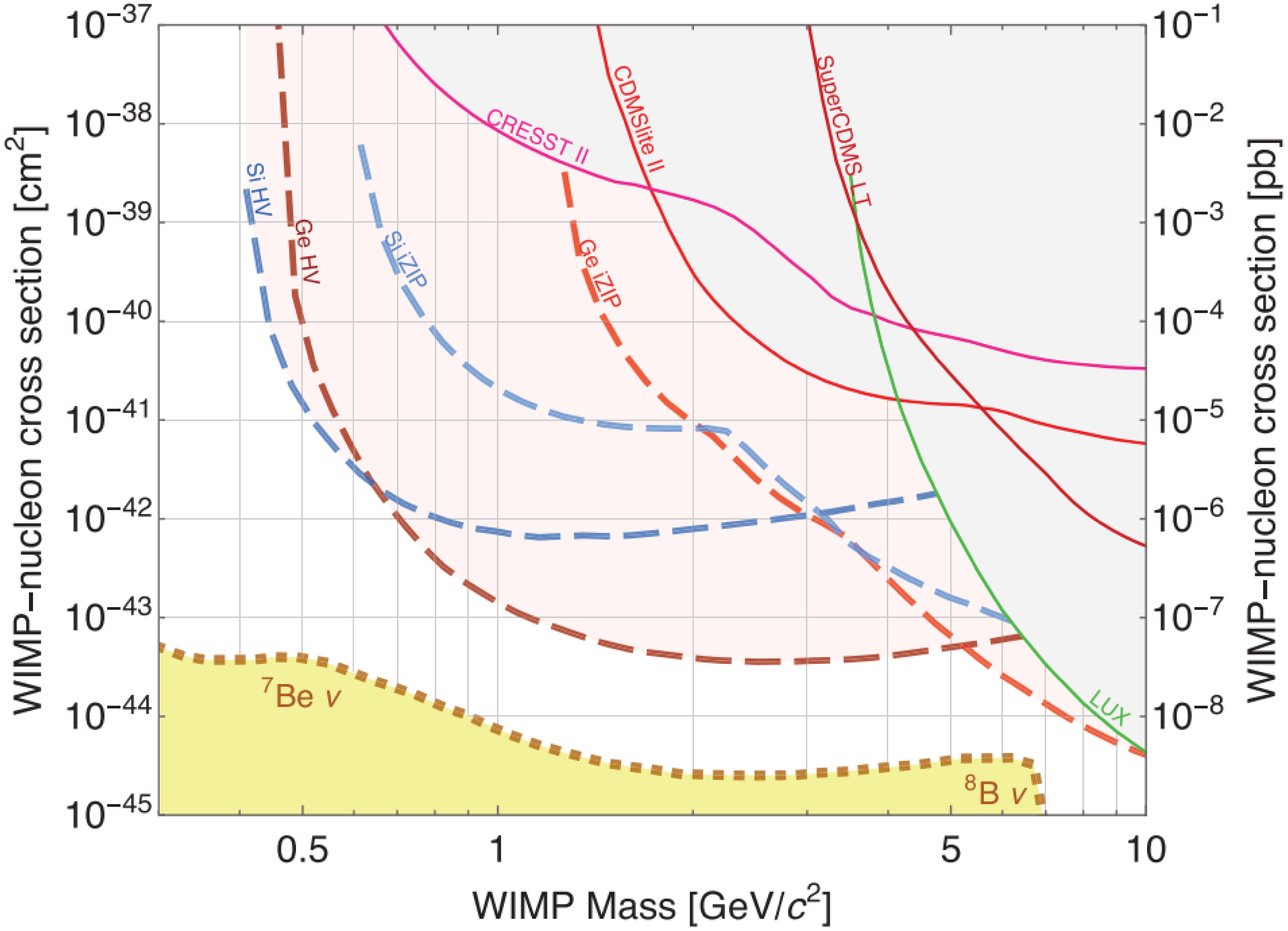
# SuperCDMS Experimental Setup



# Current Construction




# Dark Matter Sensitivity (4 year exposure)



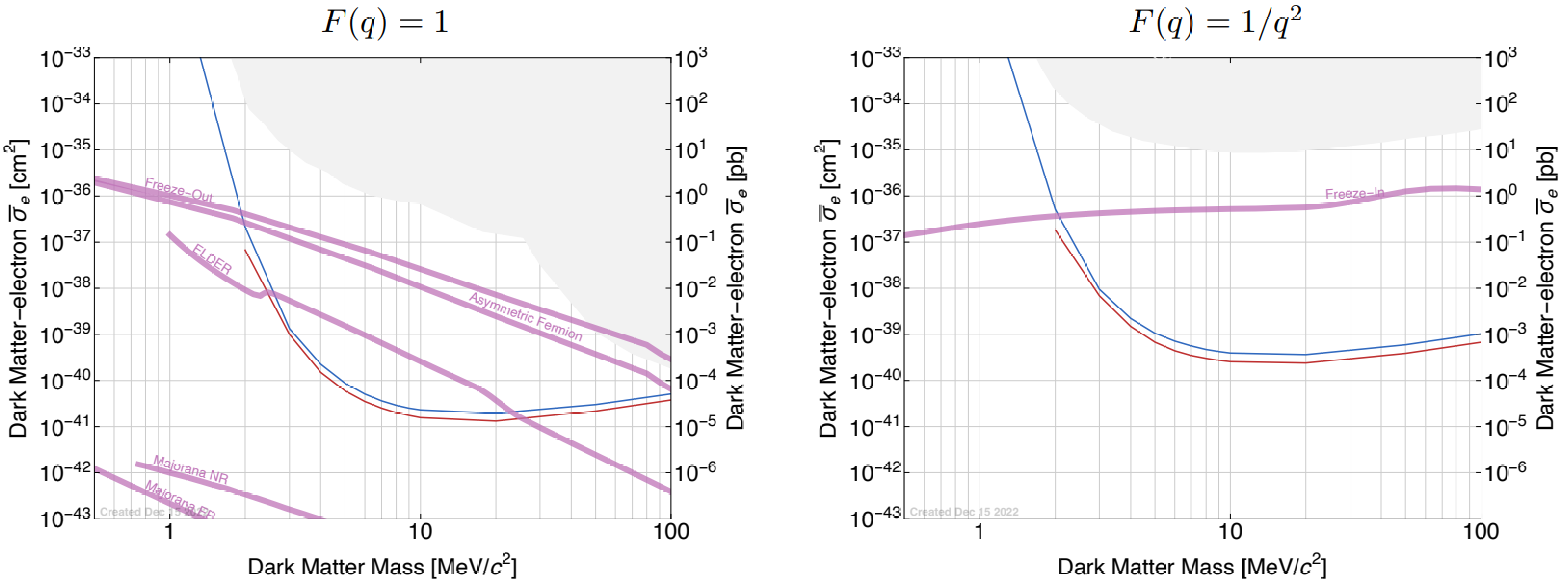

- 90% C.L exclusion sensitivity using the optimal interval method



https://doi.org/10.1103/PhysRevD.95.082002

# DM-electron scattering sensitivity

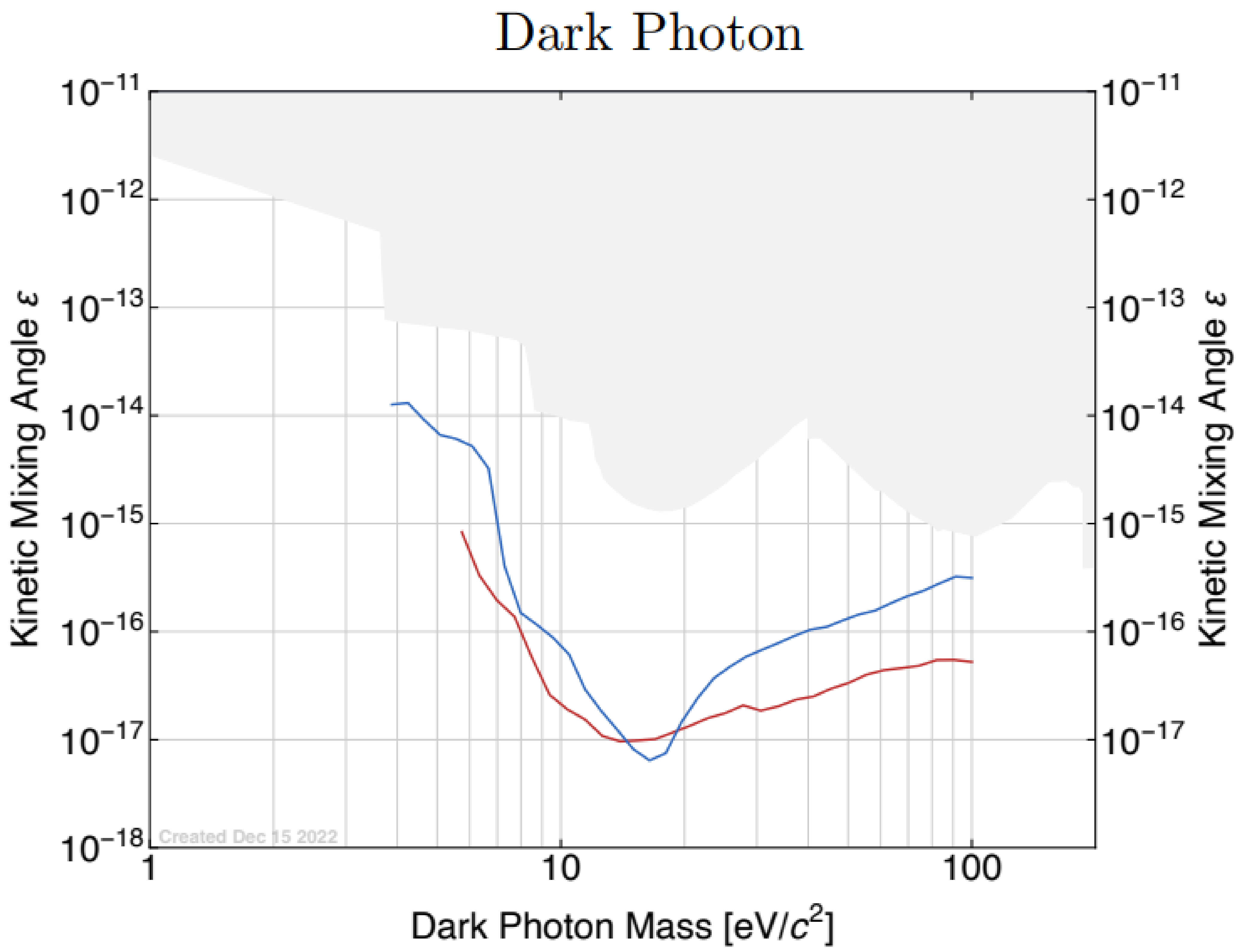
- SuperCDMS can probe electron scattering from photon coupled light DM (O(MeV)). Si = blue, Ge = Red

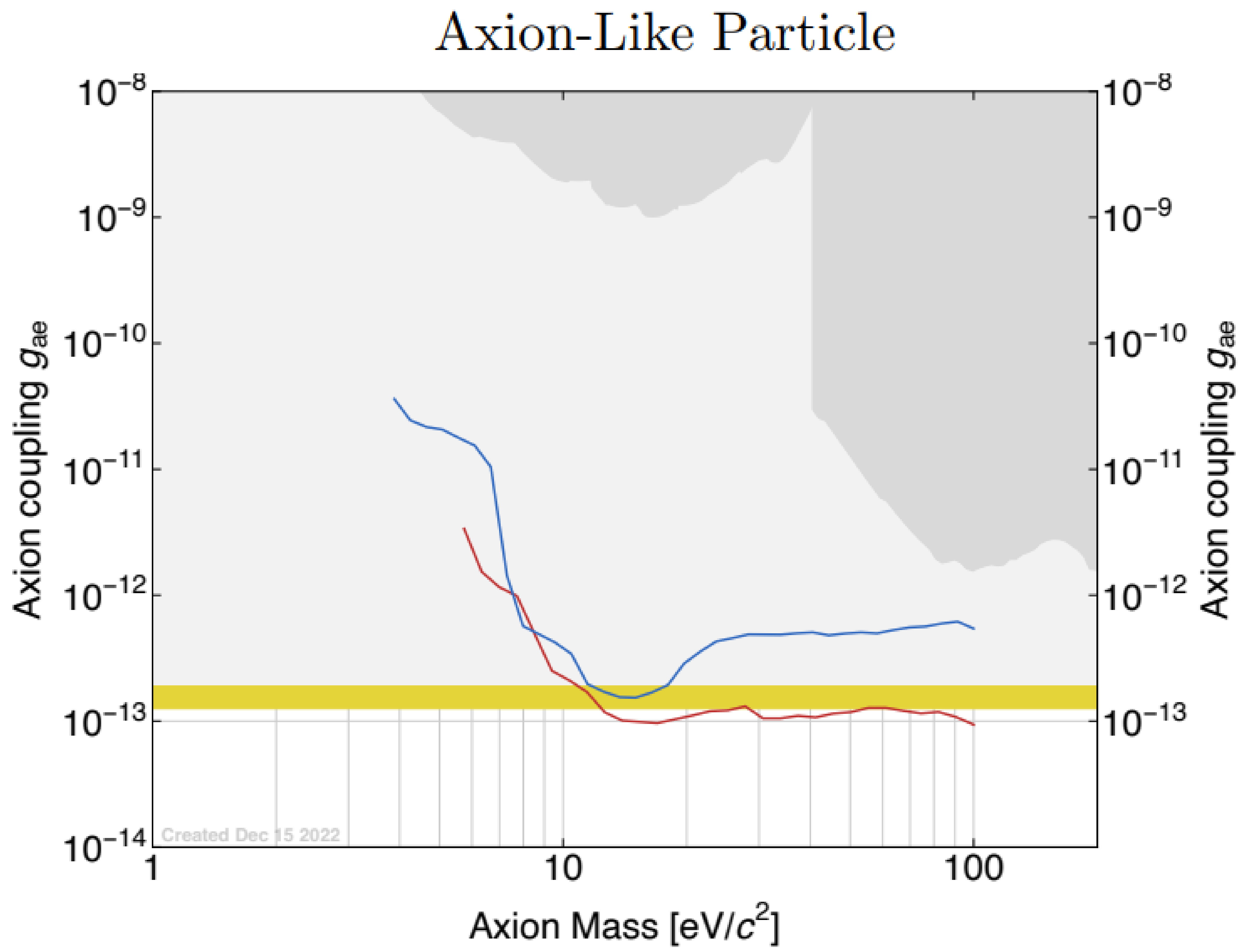



https://doi.org/10.48550/arXiv.2203.08463

# Absorption Sensitivity

- SuperCDMS can probe even further by looking for dark photon (O(eV)) absorption (peak) or axion-like particle absorption (O(eV)). Si = blue Ge = Red

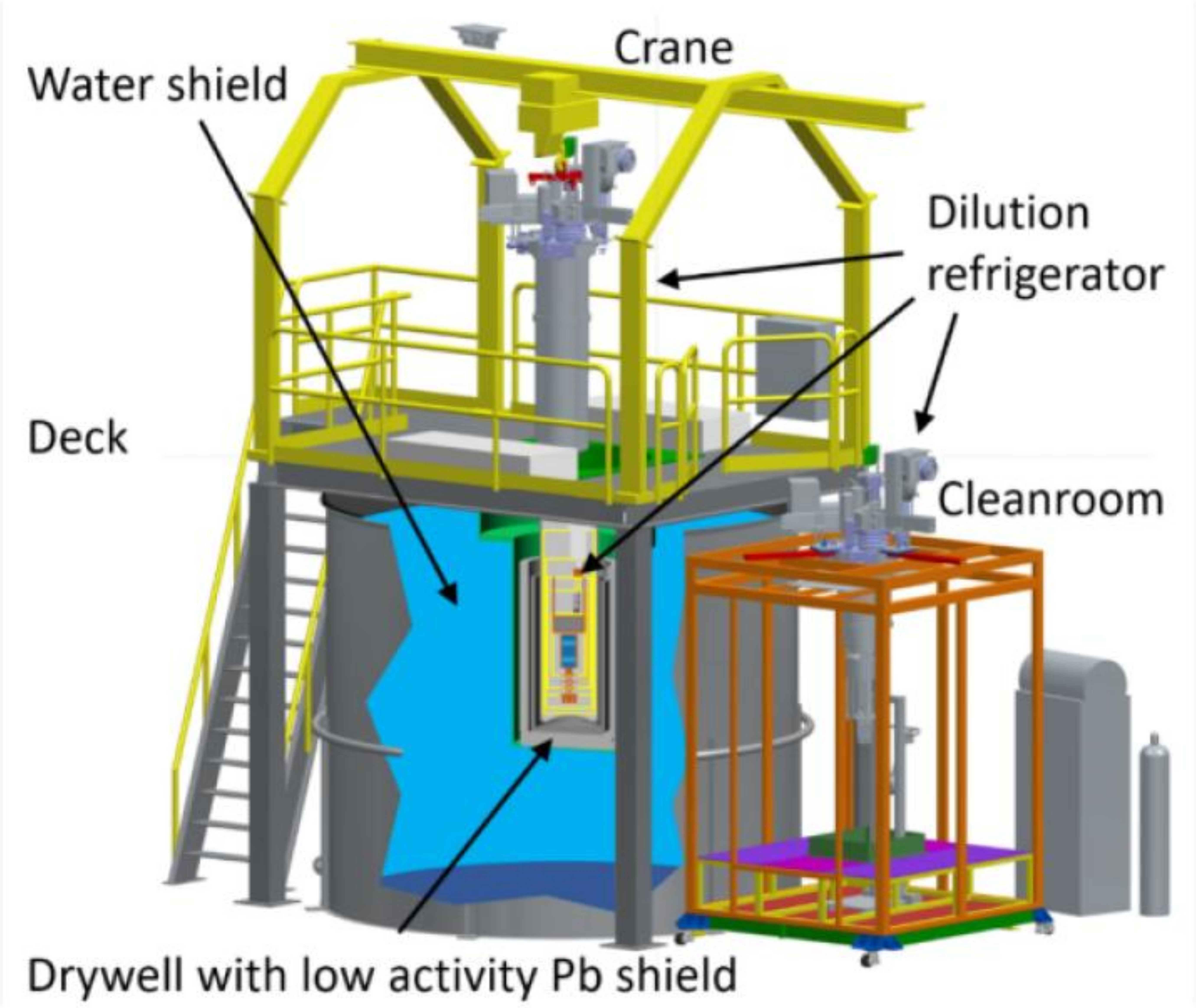



https://doi.org/10.48550/arXiv.2203.08463

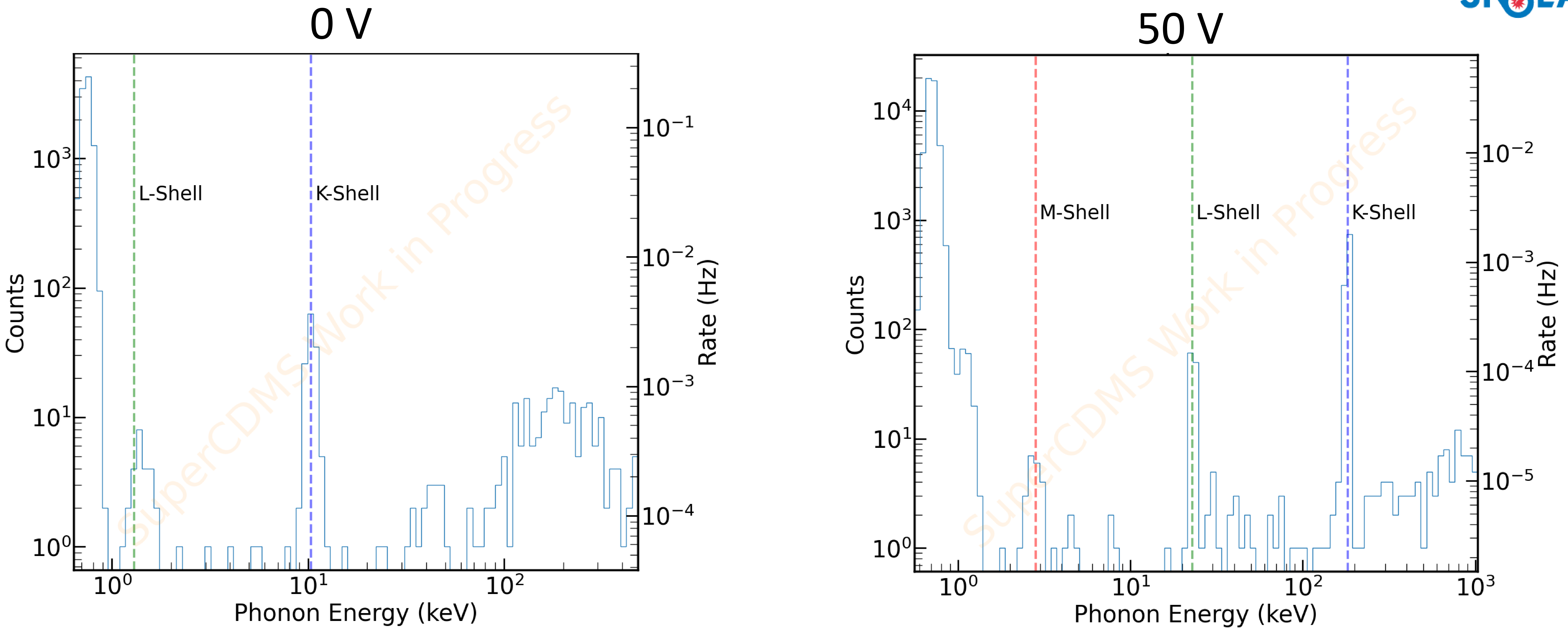
# SuperCDMS Detector Testing

# Testing at the CUTE Facility




- Cryogenic Underground TEsting Facility
- One full SuperCDMS HV tower (6 detectors) was placed into CUTE and operated for ~6 months
- Allowed for detector characterization (SQUIDs, Tc etc.),Noise modelling, calibration, Pulse shape characterization, data pipeline testing, HV operation and more

# Ge Detector Calibration I



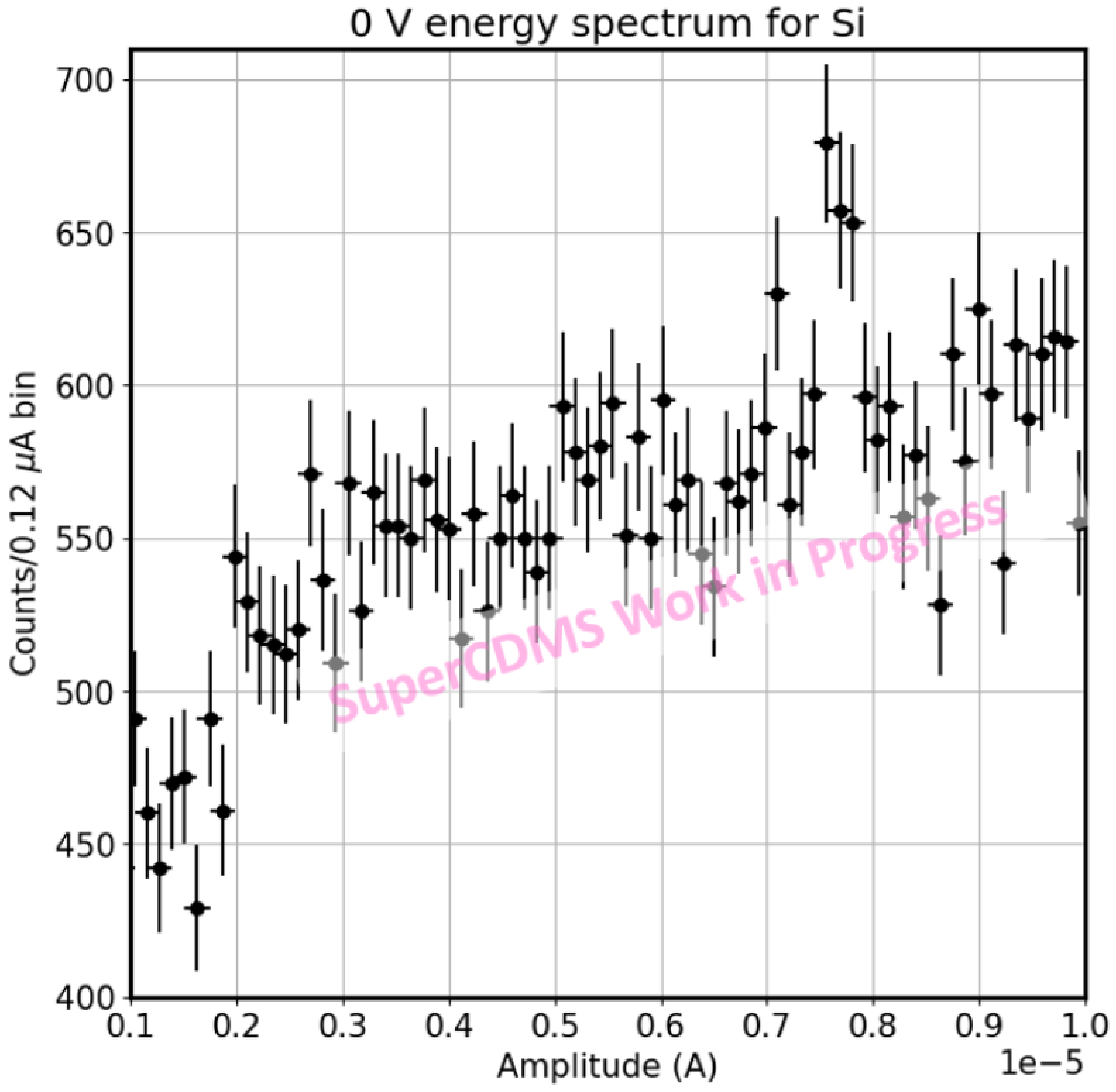

- Cf-252 neutron capture on Ge-70 -> leads to EC of Ge-71
- K-shell: 10.37 keV, L-Shell: 1.3 keV and M-shell: 0.16 keV

# Ge Detector Calibration II

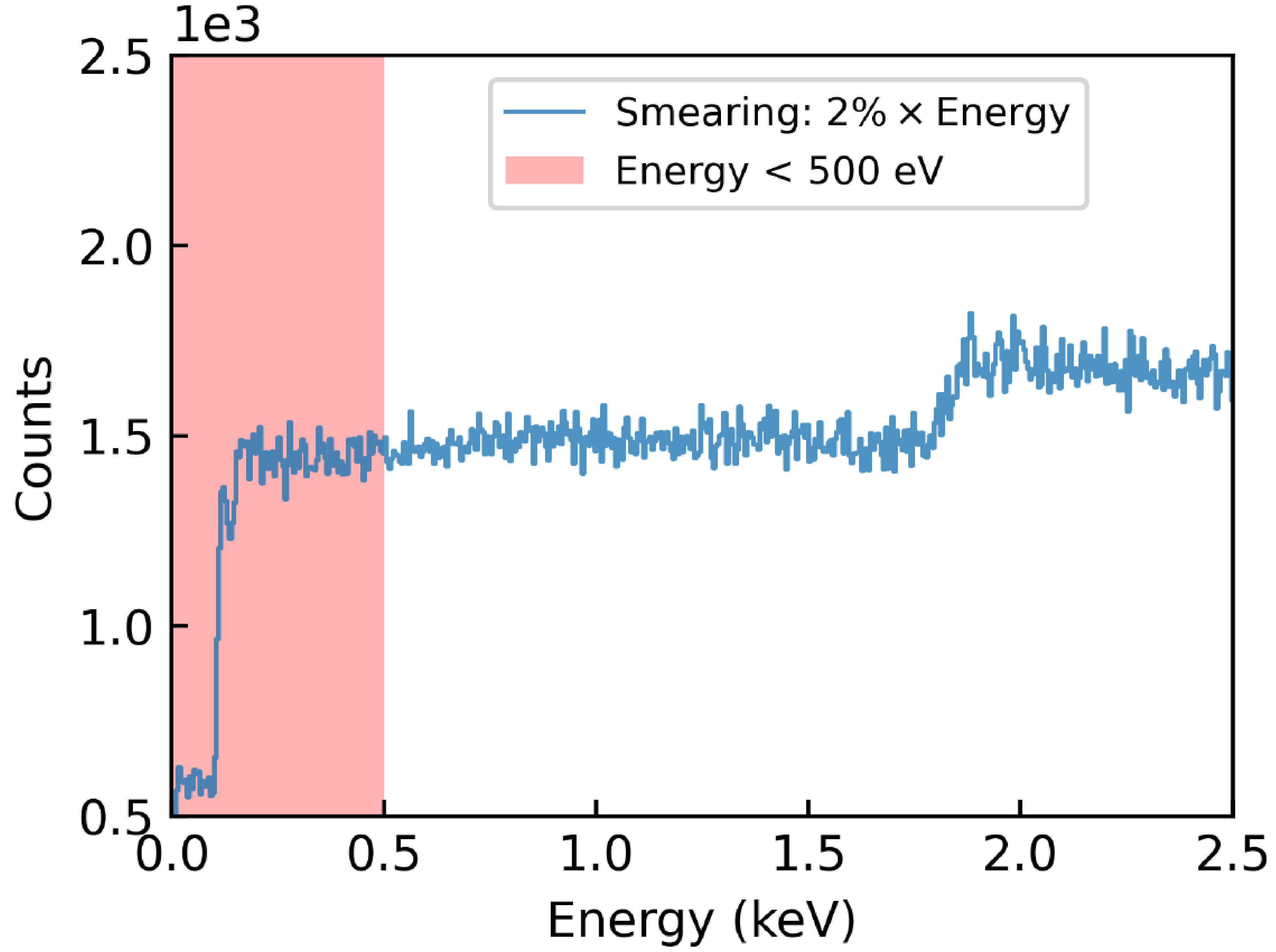
| Summary of the measured baseline resolutions in total phonon energy units; SuperCDMS Work in Progress Results | |
|---|---|
| **Detector/Voltage** | **Best Measured Baseline Resolution (eV)** |
| Z1@0V | 84.6 ± 0.7 |
| Z3@0V | 73.2 ± 1.0 |
| Z6@0V | 307.7 ± 13.0 |

- Z1 and Z3 are in-line with expected SNOLAB performance
- Improvements expected when operated in final setup
- Z6 is underperforming and not representative of SNOLAB detectors

# Si Detector Calibration



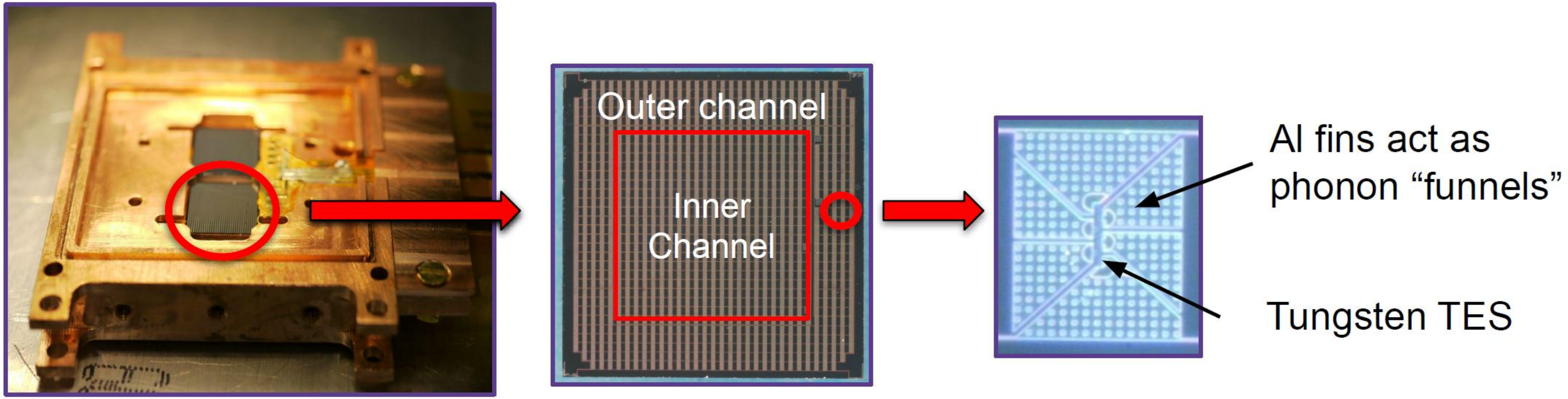

- Compton scattering will produce visible “steps” at K, L and M shell energy levels
- K-Shell: 1.8 keV
- Cu fluorescence peak ~8.1 keV




https://arxiv.org/abs/2508.02402

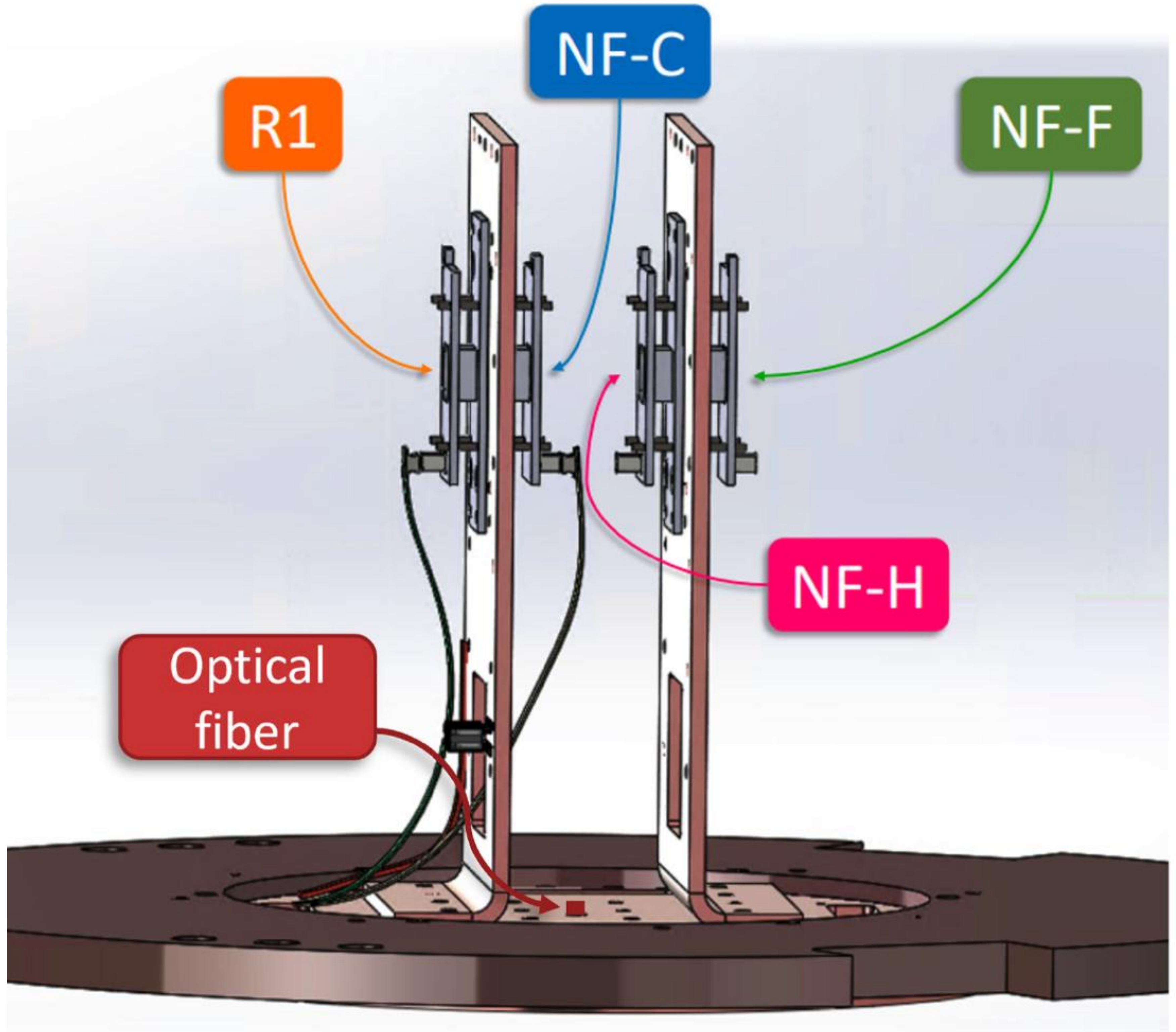
# SuperCDMS HVeV Program

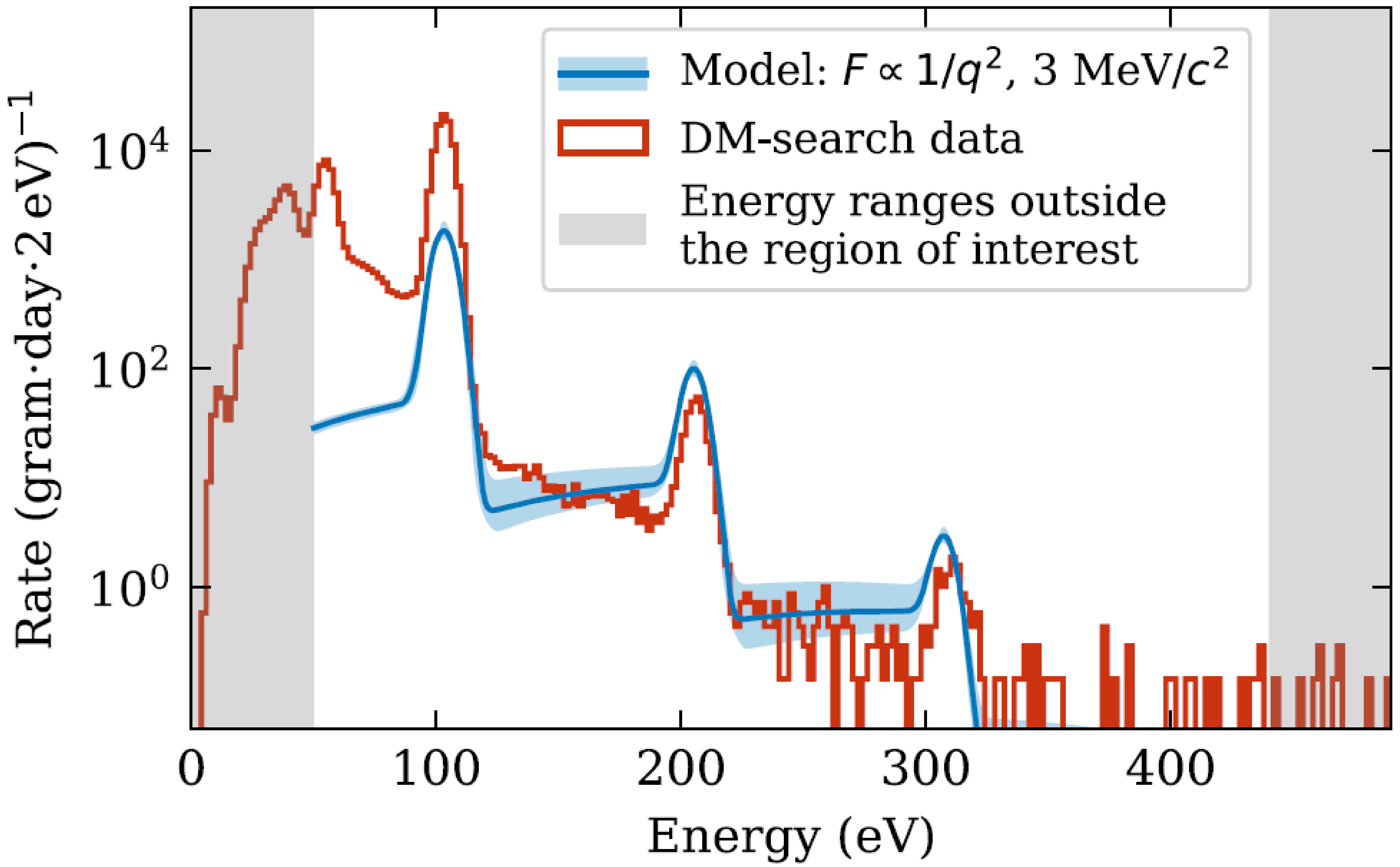
# SuperCDMS- HVeV Program




- Gram-scale detectors aimed at achieving eV energy resolution
- Si: 10x10x4 $mm^3$
- Two channels (inner and outer), similar technology to SuperCDMS detectors
- Background studies, Low-mass dark matter searches

# HVeV Run-3

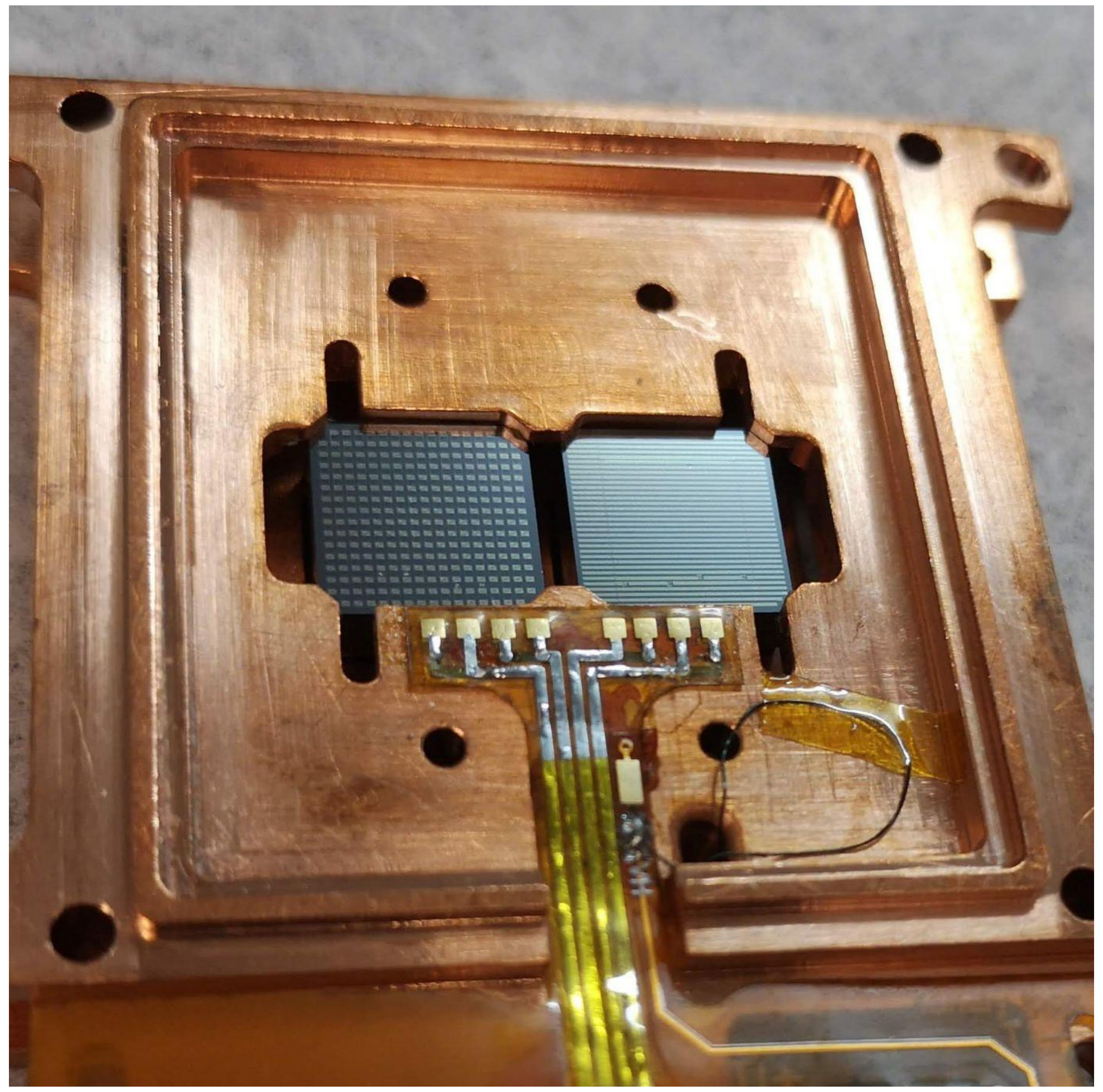


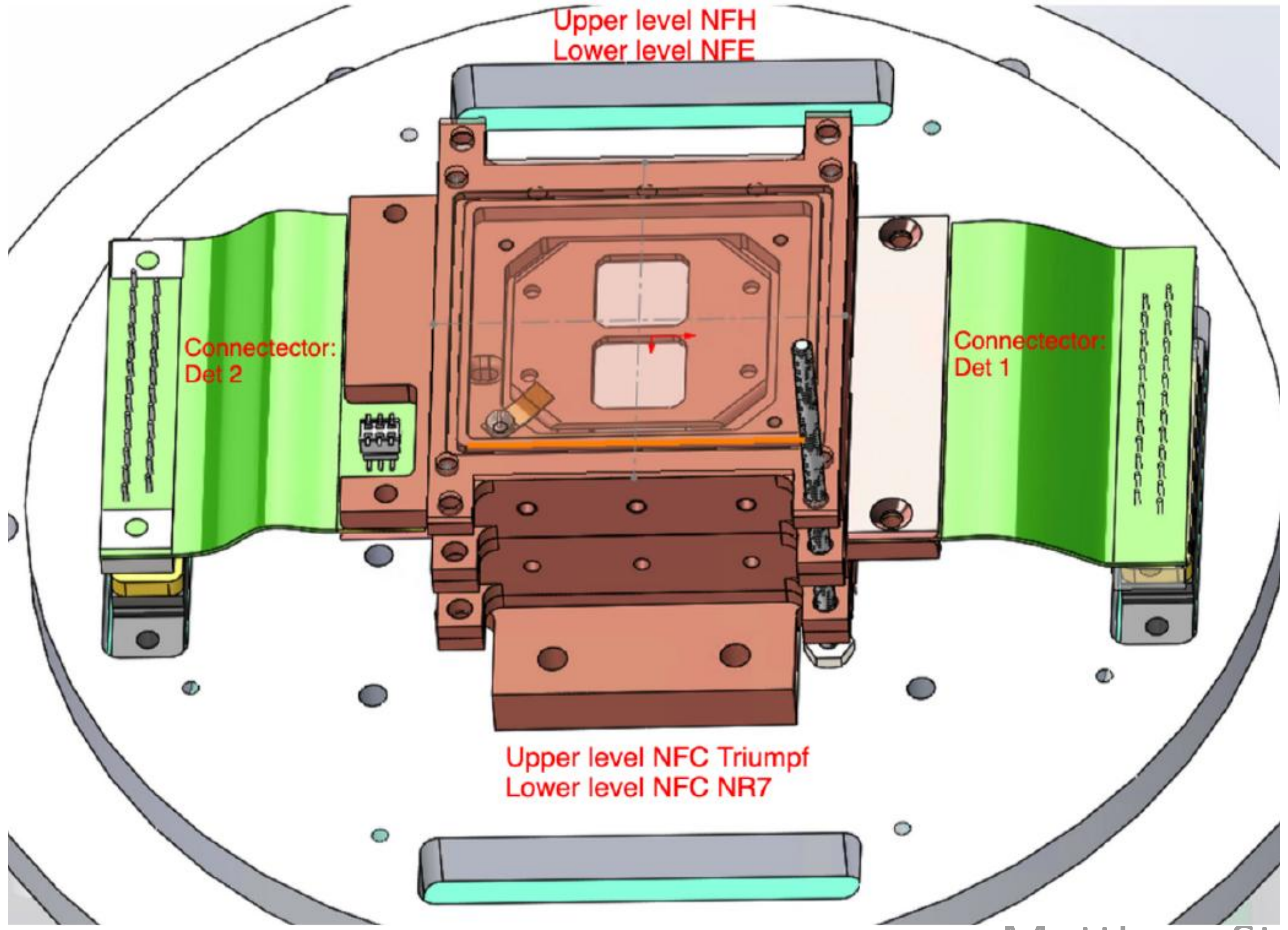



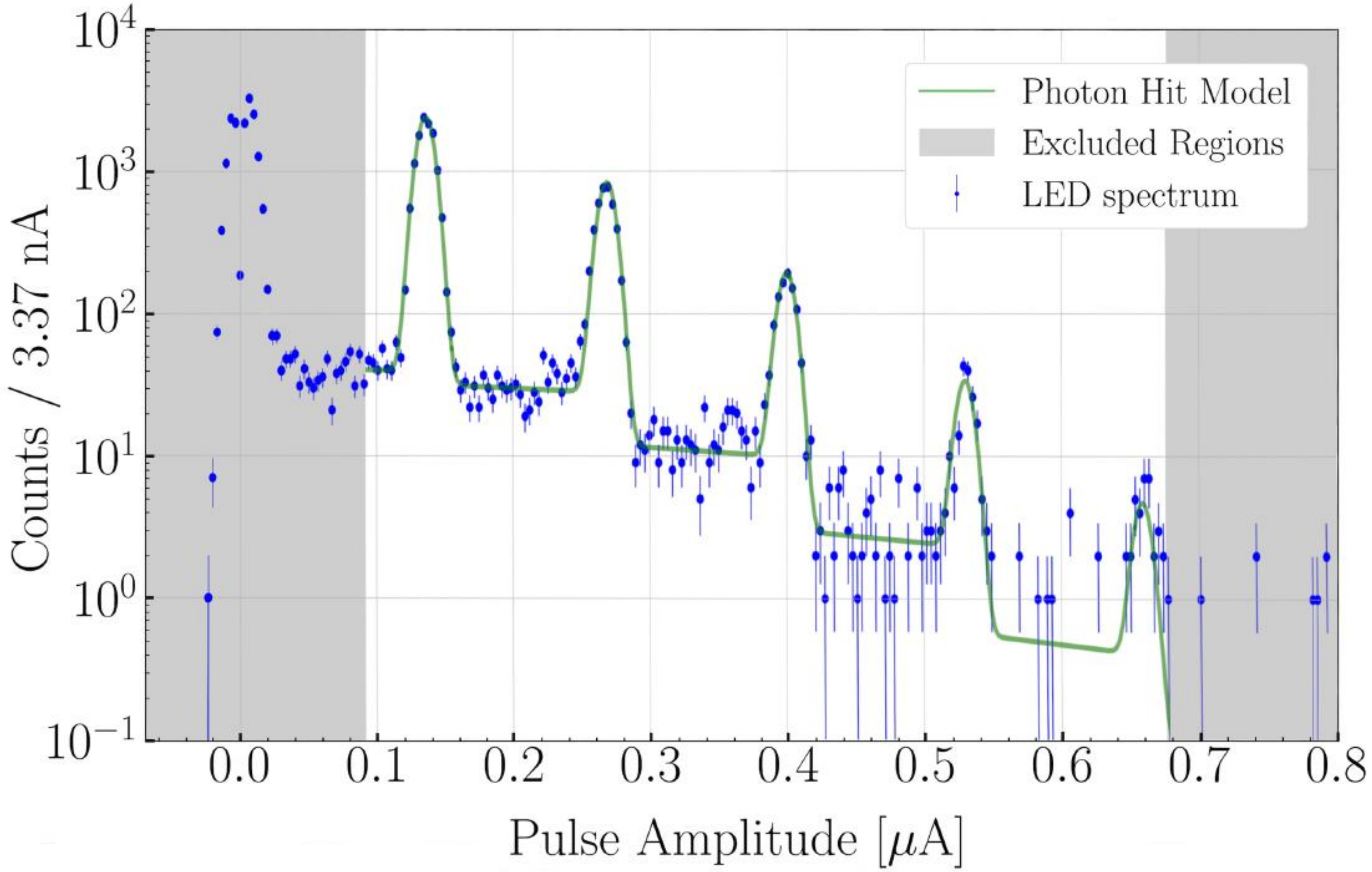

- First underground Dark Matter search using the NEXUS facility
- Achieved a 3.03 eV baseline resolution, w/ 100V applied
- Optical fiber allows for detector calibration
- Burst events present in data due to luminescence of the PCB

https://doi.org/10.1103/PhysRevD.111.012006

# HVeV Run-4



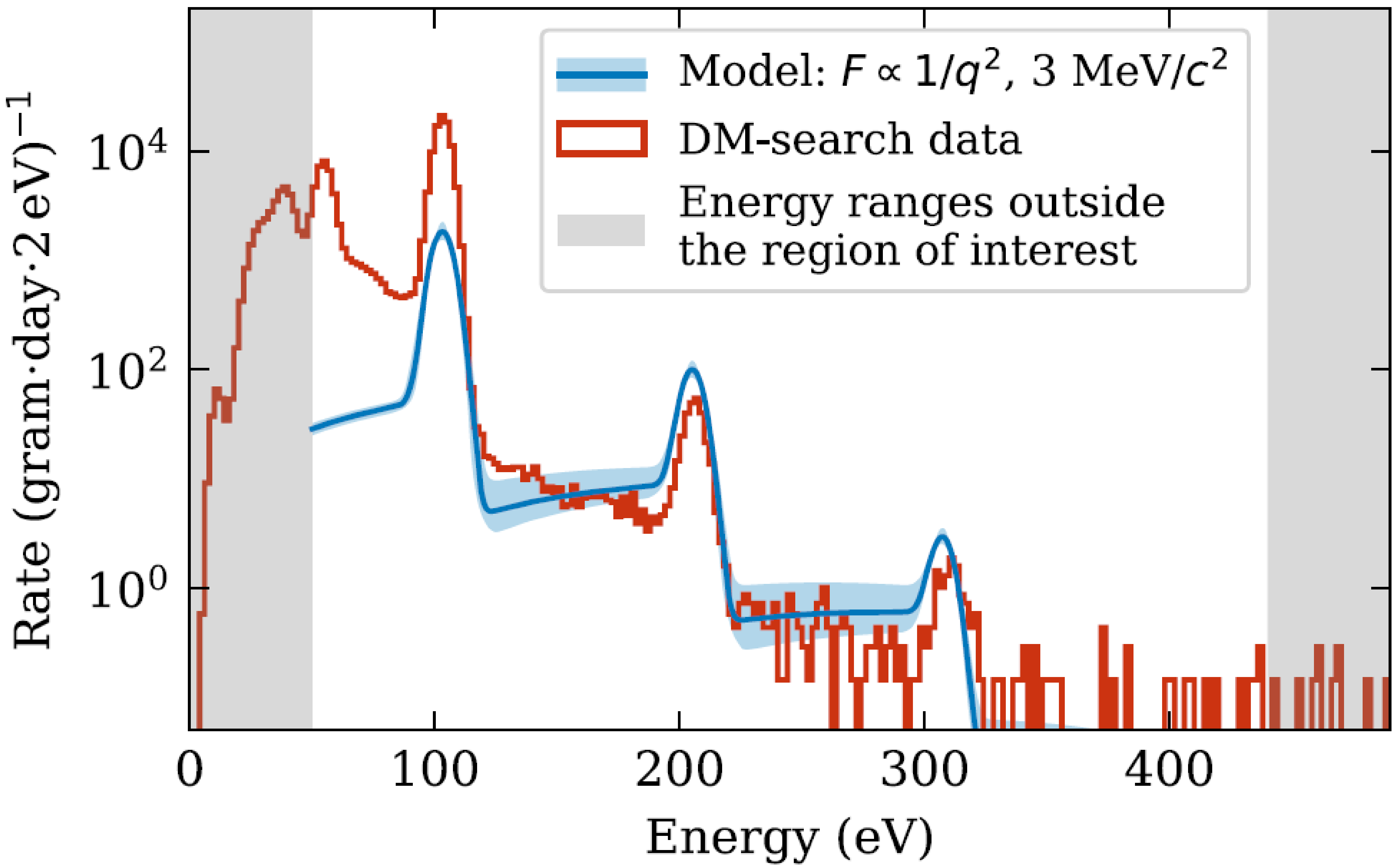


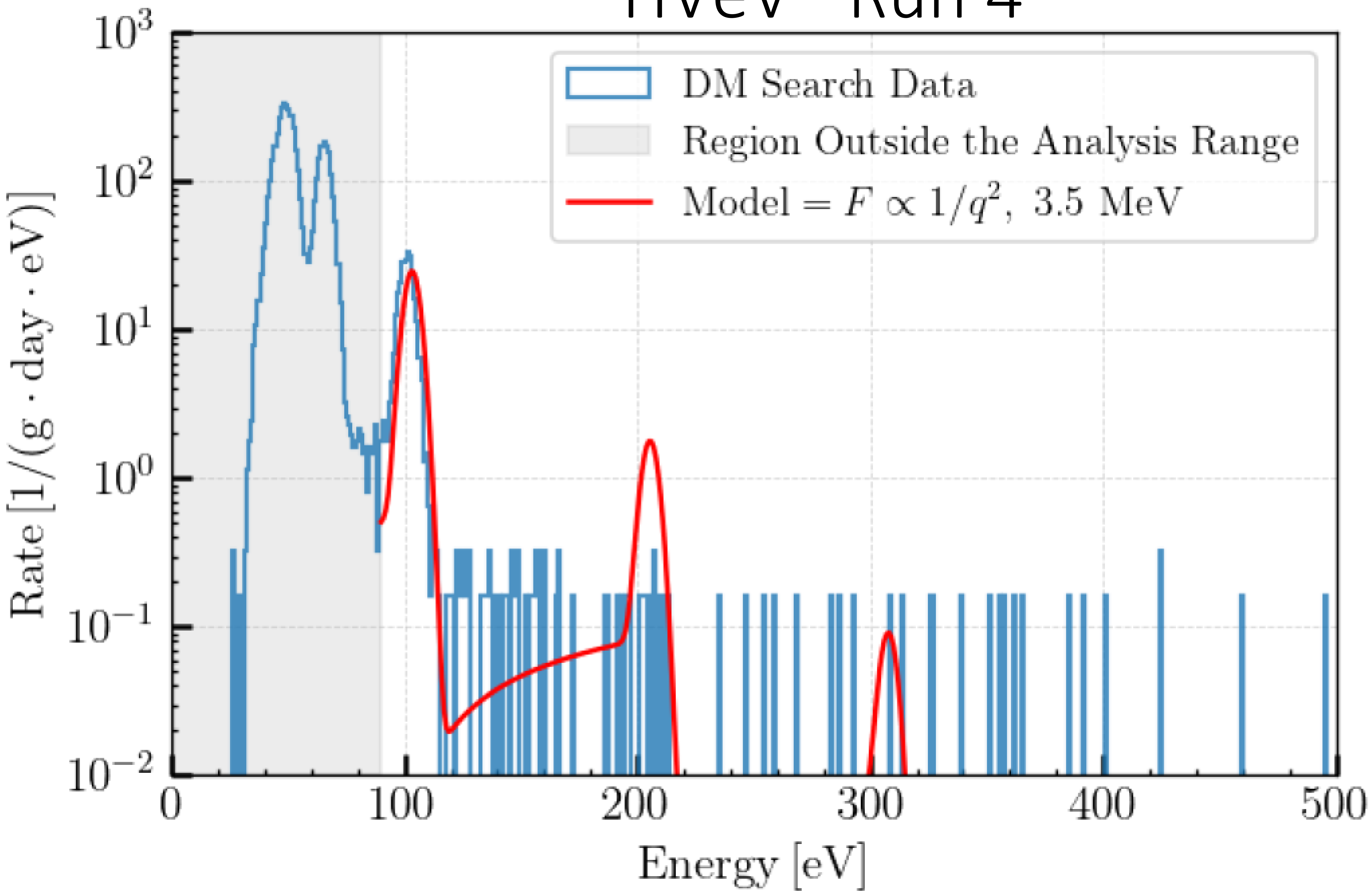

- Improved light-tight copper housing with individual LED for each detector
- Baseline Resolution: **3.2 +/- 0.1 eV**
- https://doi.org/10.48550/arXiv.2509.03608

# HVeV Run-4: Comparison

HVeV –Run 3

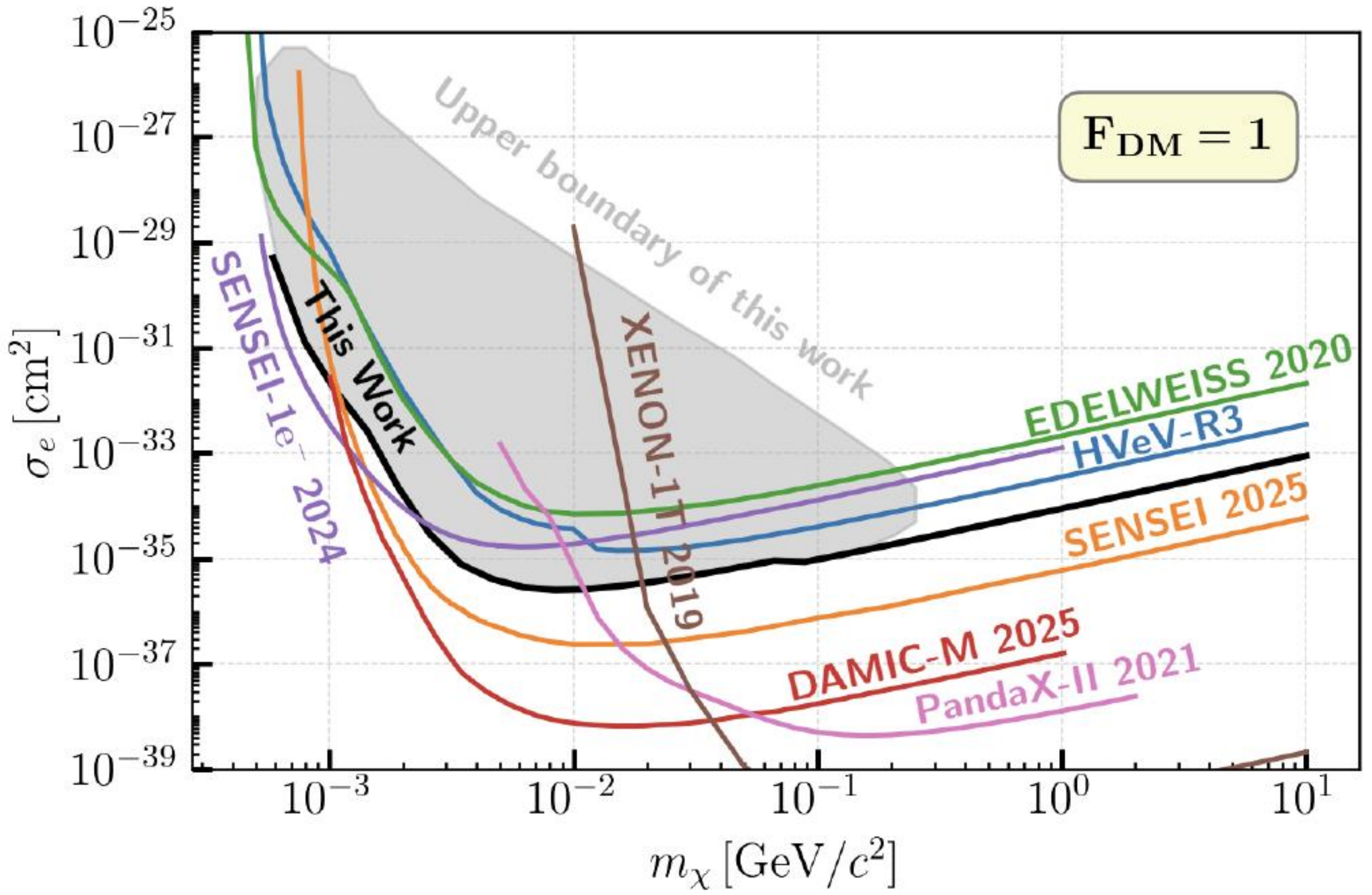


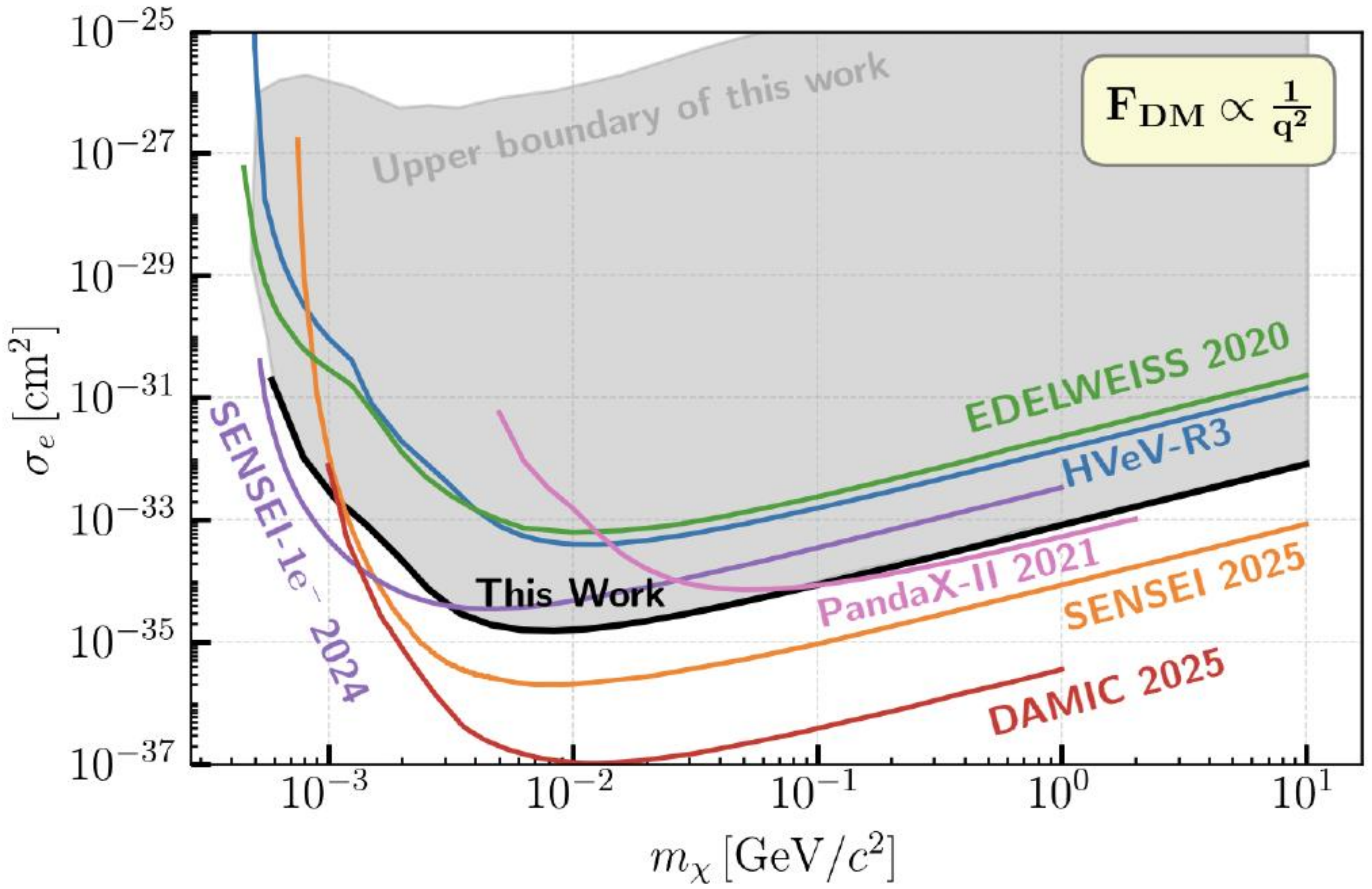

HVeV –Run 4

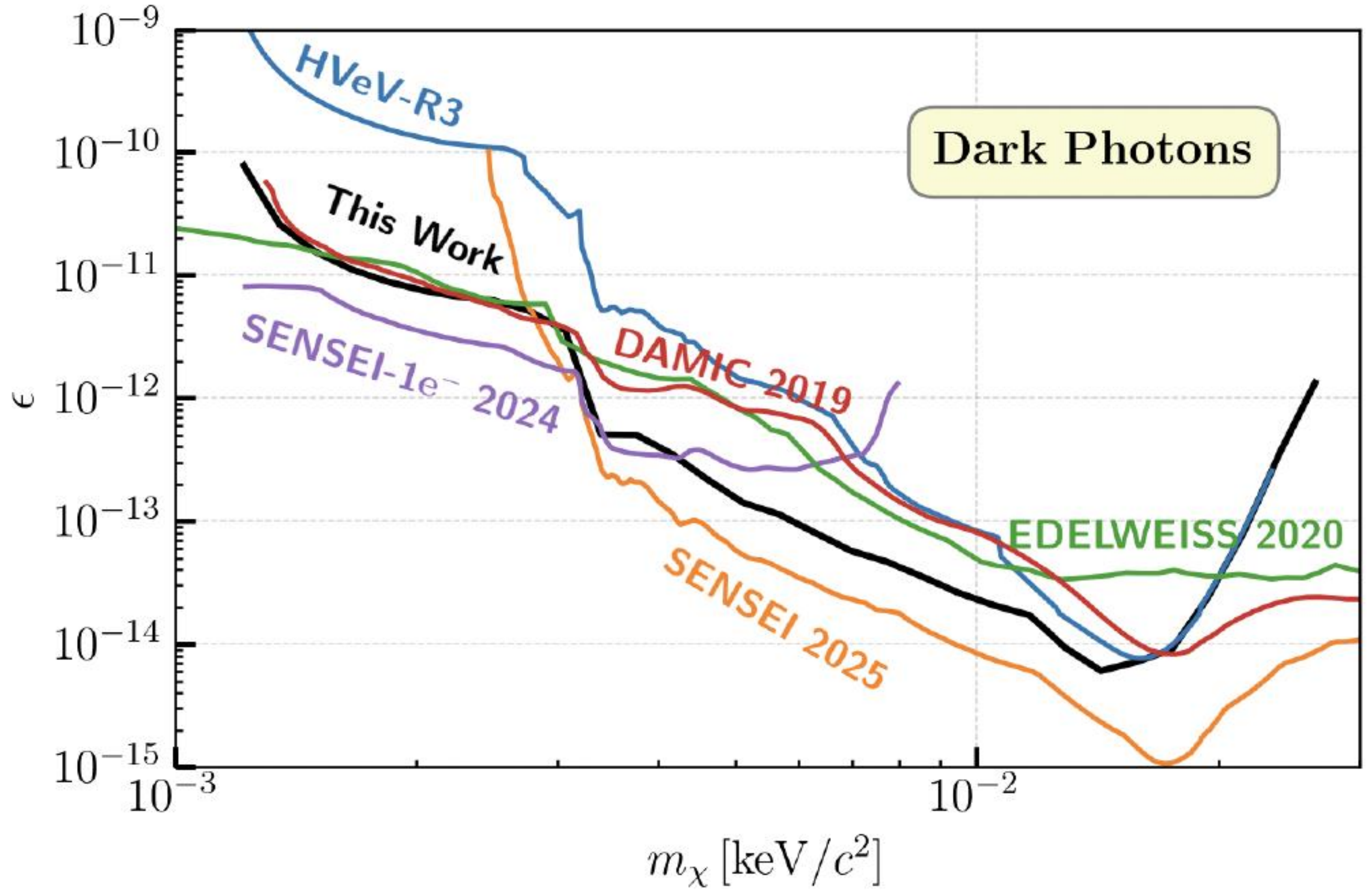


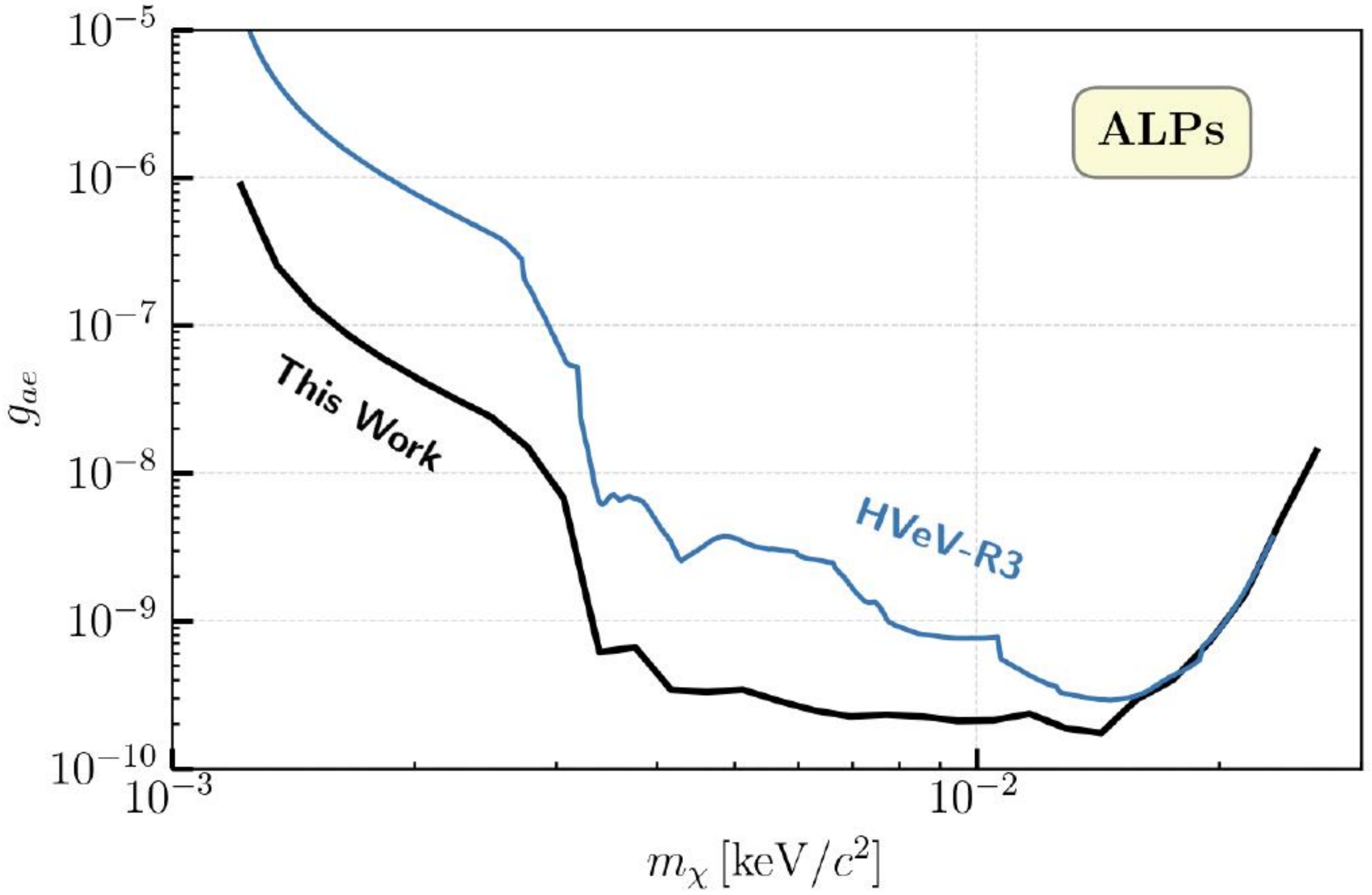

- Significant improvement in the background energy spectrum at the 2 and 3 eh level

# HVeV Run-4: Results

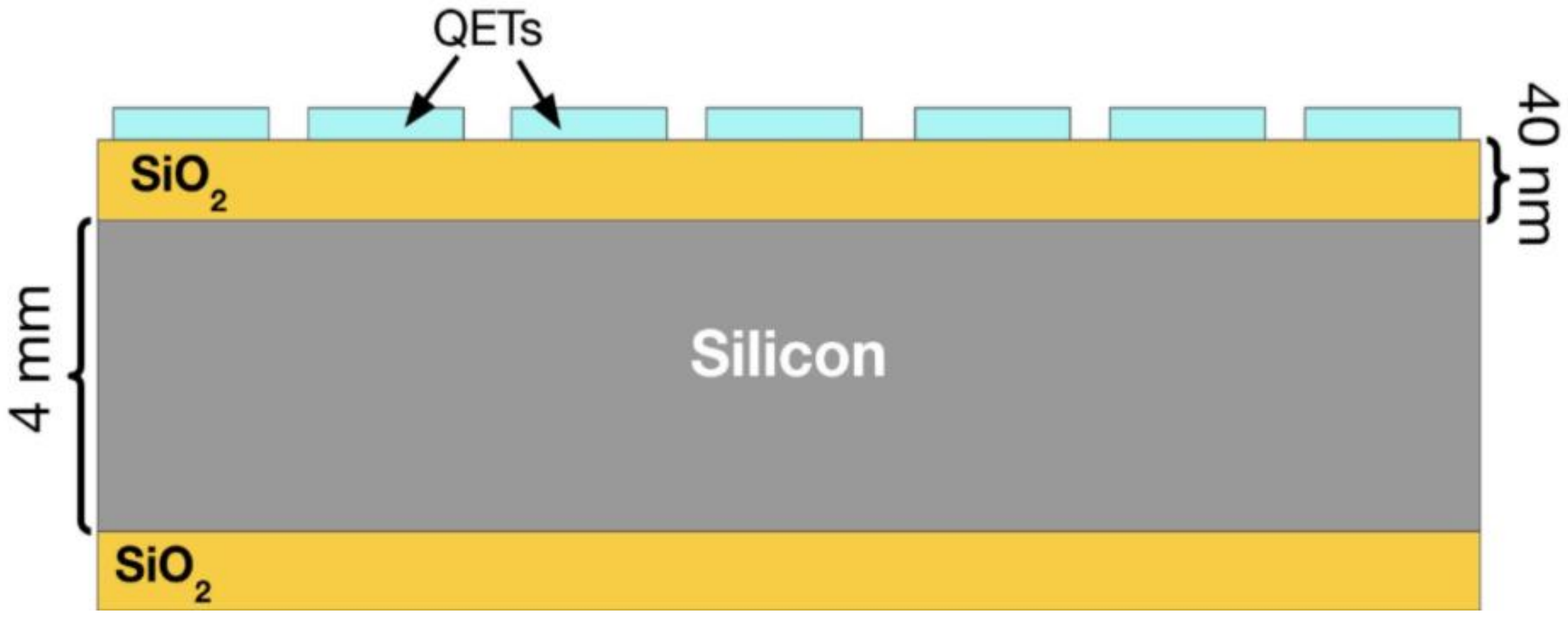


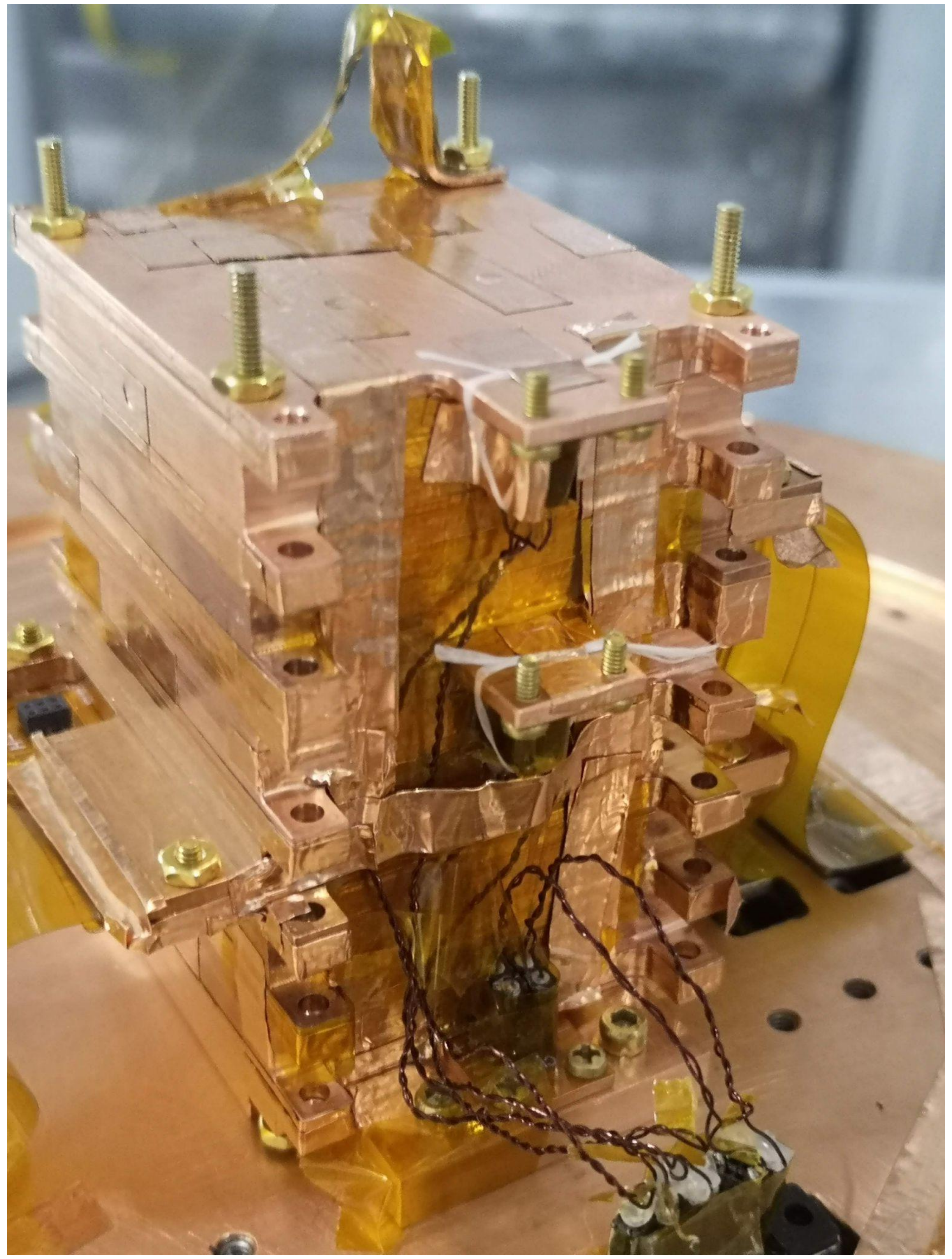



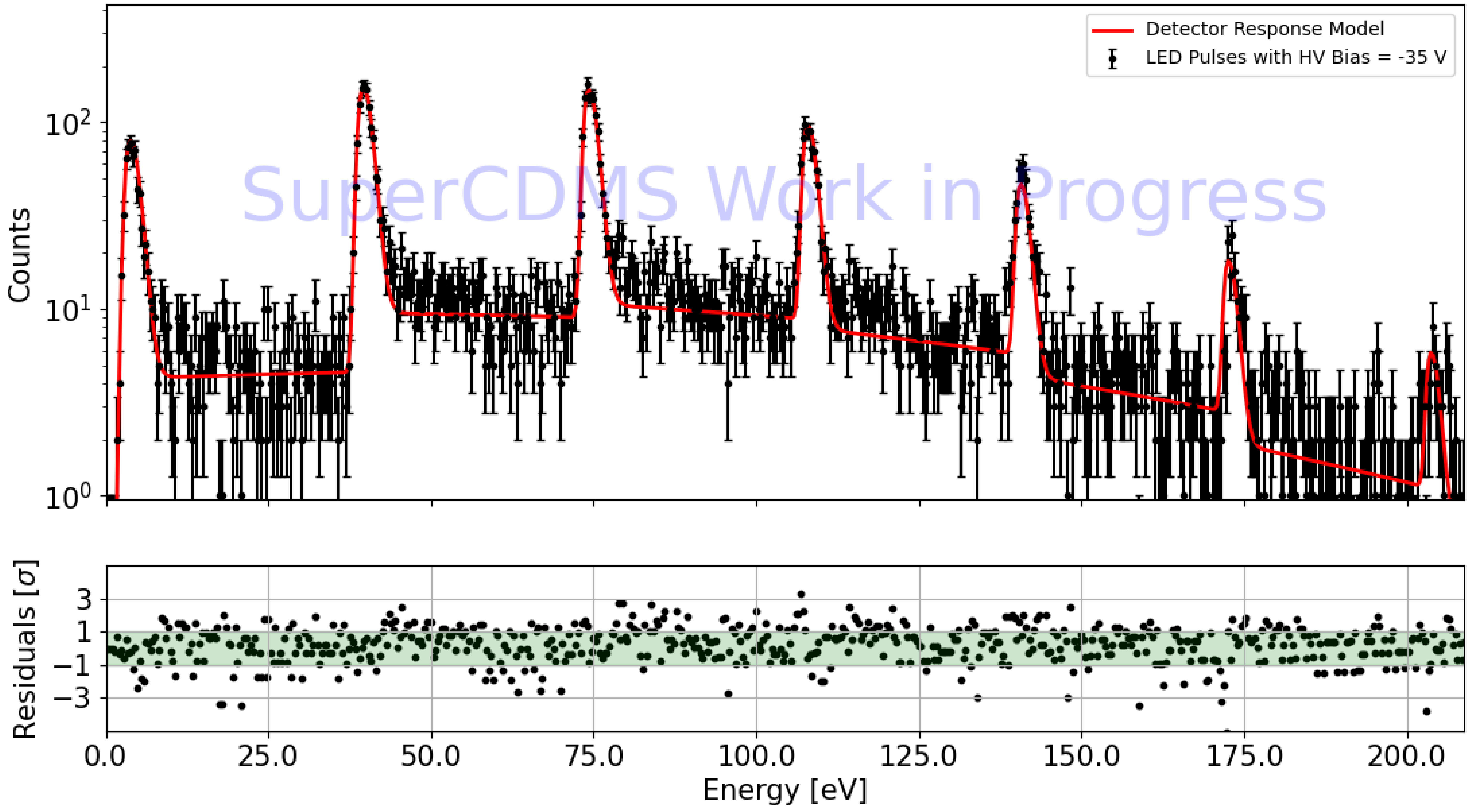
# HVeV-Run 5

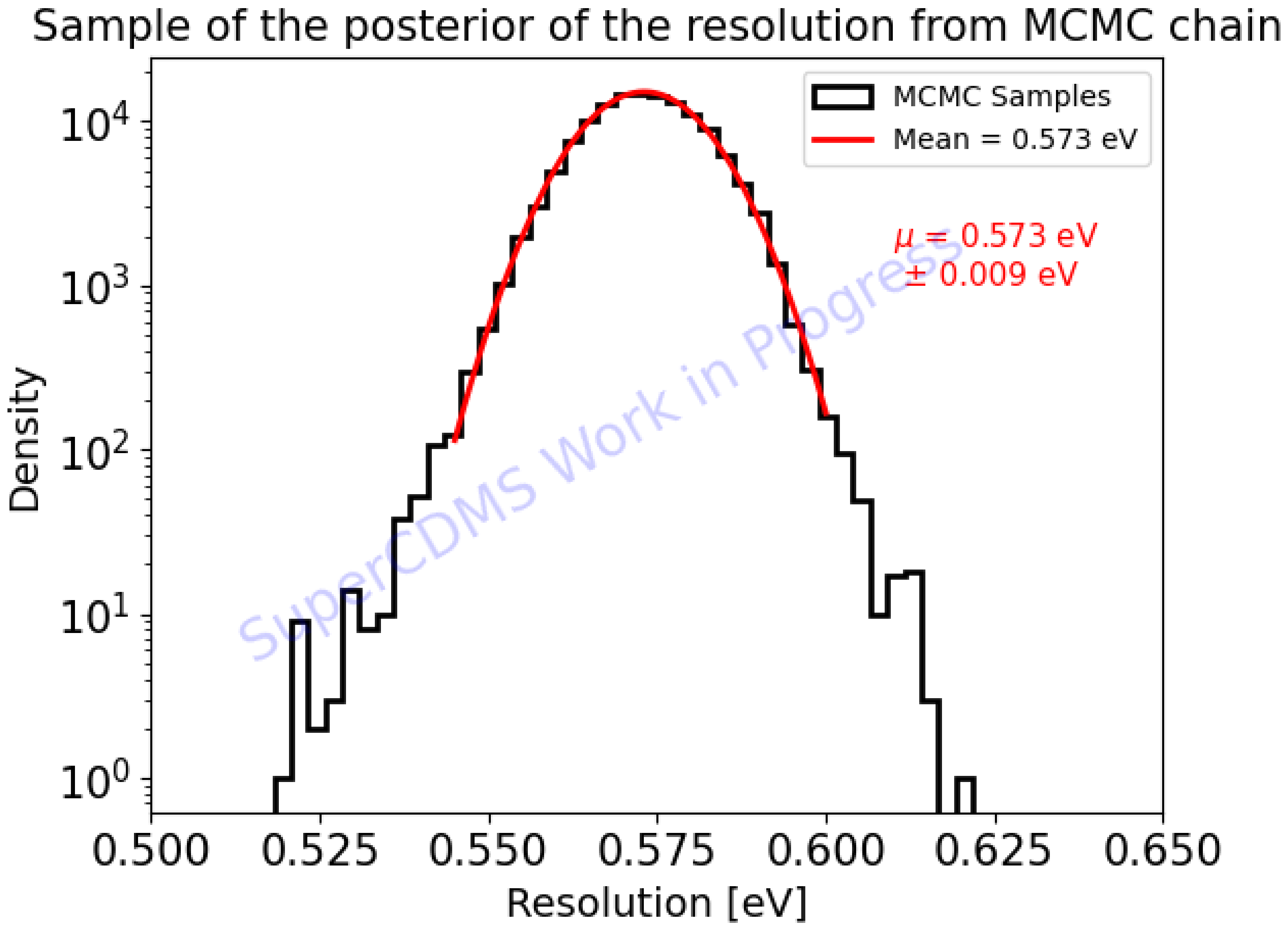


- Ran 6, 1g Si detectors capable of reaching 1 eV threshold at the CUTE facility
- Two new detectors with lower $T_c$ (60 -> 45 mK) and $SiO_2$ layer to reduce leakage from QETs
- Detector tower was put into CUTE at the end of March, 2024 and ran until the end of September

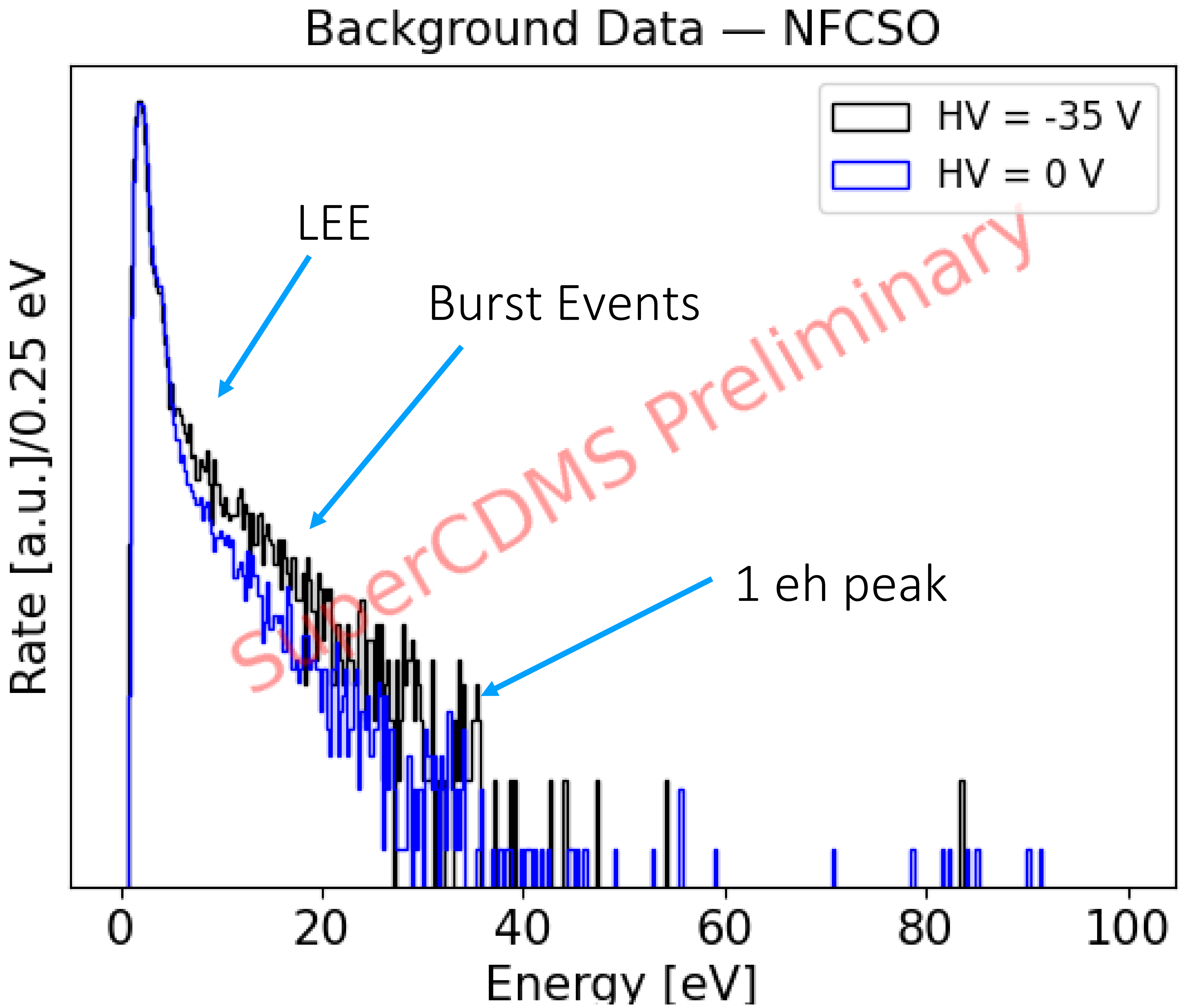
# HVeV – Run 5 Results



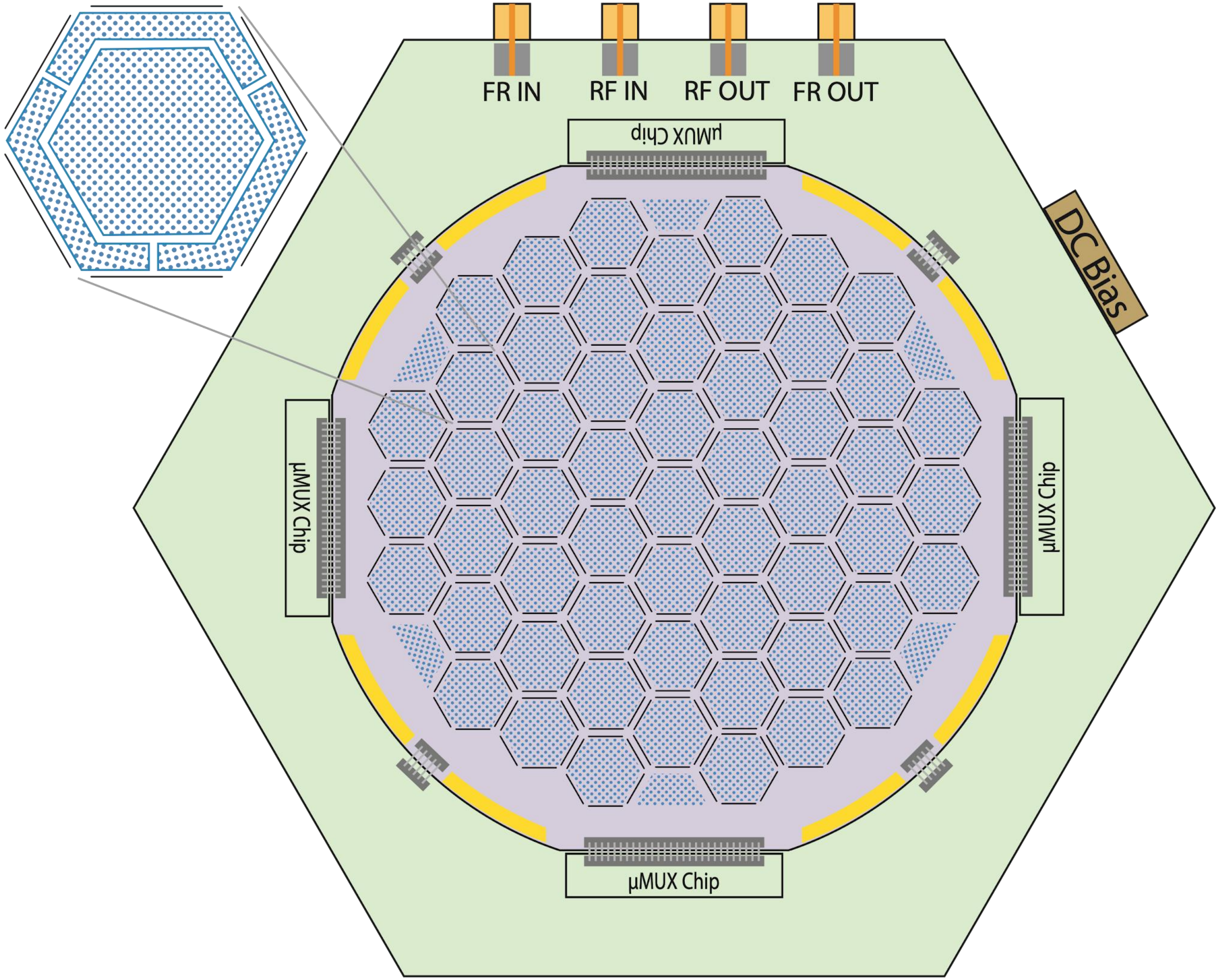

- HVeV achieved a baseline resolution 0.573 eV+/- 0.009 eV

# HVeV – Run 5 Results



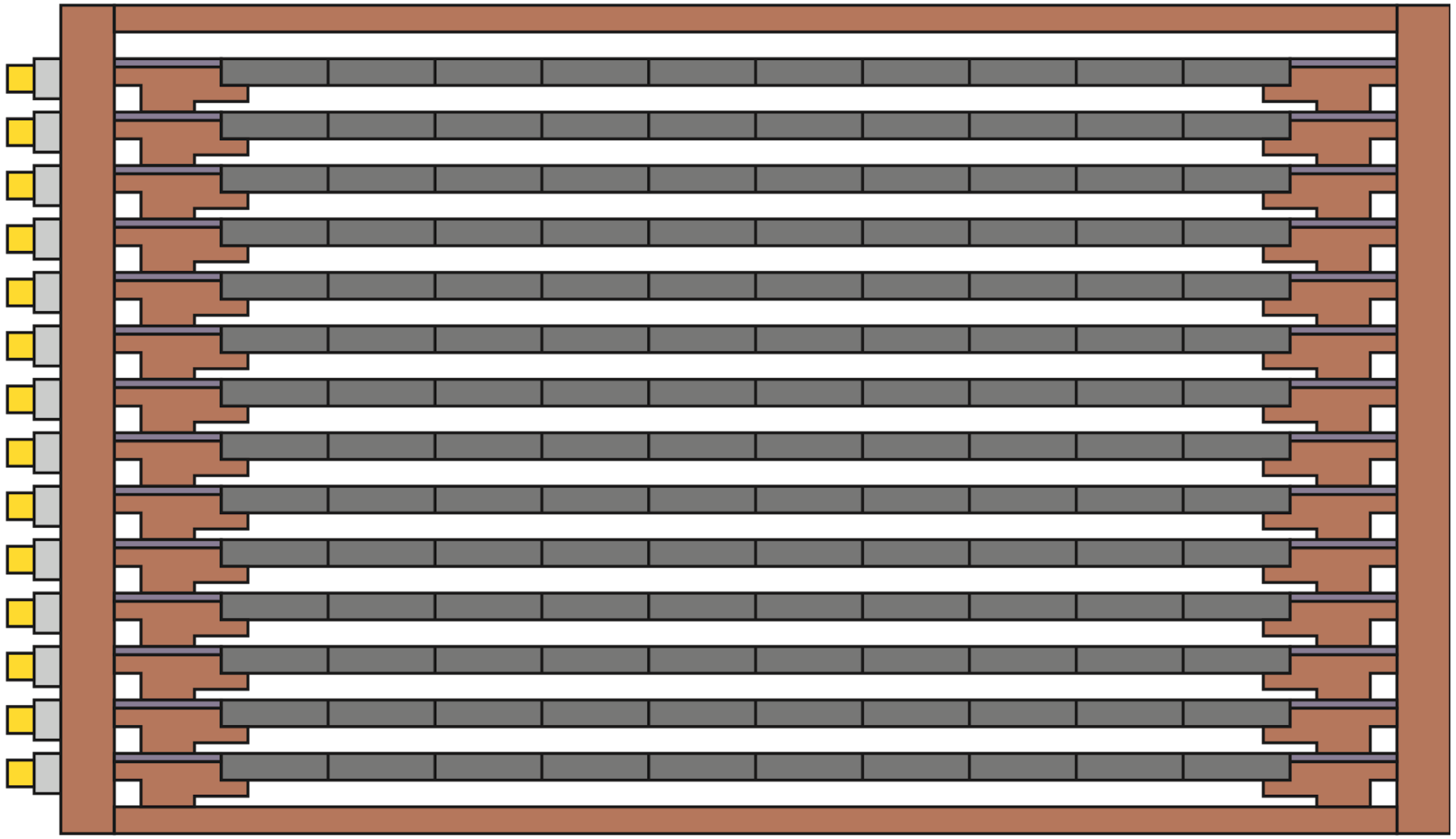

- Reduced 1eh rate compared to Run 3 and 4
- Took DM search data (-35V for 13 days of exposure)
- 90% of data is blinded
- DM result is coming very soon
- Allowed for studies of LEE

# HONEYCOMB




- Scaling up the HVeV concept
- “Dicing” wafer, small bridge for thermal conduction
- Stress-free mounting
- Multiplexing readout w/ multi-stage cryogenic amplifiers

# HONEYCOMB



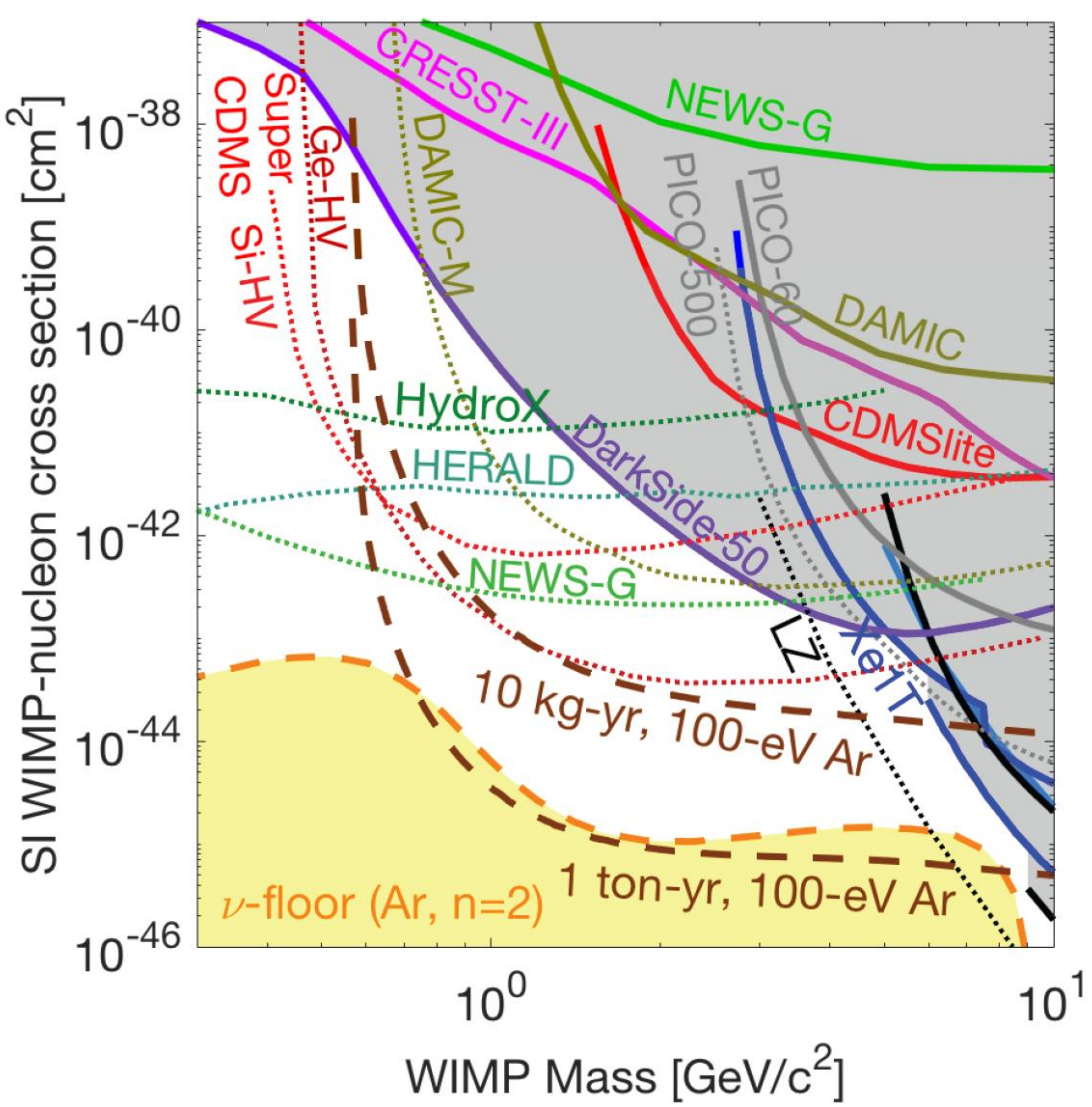
- Hodoscopic Nonrelativistic-EnergY CryOgenic Multiplexed Bolometer
- Multiple stacked together in order to achieve 1 kg mass with

# Conclusion

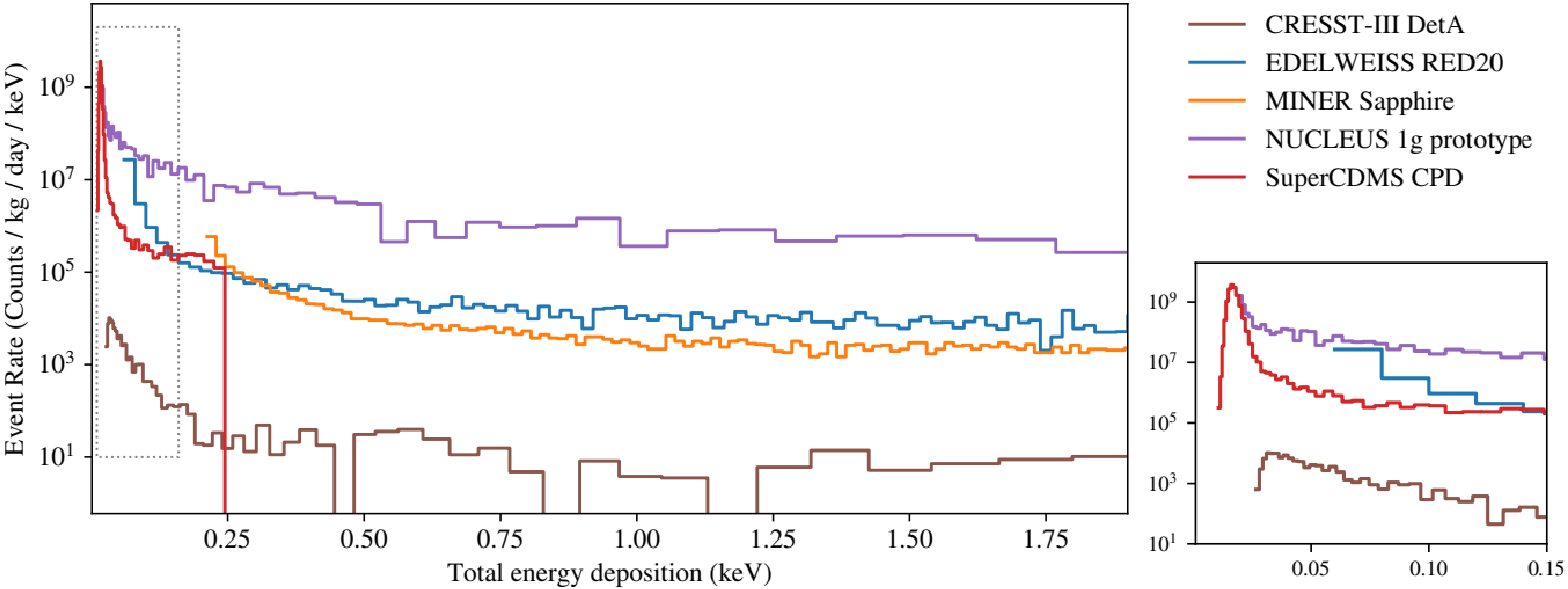
- SuperCDMS will push the boundaries of Sub-GeV dark matter searches at SNOLAB: Begin commissioning this year
- 30 kg of Si and Ge detectors. 4 towers with 6 detectors in each
- 12 iZIP and 12 HV detectors
- HVeV is a promising R&D program that has achieved incredible energy resolution: 0.53 eV
- There is a dedicated research program to upgrade the payload for the HVeV program

# Extra Slides

# SBC projections



# Low Energy Excess




- Low-energy excess observed in a variety of experiments over a variety of conditions
- Common origin? Understanding the low energy frontier

# First Big Questions

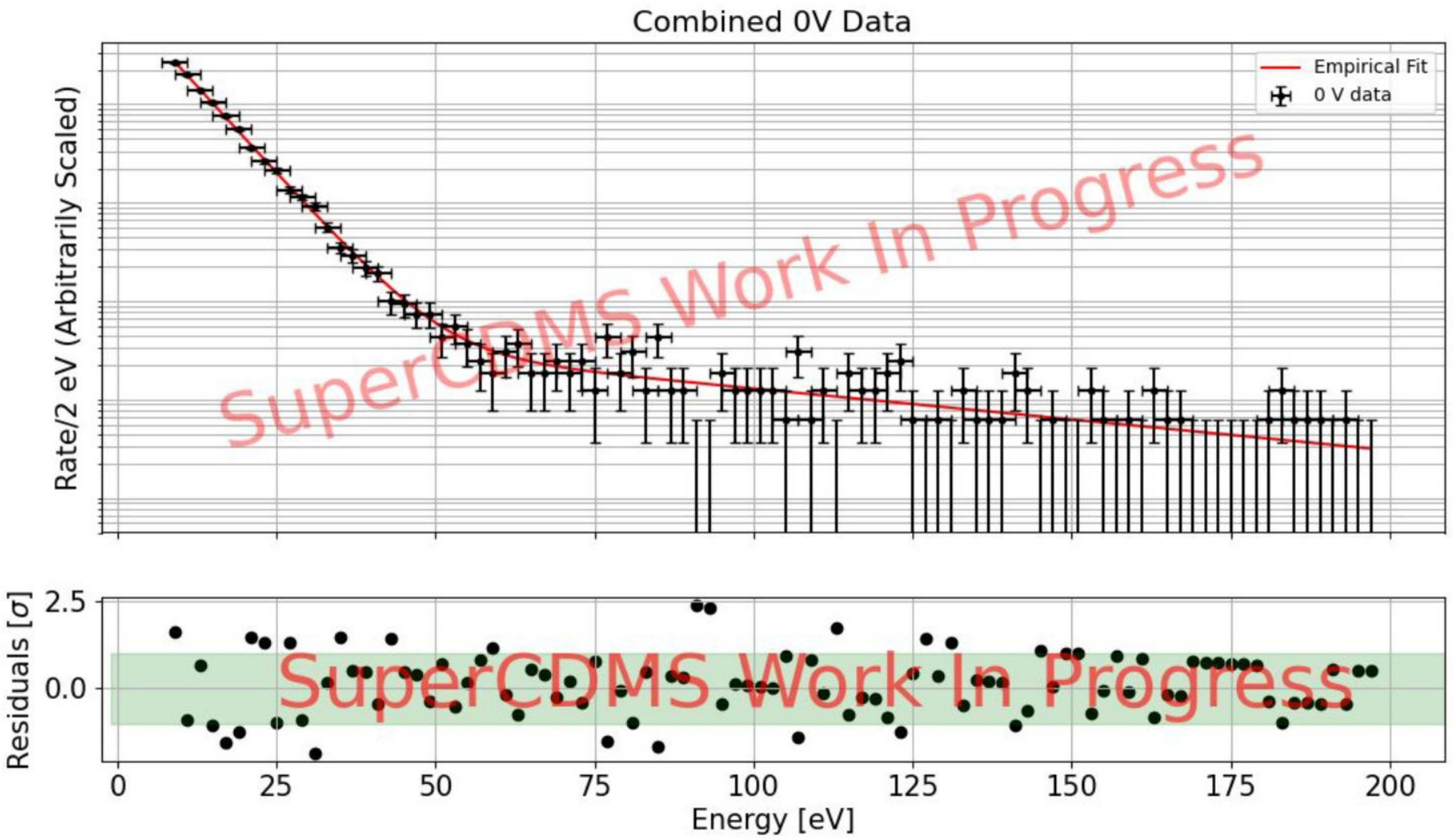
**Much work to be done but a few questions to start with…**

| | |
|---|---|
| Are there ionizing components of the LEE? | Compare backgrounds in HV data to 0V. |
| How does the LEE change with time? | Examine shape and rate of 0V background throughout the run. |
| Is the LEE shared between channels? | Study how the energy of LEE events are distributed among channels. |

Slides from Kyle Kennard, LTD 2025

# 0V Spectrum

| Are there ionizing components of the LEE? | No! |
| --- | --- |

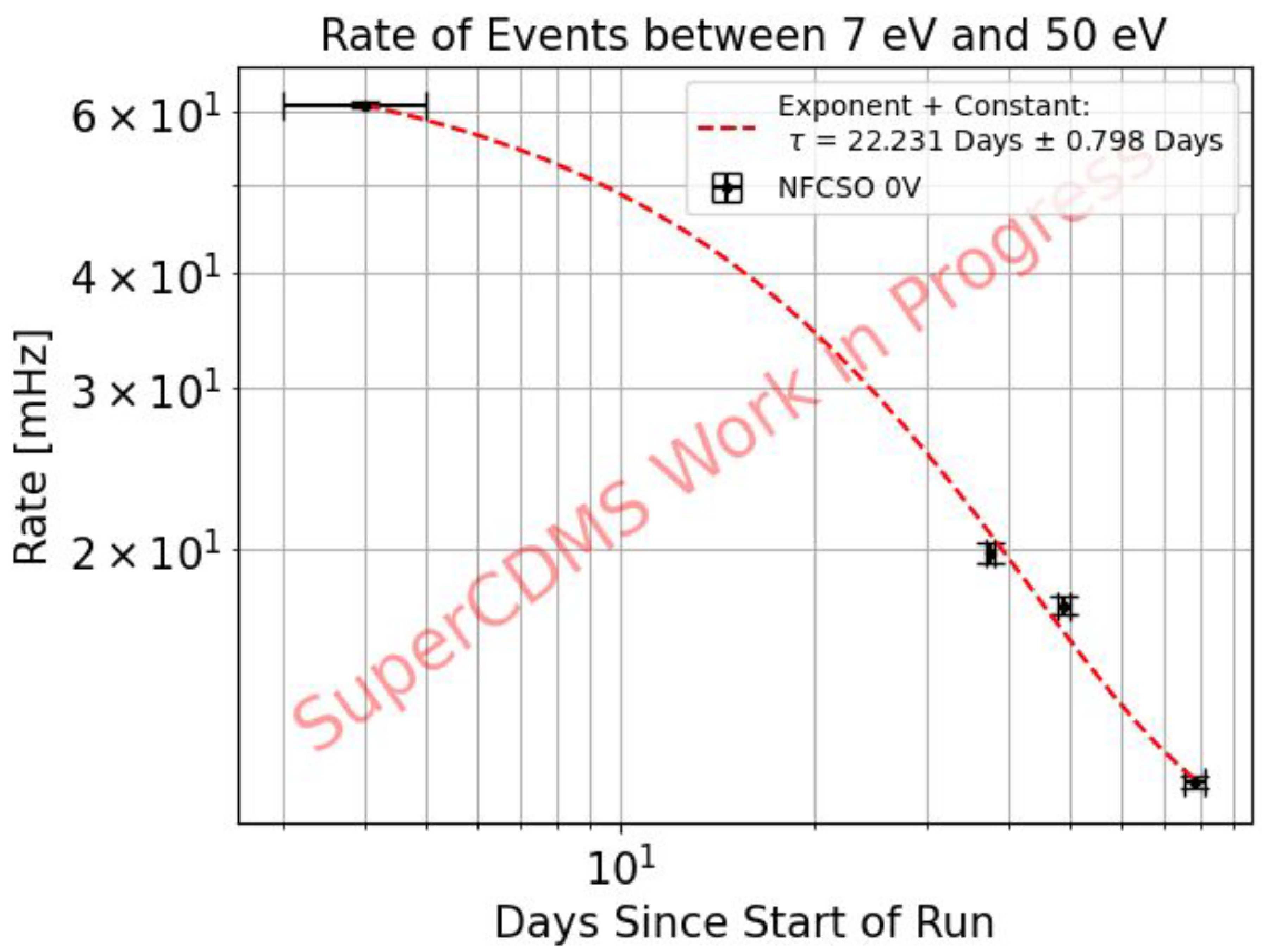



Data taken with various HV biases have a background component described by the 0V spectrum!

Slides from Kyle Kennard, LTD 2025

# LEE Rate vs. Time

| How does the LEE change with time? | **Same shape, different rate** |
| --- | --- |




**Shape of 0V spectrum is constant over the run**

- Rate of decay well-described by an exponential + constant
  - Power law not able to describe data as well
  - Not enough data to fit to models that decay to 0 (e.g. double exponential)
- Rate of decay seems constant for different energy slices up to ~150 eV

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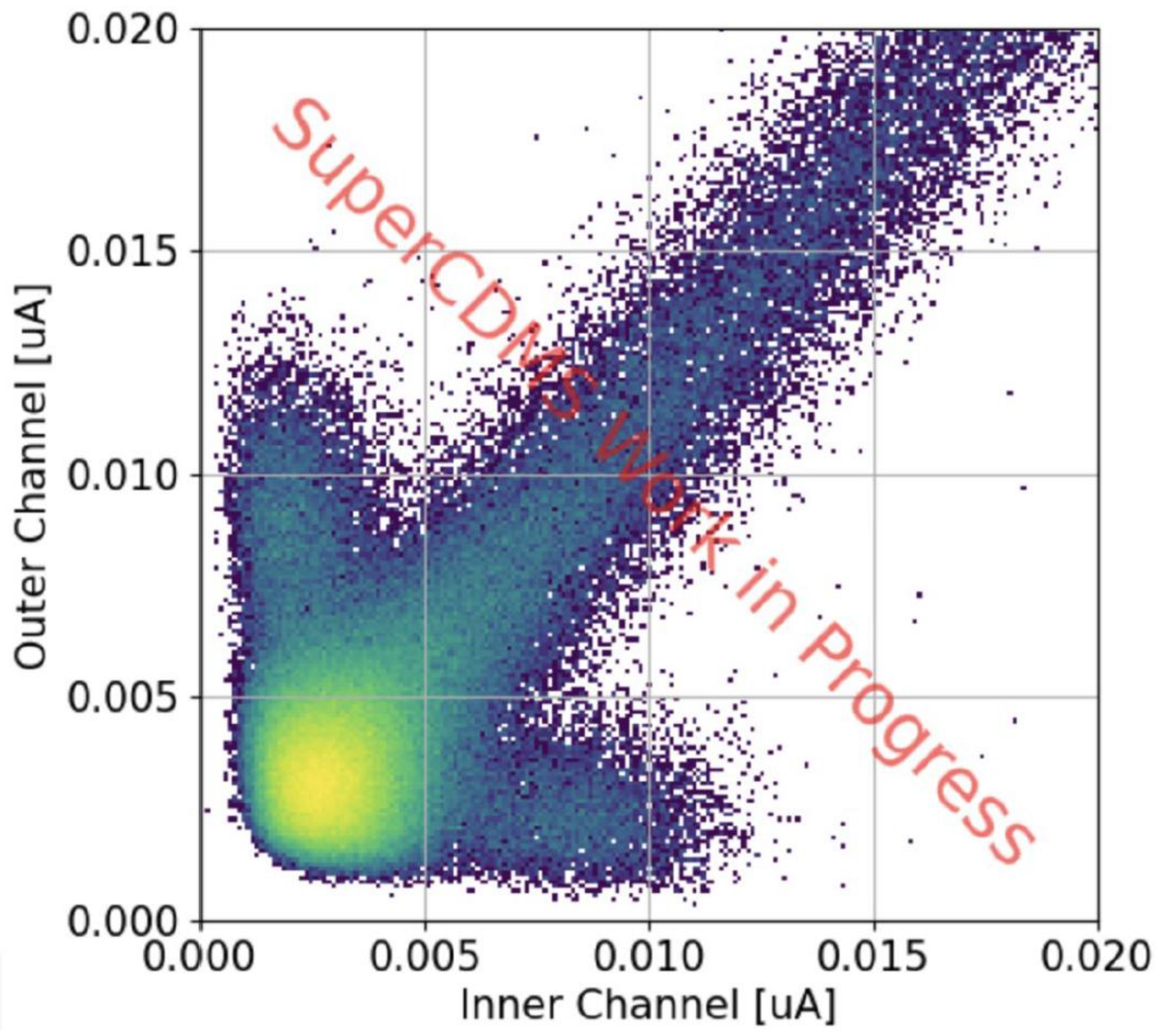
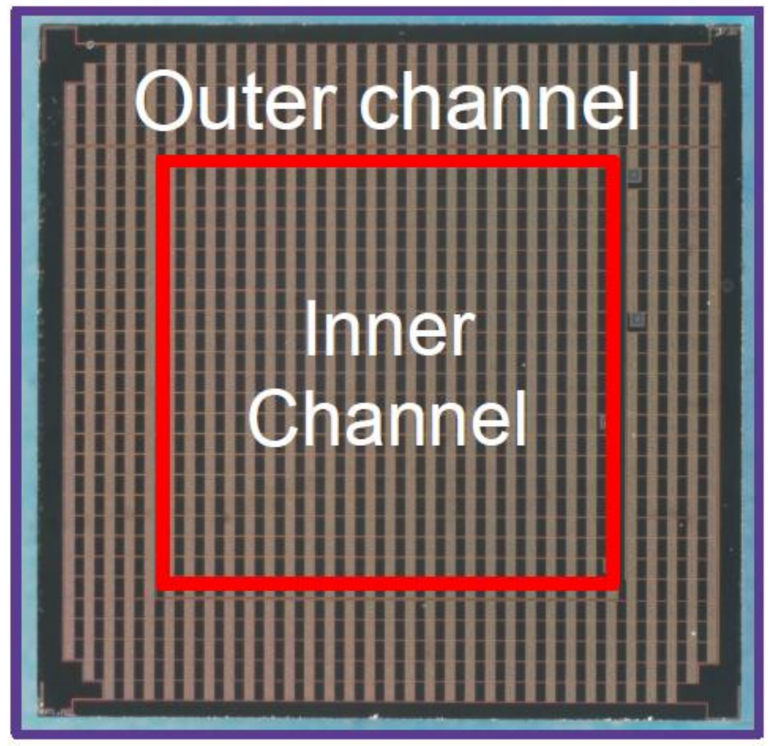
Slides from Kyle Kennard, LTD 2025

# Partition of 0V Background

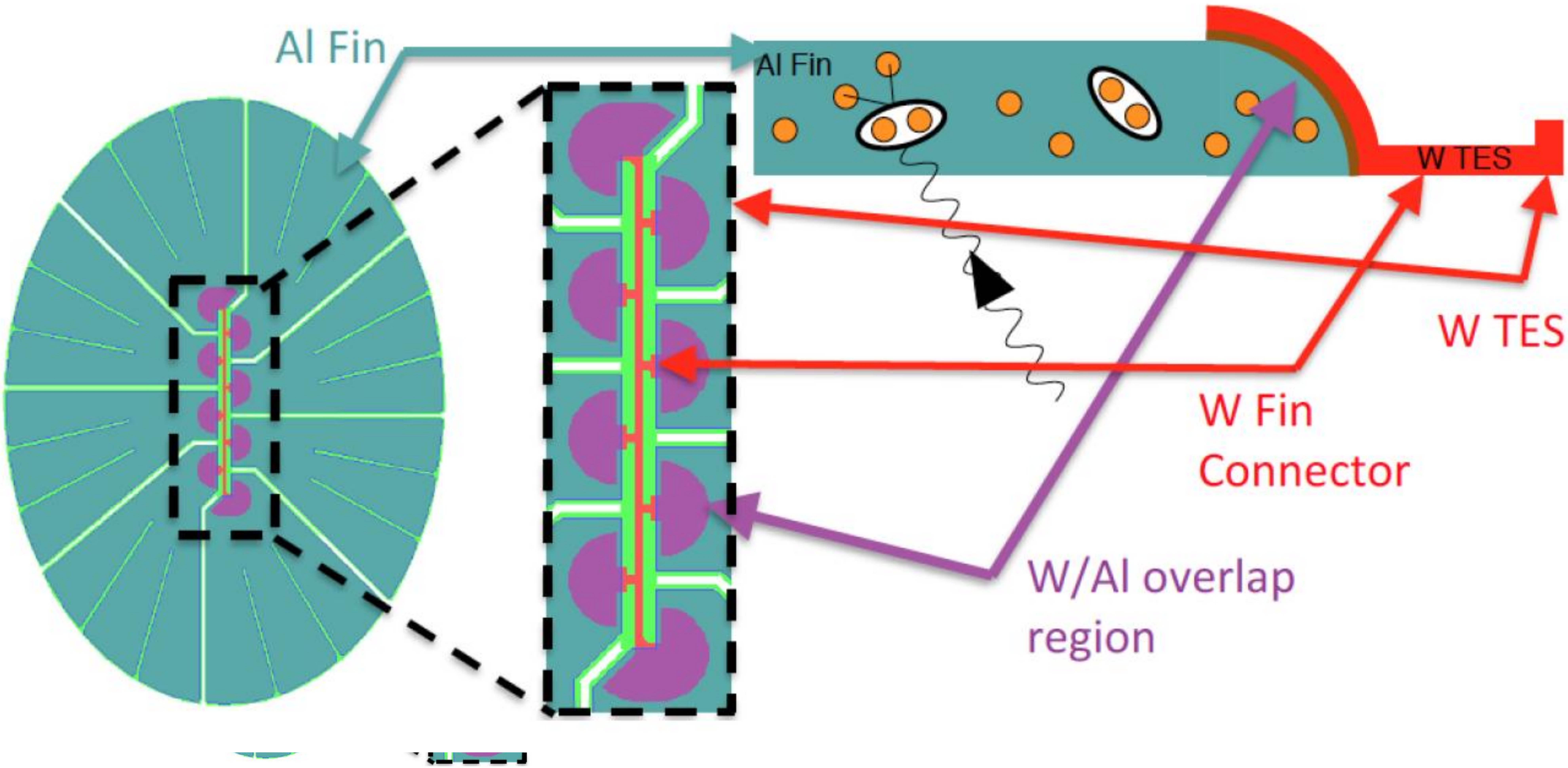
| Is the LEE shared between channels? | **Mostly! But not all of it!** |
|---|---|



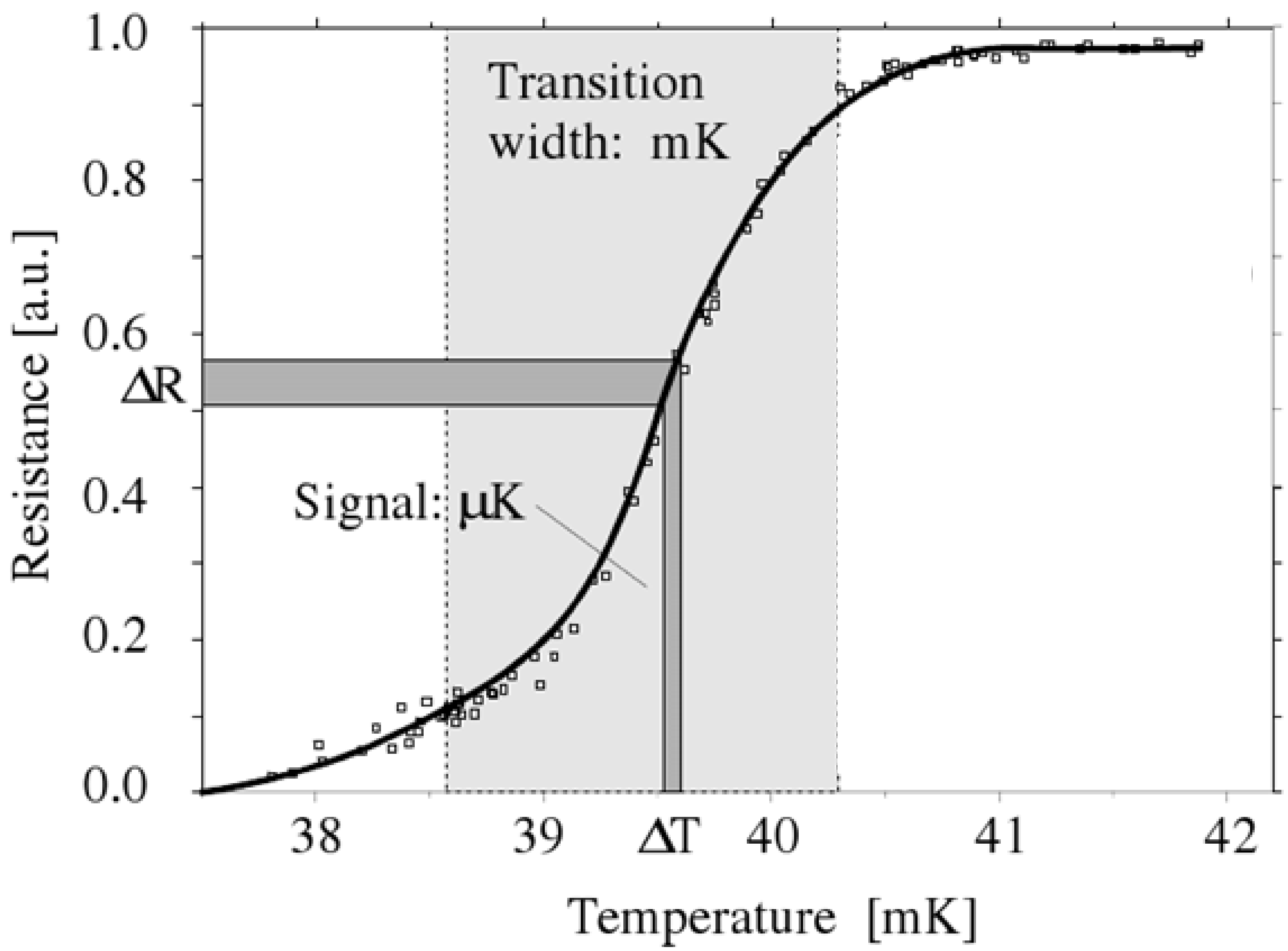



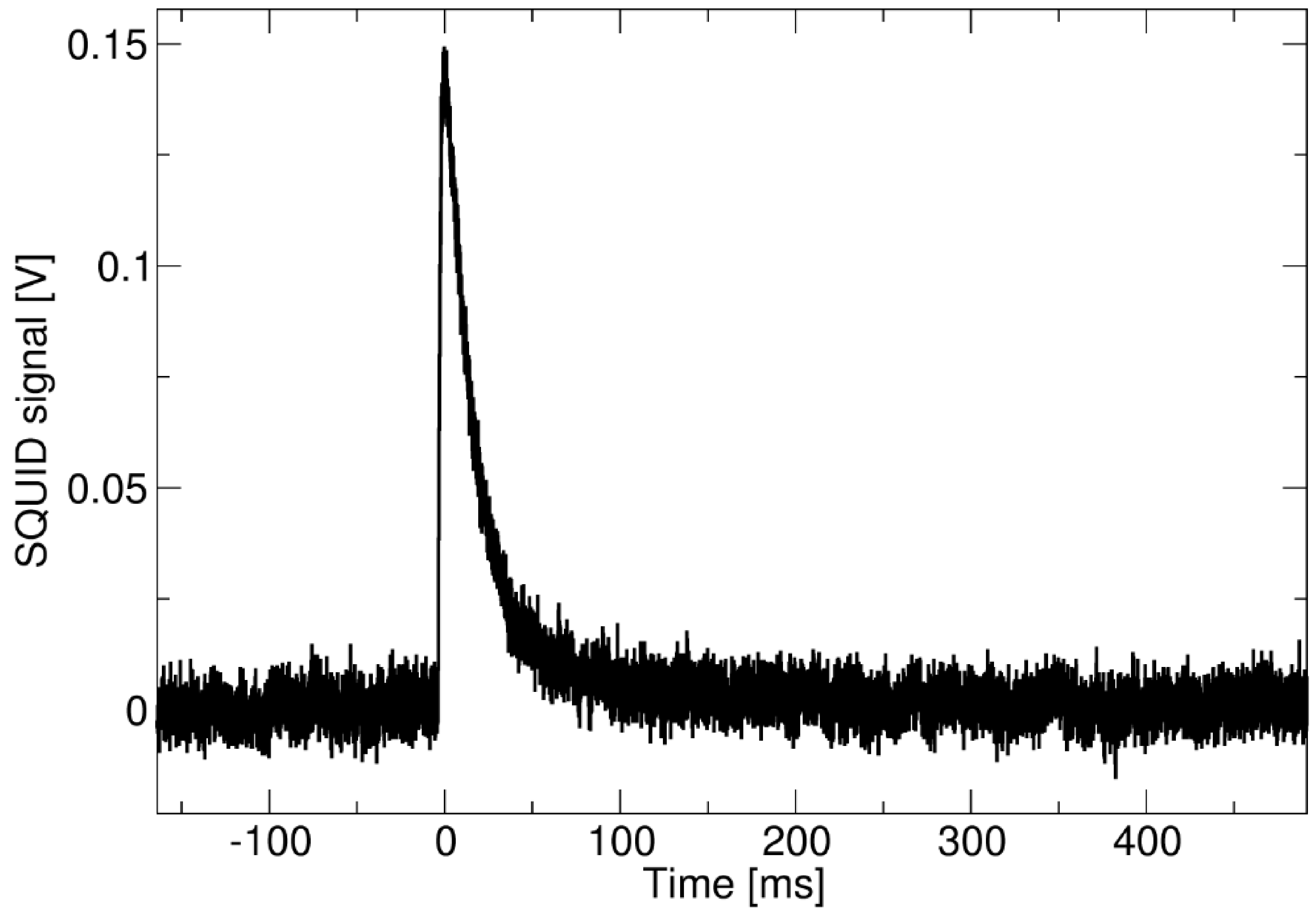

Can estimate radial position of events using two-channel layout.

**We see singles!**
**(events primarily on one channel)**


Al Fin
Al Fin
W TES
W TES
W Fin
Connector
W/Al overlap
region

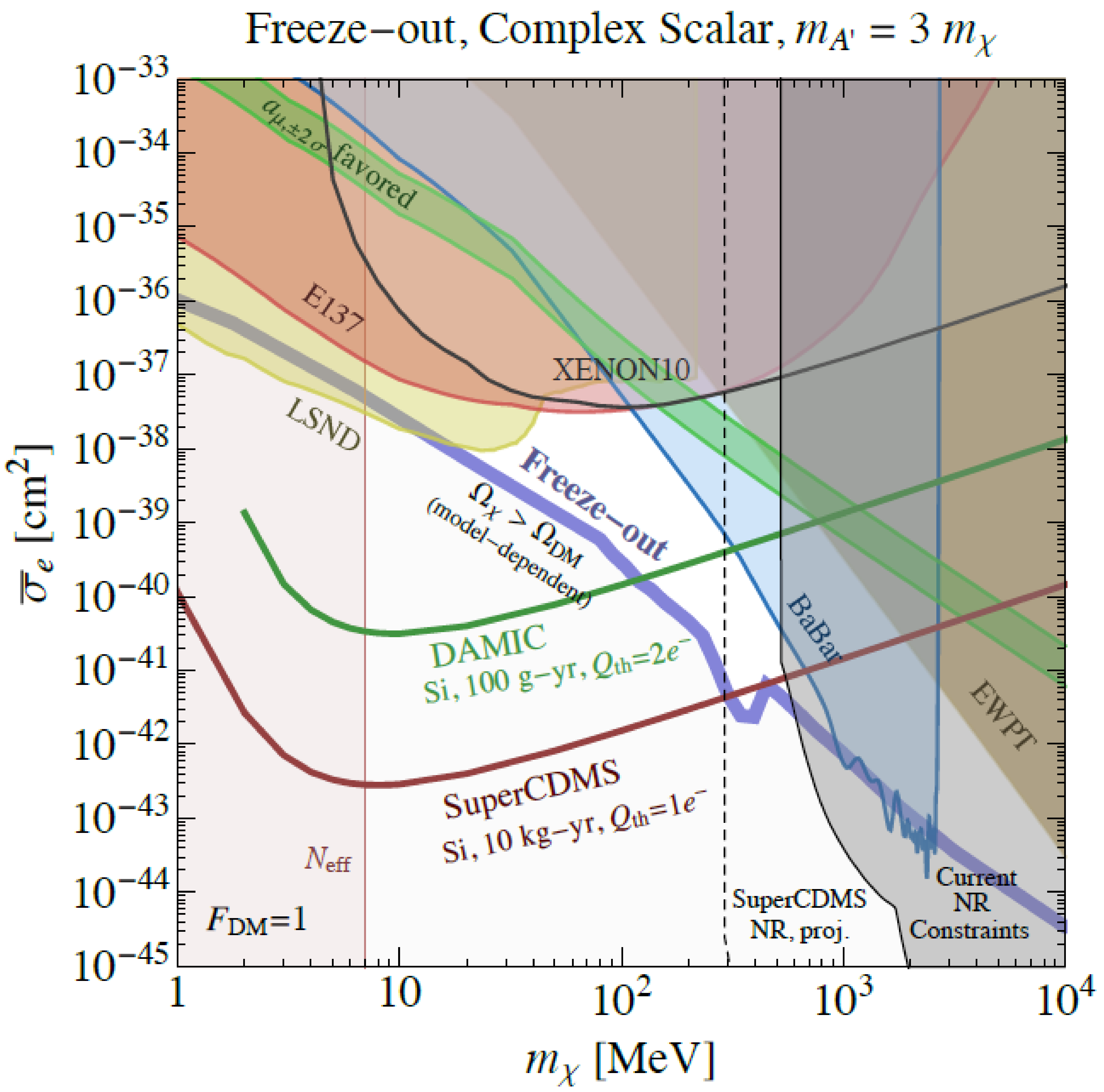
# Transition Edge Sensors (TES)

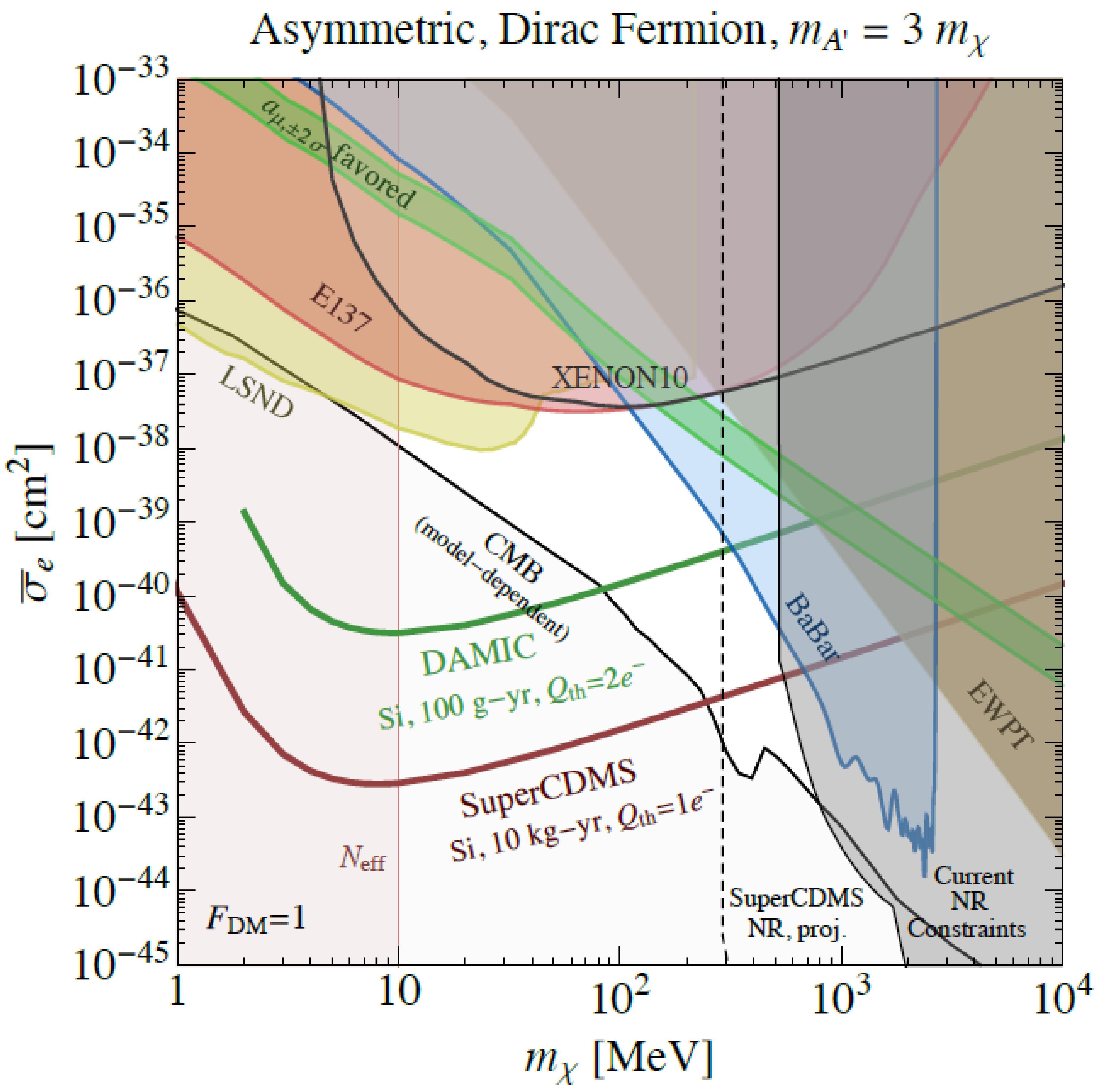


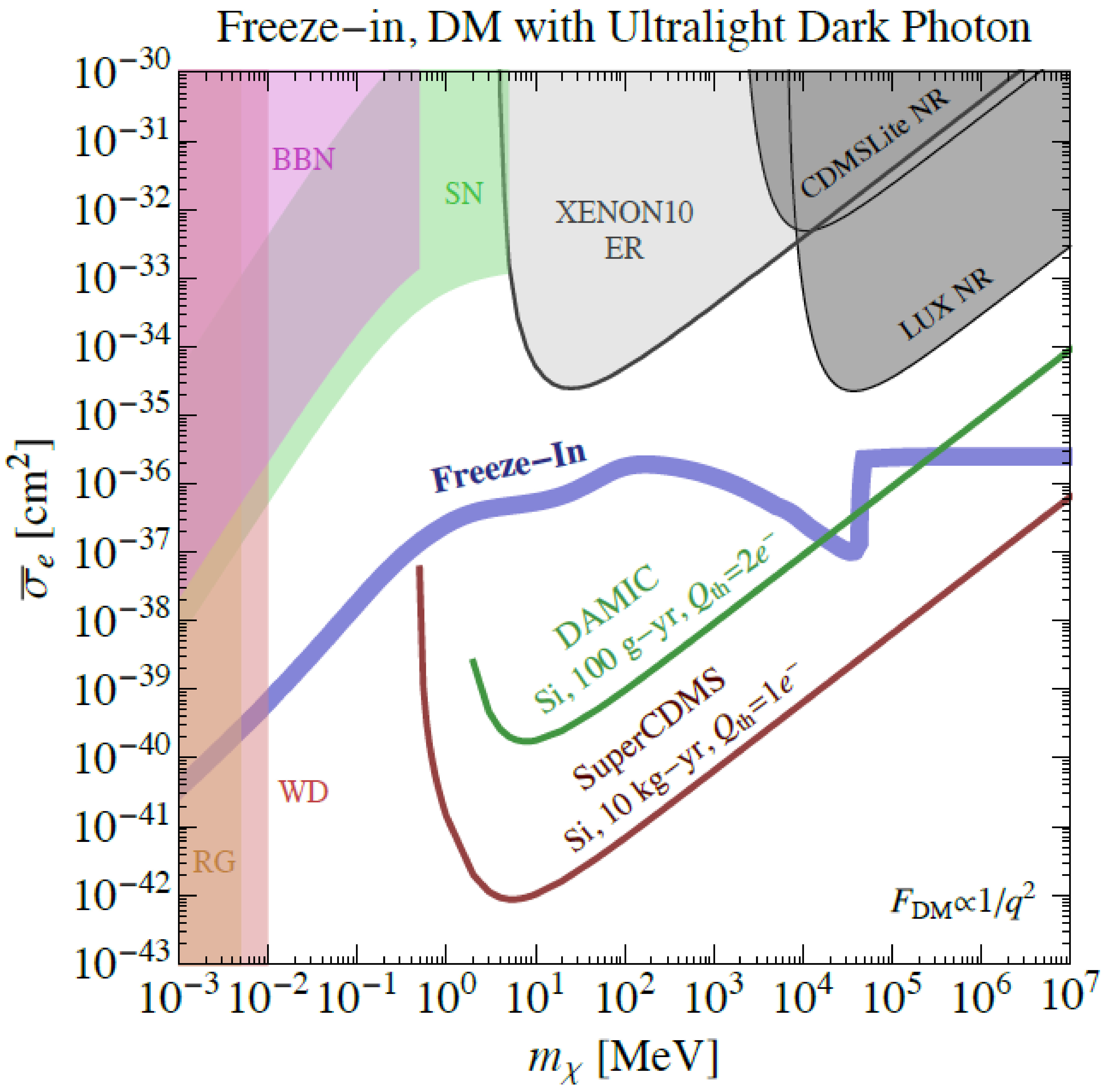

- Deposition of energy → Lattice vibrations (**<u>Phonons)</u>** → Change of temperature → Change in resistance → Signal
- Critical temperature reduced from 90 mk (Soudan) to 40 mk.
- Resolution will scale $T_c^3$
- TES are widely used in the field of rare event searches

# Non-WIMP Dark Matter Sensitivities

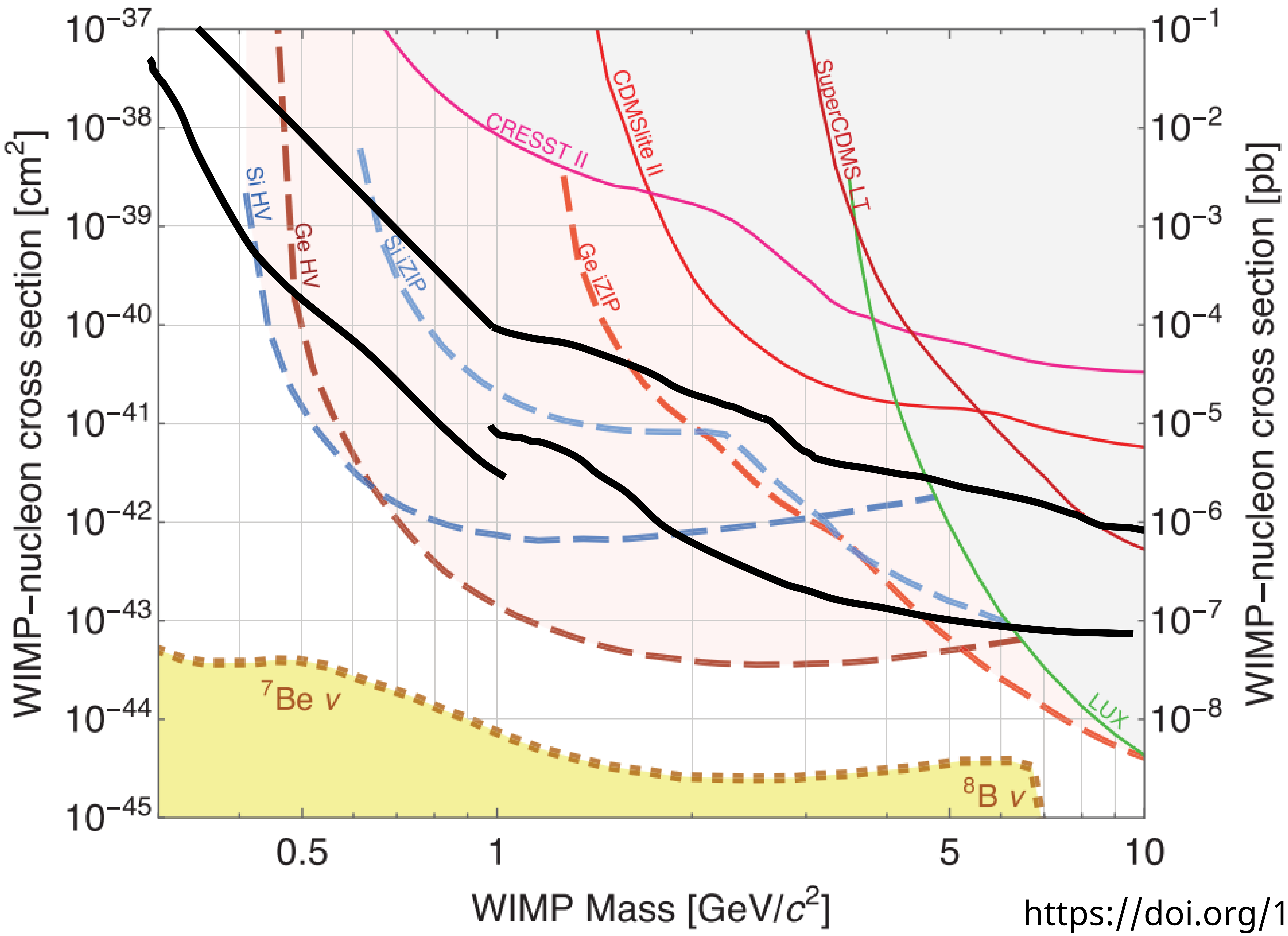


# Non-WIMP Dark Matter Sensitivities



# Dark Matter Sensitivity (4 year exposure)

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- 90% C.L exclusion sensitivity using the optimal interval method