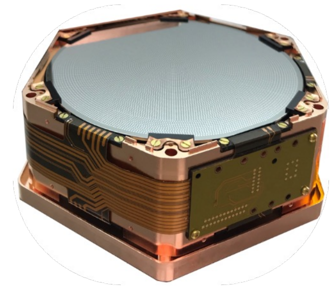
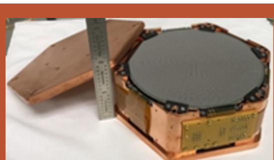
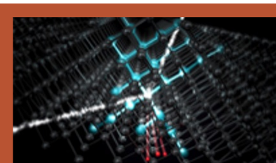
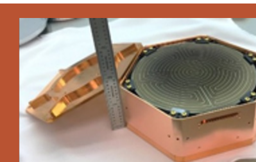


Searching for low-mass Dark Matter SuperCDMS at SNOLAB

Pekka K. Sinervo, C.M.
University of Toronto
March 20, 2025

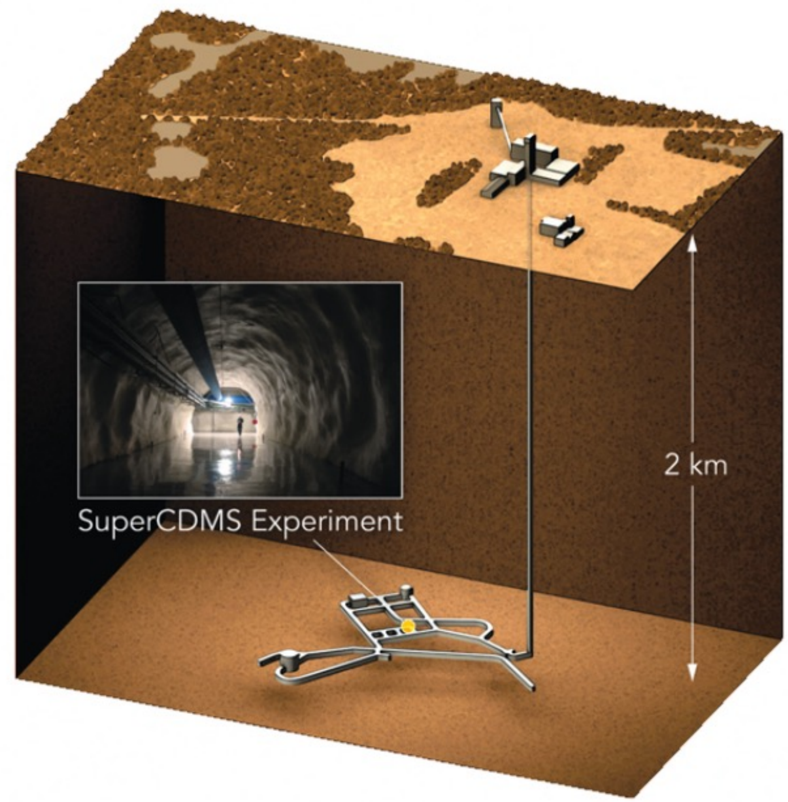






OUTLINE

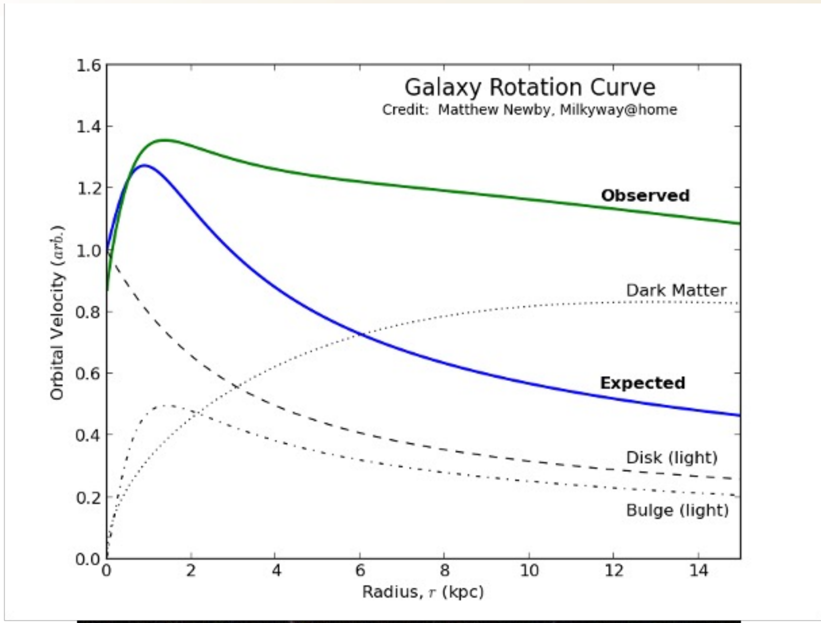
- SuperCDMS at SNOLAB motivation
  - Dark matter landscape
  - Detector physics
  - Dark matter modelling for SuperCDMS
- Experimental design and installation
- Detector construction & installation
- Detector testing
  - Preliminary data from NEXUS and CUTE
- Background control and analysis
- Preparing for “first dark” data
- Summary

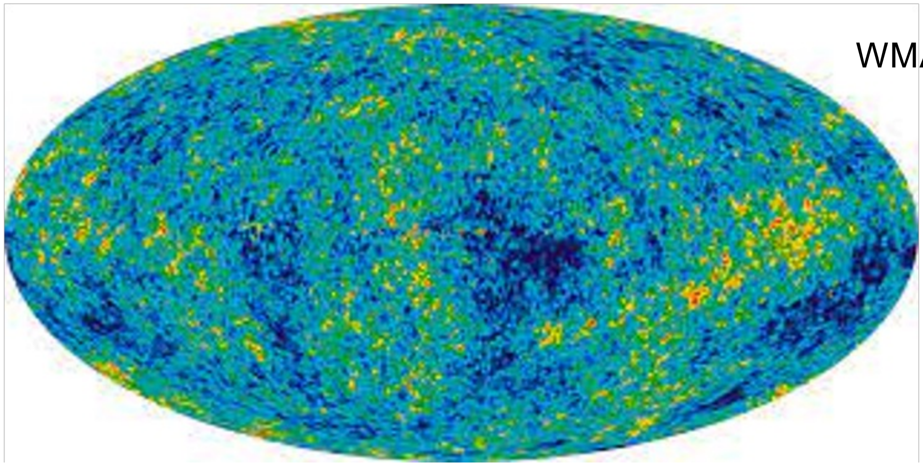


Greg Stewart/SLAC National Accelerator Laboratory

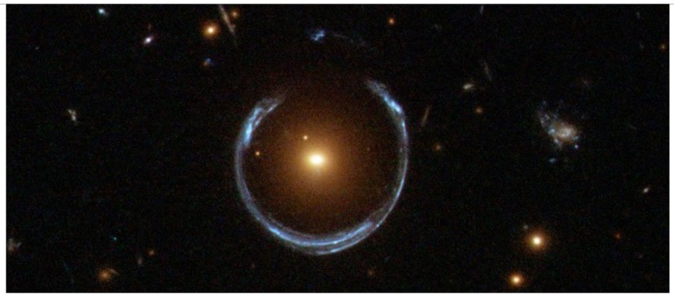
Dark Matter: Why and What?

Well-established phenomena motivate DM

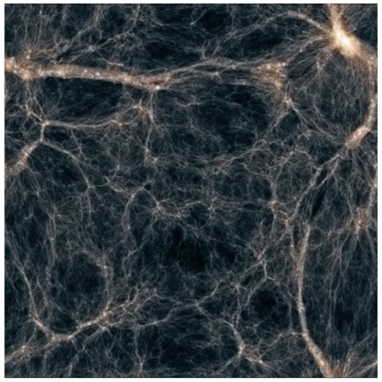




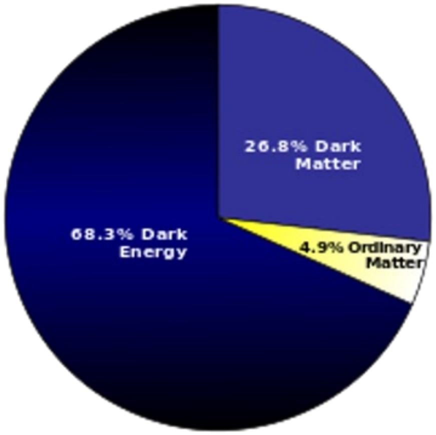
WMAP



Strong Lensing

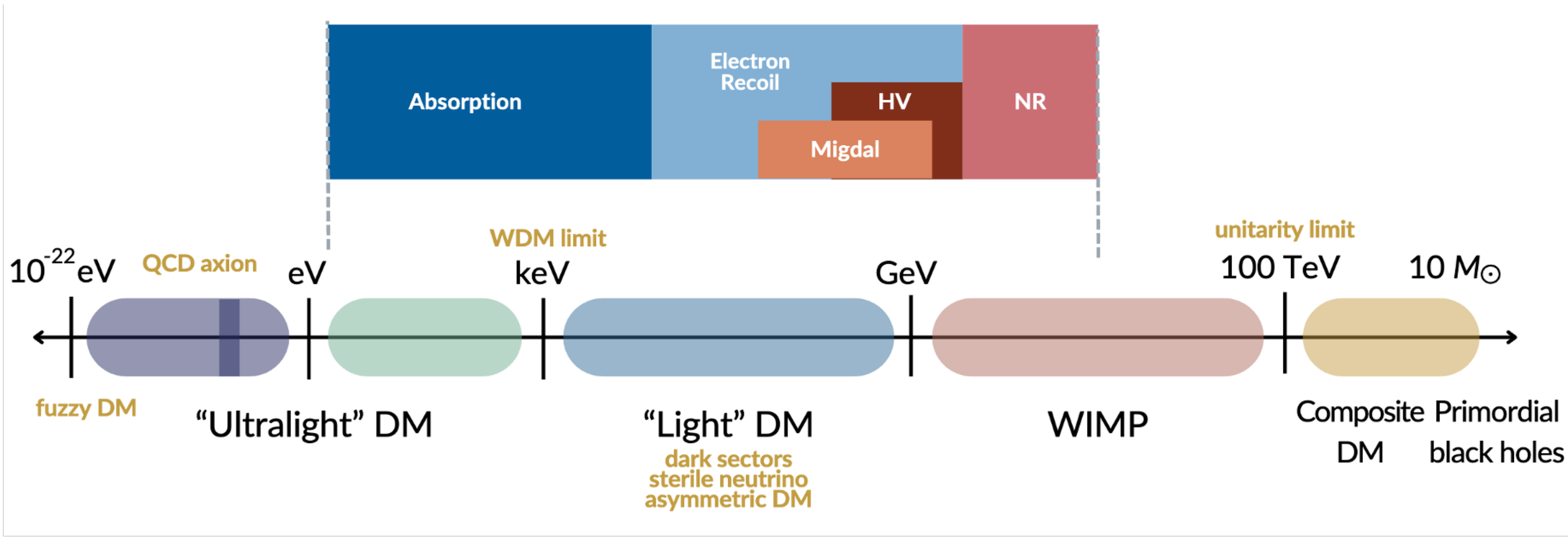


Large-Scale Structure



Many Models of Dark Matter

Characterized by an unknown mass scale



Ingredients for direct detection

Interaction rate in a target (T) a function of recoil energy, target and DM model

DM density/mass

Target density

Velocity distribution

Interaction cross section

$$\frac{dR}{dE_R} = N_T \frac{\rho}{m_\chi} \int_{v_{\min}}^{v_{\rm esc}} v f_{lab}(\vec{v}) \frac{d\sigma_T}{dE_R} d^3v$$

$$\frac{d\sigma_T}{dE_R} = \frac{m_T}{2v^2} \frac{\sigma_\chi}{\mu_N^2} \left[\sum_{i,j} \sum_{a,b=0,1} \hat{c}_i^{(a)} \hat{c}_j^{(b)} F_{ij}^{(ab)}(v,q) \right]$$

Interaction model (coupling constants)

Nuclear structure (form factors)

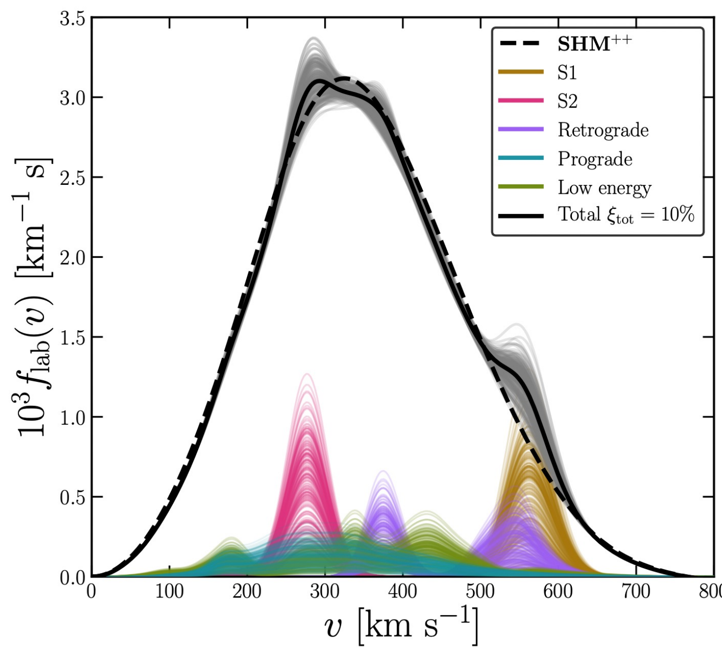
Key point:

- Many ingredients
- Requires some assumptions

These ingredients are not well-known

Most limits assume:

- $\boldsymbol{\rho}$ ~ 0.3 GeV/cm^3
- f_{lab} given by the Standard Halo Model – 220 km/s
- Interaction model:
  - elastic
  - spin independent/dependent
  - Simplest nuclear channel



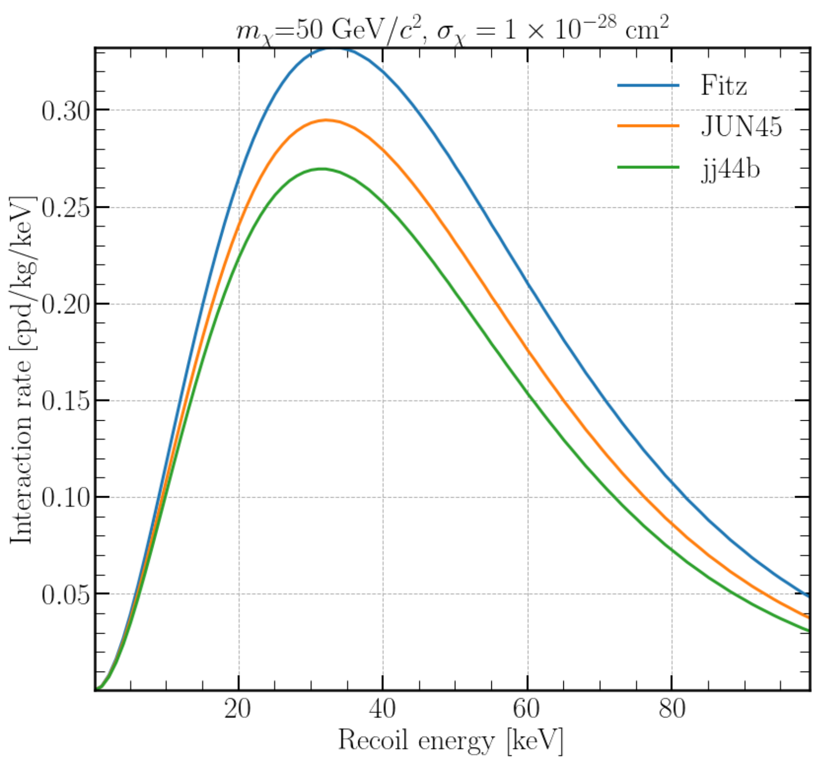
O'Hare et al. Phys. Rev. D 101, 023006 (2020)

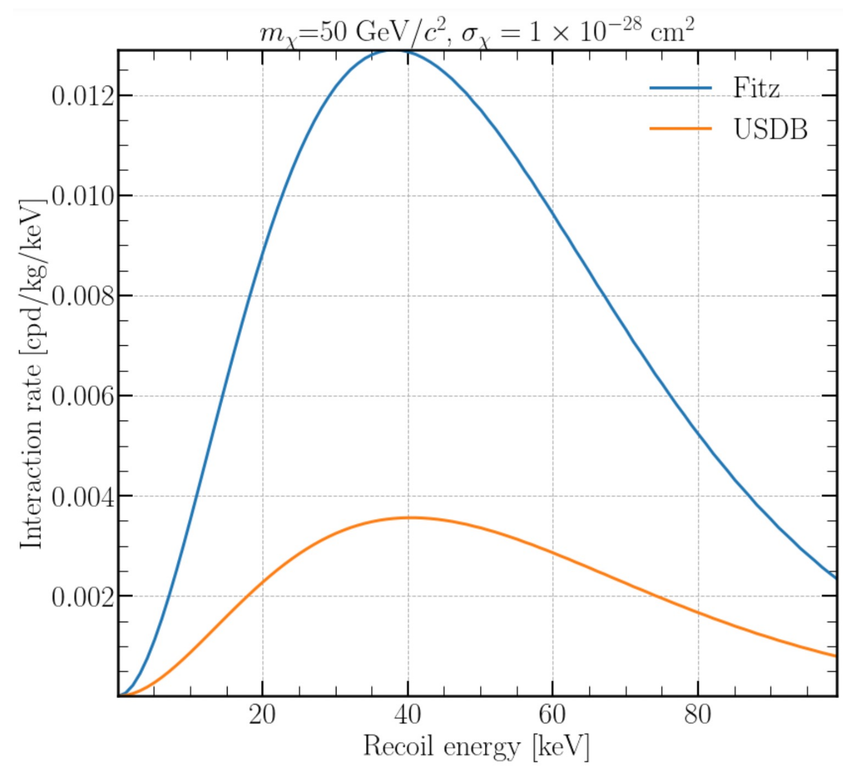
But these aren't necessarily the case!

- $\boldsymbol{\rho}$ ~ 0.2 - 0.5 GeV/cm^3
- f_{lab} can have substructure that impacts targets differently
- Additional nuclear interaction channels
- Uncertainties in nuclear structure ⇛ uncertainties in interaction strength

Nuclear structure constants also uncertain

- Form factors depend on nuclear shell structure calculation
- Effects depends on model -- largest changes for spin-dependent, velocity and momentum suppressed interactions



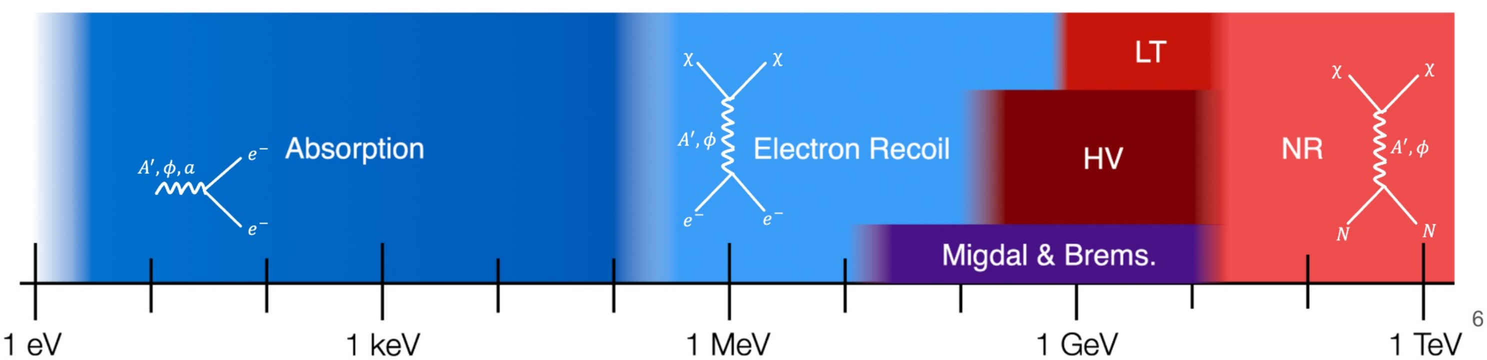


SuperCDMS at SNOLAB designed for low-mass DM

Key design criteria:

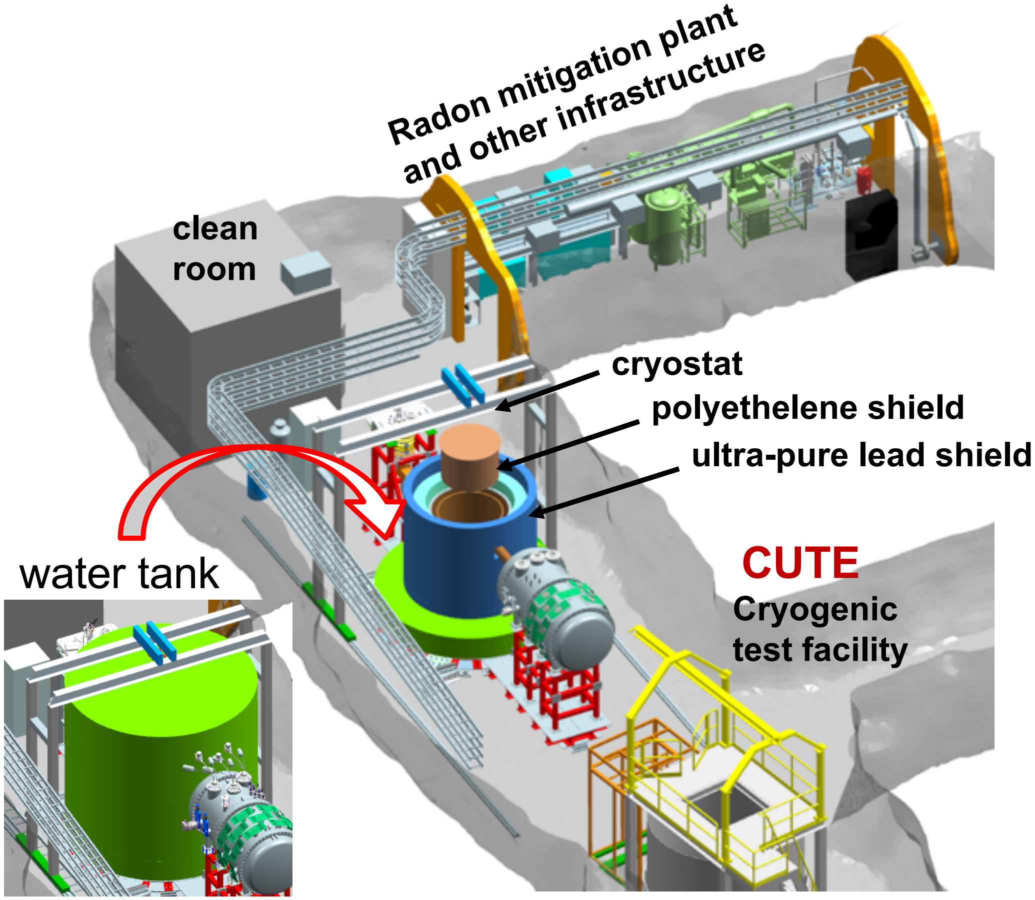
- Sensitive to lowest possible nuclear recoil energies
- Very low backgrounds
- Large target mass and exposure
- Complementary detector technologies

○ "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")

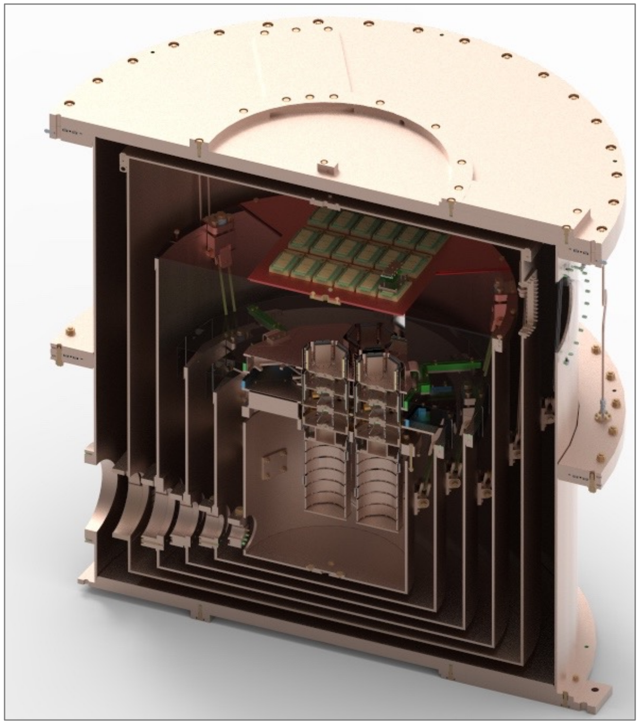


Experiment and Detector Design

SuperCDMS at SNOLAB Infrastructure



Cryostat or “SNOBOX”



SuperCDMS Detector Technology

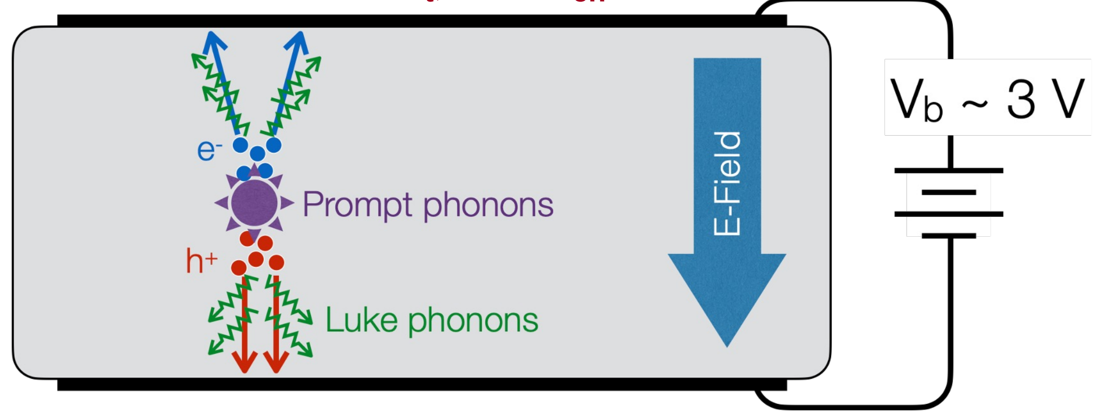
iZIP Detector

- Low backgrounds
- Yield: Prompt phonon and ionization discriminates between Nuclear Recoils (NR) and Electron Recoils (ER)

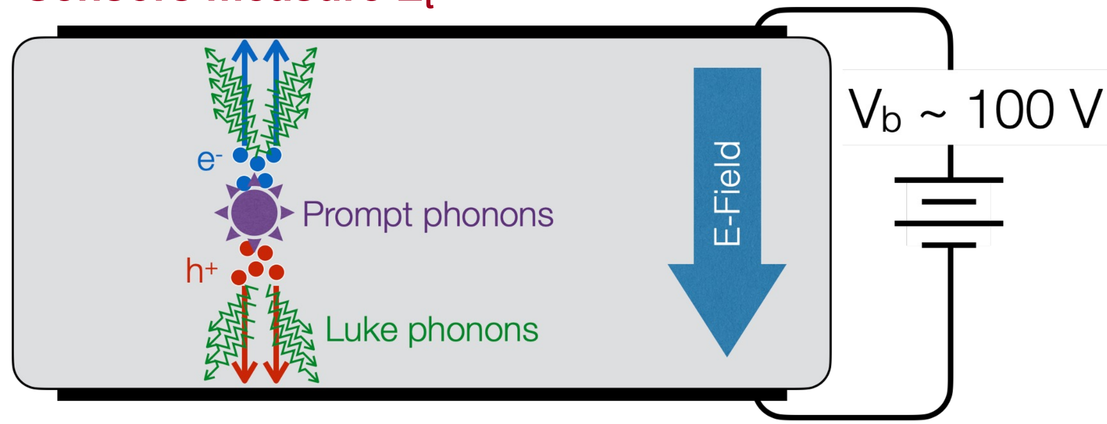
HV Detector

- Low threshold
- Phonon Amplification: secondary phonons produced by drifting e/h across the high V_b
- No yield-based NR vs ER discrimination.

Sensors measure E_t, and n_{eh}



Sensors measure E_t



Employing 4th generation CDMS detector conceptr

Key concept: use NTL effect to reduce energy threshold

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

$$E_t = E_R + n_{eh} e V$$

Voltage bias

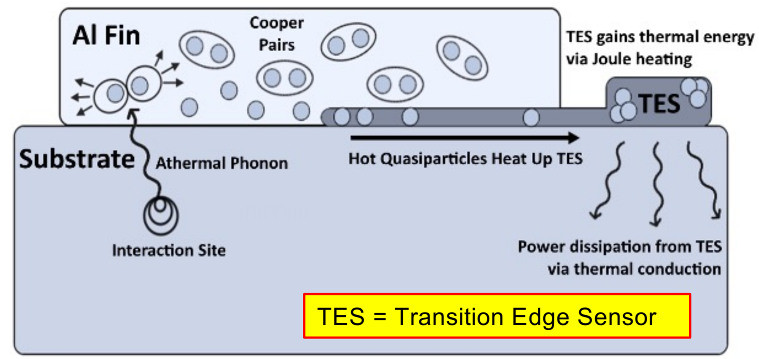
Total phonon energy

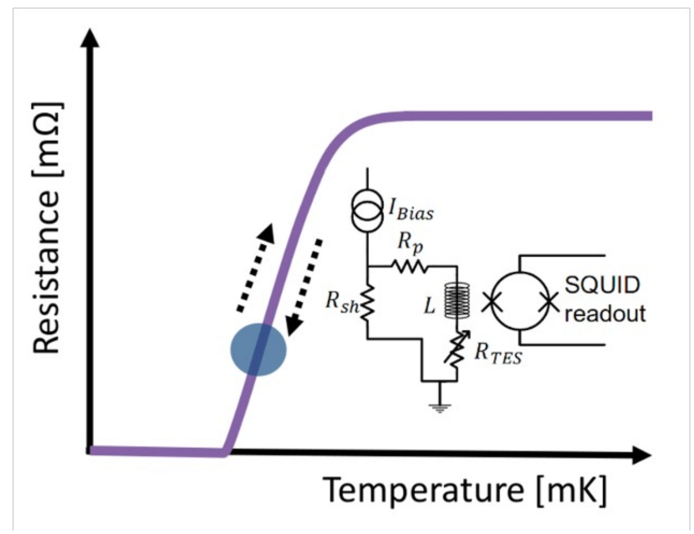
Initial recoil energy

Number of eh pairs

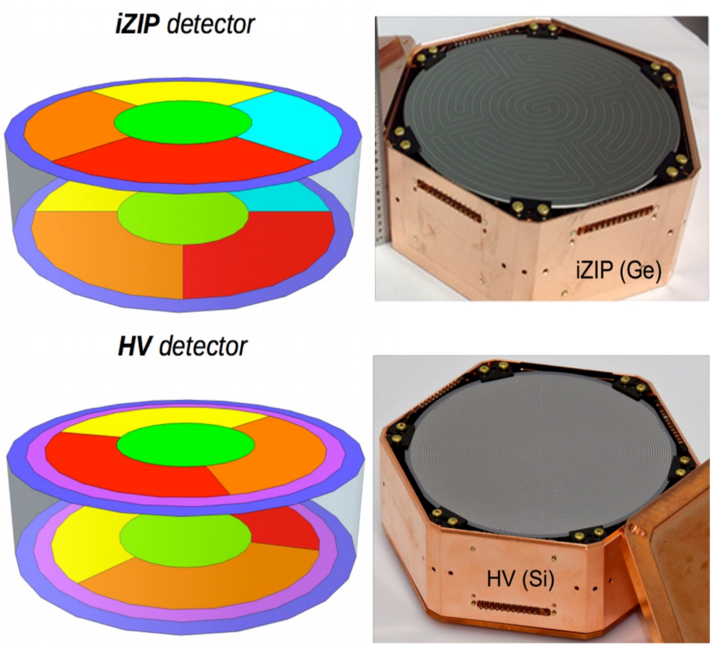
- Increased potential ⇒ increased total energy
- Phonon E_t measured with TES at ~50% bias point
- 12 equal area sensors on each HV detector

NTL = Neganov-Trofimov-Luke

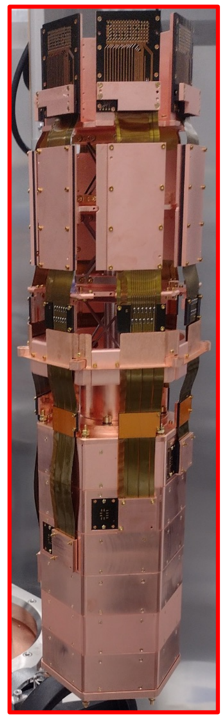


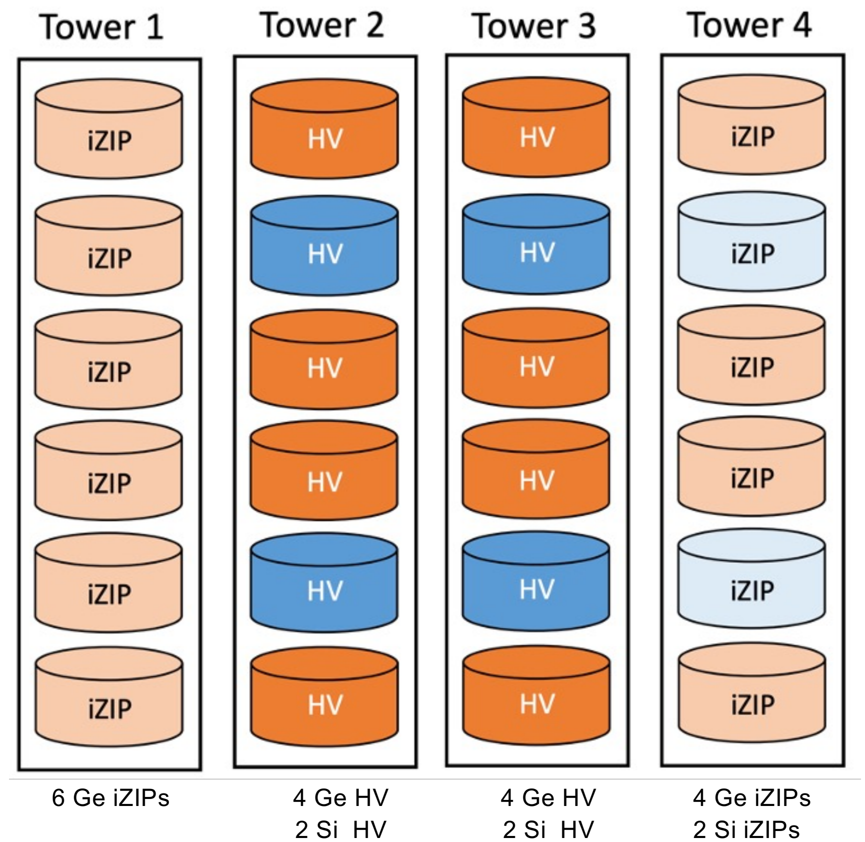


Detectors and payload optimized for sensitivity



Detector Tower





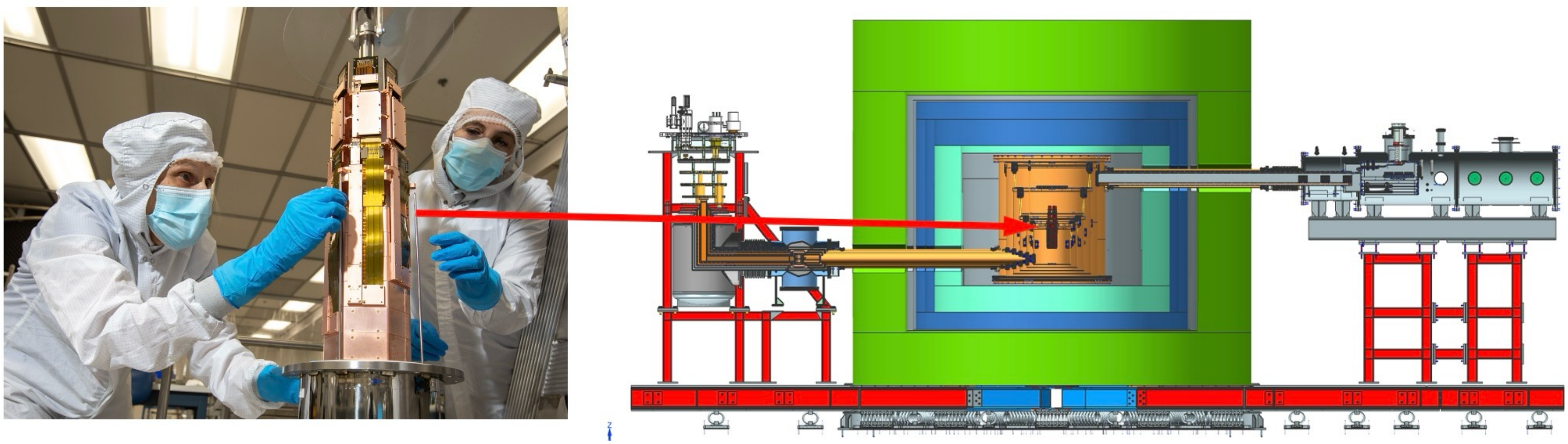
Four detector configurations employed

	Germanium	Silicon
HV	Lowest threshold for low mass DM Larger exposure, no ^{32}Si background	Lowest threshold for low mass DM Sensitive to lowest DM masses
iZIP	Nuclear Recoil Discrimination Understand Ge Backgrounds Sensitive to ^{8}B ν-scatter	Nuclear Recoil Discrimination Understand Si Backgrounds Sensitive to ^{8}B ν-scatter
Mass Dimensions	1.5 kg 10 cm ⌀, 3.3 cm thick	0.6 kg 10 cm ⌀, 3.3 cm thick

Detector Construction and Installation

Installation and Integration underway

- Current I&I team in place June 2023, schedule baselined in August 2023
- Progress is tracked using ~40 milestones with early finish and late finish dates
- The forecast I&I completion date August 22, 2025



Building SuperCDMS

Key components installed onto the seismic platform

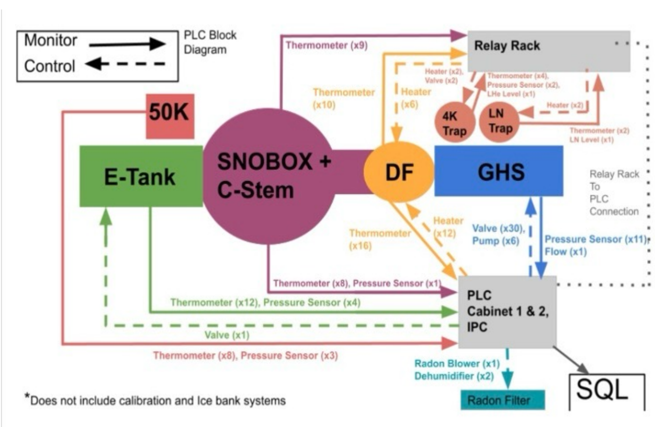
- Shield base and lower section of lead/poly shield wall up to C-stem
- Outer Vacuum Chamber: holds nested inner chambers and detectors
- Support frames for the E-Tank and the Dilution Refrigerator

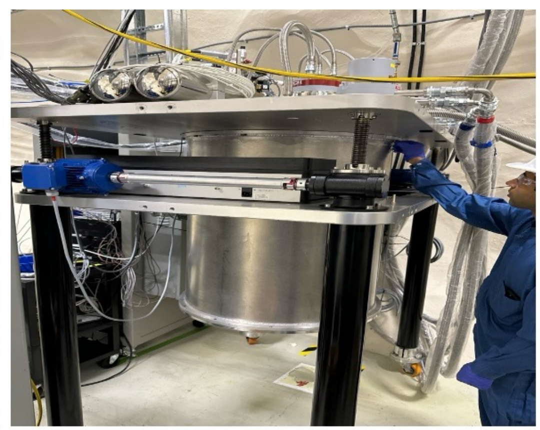
Etching and Passivation of Cryostat Components

- Copper cryostat parts required etching and passivation (“cleaning”)
  - Removes surface contamination and provides required thermal performance
- Major undertaking due to the size, weight of parts
  - 6 nested cylindrical chambers and lids
  - 5 nested cryogenic stems (C-Stems) that provide cooling to these chambers
  - 4 “tails” that connect the C-Stems to the DR,
  - 3 nested E-Stems that bring out the readout cables


Dilution refrigerator integration underway

- Programmable Logic Controller (PLC) - slow control and monitoring
- DR cold-testing with PLC in progress
- Currently operating DR with manual-fill liquid N_2 cold trap, internal 4K He cold trap
  - Commissioning N_2 reliquifier
  - External 4K cold trap is ready to go

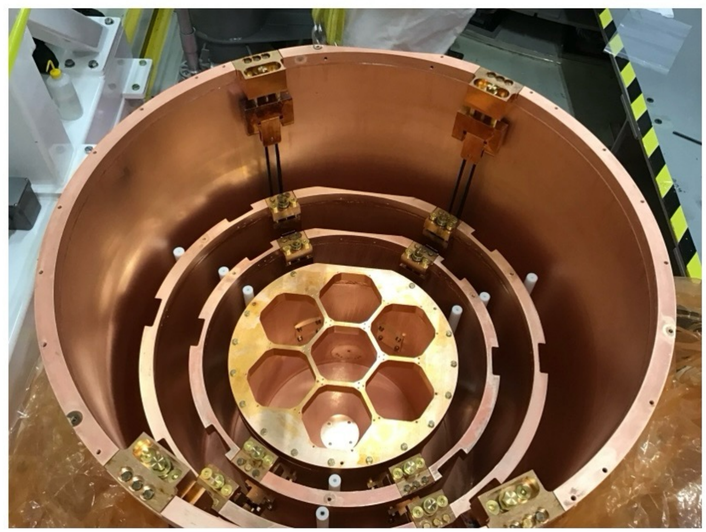


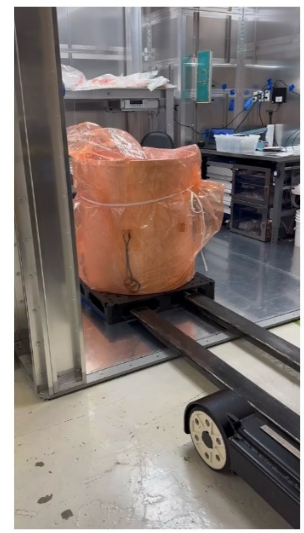




Cryostat Assembly

Assembled thermal stages of DR -- nested cans

- Mixing Chamber (15 mK)
- CP (100 mK)
- ST (700 mK)
- LH (4K) thermal stages of the DR

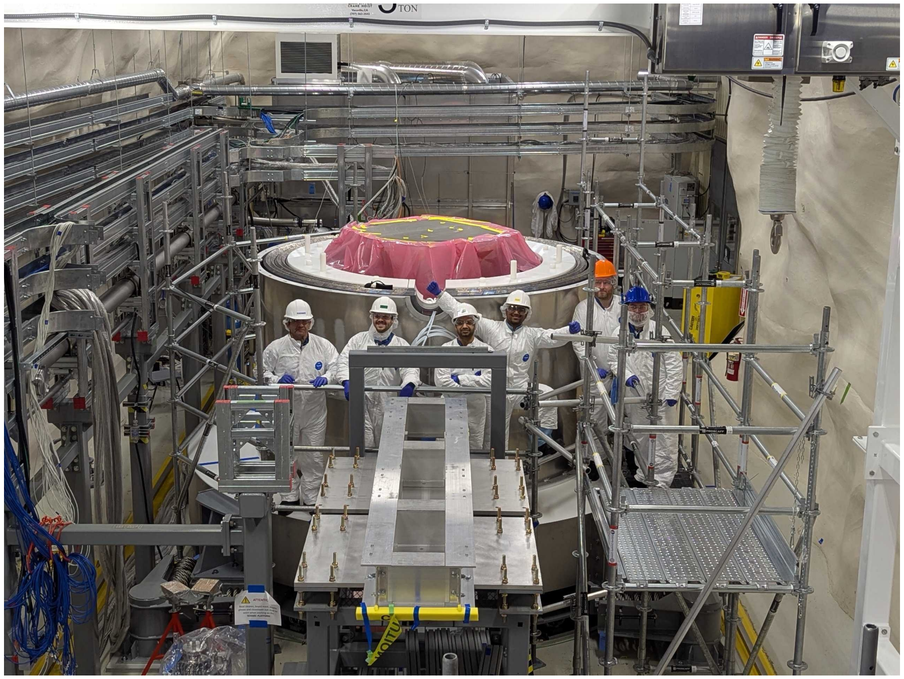




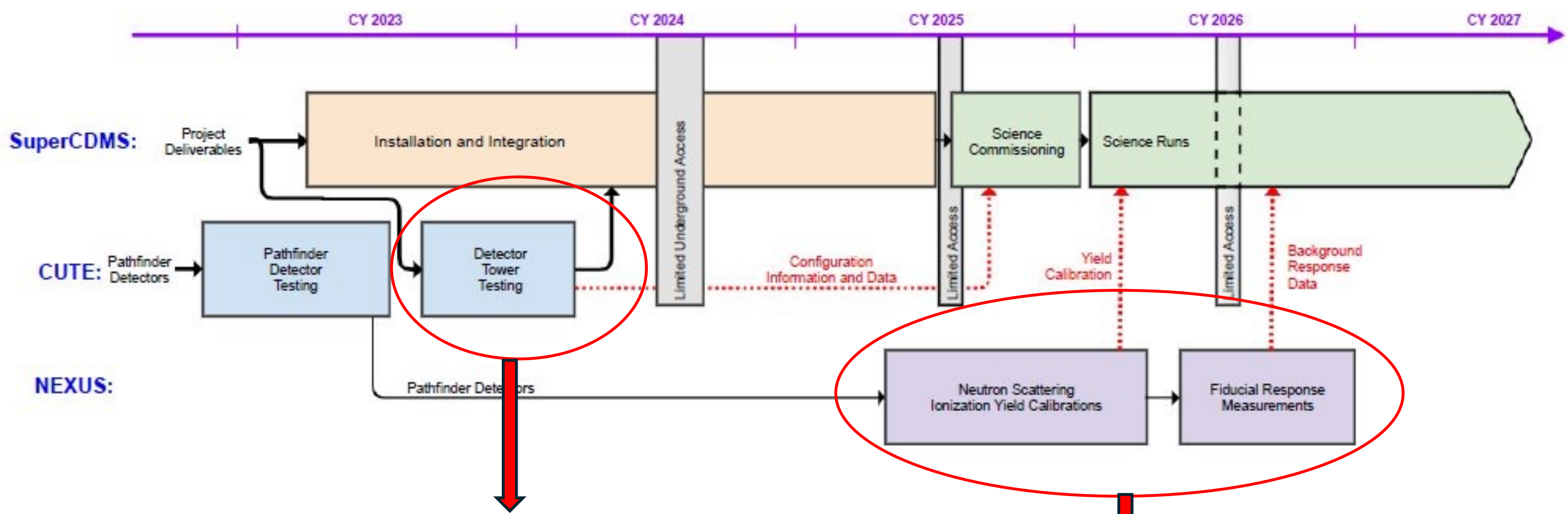
Pb shield and tower installation underway

- Ultra-low background lead shield installed up to E-stem
- First tower installed – Tower 2

Friday, 14 March 2025



Schedule includes detector and physics studies



CUTE Tower 3 Test Run

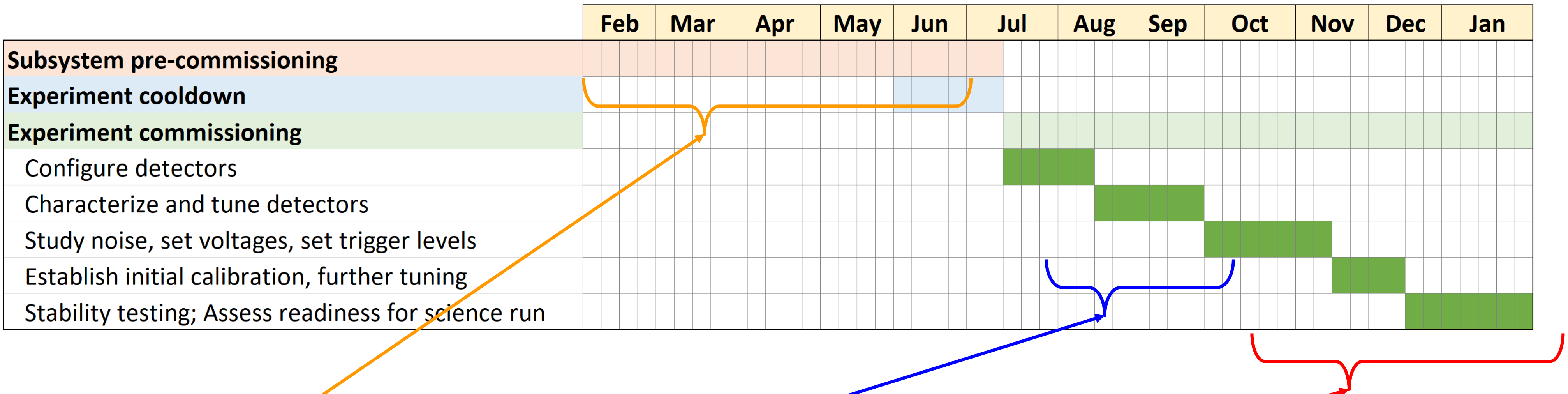
NR yield measurements
NEXUS program

Science Commissioning Plan

Goal of Commissioning is to deliver a well-performing experiment that meets or exceeds Operations Requirements

1. Effective handoff from I&I to Operations
2. Data flow from detectors to off-site processed data
3. Test and tune monitoring systems
4. Noise performance consistent with requirements
5. Stable cryogenic operations
6. Establish settings & data-taking procedures
7. Comprehensive documentation
8. Implement shift model and training

Science Commissioning Plan



Preparation Tasks	Early Commissioning Tasks	Analysis Tasks
Develop pulse reconstruction algorithms	Validate pulse fitting with commissioning data	Generate pulse templates
Import environment variables into analysis files	Validate environment variables	Generate relative-channel calibrations
Develop methods to deal with missing channels	Validate missing channel methods	Address missing channels

Event Reconstruction

Tower Testing and NR Ionization

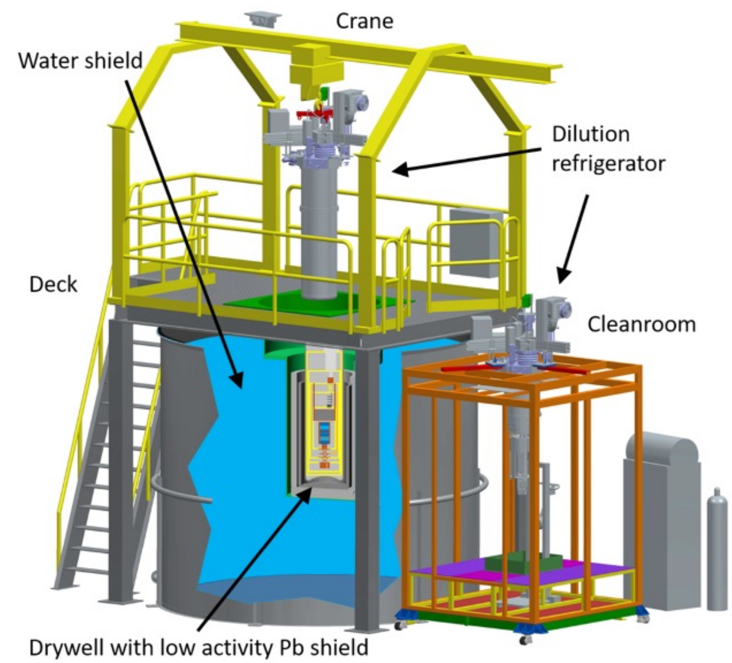
Tower 3 testing in CUTE

Tested Tower 3 in CUTE

- Collected data October 2023 – March 2024
- Main goals:
  - Exercise detector operation, DAQ, data handling and processing
  - Train workforce
  - Develop operational procedures (e.g., setup, neutralization)
  - Understand HV performance
  - Detector calibration and performance assessment
  - Develop event reconstruction and other analysis tools
- Secondary goal: acquire low-background data for science
- Run very successful – all operational goals achieved

CUTE: Cryogenic UG Test Facility

Used for HVeV studies, pathfinders, detector characterisation



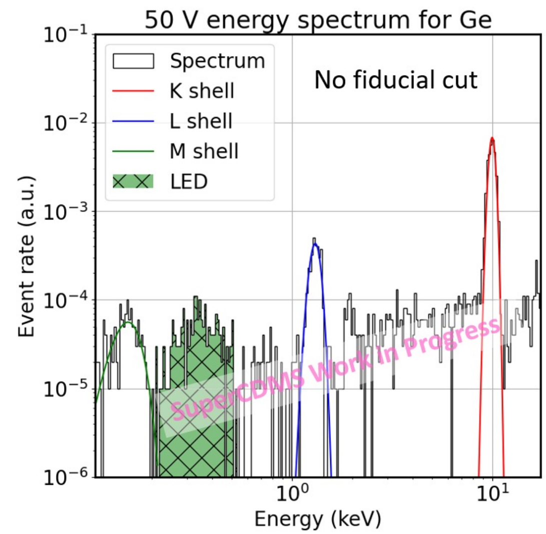
Tower 3 testing in CUTE – Calibration

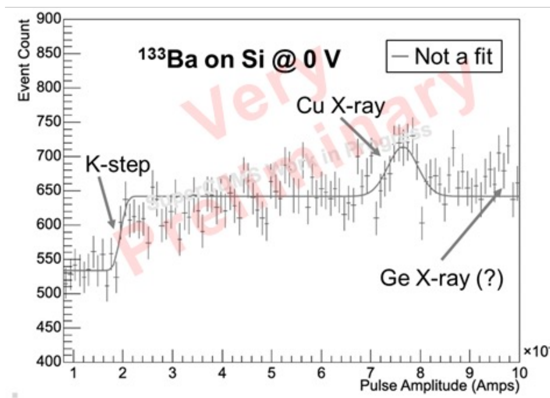
Ge calibration

- Neutron activation → ^{71}Ge,
  EC capture (10.4 / 1.3 / 0.16 keV)
- Used for calibration of all detectors
- Working to understand baseline resolution
- Repeat for all Ge detectors and all voltages

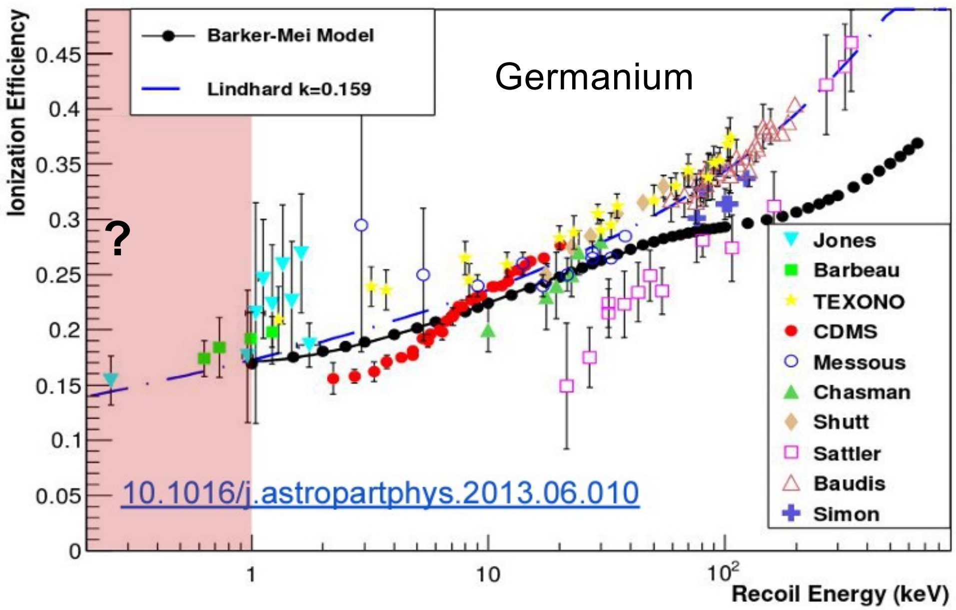
Si calibration

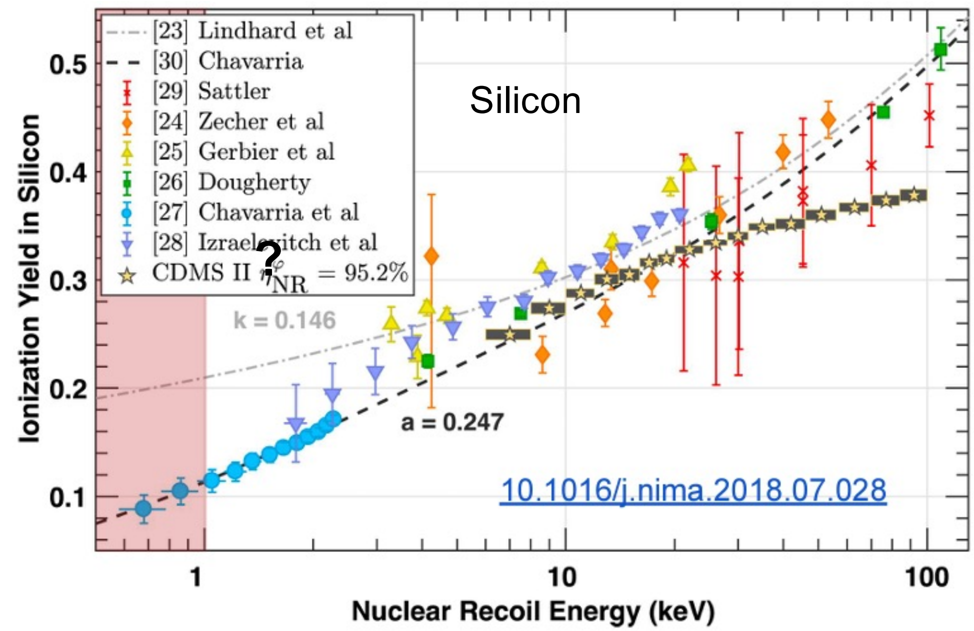
- Change in Compton scattering rate near electron binding energies (→ "Compton steps")
- Used ^{133}Ba source for gamma source
- Initial findings promising; full analysis underway



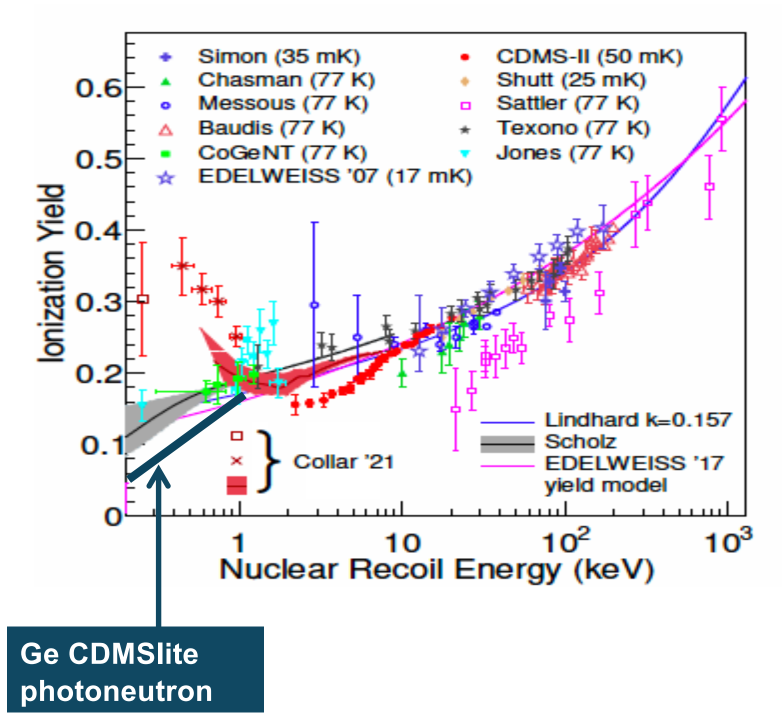


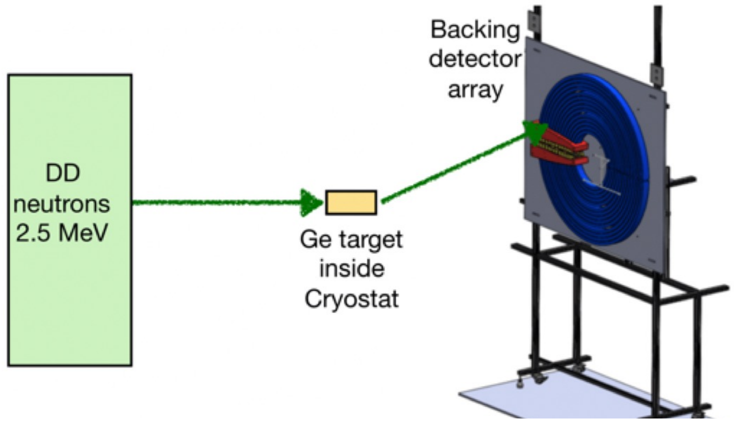
What is the Nuclear Recoil Scale at low energies?





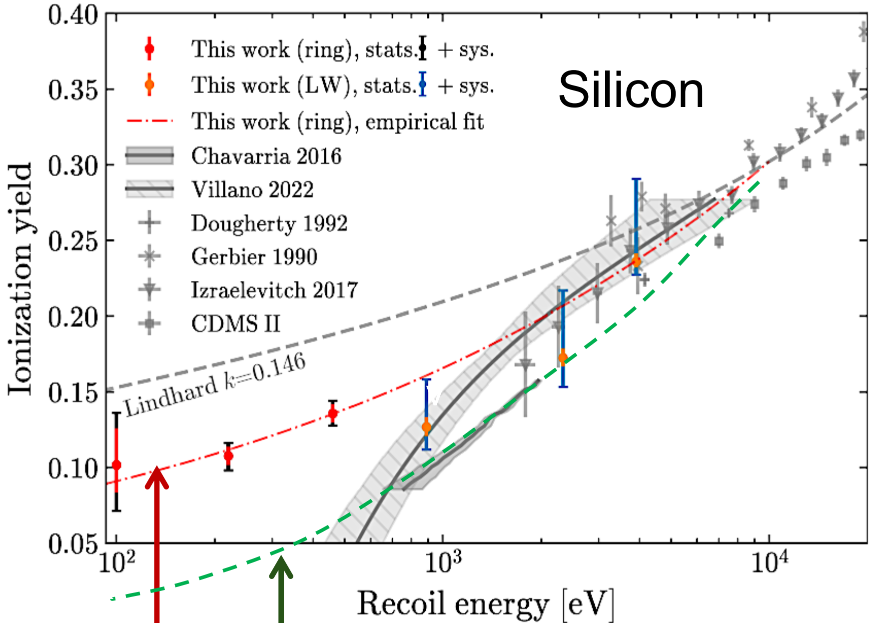
NEXUS will measure the NR scale in a Ge HV





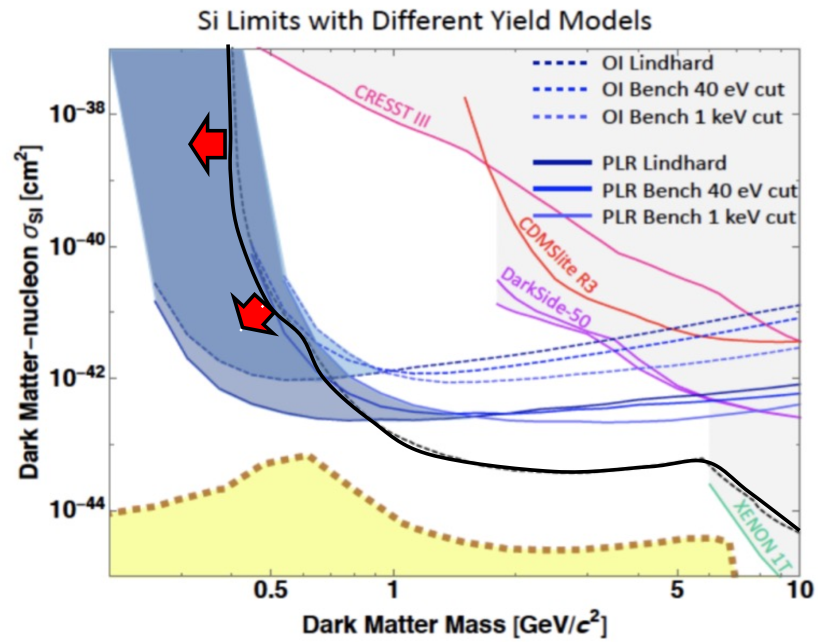
- Pathfinder Ge detectors with new HV sensors (Tc is 50-60 mK)
- An existing Tower repurposed for NEXUS
- DD Generator installed and powered up
- Backing Array designed and in fabrication
- Integration of Generator, Detector DAQ, Backing array readout with ~0.1 Hz synchronization pulse
- Tests of prototypes provide trigger efficiency and threshold estimates.
- Data-taking this summer 2025 ➔ Results in time for first paper

Why does it matter?



New Results from IMPACT

Yield model previously used for SuperCDMS project limits



Our original Si project limits were based on a modified Lindhard (green) that passes through Chavarria 2016

Backgrounds and Analysis Strategy

Background Control

Background control absolutely critical

- Cleanliness and control of radon, dust, cosmic-ray exposures
- Requirement of < 100 (1100) events/keV/kg/year for Ge(Si) detectors

Procedures

- Limit cosmogenic backgrounds (e.g., UG storage)
- Limit Rn exposure
- Operation of low-radon cleanroom to support I&I activities
- Cleaned and passivated copper
- Assay EVERYTHING!

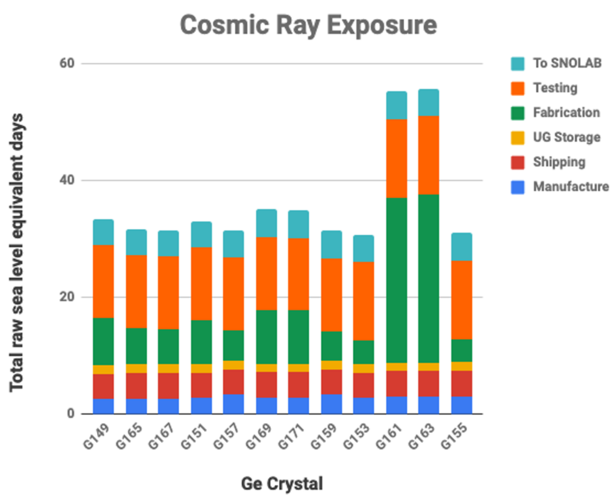
Example:
C-stem rod remade from newly sourced copper; measured radiopurity:
^{232}Th,^{238}U,^{40}K < 1,3,13 μBq/kg

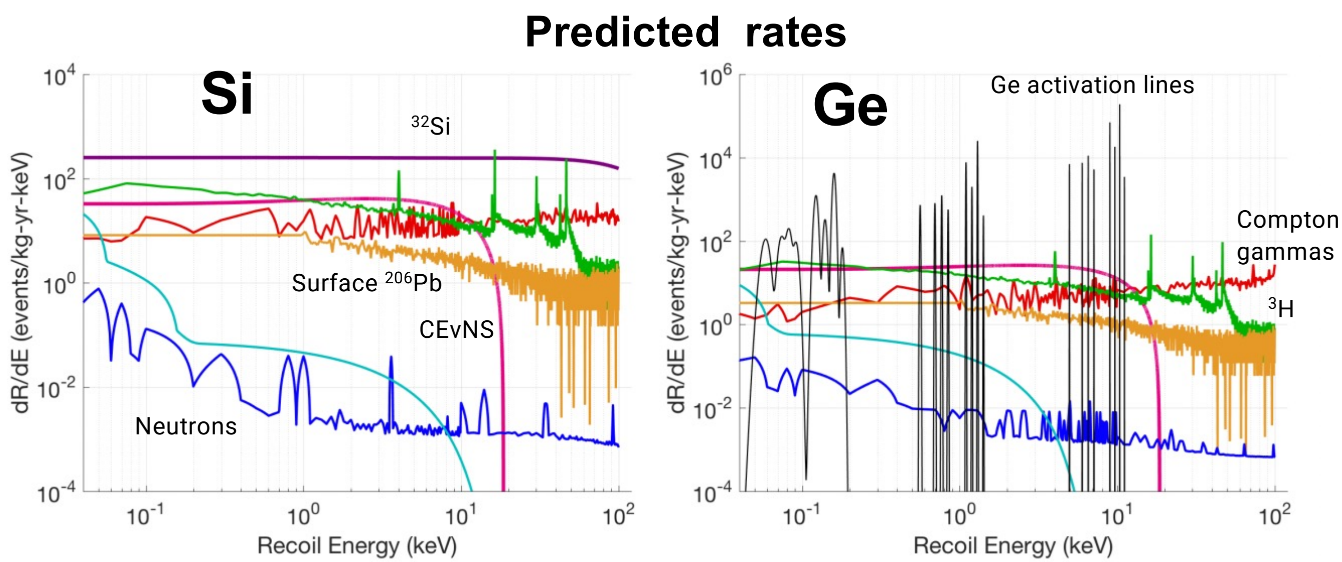
Background Control

Background mitigation complete when Pb shield assembled and under N_2 purge

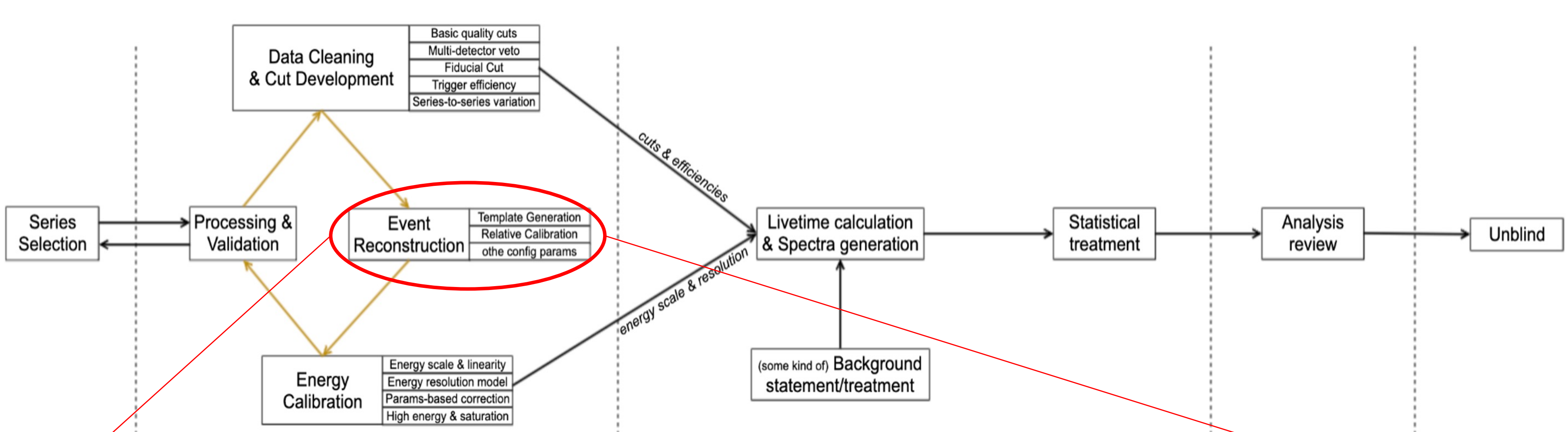
- Handoff assay results and exposure tracking to Backgrounds WG

Verification strategy -- measure background rates using spectra & simulation





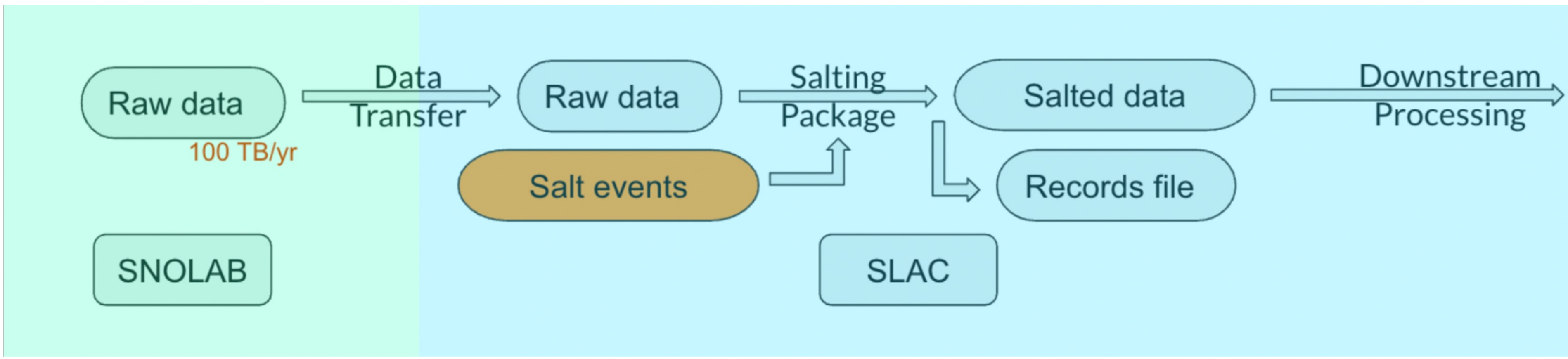
Analysis framework increasingly mature



Preparation Tasks	Early Commissioning Tasks	Analysis Tasks
Develop pulse reconstruction algorithms	Validate pulse fitting with commissioning data	Generate pulse templates
Import environment variables into analysis files	Validate environment variables	Generate relative-channel calibrations
Develop methods to deal with missing channels	Validate missing channel methods	Address missing channels
Event Reconstruction		

Blinding strategy development

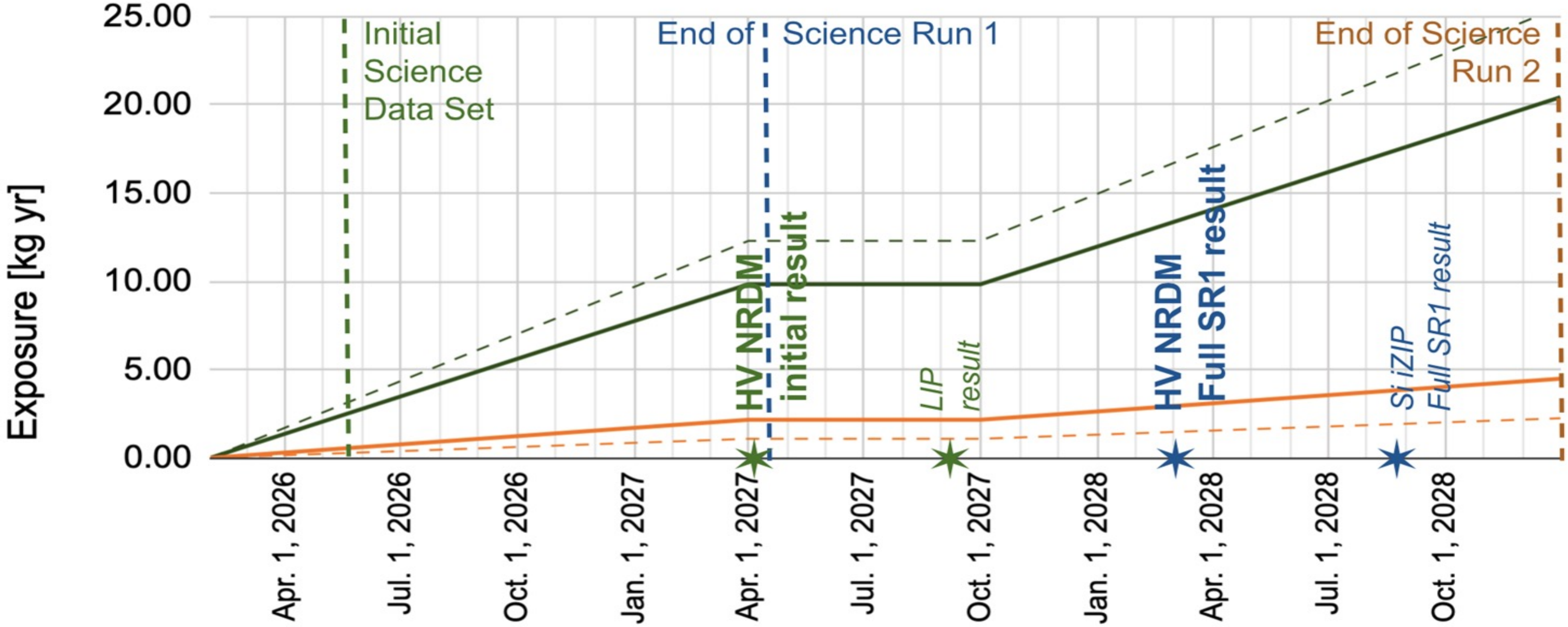
- Blinded analysis will be used to improve the credibility of results
- Have collaboration buy-in and implementation underway
- Baseline proposal includes salting with data division as a fallback strategy



Proposed data flow after salting is implemented

Science Running and Sensitivity

Two science runs planned for 2026-2028

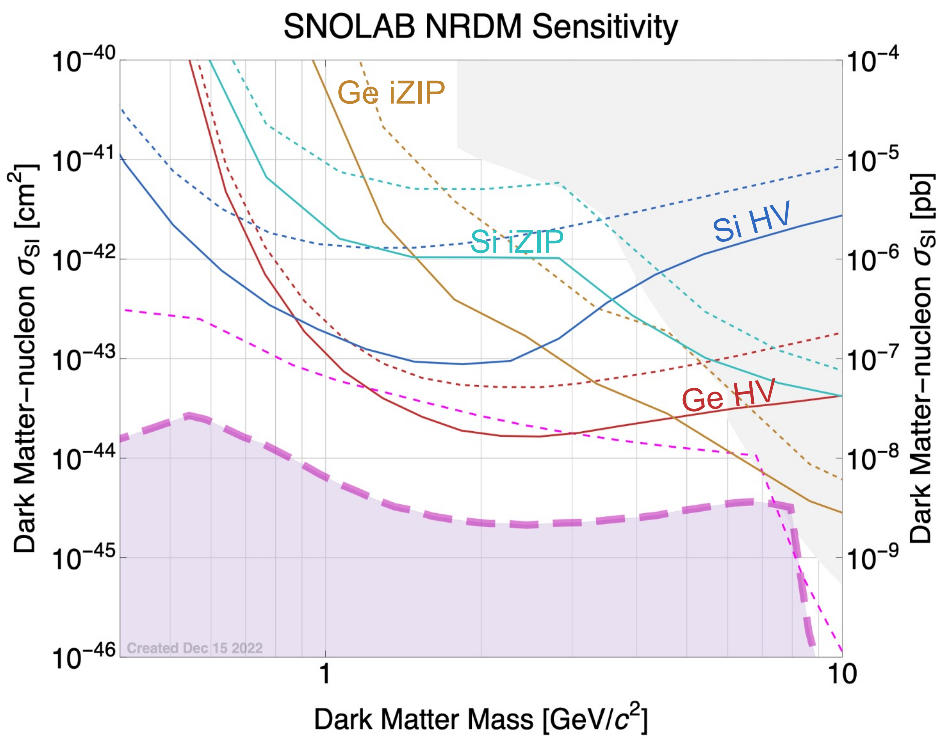


Approved 3-year science run (DOE, NSF, NSERC)
+ 9-month decommissioning takes us to October 2029

Benchmark: Nucleon-Coupled Dark Matter

Elastic Nuclear Recoil Interactions: 0.4 GeV/c^2 – 6 GeV/c^2

- Optimum Interval (Dashed Lines)
  - No detailed knowledge of background
  - Rapid improvement with time
  - Less sensitive with increasing # of detectors
  - No discovery potential
- Profile Likelihood (Solid lines)
  - Uses information from all detectors
    - iZIPs to determine backgrounds
    - HV to maximize low-mass sensitivity
  - Benefits from full exposure



The low-mass region is already being probed

Recent result from TESSERACT Collaboration

- Exposure is 0.223 g x 12 hours
  - Technology similar to SuperCDMS sensors
  - Improved resolution, noise performance and sensitivity
- Reflects the potential of smaller detectors
  - Has single-electron resolution

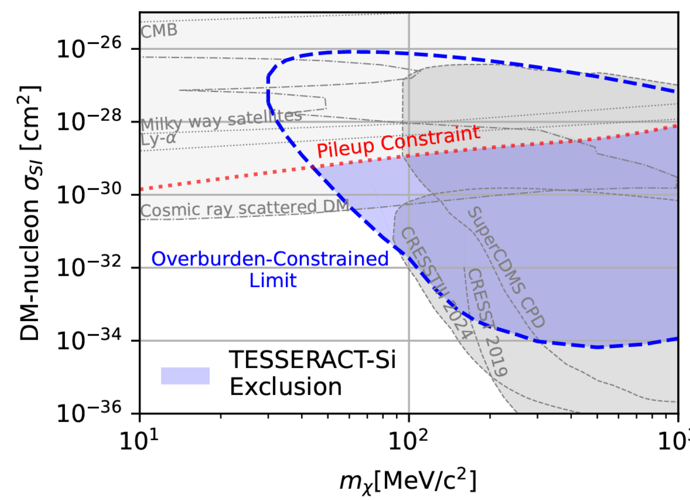


FIG. 5. The 90 % C.L. limits on spin-independent DM below 1 GeV/c^2. The blue shaded region shows the exclusion from this work. The blue dashes line represents the exclusion from the Yellin optimum interval test when considering the effect of the overburden. The red dotted line is from the requirement that there be no DM signal pileup. Previously excluded DM phase space from the CRESST [8, 40] and SuperCDMS [11] collaborations are shown in gray. Constraints from cosmology and astrophysics are shown in light gray [47–51].

TESSERACT Collaboration, C.L. Chang et al., arXiv:2503.03683

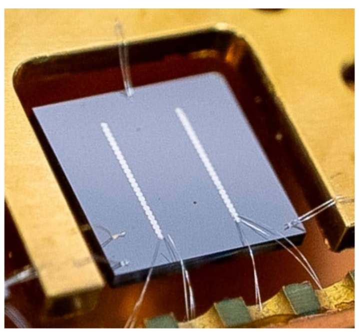
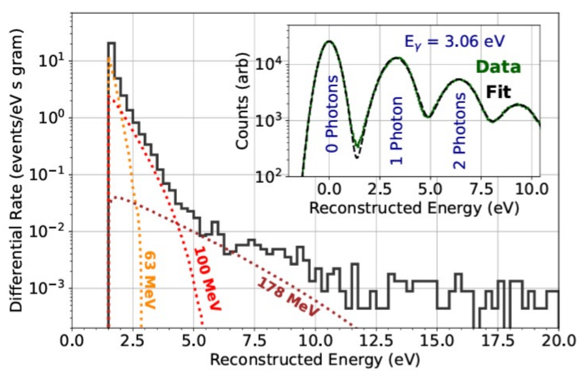


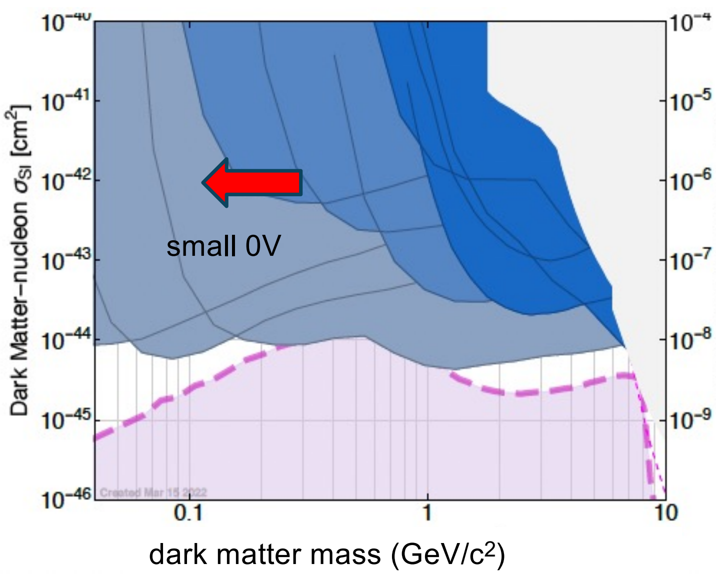
FIG. 1. The TESSERACT 1 cm^2 detector used in this analysis [32]. The detector is supported by wirebonds attached at the top center and bottom corners of the detector. A gold wirebond (left side) is used to cool the detector. The two sensor channels ("left" and "right") can be seen as the parallel lines, each biased and read out separately (see electrical wire bonds to readout PCB).

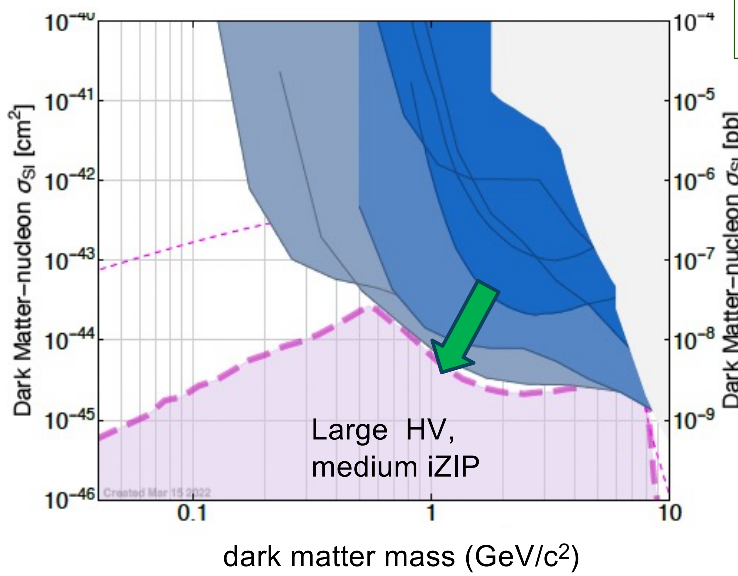


Next phase of SuperCDMS in planning

Augmented payload already sketched out at 2022 Snowmass Meeting

Nucleon-coupled dark matter (50 MeV – 5 GeV)





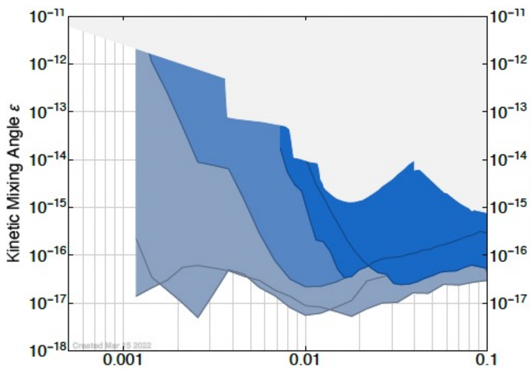
A Strategy for Low-Mass Dark Matter Searches with Cryogenic Detectors in the SuperCDMS SNOLAB Facility.
https://arxiv.org/abs/2203.08463

Large = 260 cm^3 (SNOLAB-size Detector)
Medium = 10 cm^3
Small = 1 cm^3

Dark blue = SNOLAB limits with current payload.
Light blue = In-hand small detector mosaics filling two towers running at 80% duty cycle for 4 yrs.
Dark Grey = Mosaics of upgraded detectors in two towers.

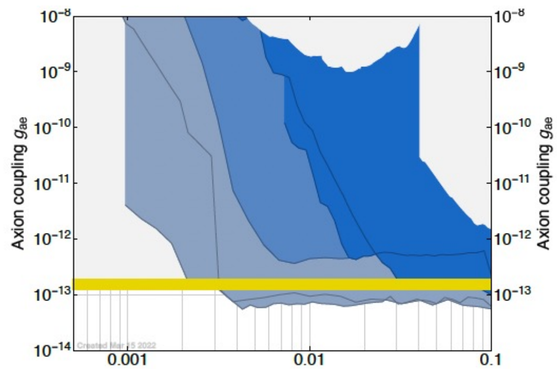
Light (5-100 MeV) DM & dark photons and ALPs (10 -100 eV)

Dark photon kinetic mixing

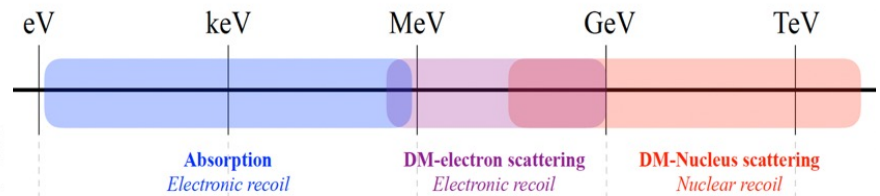


dark photon mass (keV/c^2)

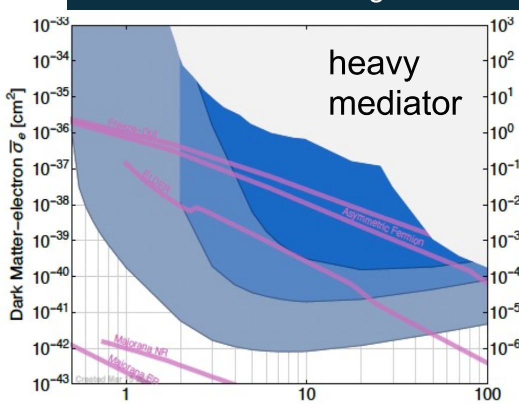
ALP effective coupling



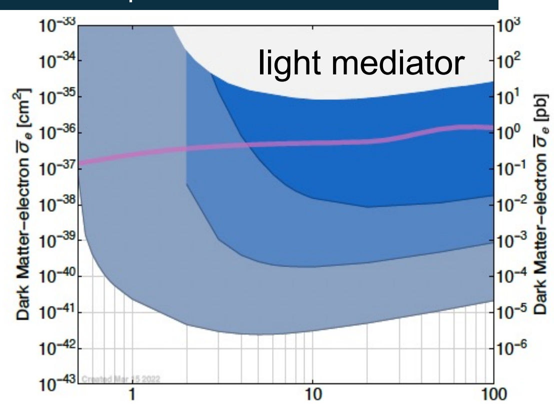
ALP mass (keV/c^2)



Light DM coupled to dark photon



dark matter mass (MeV/c^2)



dark matter mass (MeV/c^2)

Yellow line: parameter space consistent with the hint from white dwarf cooling.

J. Cosmo. Astro. Phys. 2016, 057

Pink lines are sharp targets for $M_{A'} = 3\,M_\chi$ from 2017 cosmic visions workshop

>130 scientists at 28 institutions & 6 Countries, including 3 US national labs and 2 Canadian labs

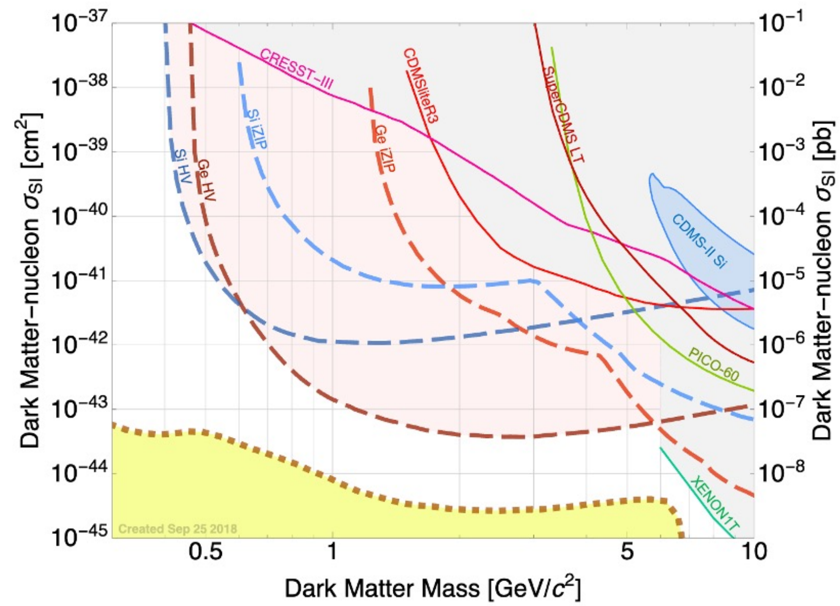
Summary

Detector completion by August 2025

- Science running expected in early 2026
- Had first UG operation of production detector in CUTE
- CUTE and NEXUS measurements reducing uncertainties

World-leading sensitivity -- DM 0.1-1.0 GeV mass

- Preparing for first paper (early 2027?)
- 3-year run will provide final reach
- The SuperCDMS SNOLAB facility has future potential



Backup Slides

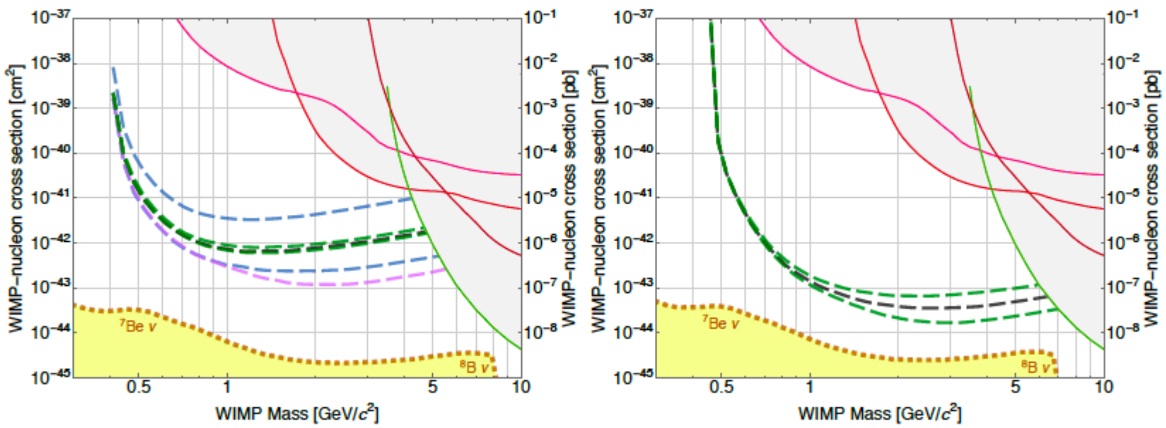
Milestones extracted from the schedule

- OVC Chamber installed on shield base and perform metrology: **Completed Sep 20, 2024**
- Remaining Chambers and Stems Received at SNOLAB: **Completed Jan 13, 2025**
- Inner Chambers Assembled and Ready for Tower Integration: **Completed Jan 27, 2025**
- Completion of component etching and passivation: **Completed Jan 28, 2025**
- Lid test assembly with operation tower (tower installation rehearsal): **Completed Jan 31, 2025**
- C-Stem Installed: Forecast Feb 5, 2025
- Completion of shield wall: Forecast Mar 18, 2025
- Dilution Fridge ready for installation with Cryostat: Forecast Apr 15, 2025
- E-Tank installed: Forecast Apr 24, 2025
- Start Cooldown for Science Run: Forecast Jun 2, 2025
- I&I complete: Forecast Aug 4, 2025

Understanding Reach vs Bkgds and Ionization Yield

Silicon HV

Germanium HV



arXiv:1610.00006v1

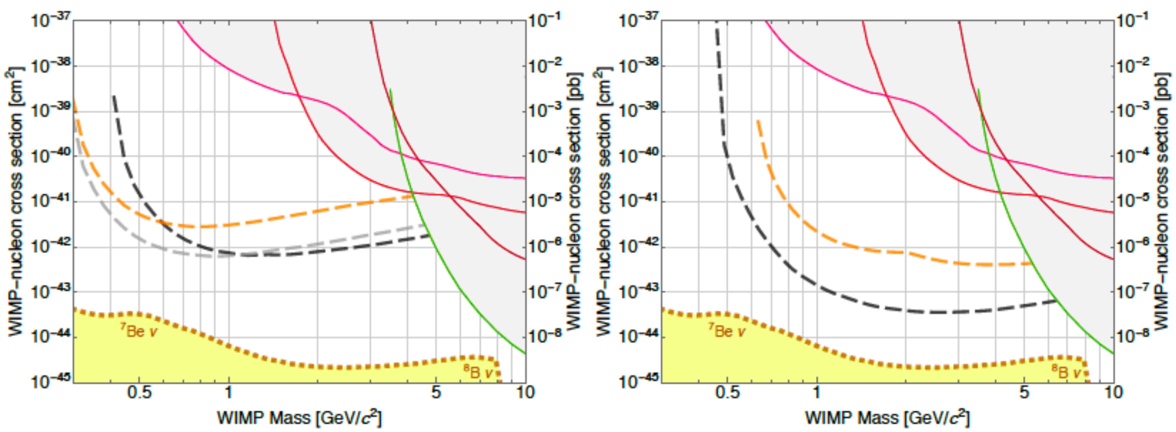
These figures were mentioned in the Space Allocation section of the EAC Report

PRD Fig 9: Varying Backgrounds

Green: ^{3}H (0 – 3 x nominal)

Blue: ^{32}Si (0 – 10 x nominal)

Pink: Both bkgds are zero



PRD Fig 10: Varying Yield

Grey: Standard Lindhard Yield Model with 40 eV cutoff

Black (nominal): uses an extrapolation based on Chavarria 2016

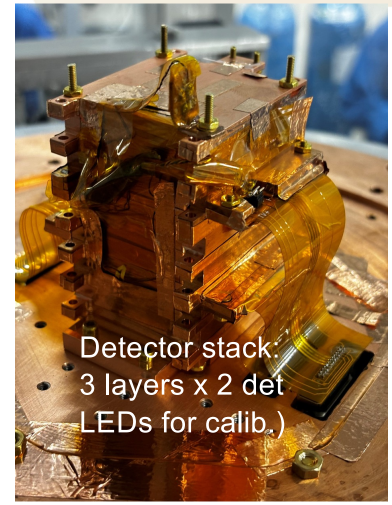
IMPACT (2023) results are in between the two.

Orange: $V_b = 0$ (nominal is $V_b = 100$ V) No Ionization-dependent amplification

HVeV detectors in CUTE

Led by E. Michielin (Marie Curie fellowship in Karlsruhe, PDF with funding)

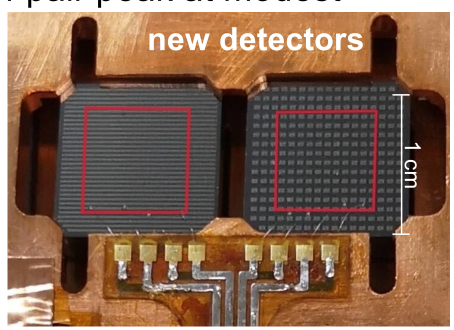
- 6 HVeV detectors (1 g each) operated April-Sept. (4 previously in NEXUS, 2 new)
- Main objective: understand low energy excess (LEE) events
- Outcomes:
    - Readout with SuperCDMS DCRC: excellent noise performance with filtering
    - New detectors (lower T_c, SiO_2 blocking layer): very good performance (baseline resolution < 1 eV, low leakage at modest voltage)
    - Acquired plenty of data at different voltages for LEE study
    - Potential for competitive DM search at very low energy (short exposure, but low rate in 1-eh-pair peak at modest voltage (35 V))

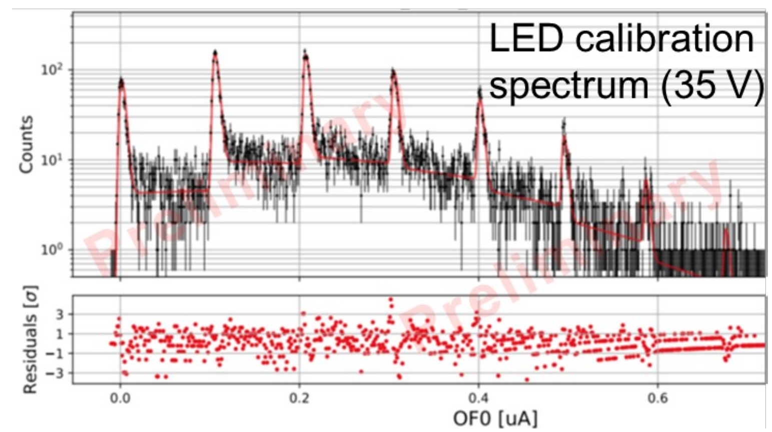


Analysis ongoing:

1st goal: complete DM search analysis

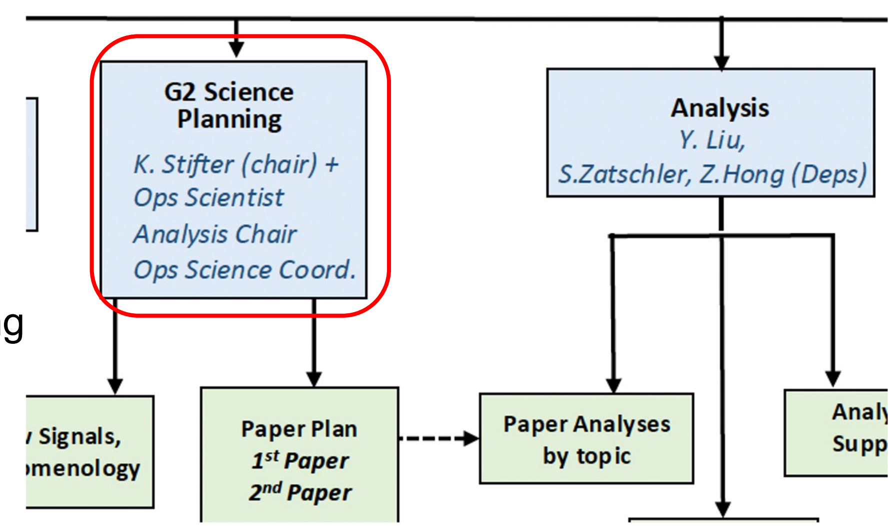
LEE analysis will follow





Define what first SNOLAB analysis entails

- The newly created science planning WG is a suitable forum to define the first SNOLAB analysis
  - What the first SNOLAB analysis/paper depends on several factors
    - Detector performance (How many working? Threshold/resolution? HV/iZIP?)
    - Background levels
    - Leakage/LEE situation
    - Calibration capabilities (NR/ER; Si HV)
    - Analysis Readiness (analysis flow)
    - …
  - Preparing for multiple scenarios
  - Final decision will be made during commissioning

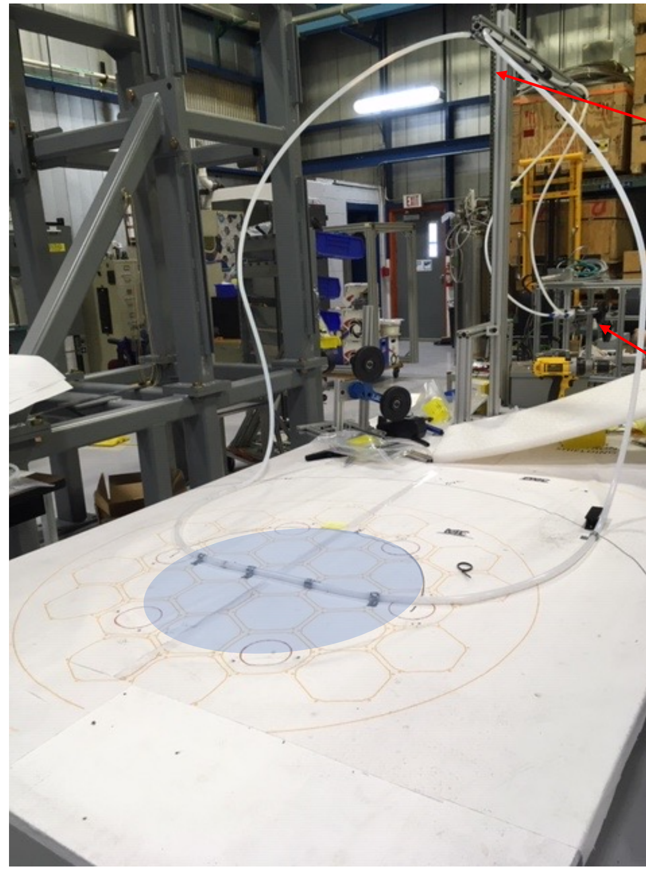


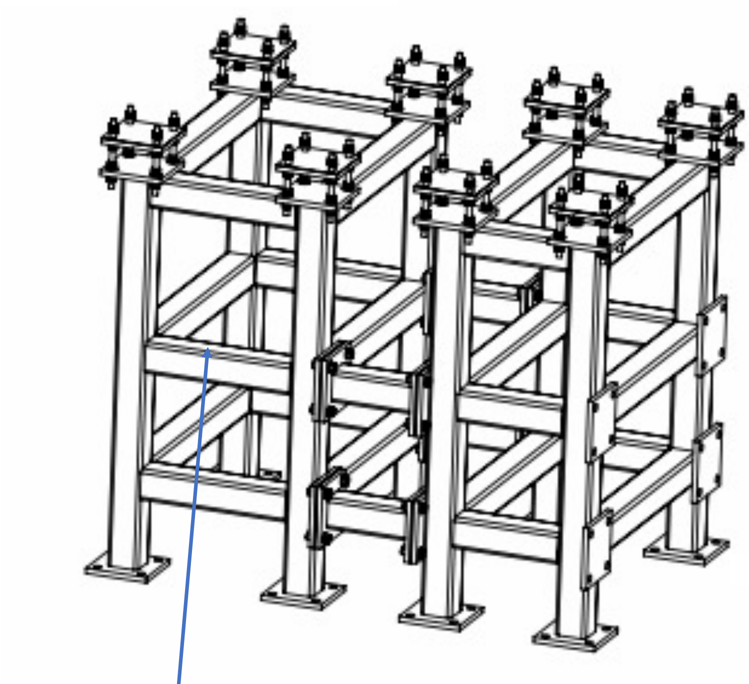
Draft collaboration org chart

Calibration System

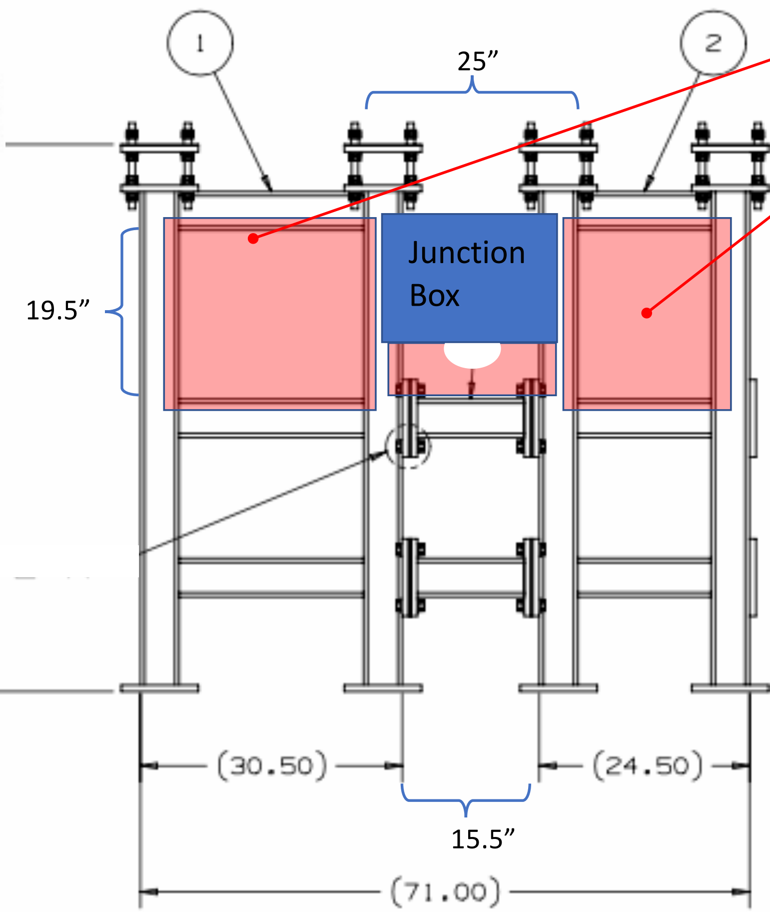
SuperCDMS Calibration

- **Systems consist of:**
  - Automated gamma deployment system (^{133}Ba), controlled via PLC
  - Manual ^{252}Cf neutron source deployment system
- In 2022, gamma skid was cleaned and packed in a crate. It, along with Ba sources have since been shipped to SNOLAB and is underground
- Ability to control system via DAQ was demonstrated at FNAL. Remaining testing will be done during commissioning at SNOLAB
- ^{252}Cf sources were encapsulated at Fermilab Fall 2024, deployment hardware was tested and finalized in 2024. Sources awaiting licensing update at SNOLAB before they can be shipped
- Guide tubing installation is interwoven with stem and can installation sequence
- Gamma calibration system is the last system to be installed, current projected time is May 2025

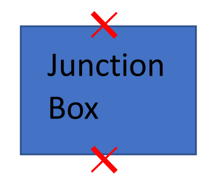




Gamma calibration instrumentation "skid" will reside in the upper portion of etank framing.



Plexiglass panels on four sides (none on bottom or top). Will be screwed onto frame.



Junction box contains PLC electronics. Hole in top for 24V DC power from cryo PLC cabinet

CUTE Backup Slides

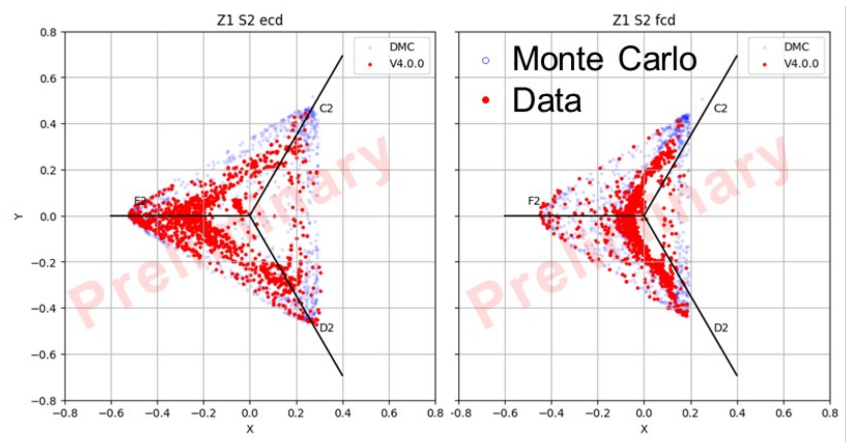
Full set of possible SuperCDMS Papers (refer back to Space Allocation Slide)

47	SuperCDMS SNOLAB science papers		
48	33	Run 1 initial HV result	2026 Q4
49	34	Run 1 initial ERDM, dark absorption result	2027 Q1
50	35	Run 1 full HV result, long paper	2027 Q4
51	36	Run 1 LIPs search	2027 Q1
52	37	Run 1 EFT results	2027 Q2
53	38	Run 1 full ERDM, dark absorption	2028 Q1
54	39	Run 1 Alternate analysis/physics channel	2029 Q1
55	40	Run 1 iZIP result	2028 Q2
56	41	Run 2 initial HV result	2028 Q4
57	42	Run 1 + 2 solar axion search	2029 Q3
58	43	Run 2 LIPs search	2029 Q4
59	44	Run 2 EFT results	2030 Q4
60	45	Run 2 ERDM, dark absorption	2029 Q1
61	46	Run 2 Alternate analysis/physics channel	2031 Q1
62	47	Run 2 HV long paper (ultimate HV result)	2030 Q3
63	48	Run 2 iZIP result	2030 Q2
64	49	Run 1 + 2 NR annual modulation analysis	2030 Q1
65	50	Run 1 + 2 ER annual modulation analysis	2030 Q3
74	51	Solar neutrino measurement	2029 Q4

Tower 3 testing in CUTE

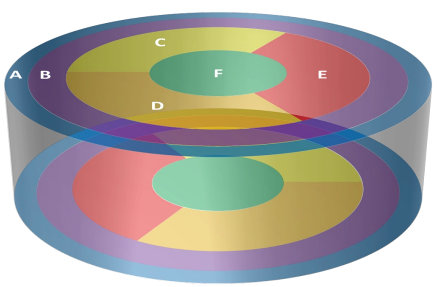
Data processing – main developments

- Template generation: settled on procedure; semi-automated process is being set up
- Relative calibration between channels (works for (inhomogeneous illumination, absence of peaks)
- Monitoring and control of processing much more shifter-friendly, partially automated
- Pre- and post-processing validation procedure in place



Data analysis – progress

- Event reconstruction developing (new fitting methods, position reconstruction, fiducialization)
- Identified and addressed data anomalies (e.g. duplicate triggers, trigger point offset)
- Good progress in developing event selection criteria
- Ge calibration analysis is expected to be finished within the next few weeks



CUTE Tower 3 Testing – Key Takeaways

Tower 3 functionality characterized:

- Reference for detector parameters (SQUIDs, TESs, etc.) → baselines expectations for commissioning

Performed dedicated noise characterization campaign:

- Identified key sources of noise → mitigations underway in advance of commissioning

Infrared photon leakage identified as limiting background in CUTE setup:

- Emphasizes IR leakage as a key concern → several measures underway to address risk

Demonstrated neutralization for HV detectors:

- Rapid procedure identified → reduces commissioning time & informs detailed procedures

Established high-voltage operating procedures:

- Monitoring, ramp-up, breakdown recovery → does not need to be developed during commissioning

Demonstrated low-energy calibration methods:

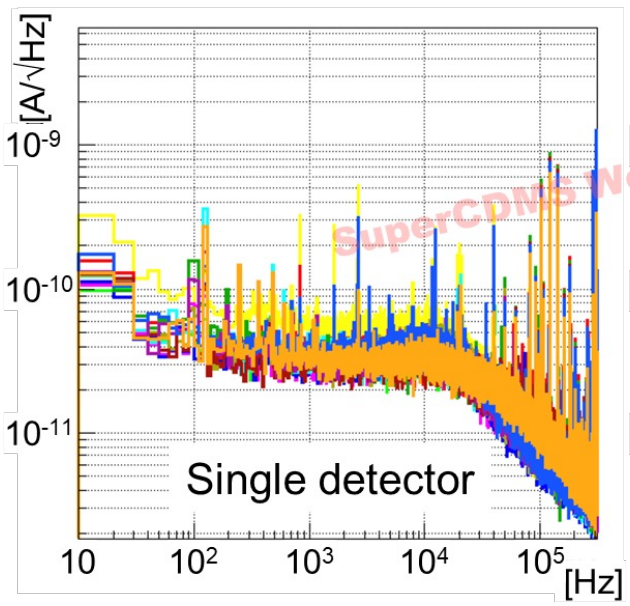
- Especially important for Si HV detectors → substantially mitigates a key commissioning risk

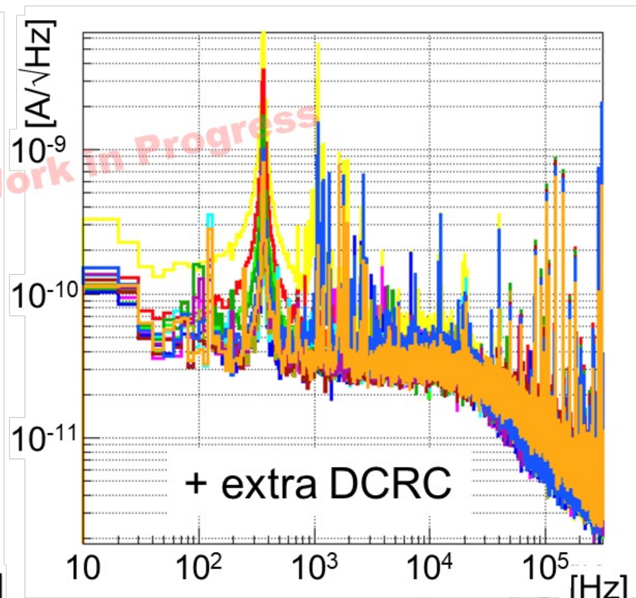
Exercised shift model, communication, monitoring methods:

- Identified need for more trained operators & to expand automated monitoring → informs shift model

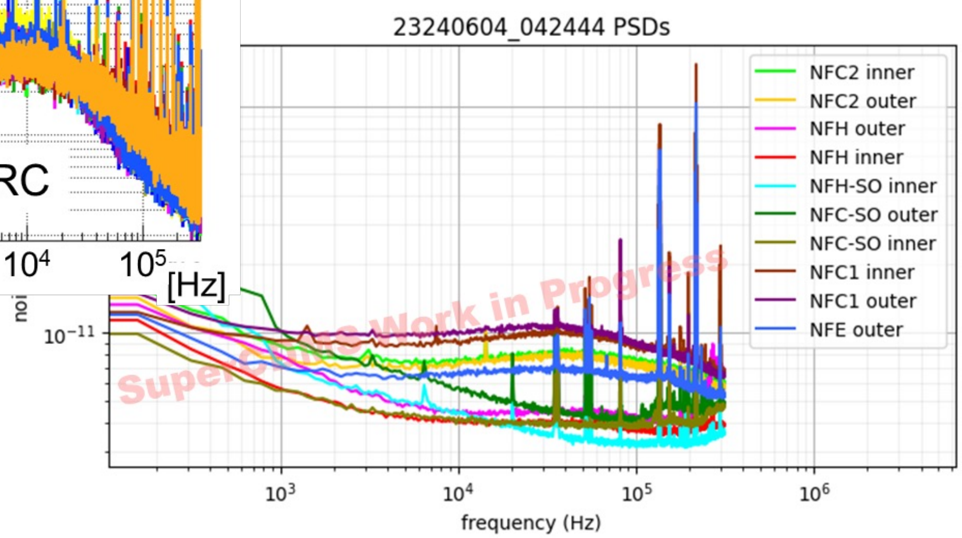
Tower 3 testing in CUTE – Backup

Noise comparison between Tower 3 and HVeV





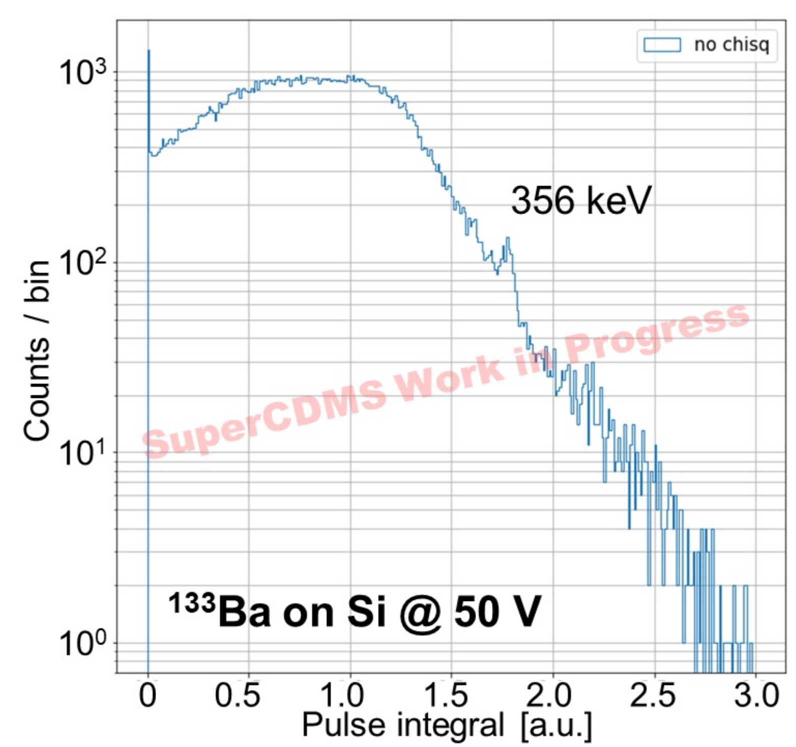
HVeV:
Very few lines <10 kHz;
Considerably fewer lines ≳ 50 kHz

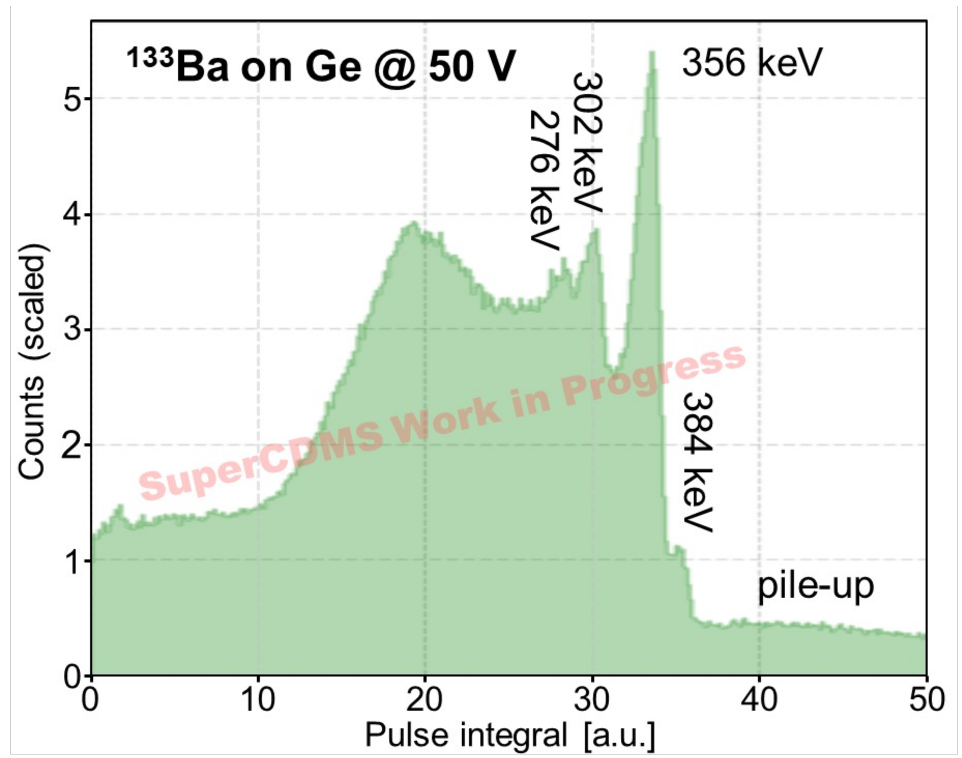


Tower 3:
Lots of lines <10 kHz;
Dense forest ≳ 50 kHz

Tower 3 testing in CUTE – Backup

High-energy calibration: features visible also at HV and for Si

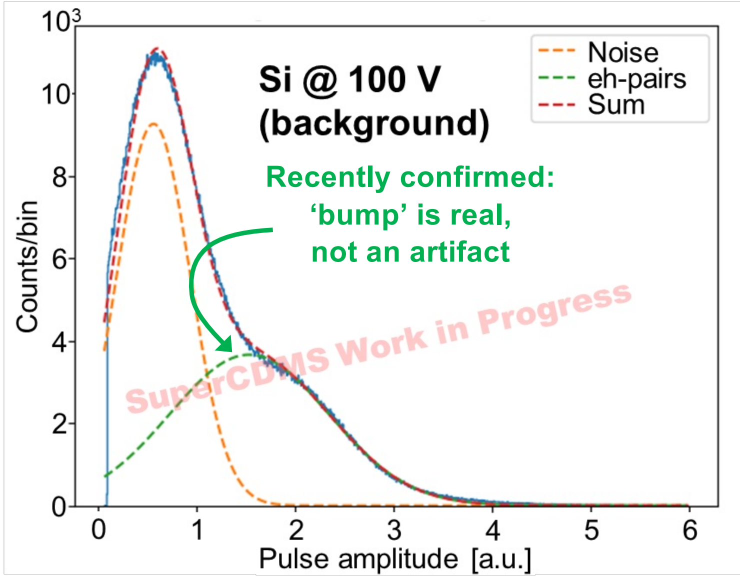


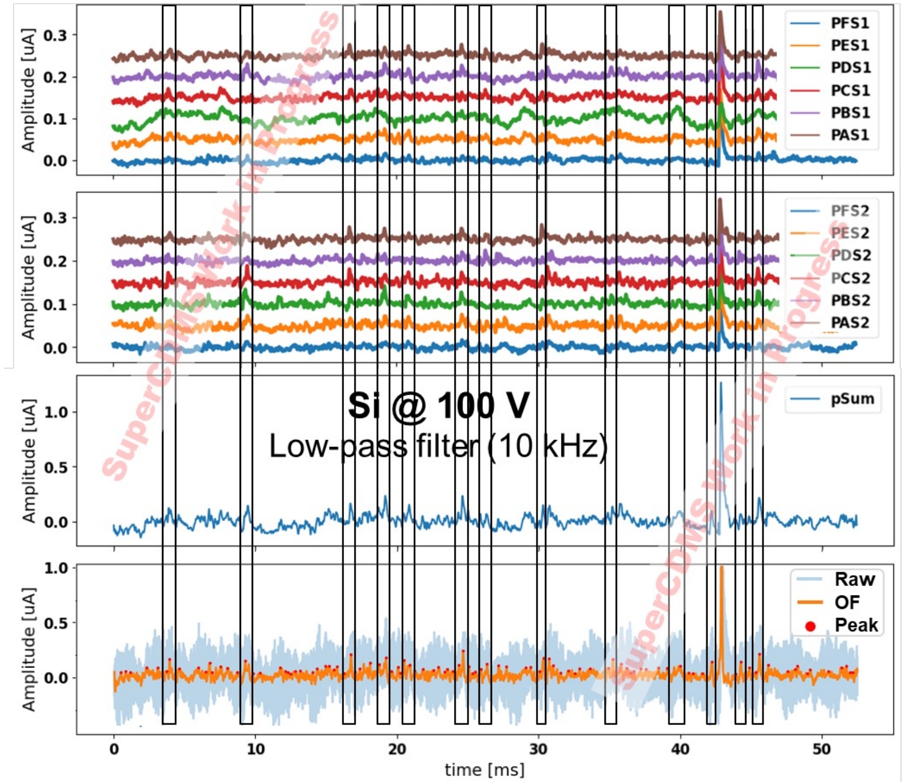


Tower 3 testing in CUTE – Backup

Si: hint for single eh-pair signals (work from early 2024)

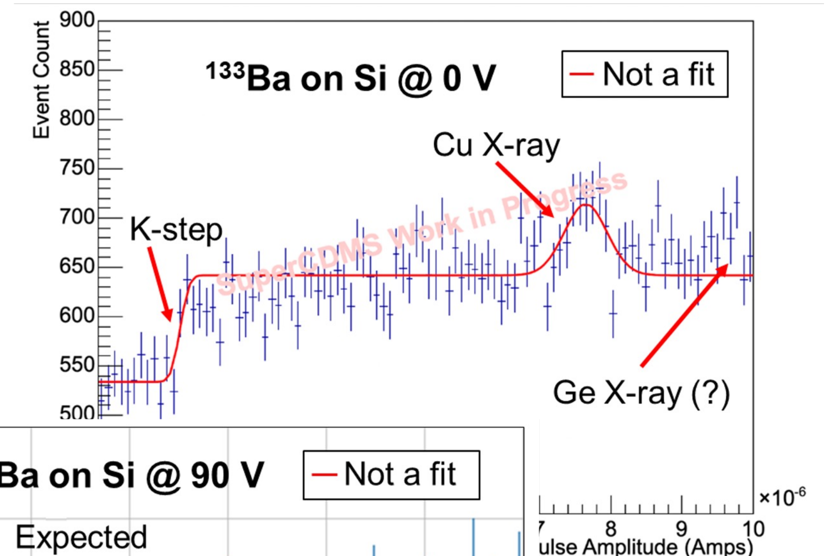
- Noise peak at 100 V bias shows shoulder; clear indication for 'real' events (not noise)
- Energy consistent with single eh-pairs
- Probably too close to noise for use in calibration
- High rate (O(100 Hz)) → likely from IR leakage

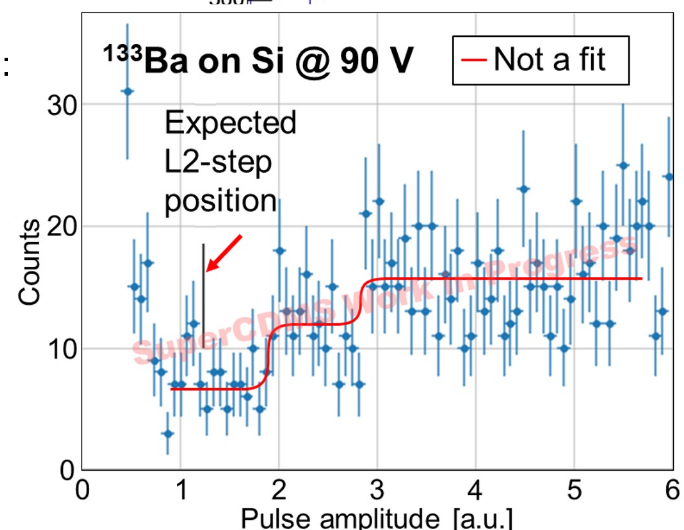




Calibration Plan Development

- Observations from HV tower testing at CUTE:
  - Si detectors are challenging to calibrate (no lines)
  - Compton steps:
    - K-shell step easily resolved with modest ^{133}Ba dataset
    - L-shell steps will require large ^{133}Ba dataset
- Implications:
  - Use K-shell for initial calibration (needed to commission)
  - Perform L-shell calibration (for science) during science run:
    - Option A: devote 25% of live time to Ba data
    - Option B: large Ba dataset after DM exposure
- Updated commissioning plan:
  - Periodic ^{252}Cf and ^{131}Ba source exposures
    - Events needed throughout commissioning
  - Last neutron exposure >2 months before science run
    - Limit activation event background





Monitoring Task Force

Monitoring Task Force

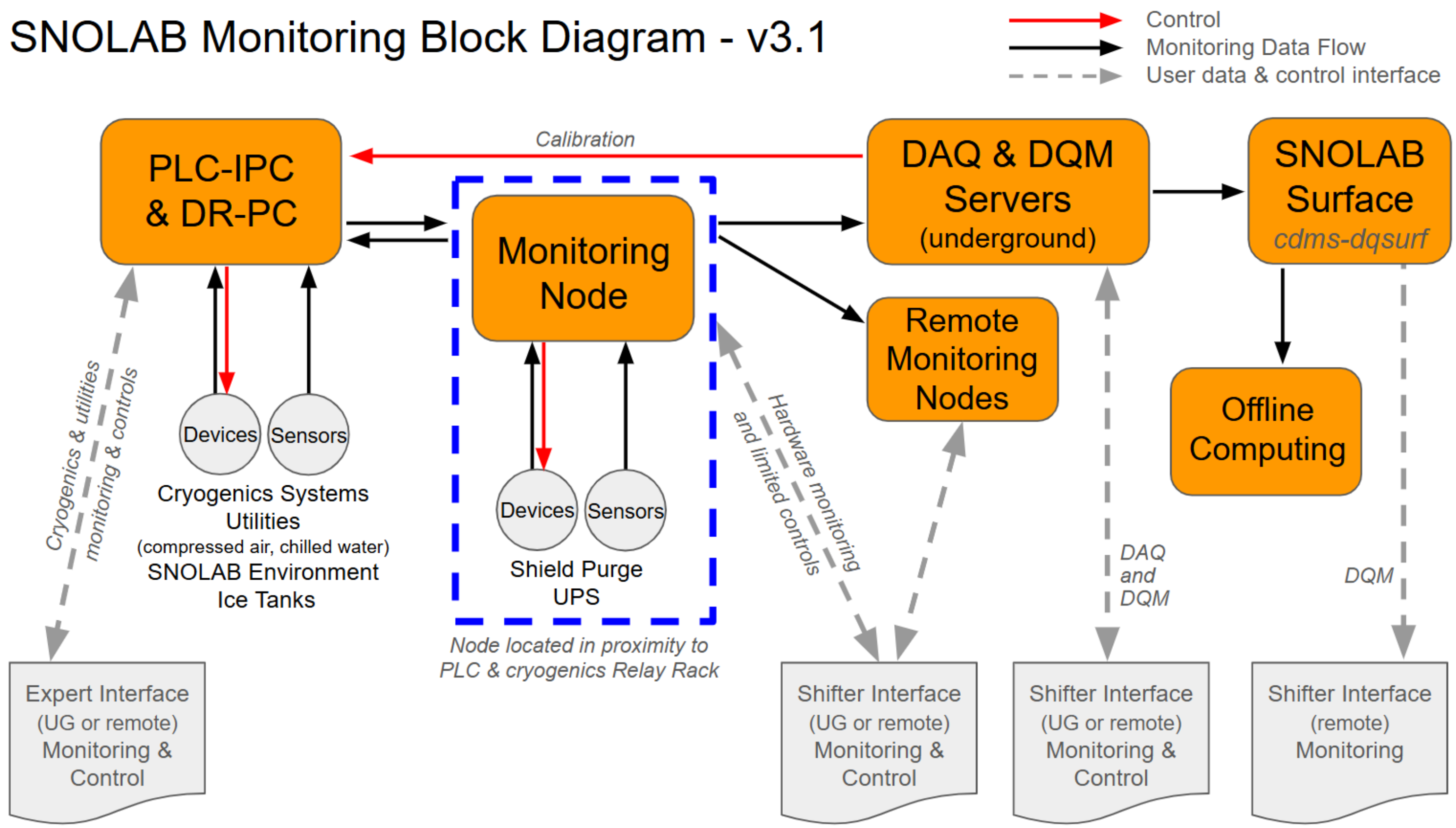
- Enumerated systems to be monitored
  - Started with list collected from system experts
  - Requested updates over course of fall
- Wrote down requirements
  - Developed by discussing with each system expert
- Developed architecture
  - Found original design needed updating
  - Incorporated realities of SNOLAB environment
- Philosophy of alerting
- Considered shifter interface
- Addressed specific elements of the charge
- Wrote draft report

Task Force Membership:

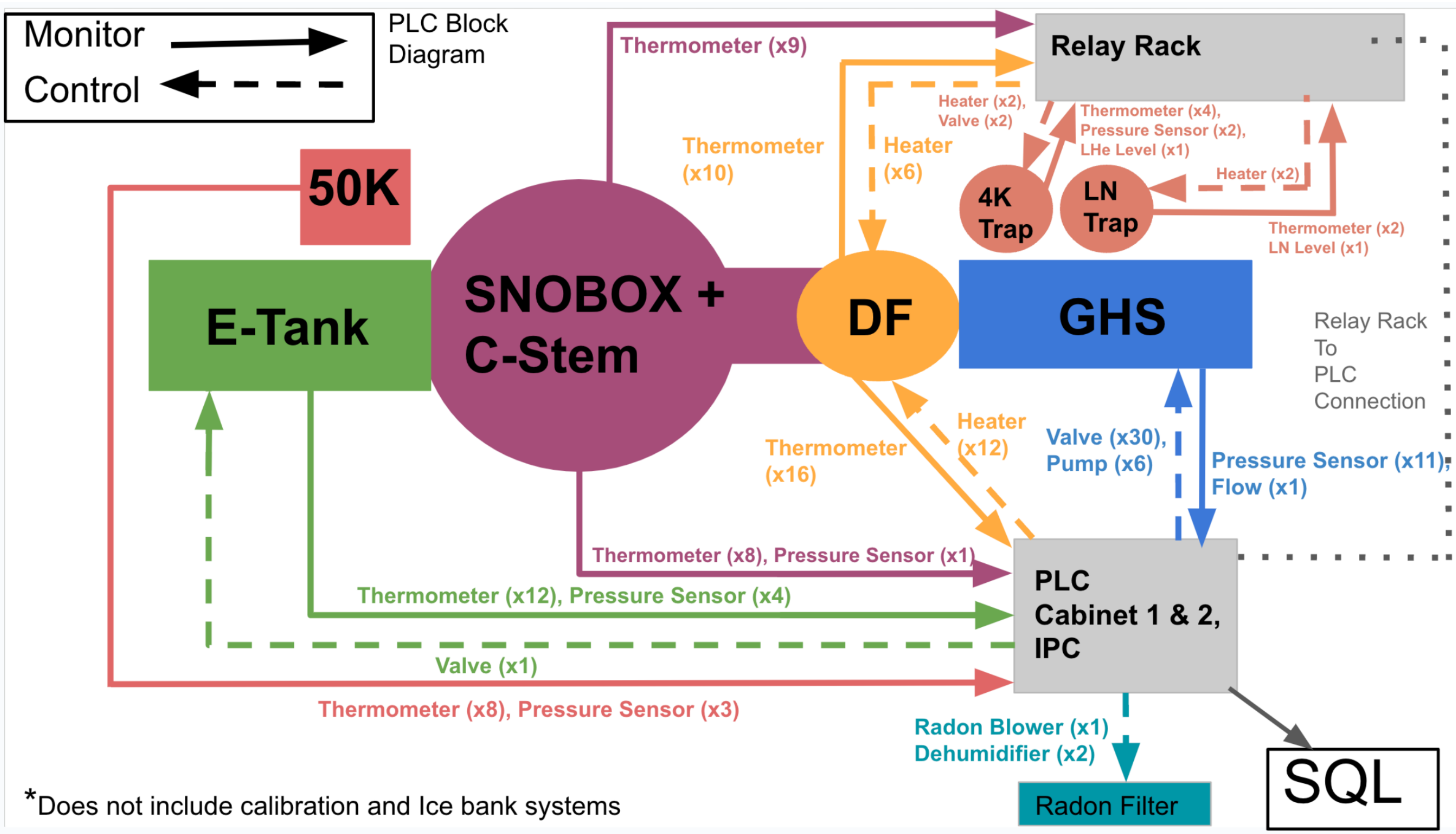
- Ray Bunker
- Yan Lui
- Joel Sander
- Pekka Sinervo (chair)
- Matt Stukel

[Monitoring Task Force Confluence Page]

Monitoring: Architecture Overview



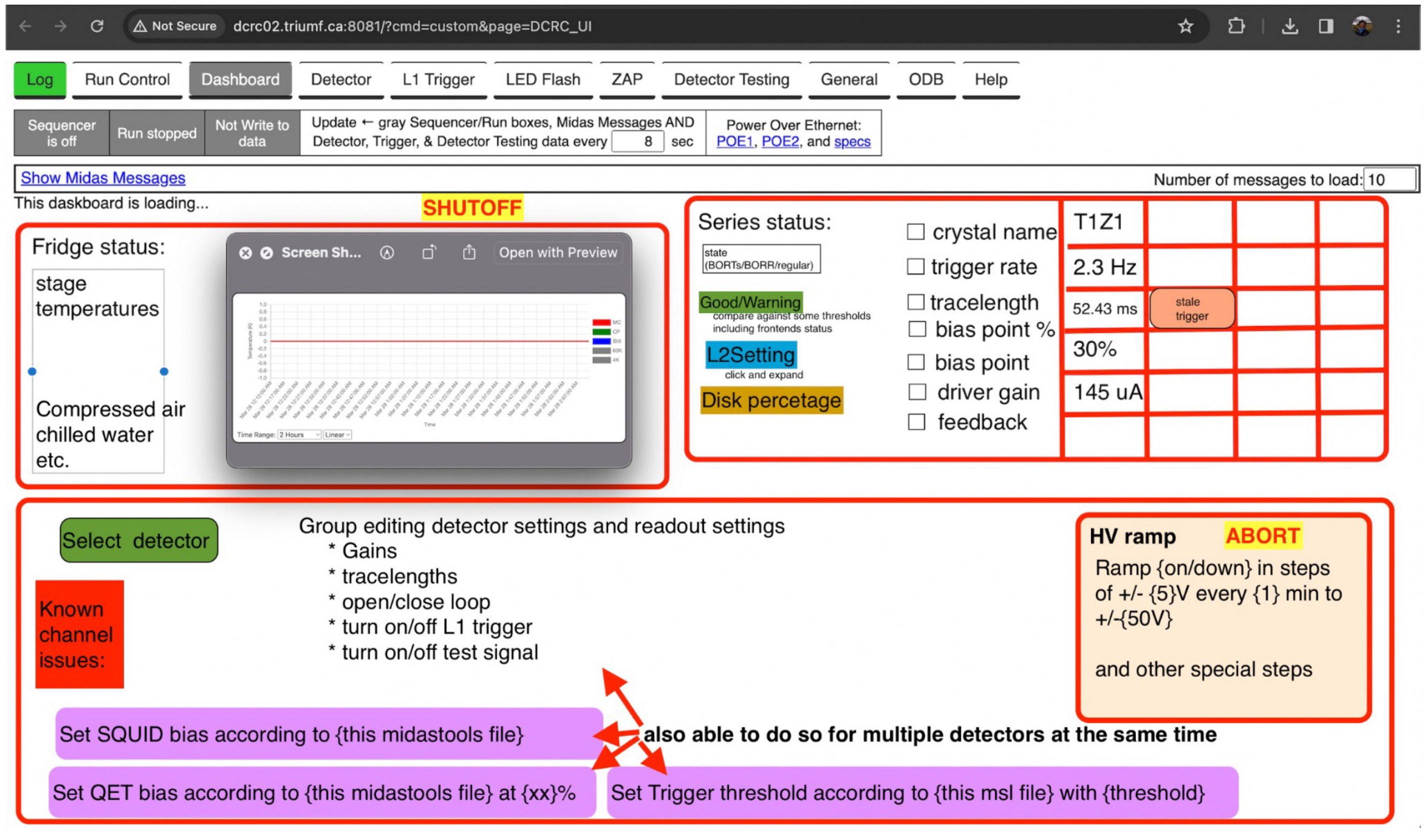
Monitoring: PLC Architecture



Monitoring: Shifter Interface (DCRC example)

Draft philosophy:

- Have top-level page to get overview
- Have dedicated pages for different systems
- Interlocks to view vs control



Monitoring Task Force Recommendations

1. An Operations Monitoring Group (OMG) should be established with the responsibility of overseeing the continued development of the various monitoring systems and working with each team involved in these systems to develop a monitoring framework that meets the requirements defined by the Task Force and the OMG. This most naturally would require adding a Level 3 task to the Operations Work Breakdown Schedule (WBS). The OMG should not be overly prescriptive in how subsystems implement their monitoring functions.
2. The OMG should develop a plan for maintaining up-to-date documentation for the monitoring system, working with the subsystem teams responsible for implementing the monitoring functions.
3. The experiment should adopt a philosophy for alarming, based on the recommendations in Section 9.
4. The experiment should develop a more complete set of metrics to monitor the performance of the experiment, as described in Section 10.
5. The architecture proposed for the monitoring system should be implemented as soon as practical, as that will allow the subsystem developers to implement monitoring functions that integrate seamlessly into the overall monitoring scheme.

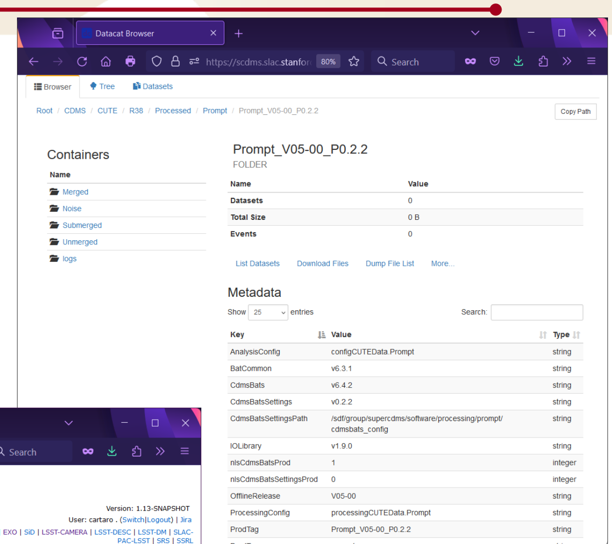
Computing Backup slides

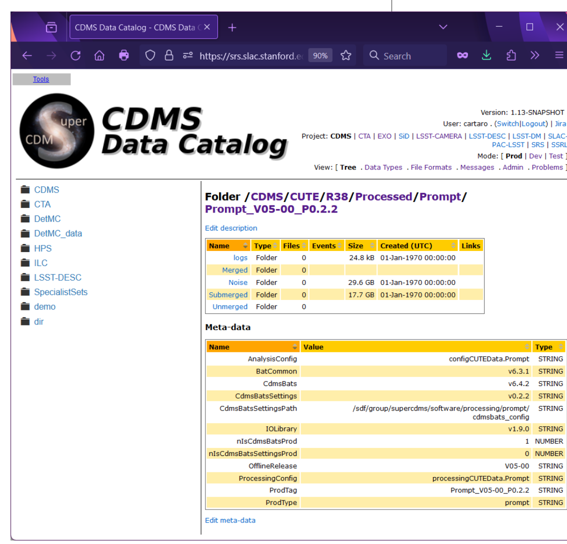
Detailed Shift Model

Shift type	On-site or Off-site	Frequency	Also for I&I?	Training, skills	Notes
Data-taking & detector operations	Both	up to 24/7	Yes	DAQ user, basic DQM	Use DAQ to configure detectors and data-taking series
Data quality & data handling	Both	several daily	No	DAQ user, basic DQM	**DQM:** use online DQM plots to assess data series
	Off-site	few daily	No	Basic DQM, may require Jupyter for in-depth investigation	**Offline Data Validation:** standardized processing output to assess data quality
	Off-site	several daily	No	data pipeline	**Data handling:** shepherd data transfer & processing, computing systems monitoring
Analysis	Off-site	up to daily	No	analysis tools, Jupyter	Fast turnaround data analysis (e.g., neutralization, calibration and rate assessments)
Hardware monitoring	Both	up to 24/7	Yes	monitoring tools	**Experiment monitoring:** primarily cryogenics
	On-site	daily	Yes	SNOLAB, SCDMS systems familiarity	**On-site infrastructure/utilities:** chilled water, UPS, shield purge, cold traps, network, etc.
Expert	Off-site	up to 24/7	Yes	system-level expertise	**Experts on call:** for specific systems
	Both	as needed	Yes	system-level expertise	**Expert shift:** to execute or support system-specific work

Bookkeeping

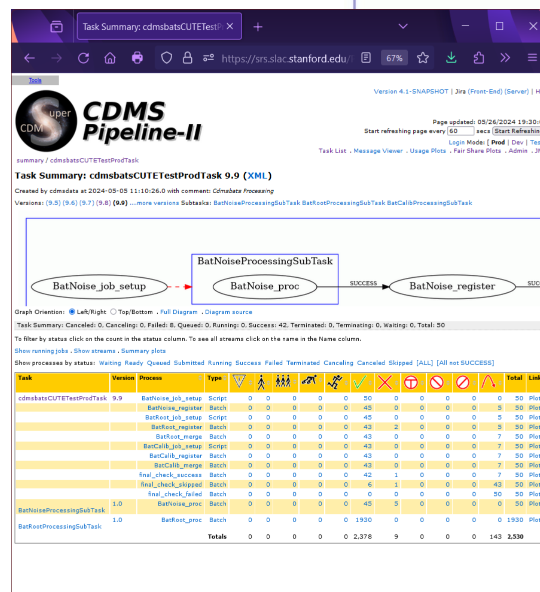
- File bookkeeping through Data Catalog v0.6
  - Support for multiple locations, download, custom metadata, metadata search, python API
  - SuperCDMS features
    - Input/output tracking at various stages of processing and the ability to define logical datasets (was there but not quite working, re-developed by SuperCDMS)
  - Data Catalog server application running in Docker through Kubernetes at SLAC
  - All the information needed to track the data is published to the Data Catalog where anyone can search for files or folders and relative metadata
    - Information between the various stages of the data path is not pushed or pulled (no need to define interfaces besides Data Catalog)



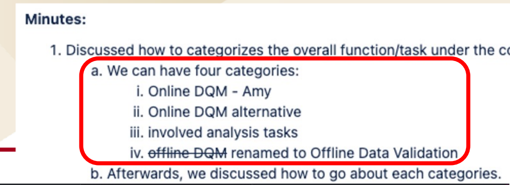


Processing

- The workflow manager for data processing is the Pipeline
  - Automated bookkeeping using Data Catalog, monitoring, reporting, roll-back of failed jobs
  - Workflows are described by tasks defined through XML files
    - Full version history and job info accessible through a web portal
    - Monitoring plots and statistics are available for each task and job
    - Log files from individual batch jobs are also accessible together with the batch job parameters and options
  - Pipeline server application and related services now running in Kubernetes at SLAC
  - Prompt processing for SNOLAB data at SLAC
- Data re-processing and large-scale MC production:
  - Use existing allocations at our institutions, primarily SLAC, Texas A&M, DRAC (formerly known as Compute Canada)
- To guarantee the traceability of the data and reproducibility of the scientific results, only tagged, unmodified, and validated software releases can be used in data processing

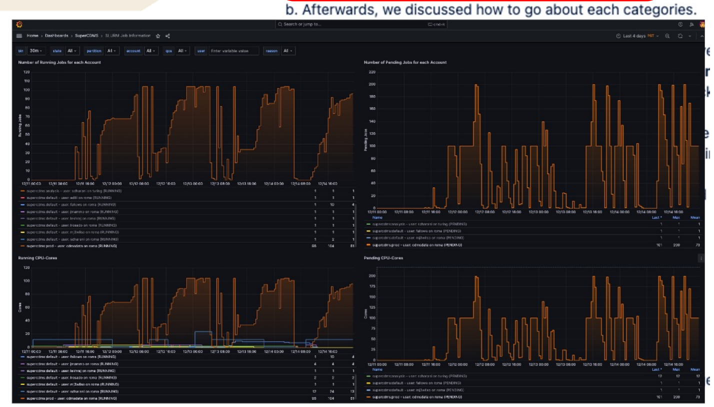


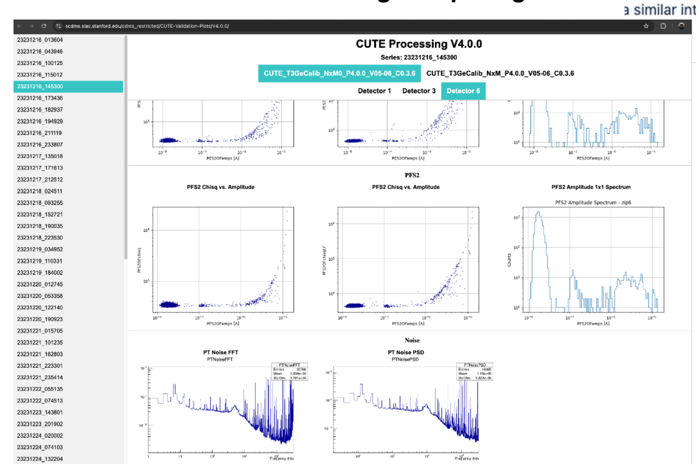
Processing and Validation


Minutes:

1. Discussed how to categorizes the overall function/task under the co
   a. We can have four categories:
      i. Online DQM - Amy
      ii. Online DQM alternative
      iii. involved analysis tasks
      iv. ~~offline DQM~~ renamed to Offline Data Validation
   b. Afterwards, we discussed how to go about each categories.

- Collaborative effort between Analysis, DQM, and O.6 to make sure the processing and validation is efficiently monitored and automated.
- Significant progress has been made by the team in clearly articulating the procedure and implementing some “low-hanging fruits” based on Tower 3 data analysis efforts. Newly implemented features include:
  - Data processing monitoring (O.6):
    - automated job submission; Bruno, Joseph (G)
    - new Grafana interface Omar
    - new automated processing status page Bruno, Joseph (G)
  - Offline Data Validation (Analysis to hand off to O.6)
    - new automated validation page Matt P., Ruchi (G)
  - Procedure for submitting processing request (Analysis) Stefan, Aditi (G)
    - new automated configuration display Bruno, Matt P.

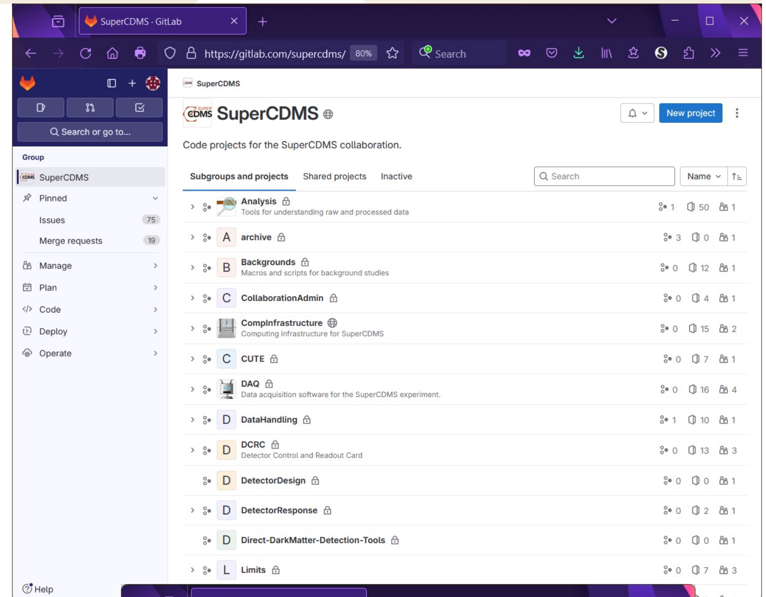

Grafana interface showing computing status

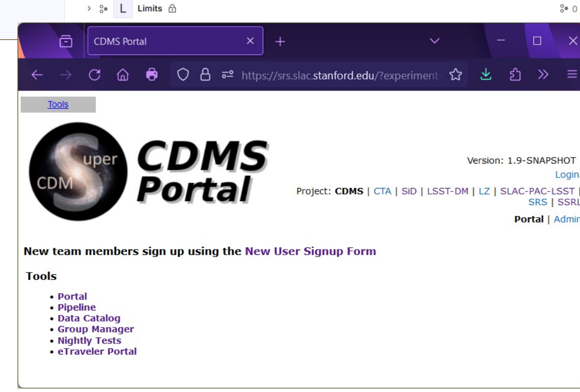


automated offline data validation page

Offline Software Releases

- The SuperCDMS software is based on few large software packages with loose compilation or runtime dependencies
  - About 30 packages in the Release
  - The total number of packages, including production, analysis, data quality, DAQ, papers, and groups repos, is around 250
  - GitLab is used for version control
- Software Releases implemented for reproducibility and for package compatibility
  - Only officially released and tagged software releases are acceptable for data analysis, data processing, and simulation production
- Software releases are distributed as apptainer/singularity images
  - SLAC scientific cluster (S3DF) supports apptainer/singularity, docker, and Kubernetes
  - Used in production for data processing and in Jupyter for data analysis
- Continuous Integration software: Jenkins
  - Looking into git runners
- Jenkins, Pipeline, and Data Catalog are all interfaced together in the CDMS Portal with a common Oracle database in the backend



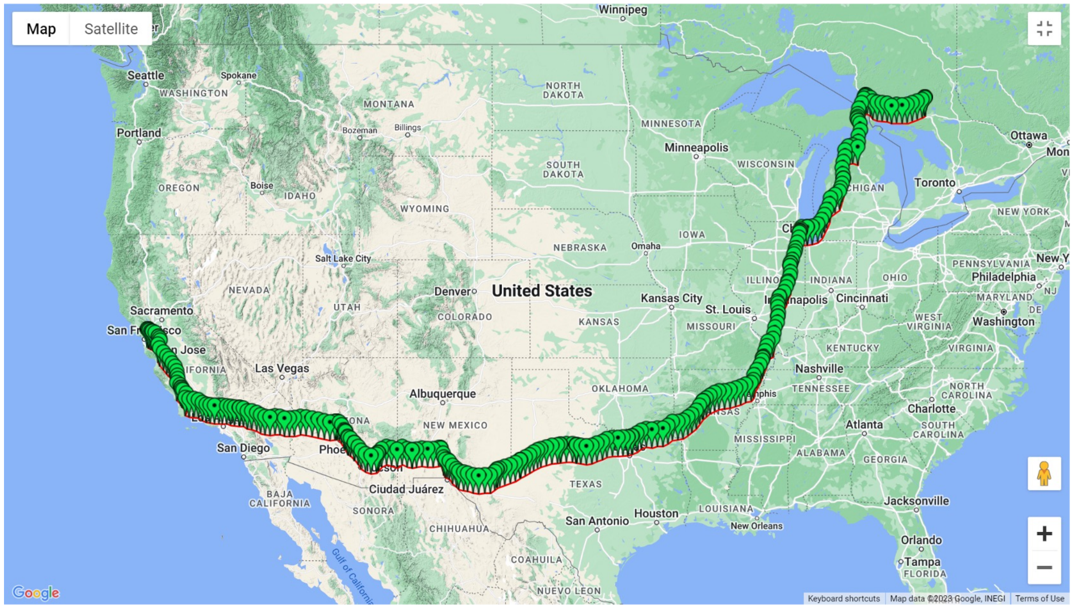


Backgrounds Backup Slides

Backgrounds – Achieved Target Cosmic-Ray Exposure for Detector Towers

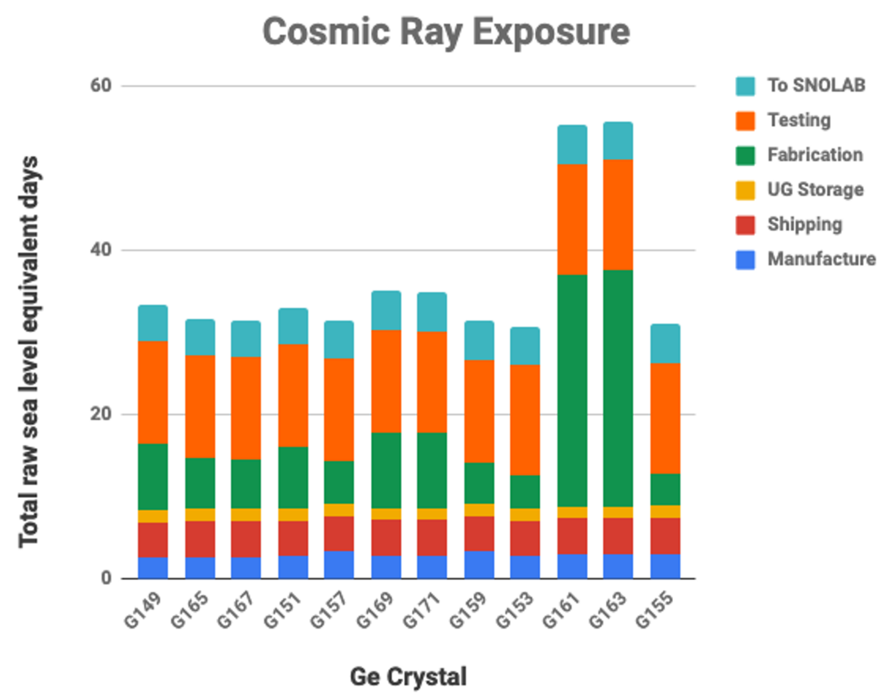
- Final planned cosmic-ray exposure of detector towers
  - Shipment from SLAC to SNOLAB
- Followed southern route to avoid high elevation mountain passes
- Shipment 1 = Towers 3 & 4
  - May 9-12, 2023
  - ~2 hours faster than estimated
- Shipment 2 = Towers 1 & 2
  - Nov 13-16, 2023
  - ~4 hours faster than estimated
- Towers now in radon-mitigated storage underground at SNOLAB

Shipment 1 clock time = 3.05 days
Shipment 2 clock time = 2.82 days
Time-weighted sea-level-equivalent days =1.6 days



Backgrounds – Achieved Target Cosmic-Ray Exposure for Detector Towers

- Final planned cosmic-ray exposure of detector towers
  - Shipment from SLAC to SNOLAB
- Followed southern route to avoid high elevation mountain passes
- Shipment 1 = Towers 3 & 4
  - May 9-12, 2023
  - ~2 hours faster than estimated
- Shipment 2 = Towers 1 & 2
  - Nov 13-16, 2023
  - ~4 hours faster than estimated
- Towers now in radon-mitigated storage underground at SNOLAB



Achieved 40 day goal for most of Ge detectors and 60 day target for all Ge detectors