Estimating Si-32 and tritium in the SuperCDMS SNOLAB detectors

July 2019

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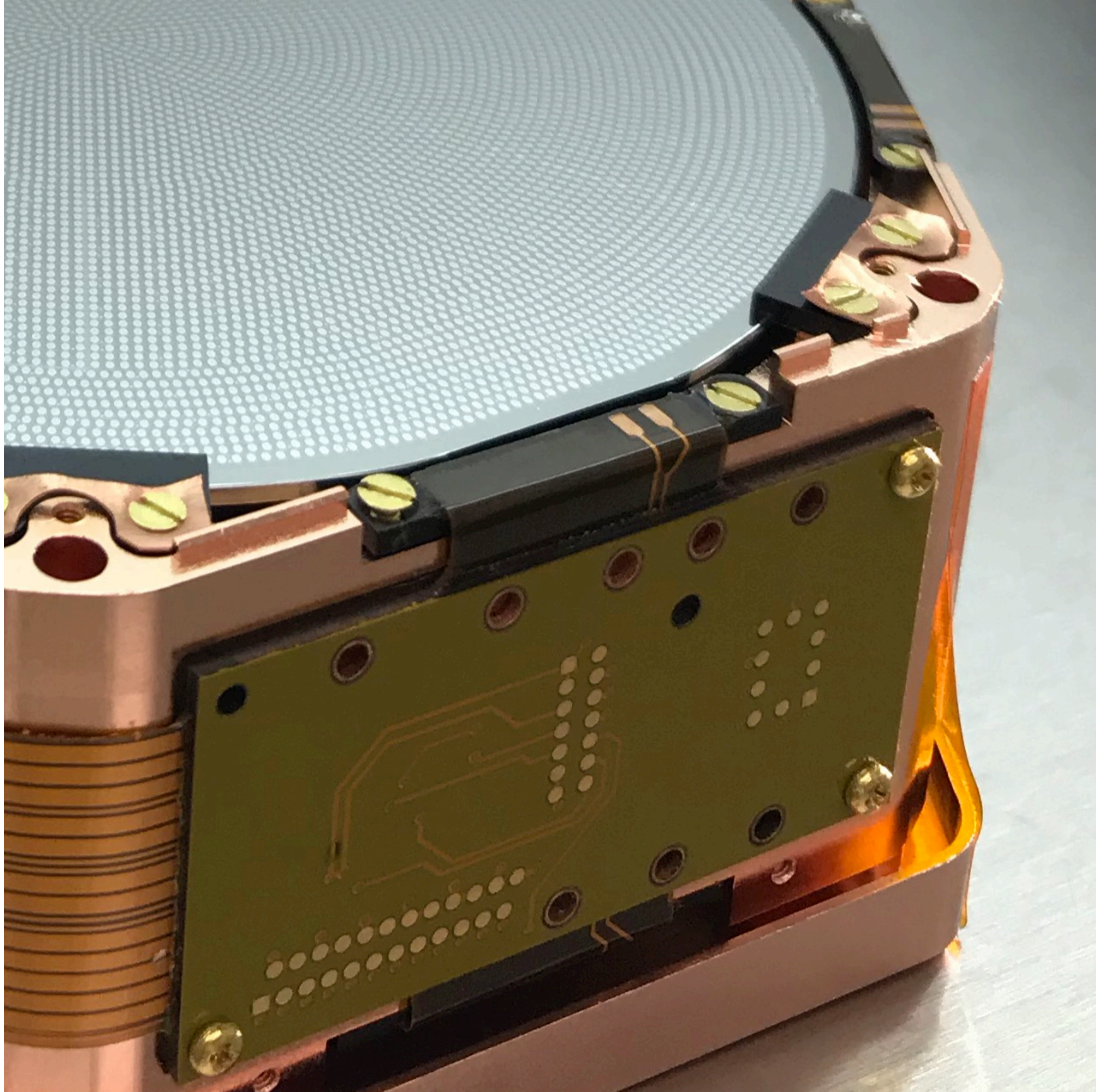
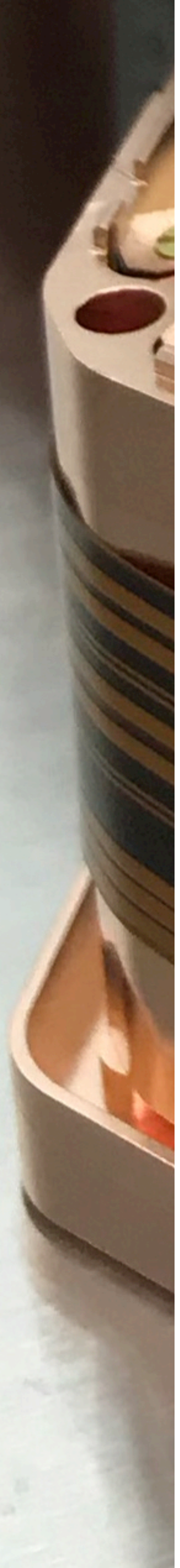
Research Scientist

PNNL is operated by Battelle for the U.S. Department of Energy





Outline

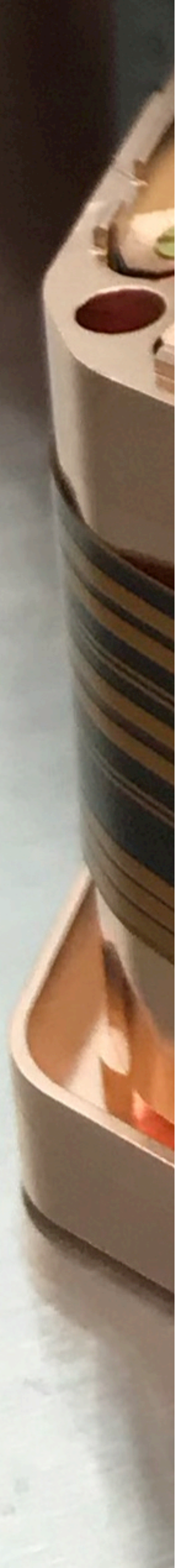
- SuperCDMS SNOLAB
  - Design
  - Detectors
  - Sensitivity
- Backgrounds
  - Overview
  - Si-32 in natural silicon
  - Tritium from cosmic rays
- Summary

SuperCDMS Collaboration

California Inst. of Tech.
CNRS-LPN*
Durham University
FNAL
NISER
NIST*
Northwestern
PNNL
Queen's University
Santa Clara University
SLAC
South Dakota SM&T
SMU
SNOLAB
Stanford University
Texas A&M University
TRIUMF
U. British Columbia
U. California, Berkeley
U. Colorado Denver
U. Evansville
U. Florida
U. Montréal
U. Minnesota
U. South Dakota
U. Toronto

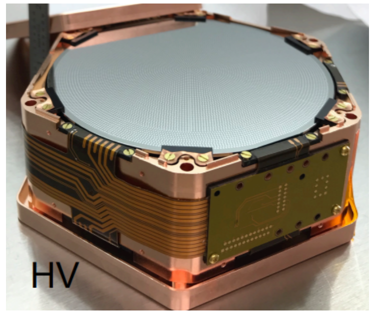
* Associate members

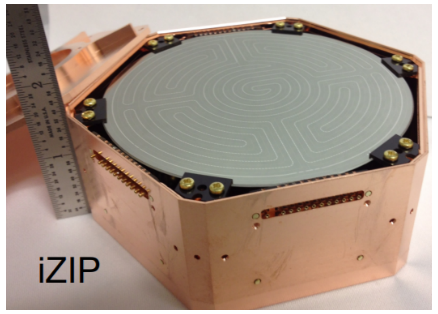
Experimental design, located at SNOLAB

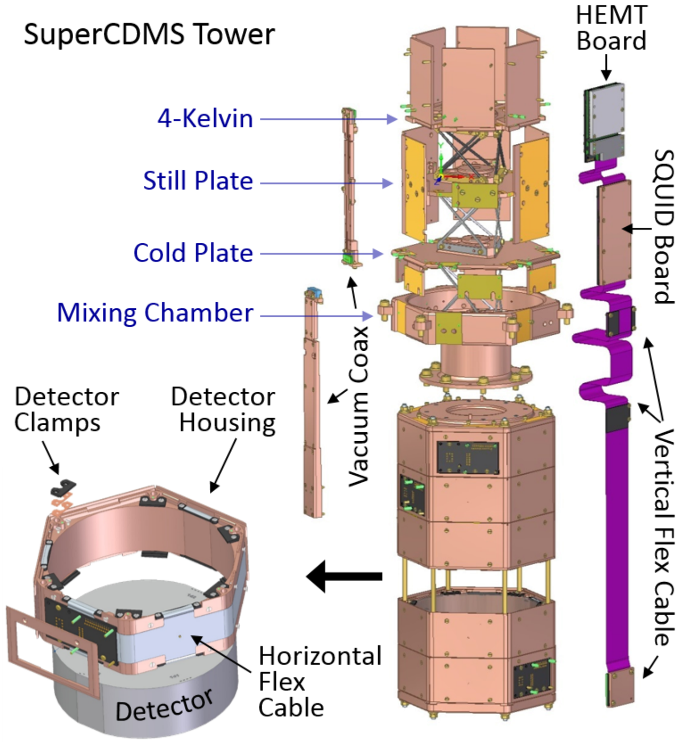


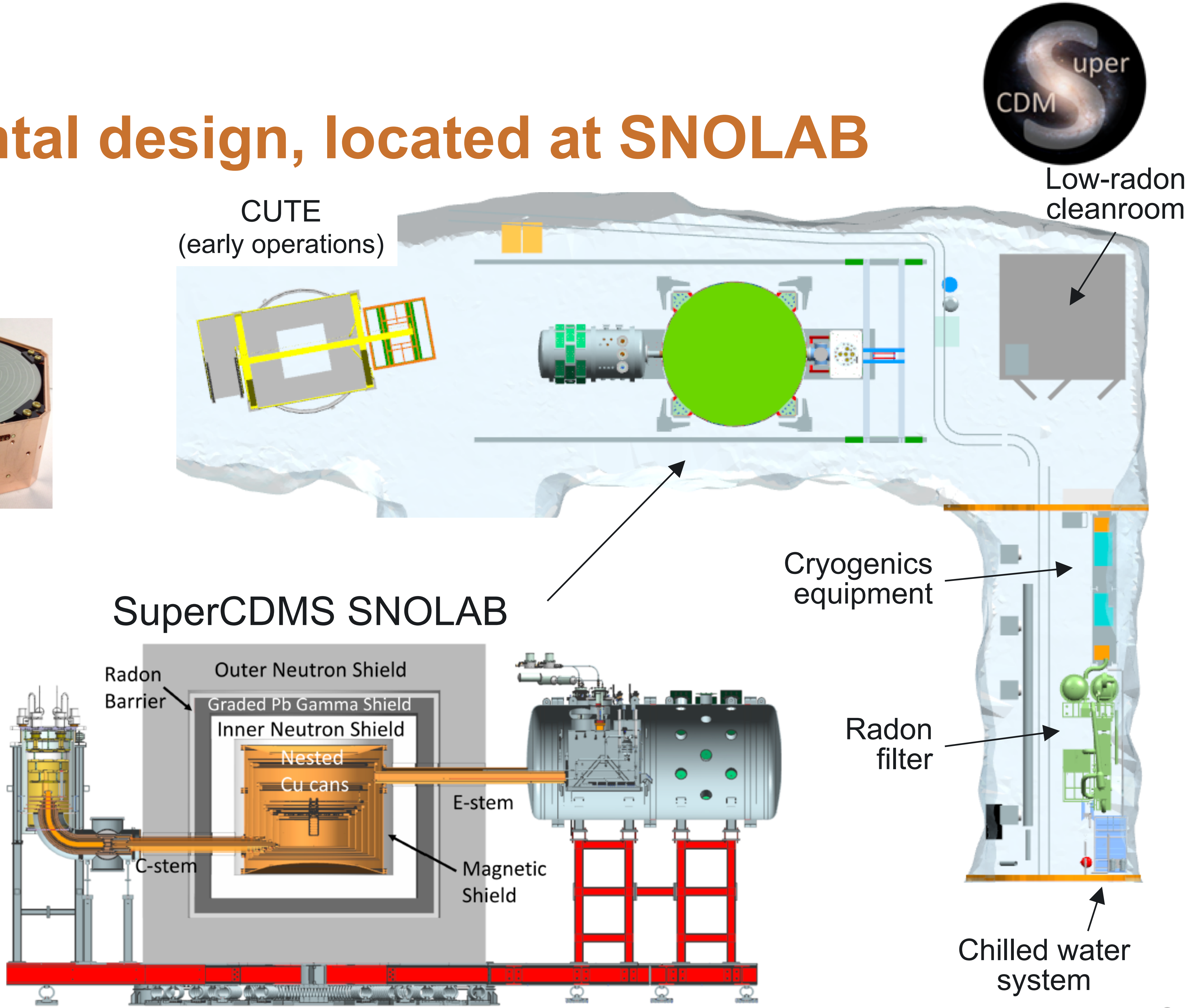
4 detector towers:

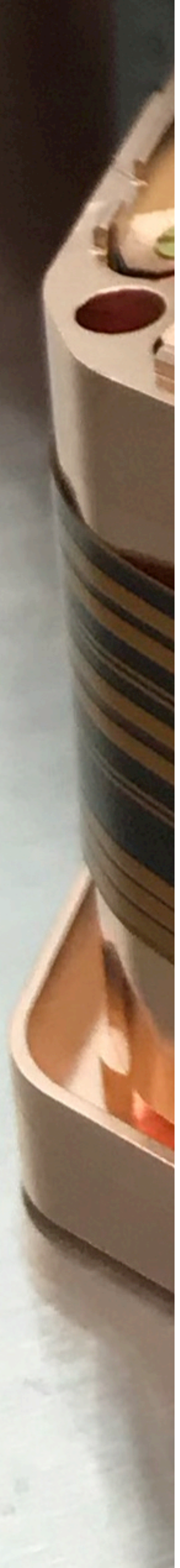
12 HV detectors:	8 Ge + 4 Si
12 iZIP detectors:	10 Ge + 2 Si





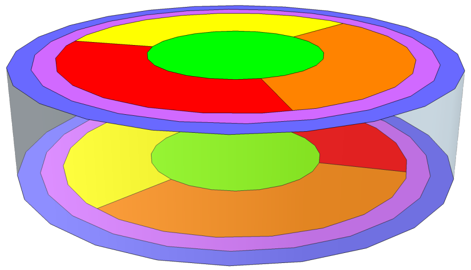


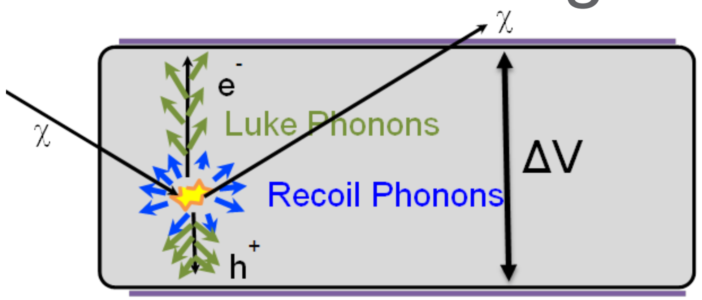




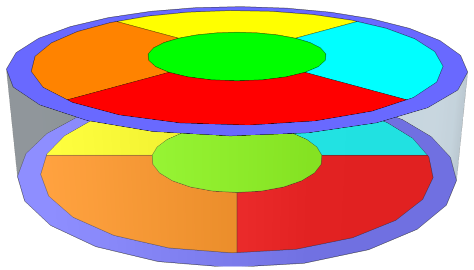
Ge & Si solid-state cryogenic detectors

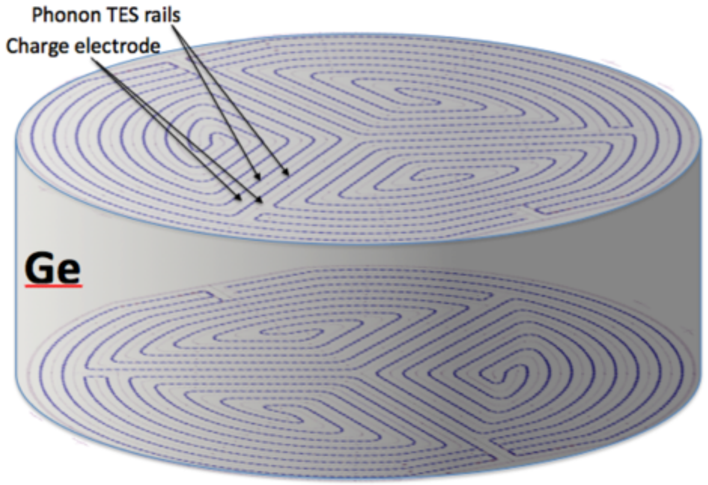
- High Voltage (HV) – Phonon-only measurement of ionization charge

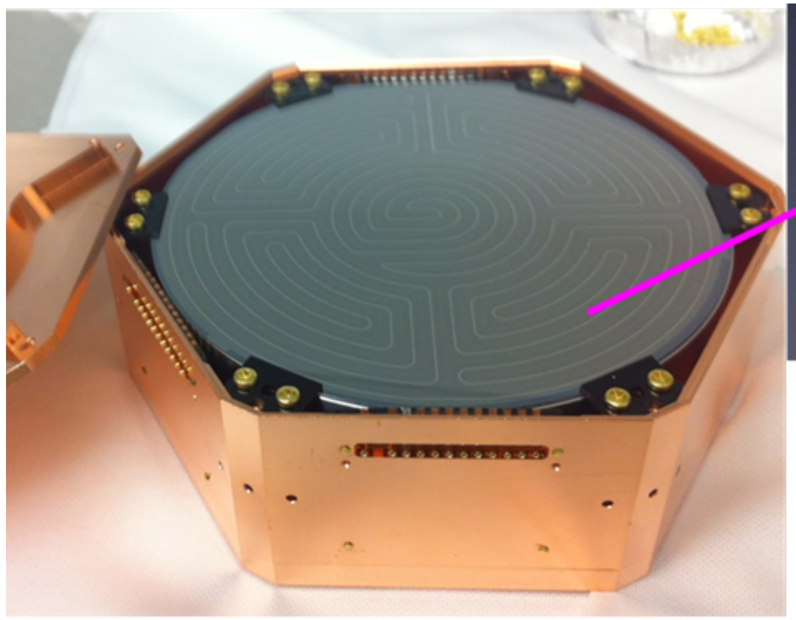


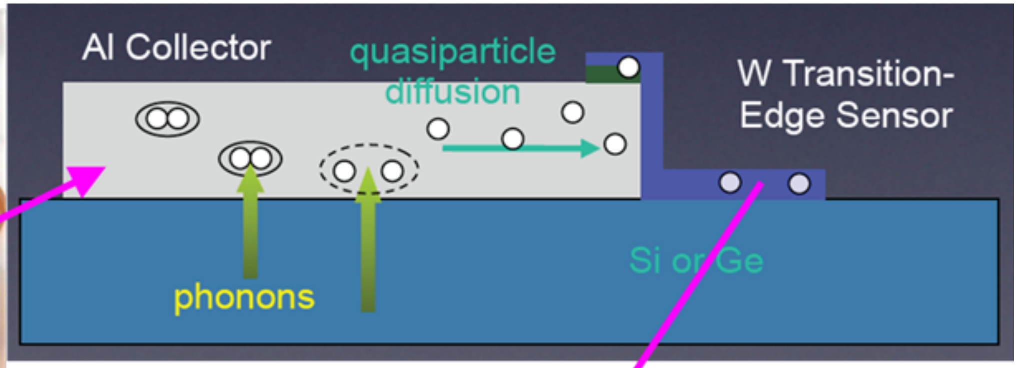


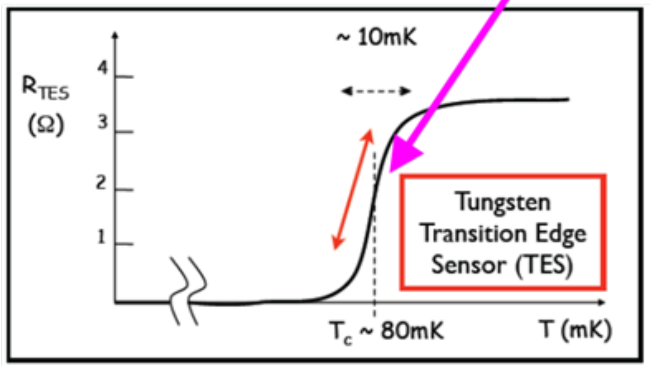
- interleaved Z-dependent Ionization & Phonon (iZIP) – NR/ER discrimination





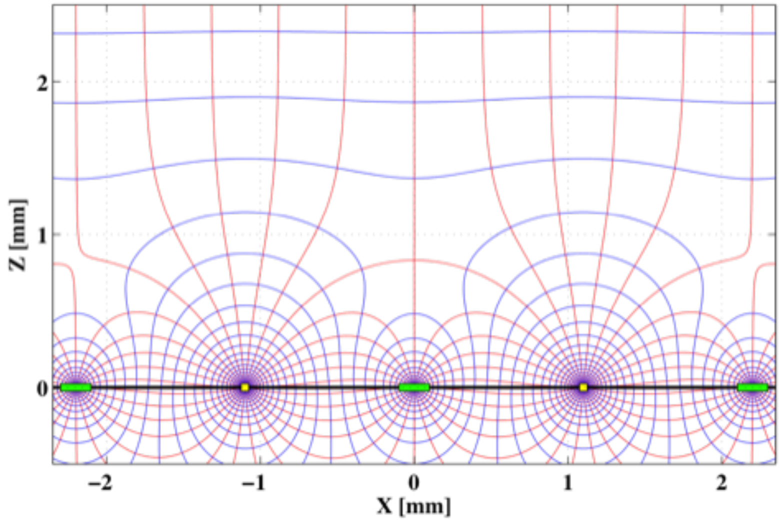






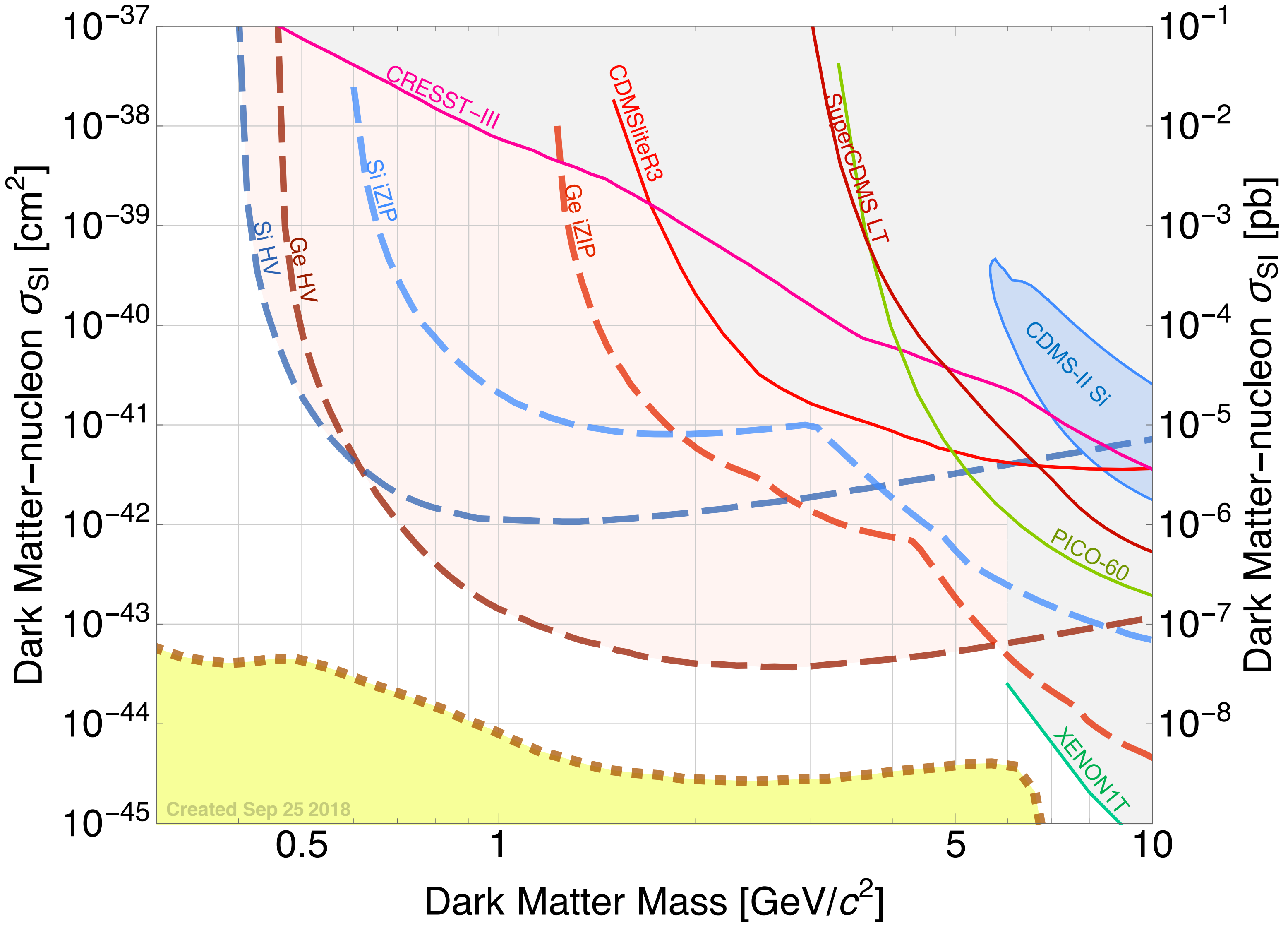
Used on both detector designs

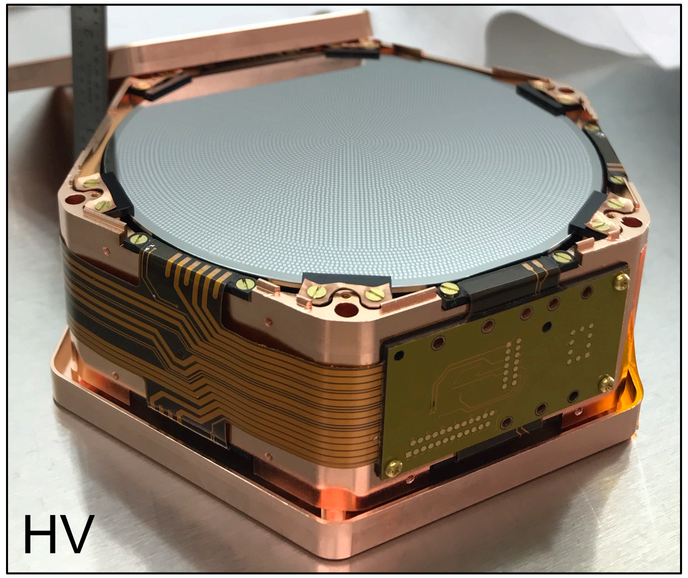
Athermal phonon sensor technology

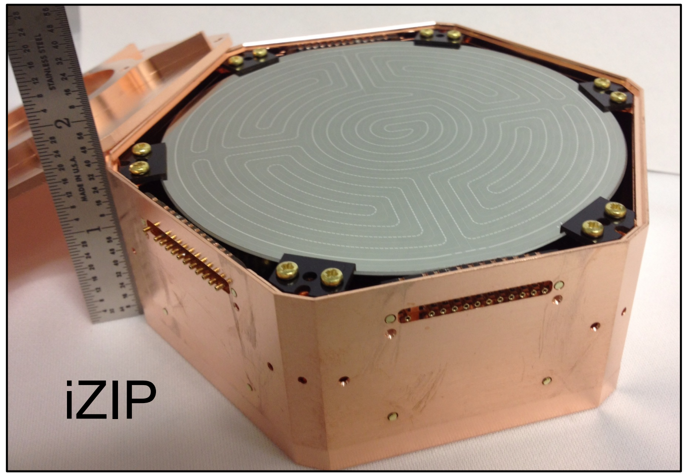


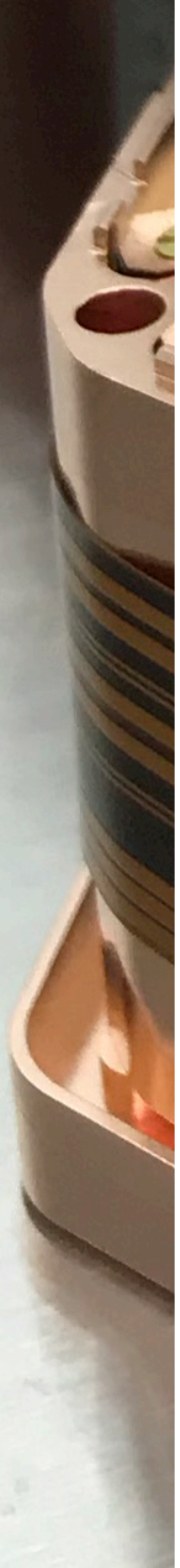
Sensitivity reach of SuperCDMS SNOLAB

- Direct detection search for spin-independent dark matter interactions



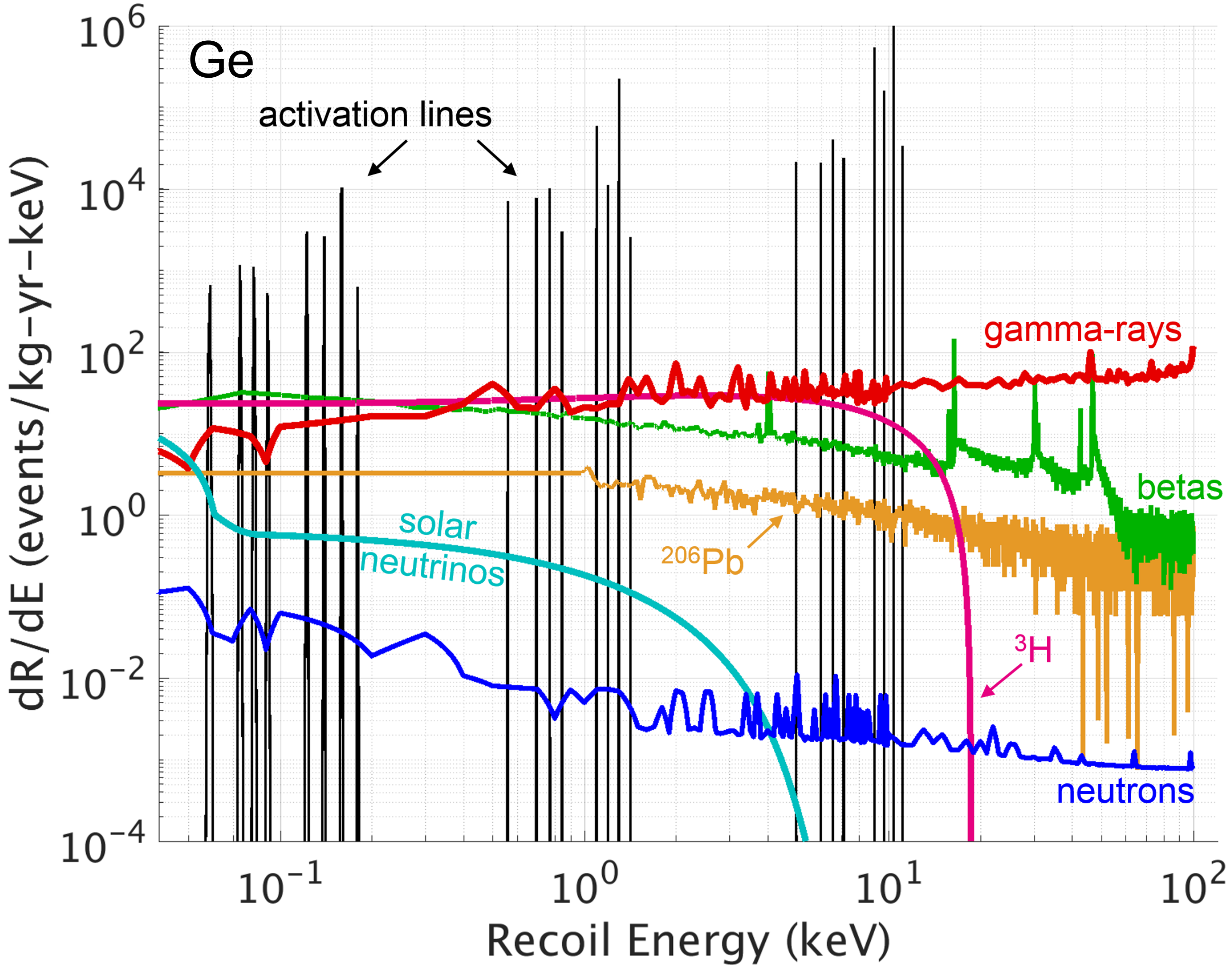


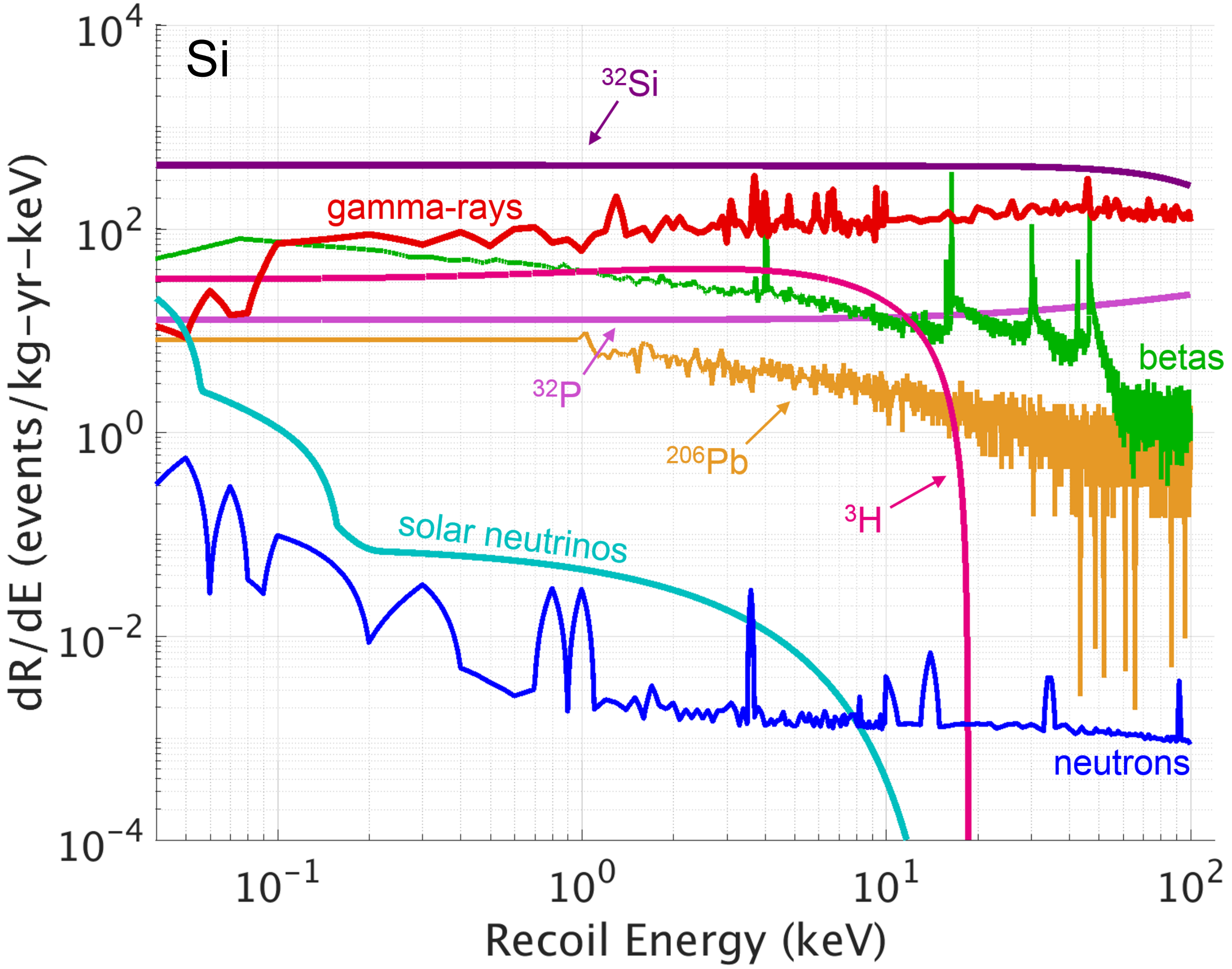




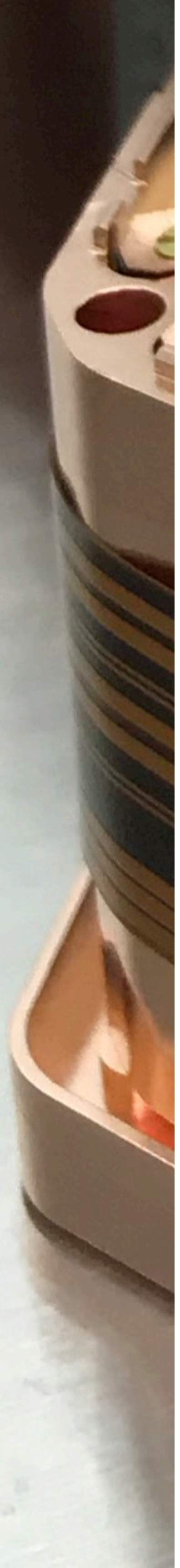
Backgrounds overview

- Expected: Tritium, ^{32}Si (only in Si), surface Rn daughters, material impurities



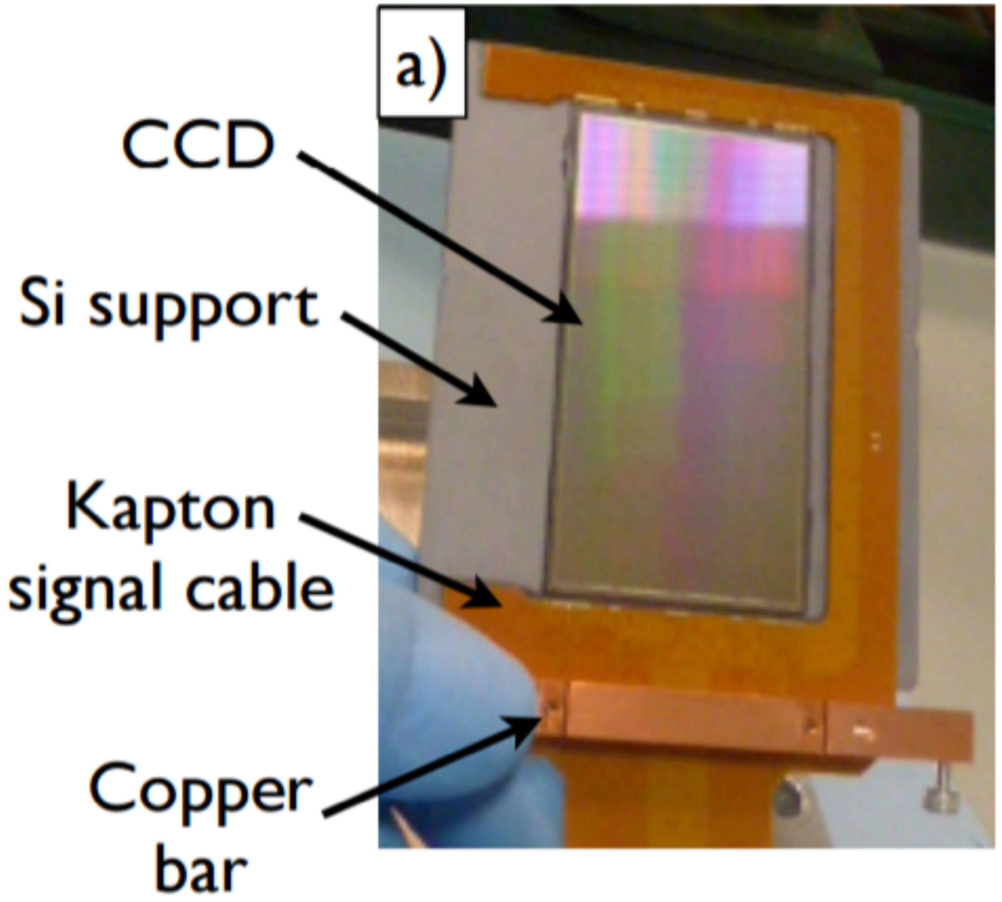


Spectra shown before detector resolution and application of single-scatter, fiducial volume, and nuclear recoil cuts

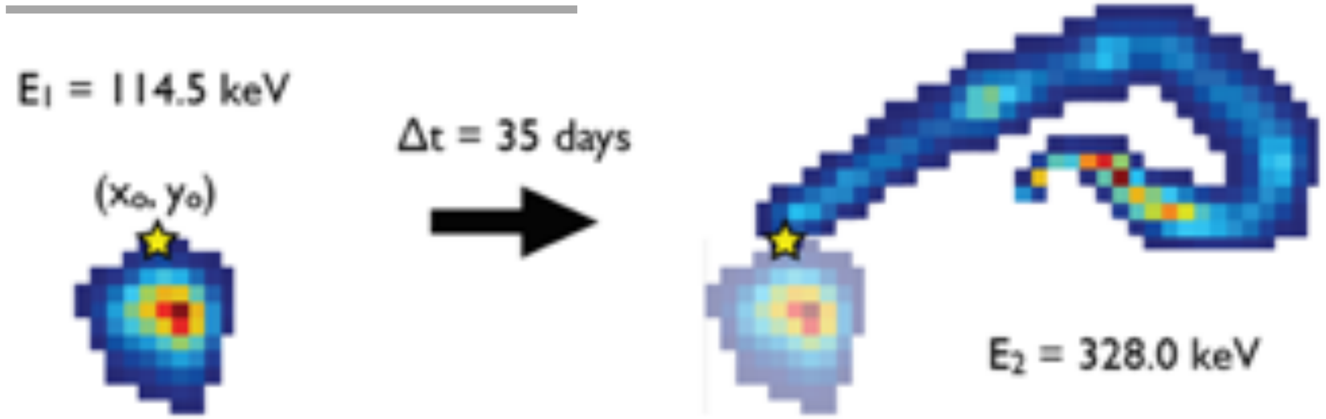


Si-32: A naturally occurring background

- Measured by DAMIC collaboration in CCD detectors
  - DAMIC measurements to date:
    - ✓ 80^{+110}_{-65} decays of ^{32}Si / kg Si / day — JINST 10 (2015) P08014
    - ✓ 11.5 +/- 2.4 decays of ^{32}Si / kg Si / day — G.C. Rich - IDM 2018 - 27 Jul 2018

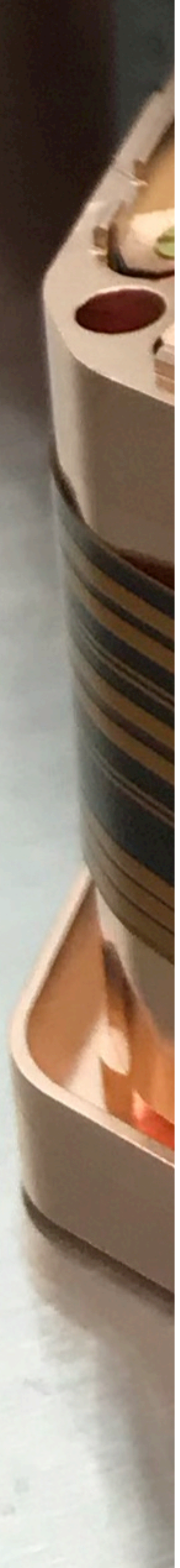


Candidate Event



^{32}Si beta
$t_{½} \approx$ 140 yr

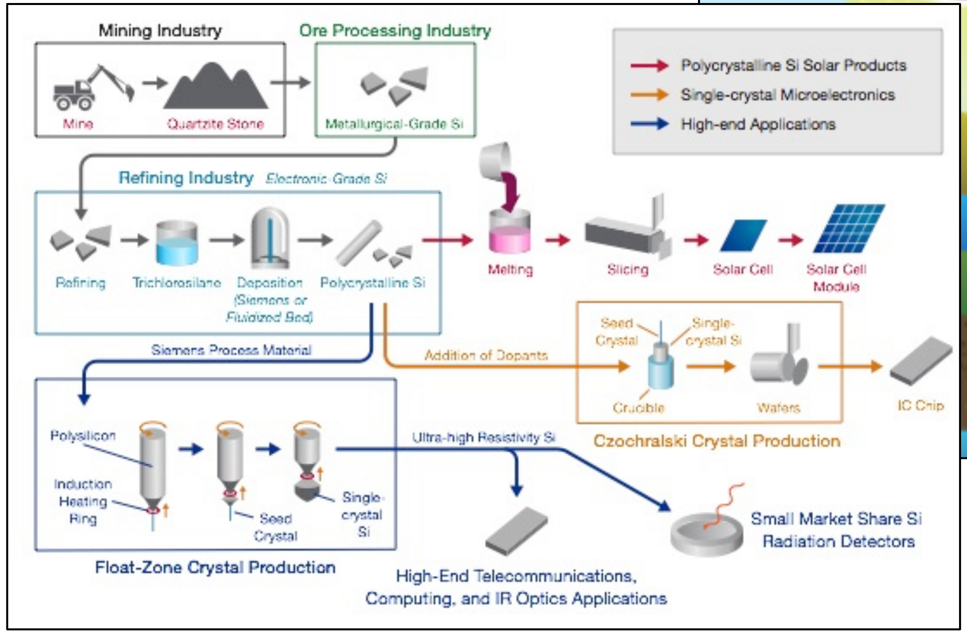
^{32}P beta
$t_{½}$ = 14 days

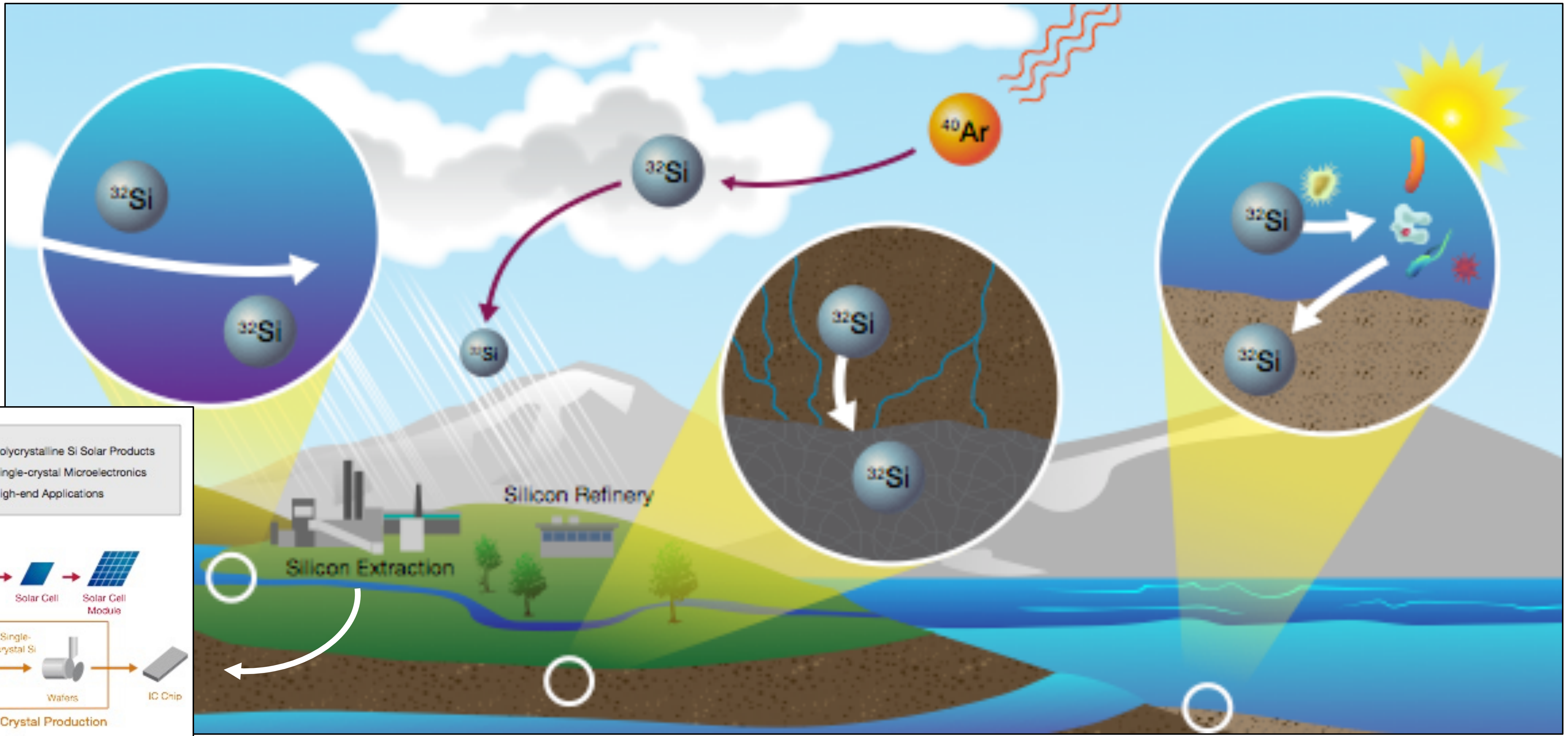


Si-32: A naturally occurring background

- Si-32 is produced in atmosphere and enters silicon commodity stream

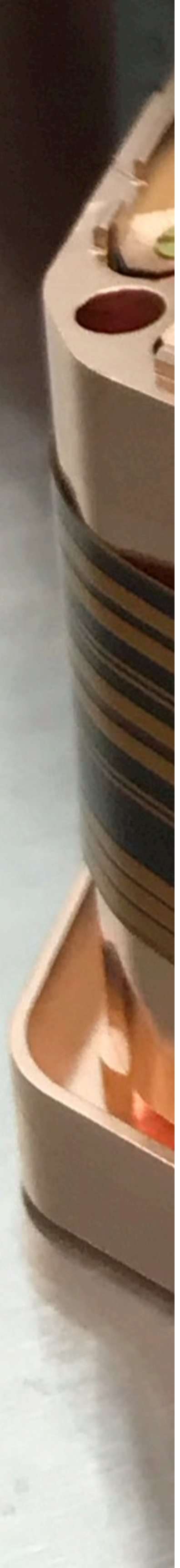
Silicon extraction & refining





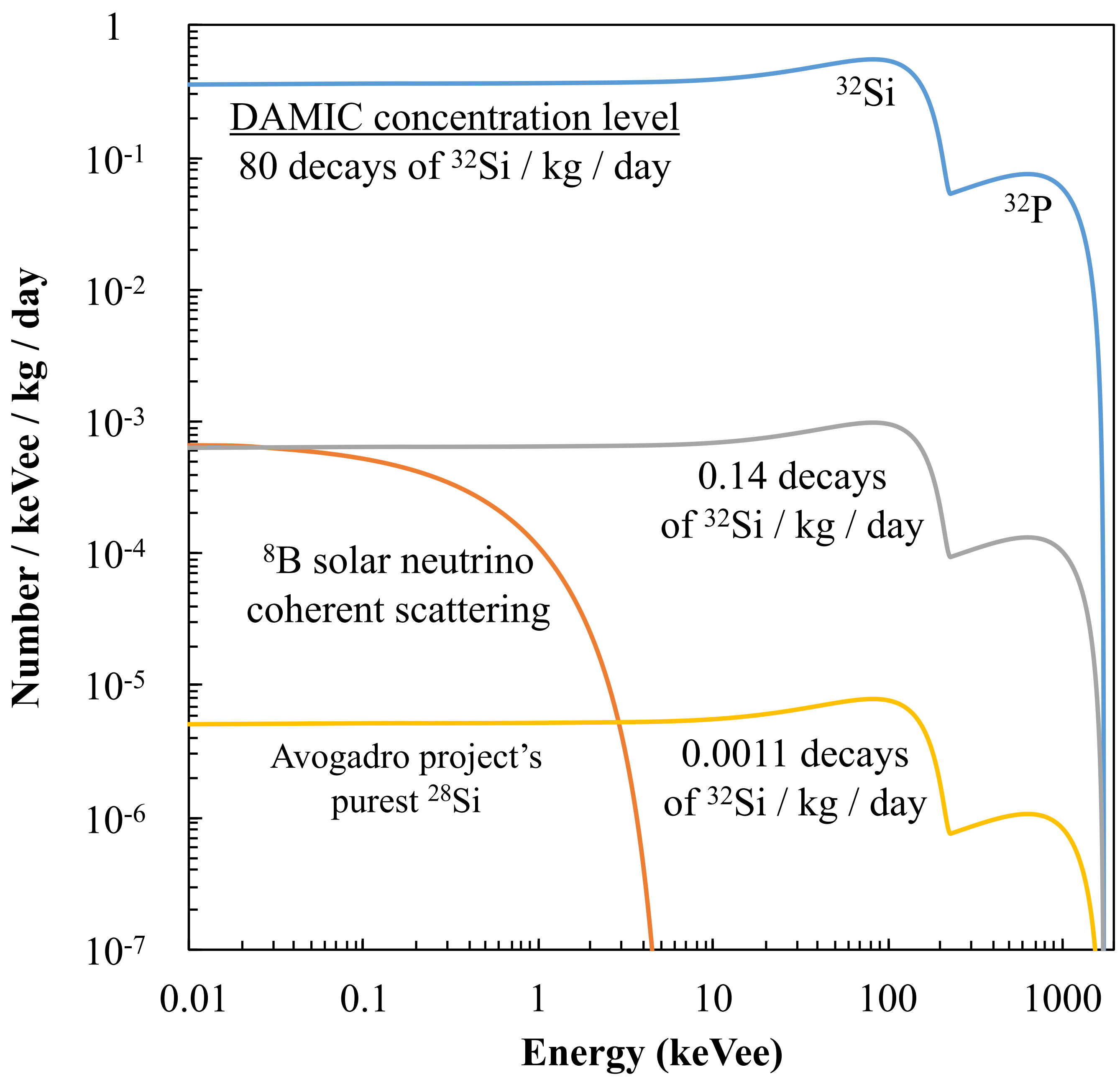
Naturally occurring ^{32}Si and low-background silicon dark matter detectors

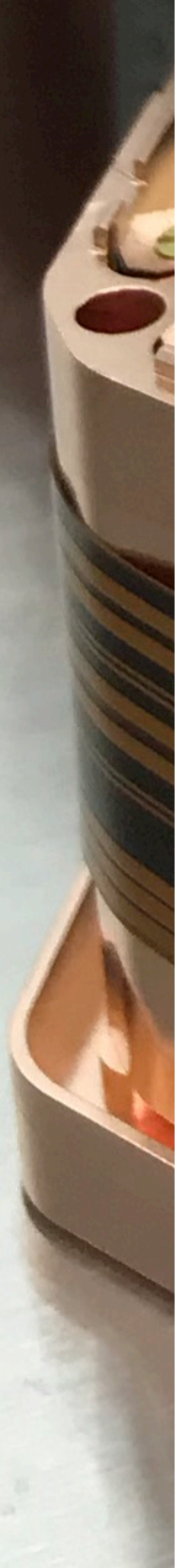
Orrell, JL, *et al.* Astroparticle Physics 99 (2018) 9-20.



Si-32: A naturally occurring background

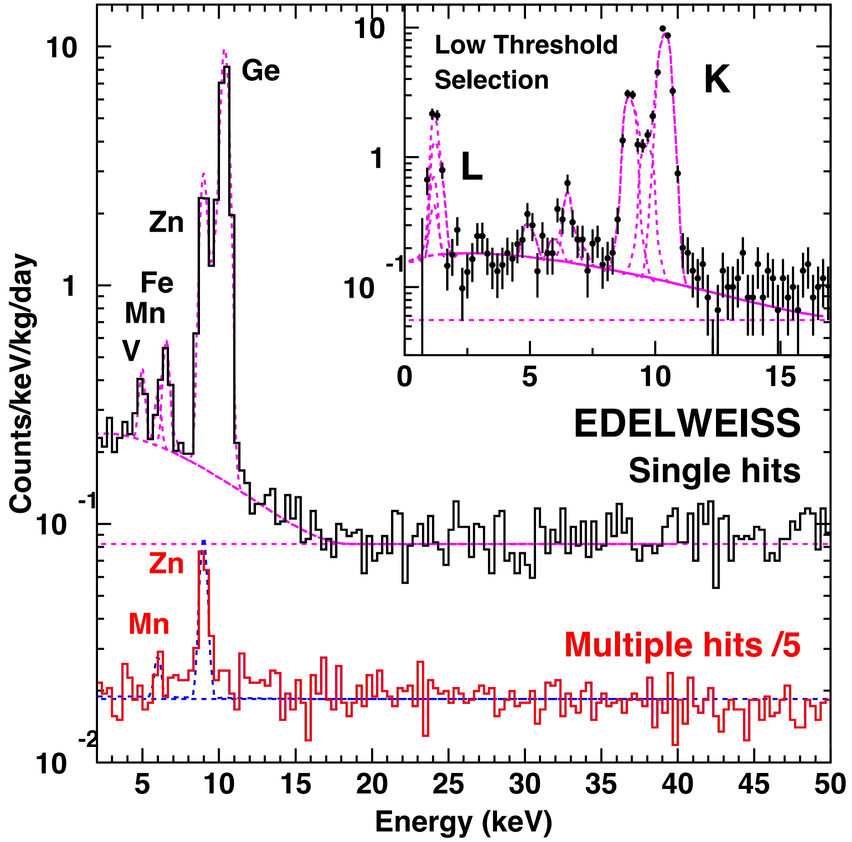
- A low Si-32 source of silicon:
  - Deep underground mines?
    - ✓ Not commercially viable
    - ✓ Must develop independent Si processing
  - Avogadro project:
    - ✓ Goal: A pure ^{28}Si kilogram standard
    - ✓ Employs enriched ^{28}Si
    - ✓ Enrichment process removes ^{32}Si
    - ✓ Existing silicon production chain exists
- Si-32 well below ^{8}B solar ν floor:
  - Production demonstrated at ~5 kg
  - Anticipate enrichment cost 'modest'
  - Independent production chain critical



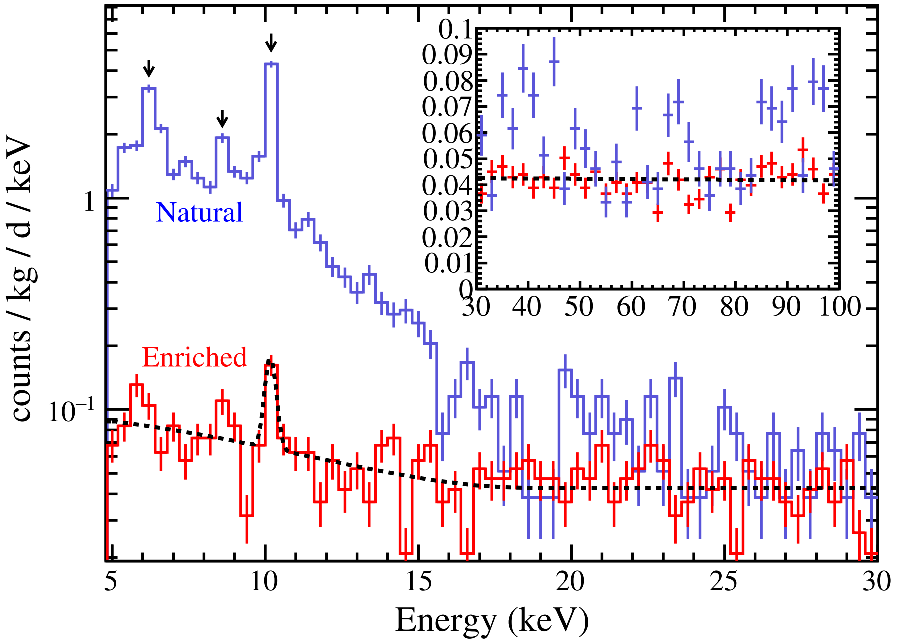


Tritium from cosmic ray spallation

- Exposure of Ge & Si crystals to secondary cosmic rays (*e.g.*, n, p, μ) causes nuclear spallation producing a variety of long-lived, unstable nuclei
  - Tritium (^{3}H) is especially problematic: $t_{1/2}$ = 12.3 yr, pure β-decay, E_β^{End} = 18.6 keV

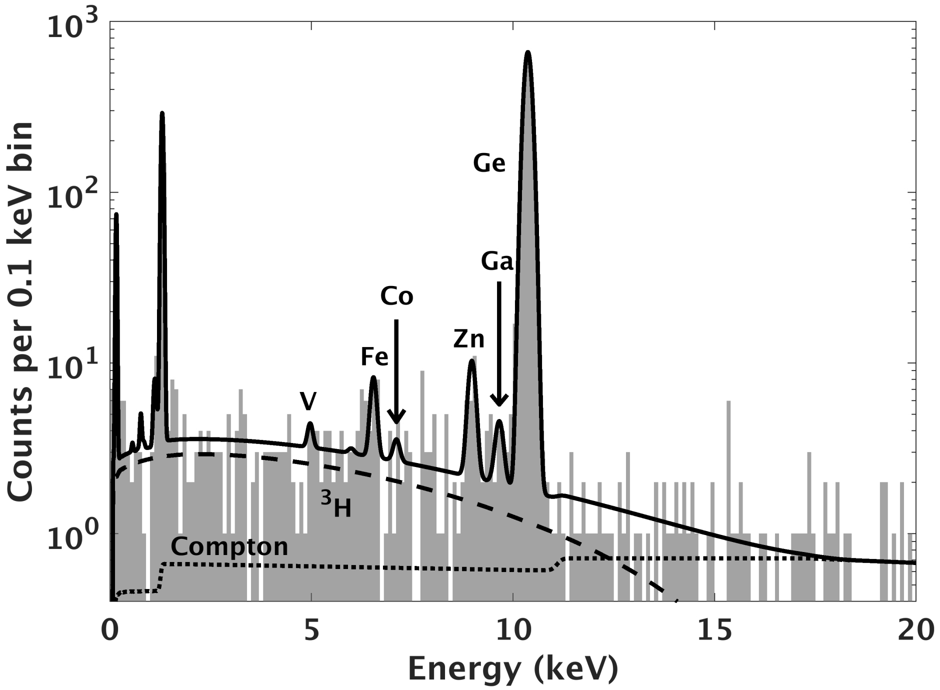


E. Armengaud *et al.*,
Astropart. Phys. 91 (2017) 51-64



MAJORANA DEMONSTRATOR

N. Abgrall *et al.*,
NIM A 877 (2018) 314-322



CDMSlite Run 2 (Soudan)

R. Agnese *et al.*,
Astropart. Phys. (2019) 1-12

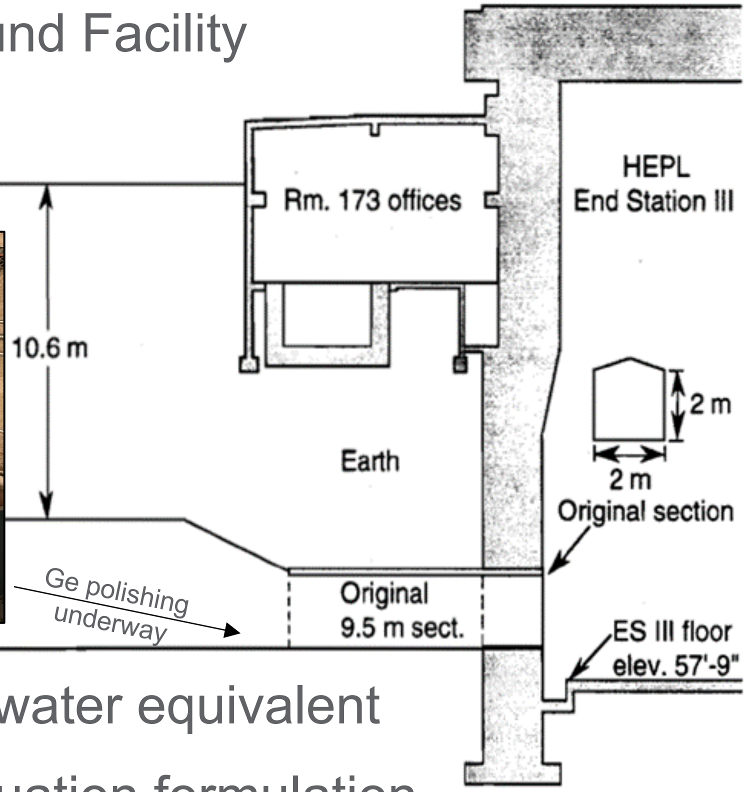
Tritium from cosmic ray spallation

- SuperCDMS SNOLAB Goal: Less than 60 days sea level equivalent exposure
  - One of four towers is composed of iZIPs with longer surface exposure

Thank you
MAJORANA & GERDA!

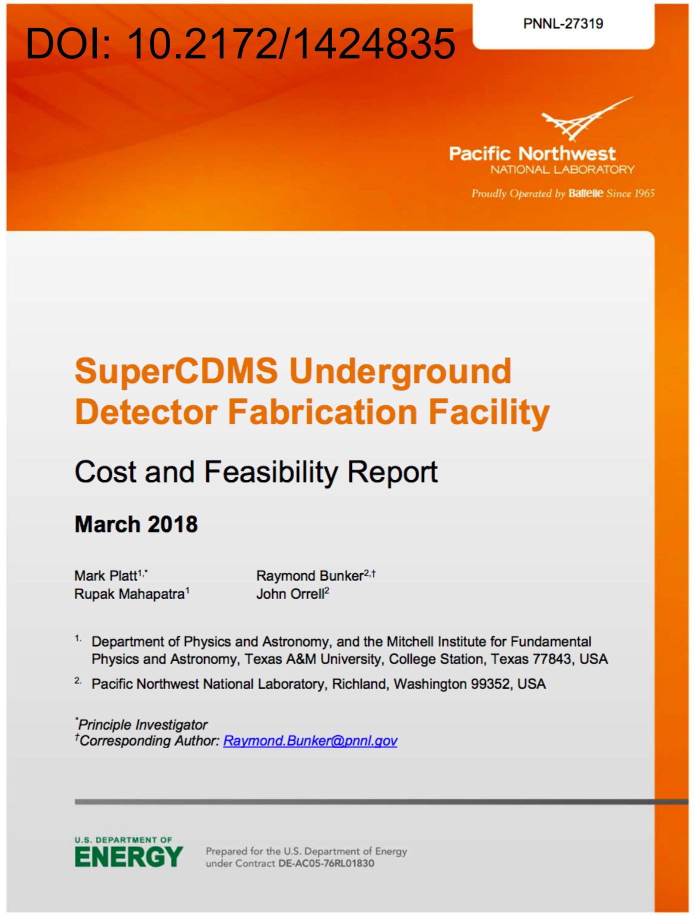
Shielded shipping container critical to meet exposure goal

Underground storage & polishing at Stanford Underground Facility



Depth 25$\pm$2 meter water equivalent

Evaluated via attenuation formulation employed by muon-tomographers → Barbouti & Rastin J. Phys. G 9 (1983)1577


DOI: 10.2172/1424835

PNNL-27319

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SuperCDMS Underground Detector Fabrication Facility

Cost and Feasibility Report

March 2018

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Rupak Mahapatra[1] John Orrell[2]

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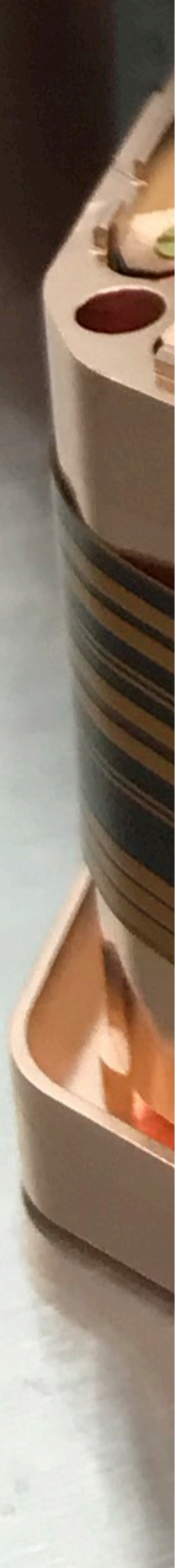
Available on www.OSTI.gov



Tritium from cosmic ray spallation

- Detectors currently moving to detector fabrication phase
  - Cosmic ray exposure minimization is on track with plan

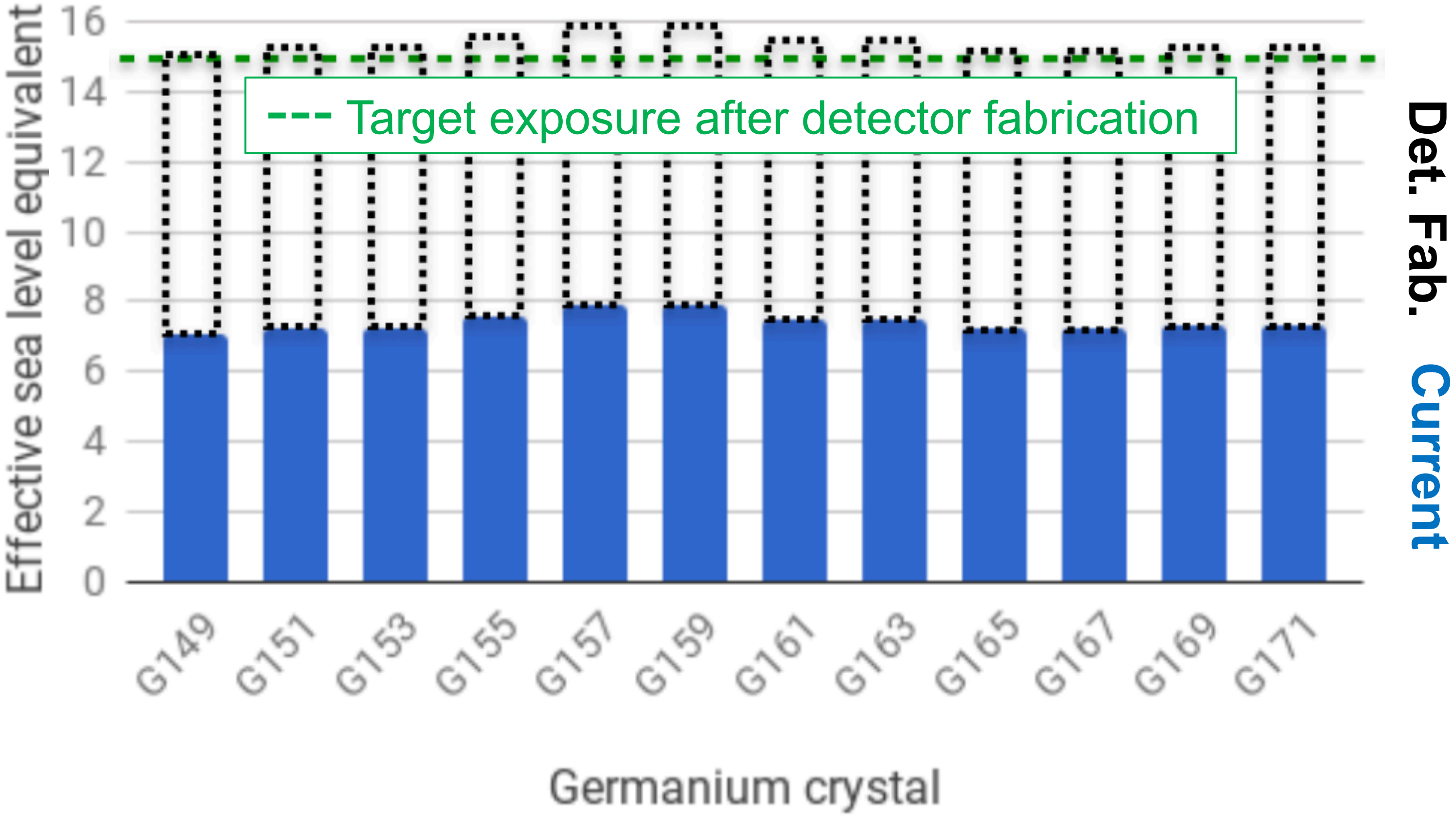
Bottom-up estimate of cosmic ray exposure during detector fabrication, assembly, and testing

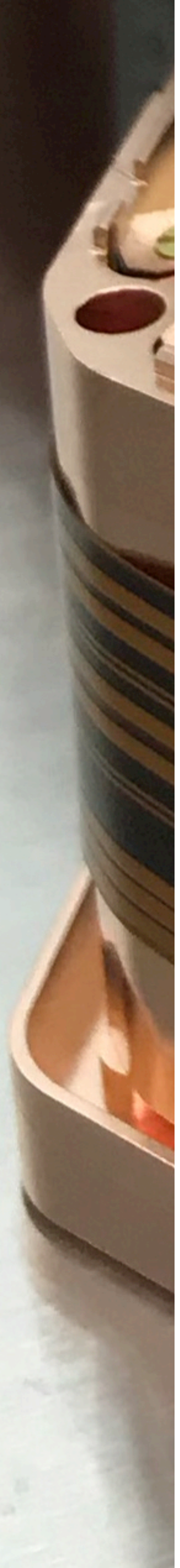
Fabrication Stage	Activity	Tower 1: Ge iZIP [Batch A: 8 Ge] Exposure (days)	Towers 2-4: HV & iZIPs [Batch B: 12 Ge, 8 Si] Exposure (days)
Boules & cut crystals	Production	N/A	5 [a]
	Storage	≈500 [3 Ge], ≈700 [5 Ge]	0 [b]
	Shipment	50	< 2 [c]
Prepare crystals	Align/shape/polish	14 [d]	0 [e]
Detector Fabrication	Lithography	25 [f]	8 [f]
Tower assembly	Install in housing	3 [g]	3 [g]
	300 mK test	6 [g]	0 [h]
	Mounting tower	2 [g]	2 [g]
Tower testing	Functional test	15 days × 3 = 45 [g]	7 [i]
Shipment	SNOLAB delivery	7 [j]	7 [j]
Total exposure		≈560 [3 Ge], ≈760 [5 Ge]	34

Goal exposure: < 60 days sea level equivalent

We are on-track!

Days of effective sea level cosmic ray exposure (shielding and elevation corrected)





Summary

- SuperCDMS searching for direct detection of low mass dark matter
  - Projected reach $\sigma \sim 10^{-43}$ cm^2 at 1 GeV/c^2 dark matter mass
  - Under construction now
  - Operation at SNOLAB in 2020
- Anticipated backgrounds: Tritium, ^{32}Si, Rn daughters, material impurities
  - Developments during construction show paths to further reduction in the future
  - Highlighted background sources are of relevance to neutrinoless double beta decay
- Future detectors expected to probe yet lower mass dark matter candidates
  - Anticipate further R&D detector development in parallel with SuperCDMS construction
  - Developments will likely also improve sensitivity to 1-5 GeV/c^2 dark matter candidates

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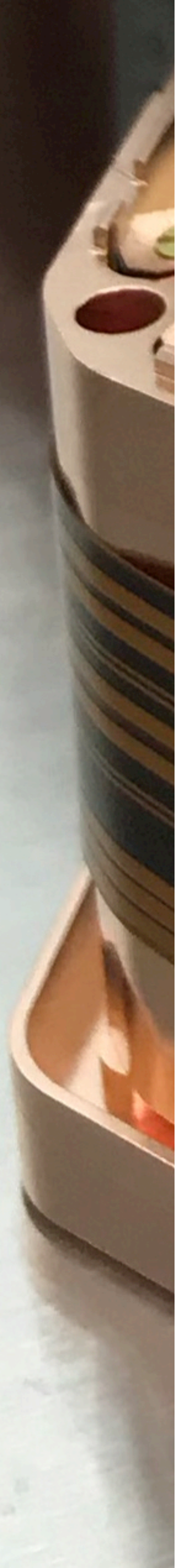

Thank you