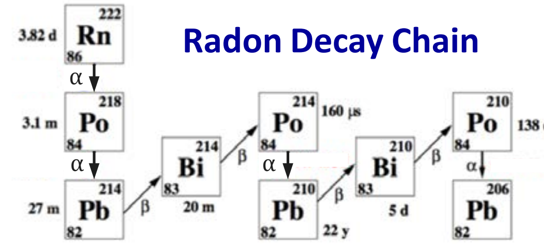
SuperCDMS & Radon

Ray Bunker

Topics in Astroparticle and Underground Physics

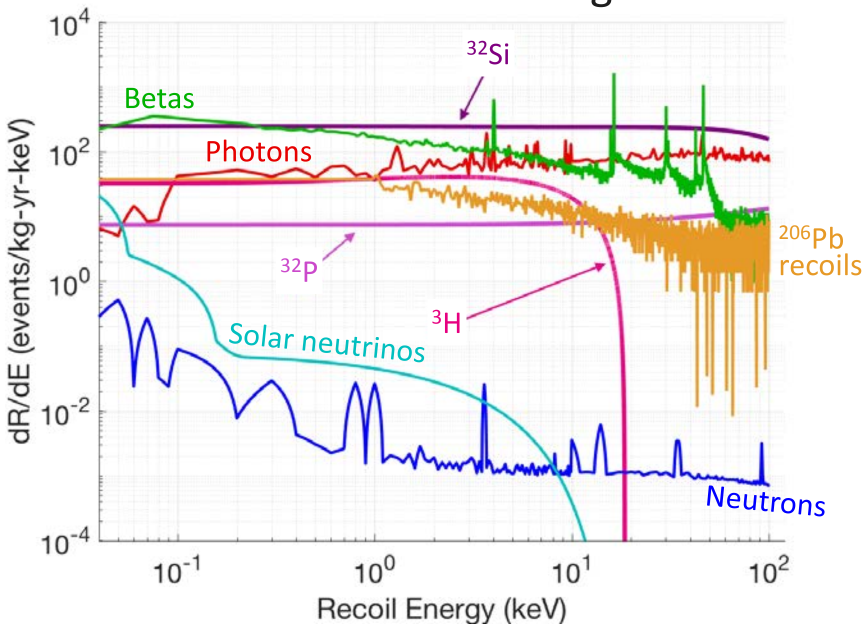
July 26, 2017

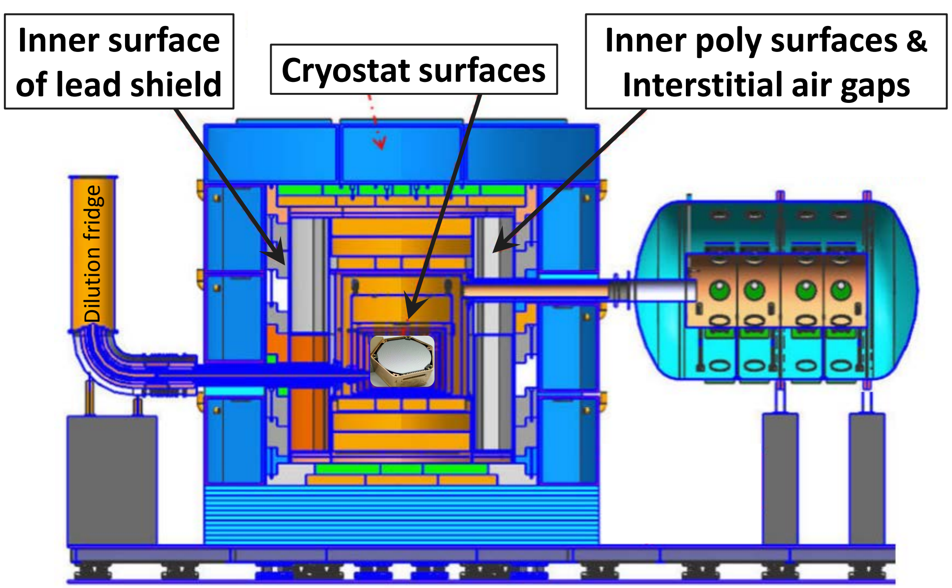
Radon Backgrounds



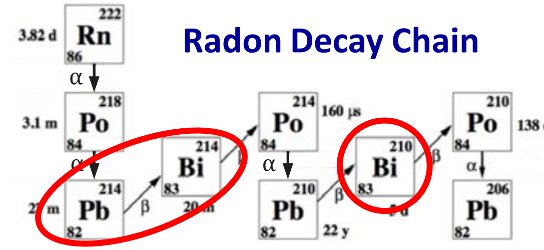
Non-line-of-sight (penetrating) Backgrounds:

SNOLAB Detector Backgrounds





Radon Backgrounds



<u>Non-line-of-sight (penetrating) Backgrounds</u>:

Electron recoils:

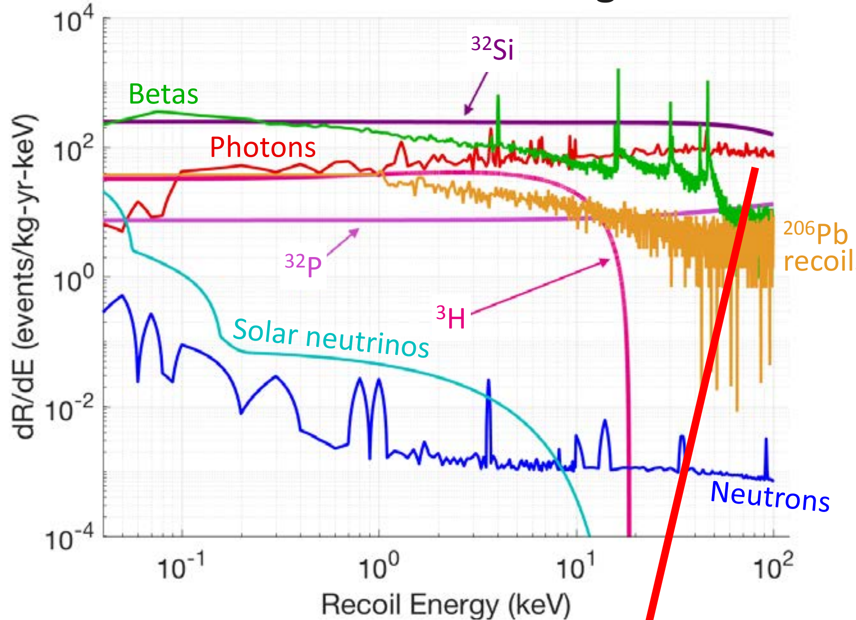
→ ^{210}Bi bremsstrahlung

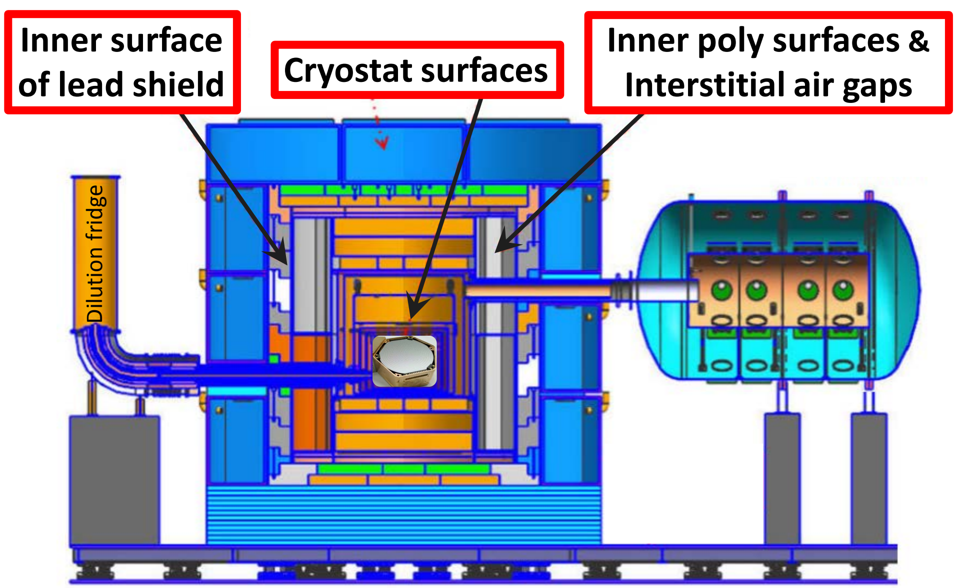
(limit exposure of surfaces to radon)

→ ^{214}Pb & ^{214}Bi gamma-rays

(purge lead shield with low-Rn gas)

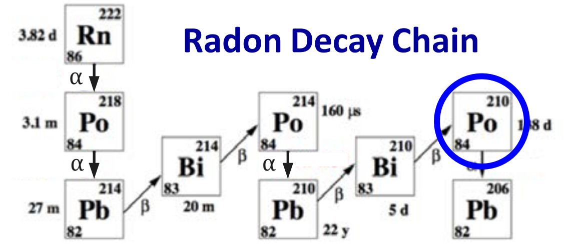
SNOLAB Detector Backgrounds





Non-line-of-sight
Radon Background
≈1% of Total Electron Recoil
Photon Background

Radon Backgrounds



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Electron recoils:

→ ^{210}Bi bremsstrahlung

(limit exposure of surfaces to radon)

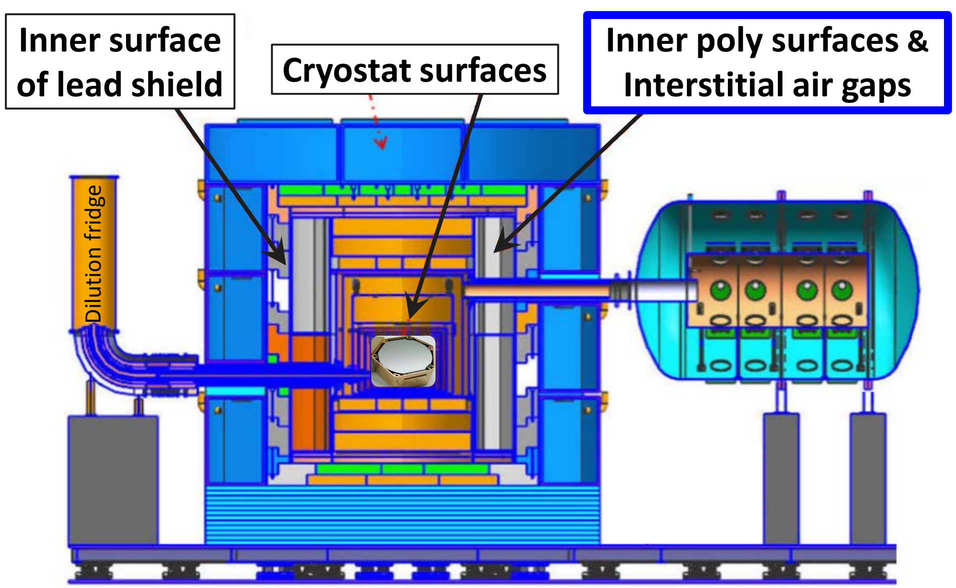
→ ^{214}Pb & ^{214}Bi gamma-rays

(purge lead shield with low-Rn gas)

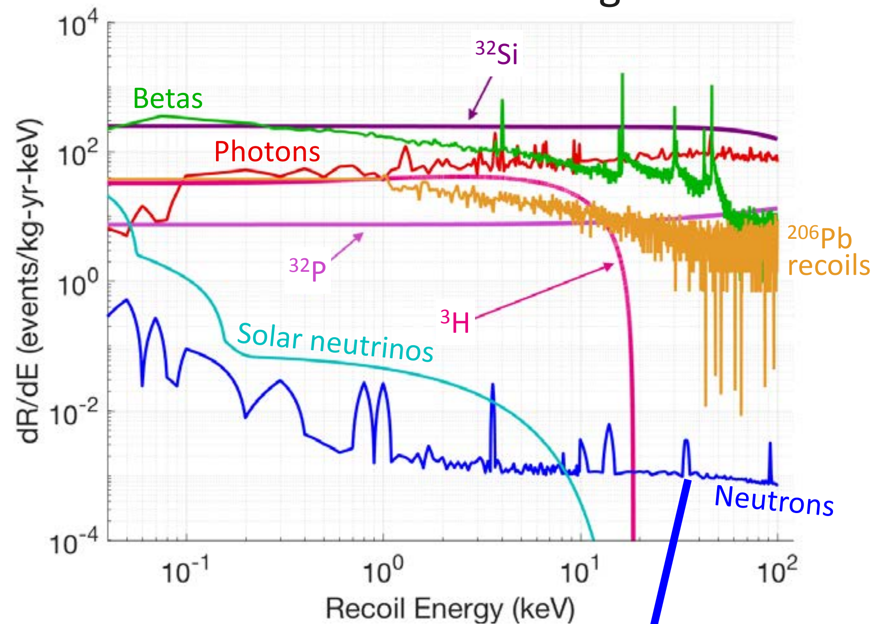
Nuclear Recoils:

→ ^{210}Po (α,n) on ^{13}C in poly

(limit exposure of surfaces to radon)

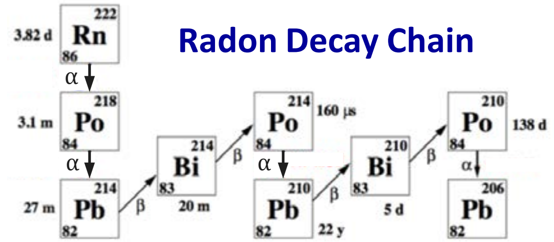


SNOLAB Detector Backgrounds



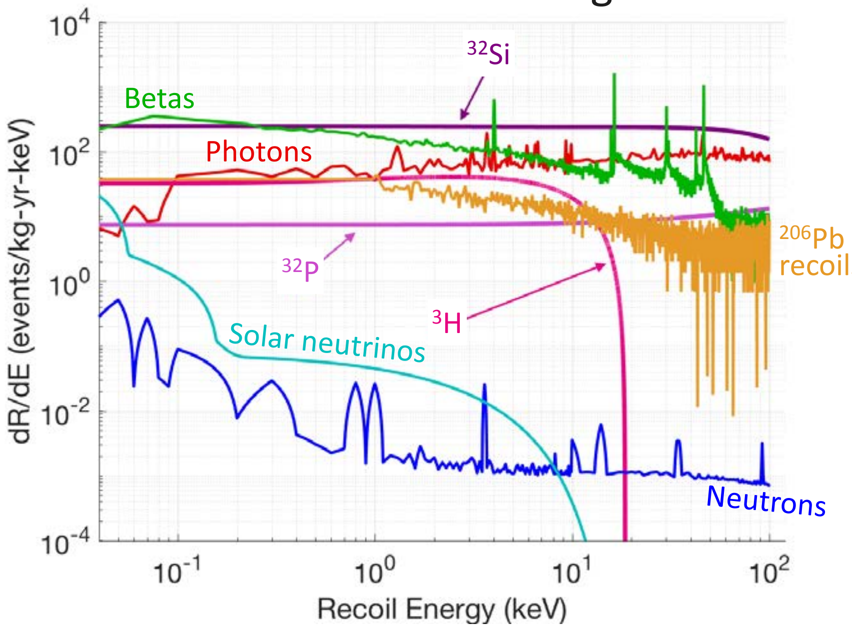
Non-line-of-sight
Radon Background
<1% of Total Nuclear Recoil
Neutron Background

Radon Backgrounds

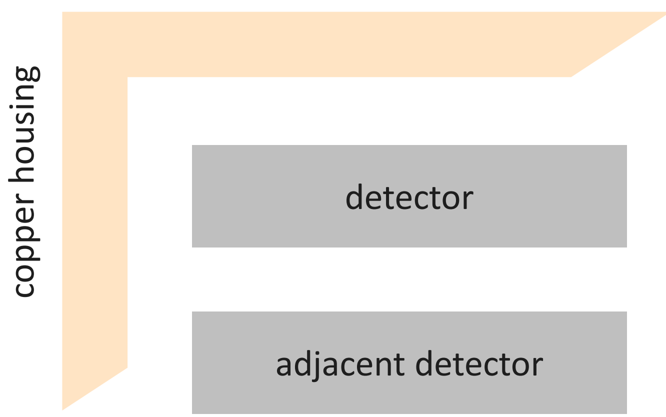


Line-of-sight (non-penetrating) Backgrounds:

SNOLAB Detector Backgrounds



Detector-surface Backgrounds



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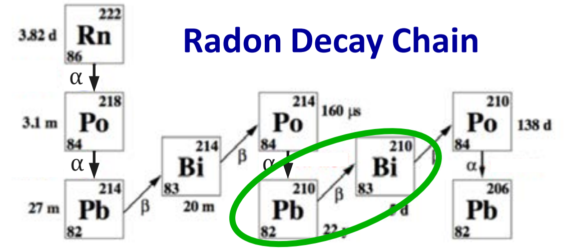
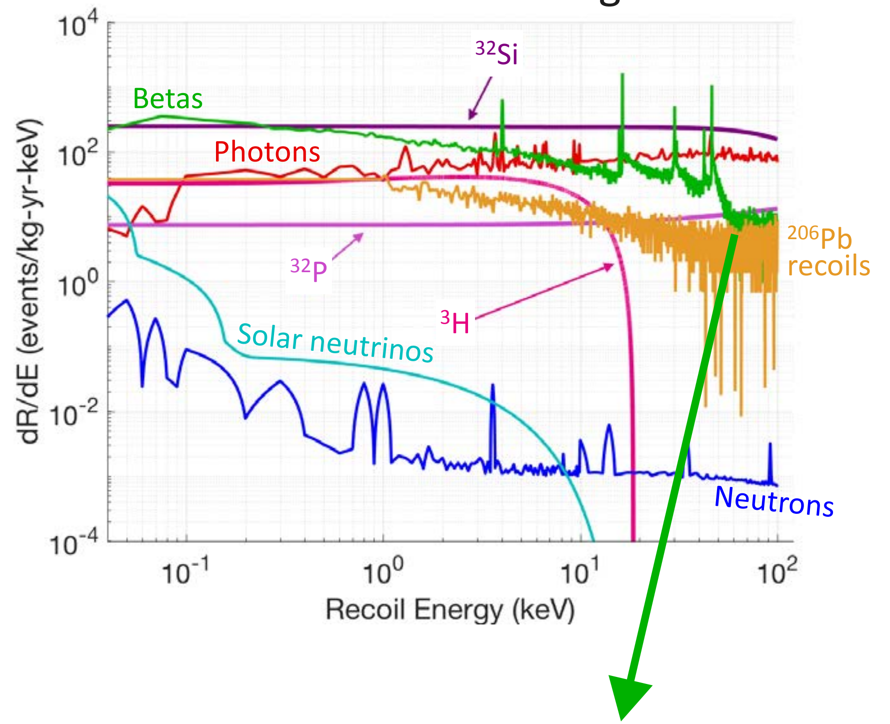


<u>Line-of-sight (non-penetrating) Backgrounds</u>:

Electron recoils:

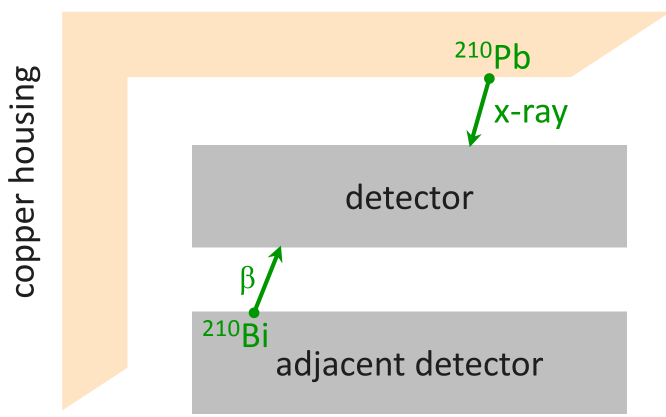
→ ^{210}Pb & ^{210}Bi betas and x-rays

SNOLAB Detector Backgrounds



Line-of-sight
Radon Background
≈100% of Detector-surface
Electron Recoils

Detector-surface Backgrounds



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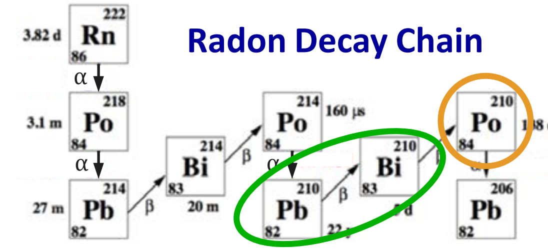


Line-of-sight (non-penetrating) Backgrounds:

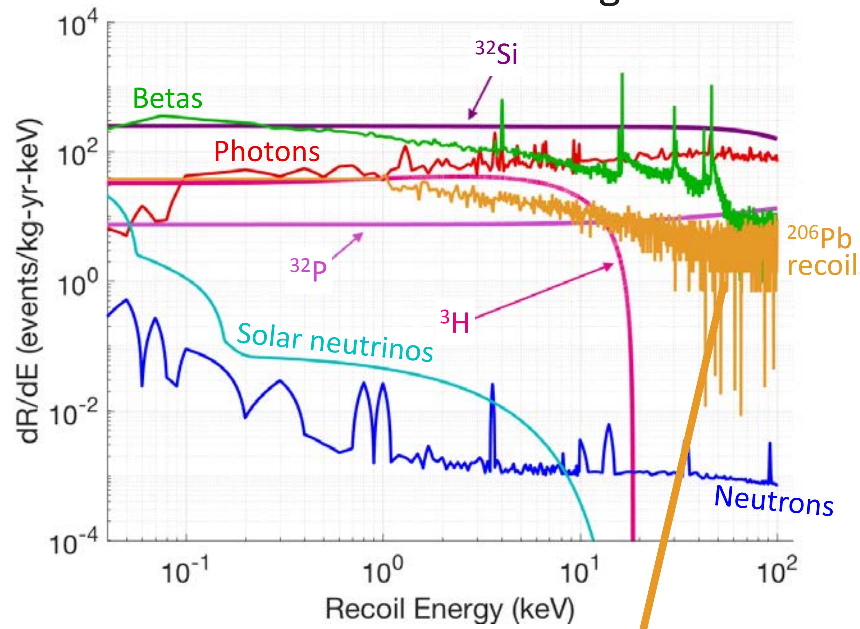
Electron recoils:

→ ^{210}Pb & ^{210}Bi betas and x-rays

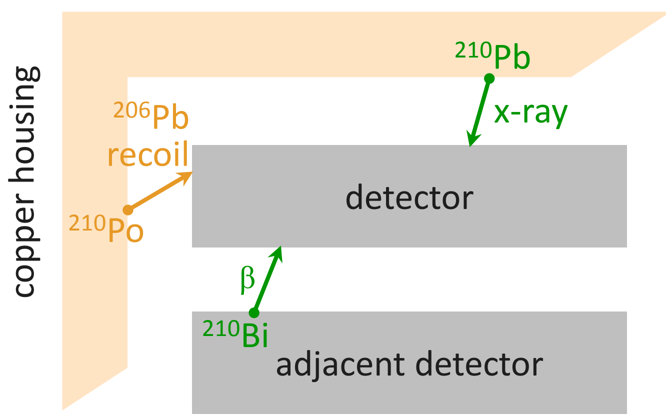
Nuclear Recoils:

→ ^{206}Pb recoils from ^{210}Po decays

SNOLAB Detector Backgrounds

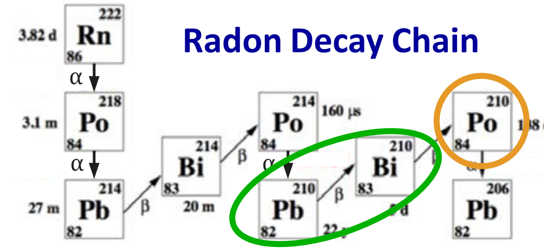


Detector-surface Backgrounds



Line-of-sight
Radon Background
≈100% of Detector-surface
Nuclear Recoils

Radon Backgrounds



Line-of-sight (non-penetrating) Backgrounds:

Electron recoils:

→ ^{210}Pb & ^{210}Bi betas and x-rays

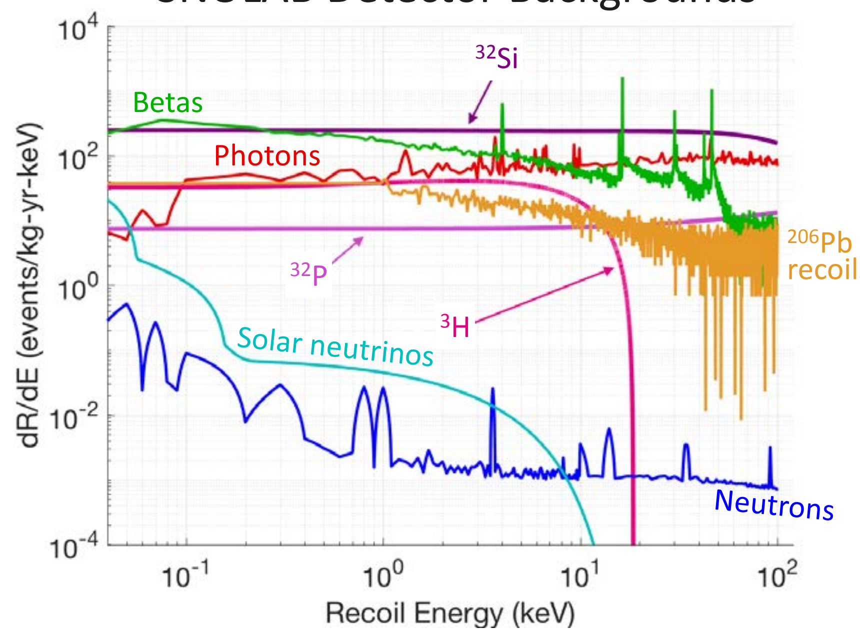
Nuclear Recoils:

→ ^{206}Pb recoils from ^{210}Po decays

Potentially dominant backgrounds unless:

- Detector/copper surfaces clean at start
- And protected from radon thereafter

SNOLAB Detector Backgrounds



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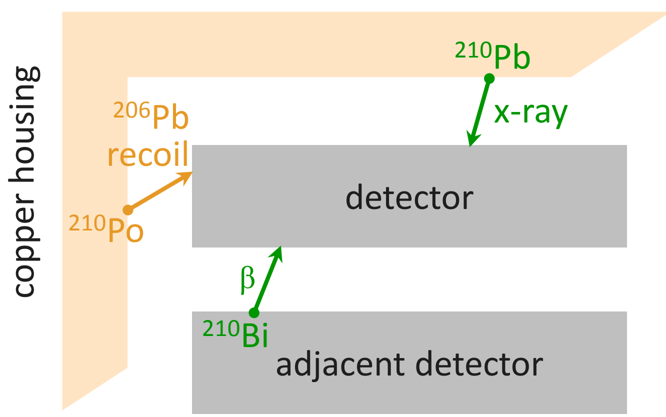

Calls for dedicated background controls:

I. Limit exposure to radon during payload lifecycle
II. Dedicated low-radon cleanroom at SNOLAB
III. Validate cleanliness of critical processes

Payload Lifecycle & Radon Exposure

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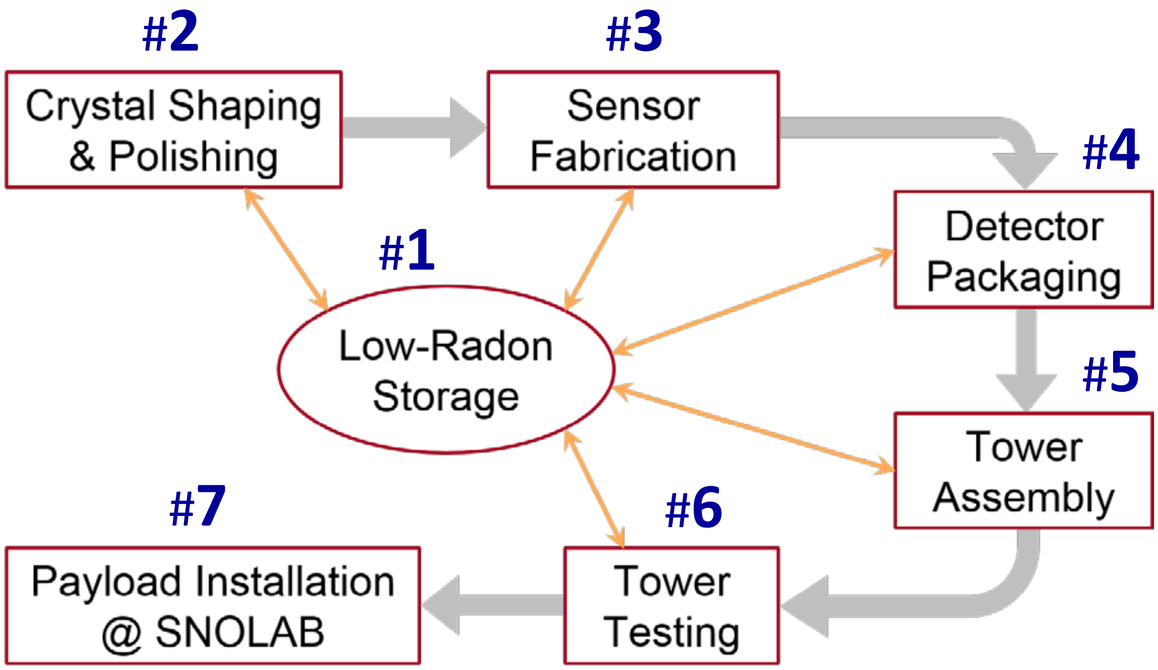
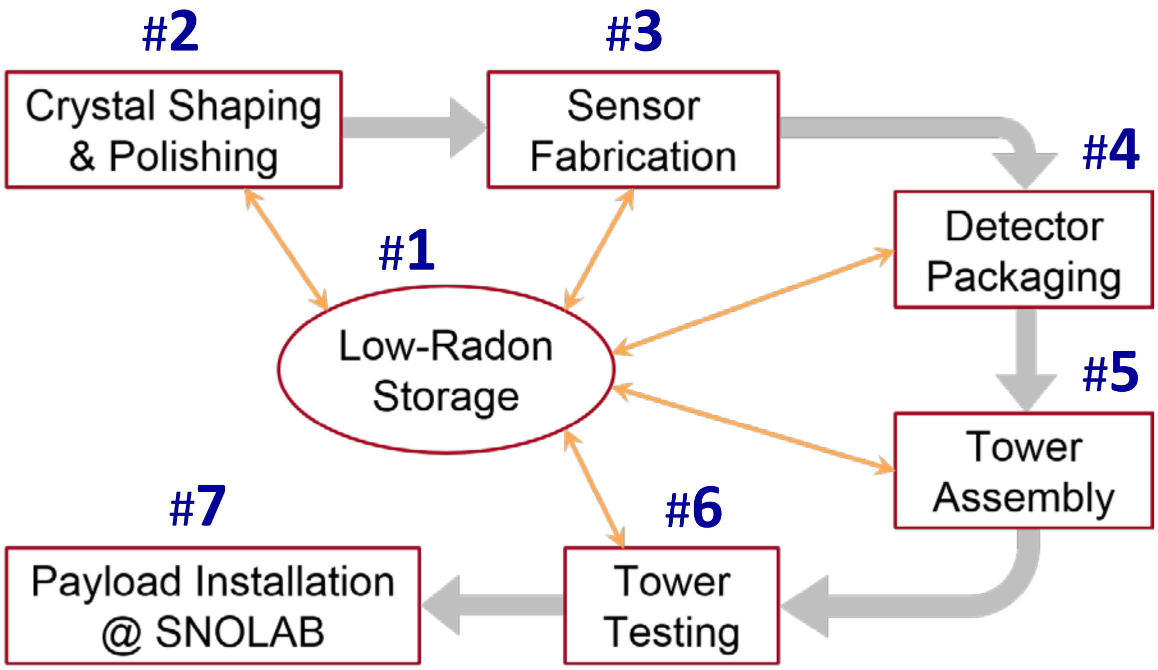


Procedure	^{210}Pb (nBq/cm^2)
#1 – storage	<0.1
#2 – polishing	12–45
#3 – fabrication	28
#4 – packaging	4.8
#5 – tower assembly	0.9
#6 – testing	1.1
#7 – installation (w/ 1000x Rn mitigation)	<0.1
#7 – installation (w/o Rn mitigation)	70

Payload Lifecycle & Radon Exposure



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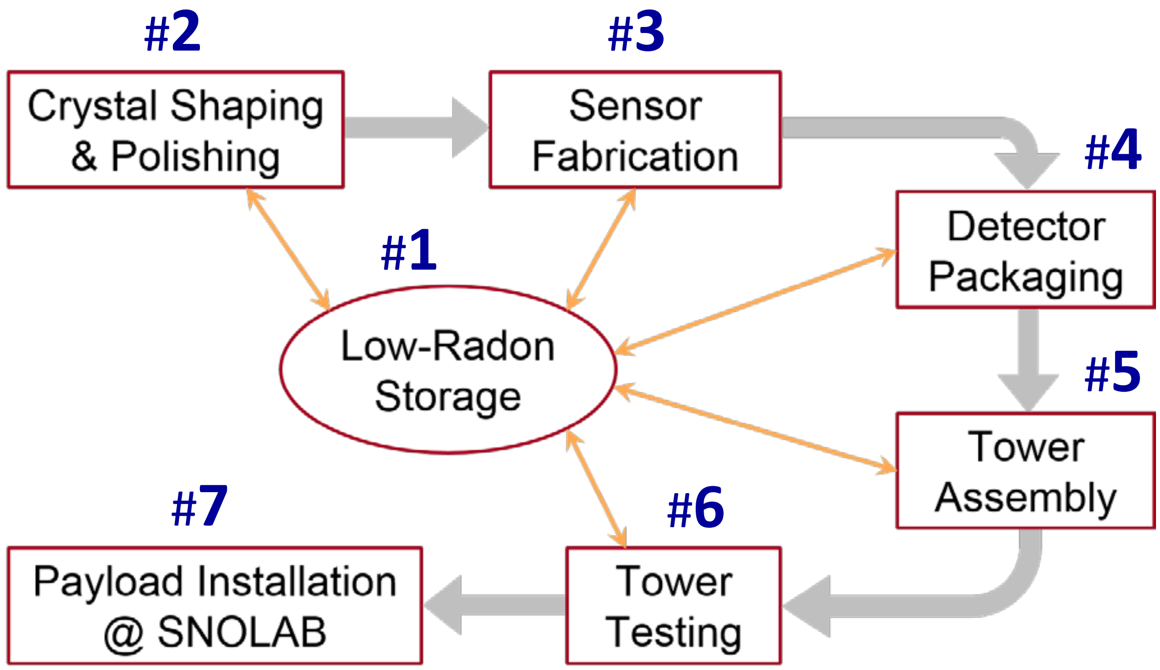
^{210}Pb from Rn exposure (conservative plate-out tally):

- Detector surfaces: 47–80 nBq/cm^2
  - Assume worst for sidewalls → 80 nBq/cm^2
  - Sensor fab removes surface area on faces → 50 nBq/cm^2
- Copper surfaces: <10 nBq/cm^2

Payload Lifecycle & Radon Exposure



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Copper surfaces: <10 nBq/cm^2

Plate-out ≈2x larger without low-radon cleanroom

Low-radon Cleanroom @ SNOLAB via Vacuum-Swing Adsorption (VSA)

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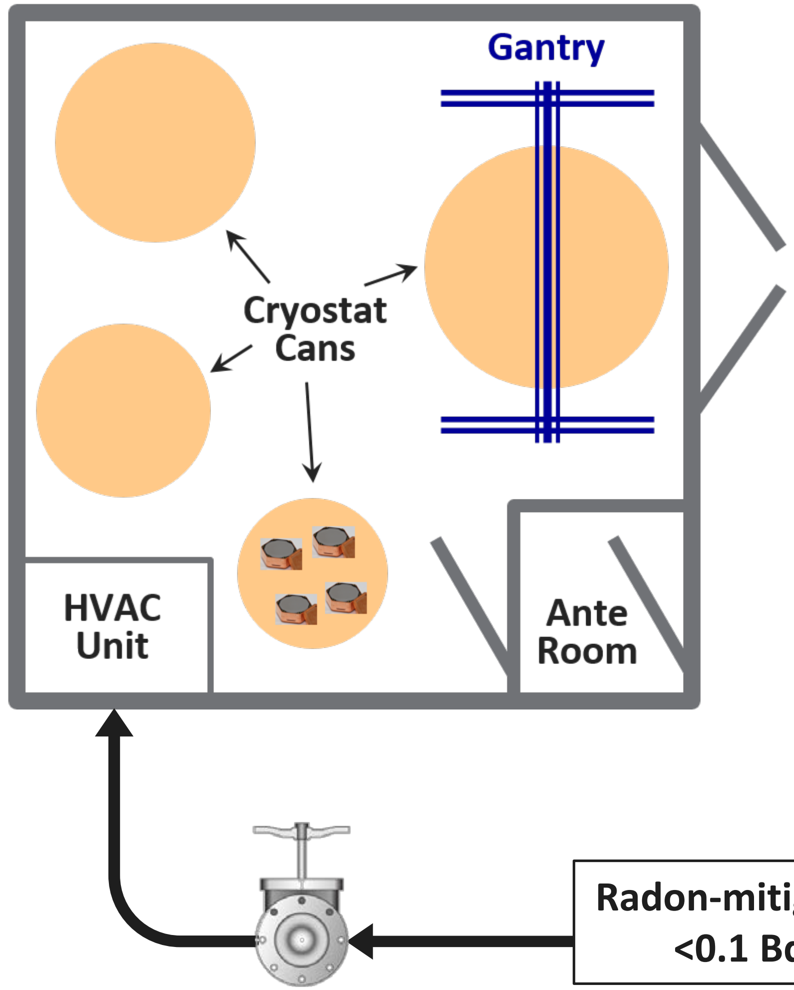
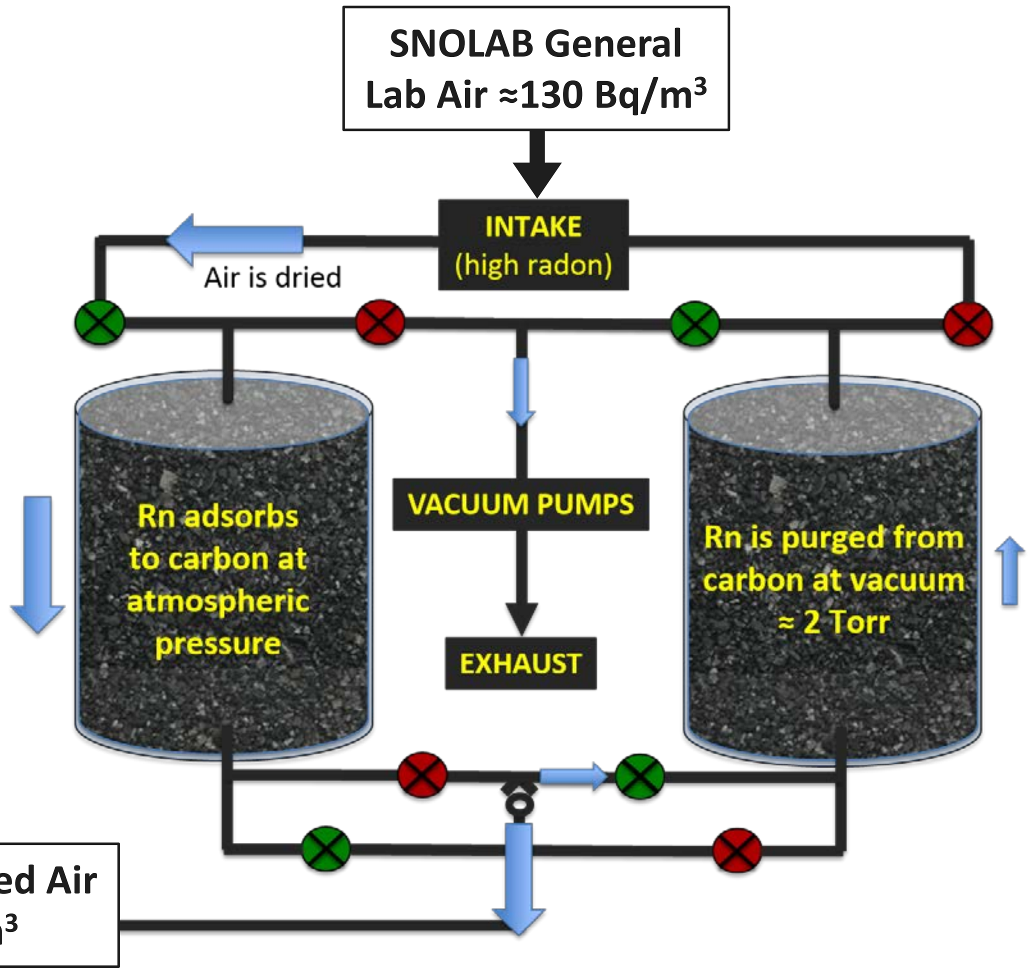
Class-100 Low-radon Cleanroom



Custom-built Radon Mitigation System



Demonstration VSA @ SDSM&T

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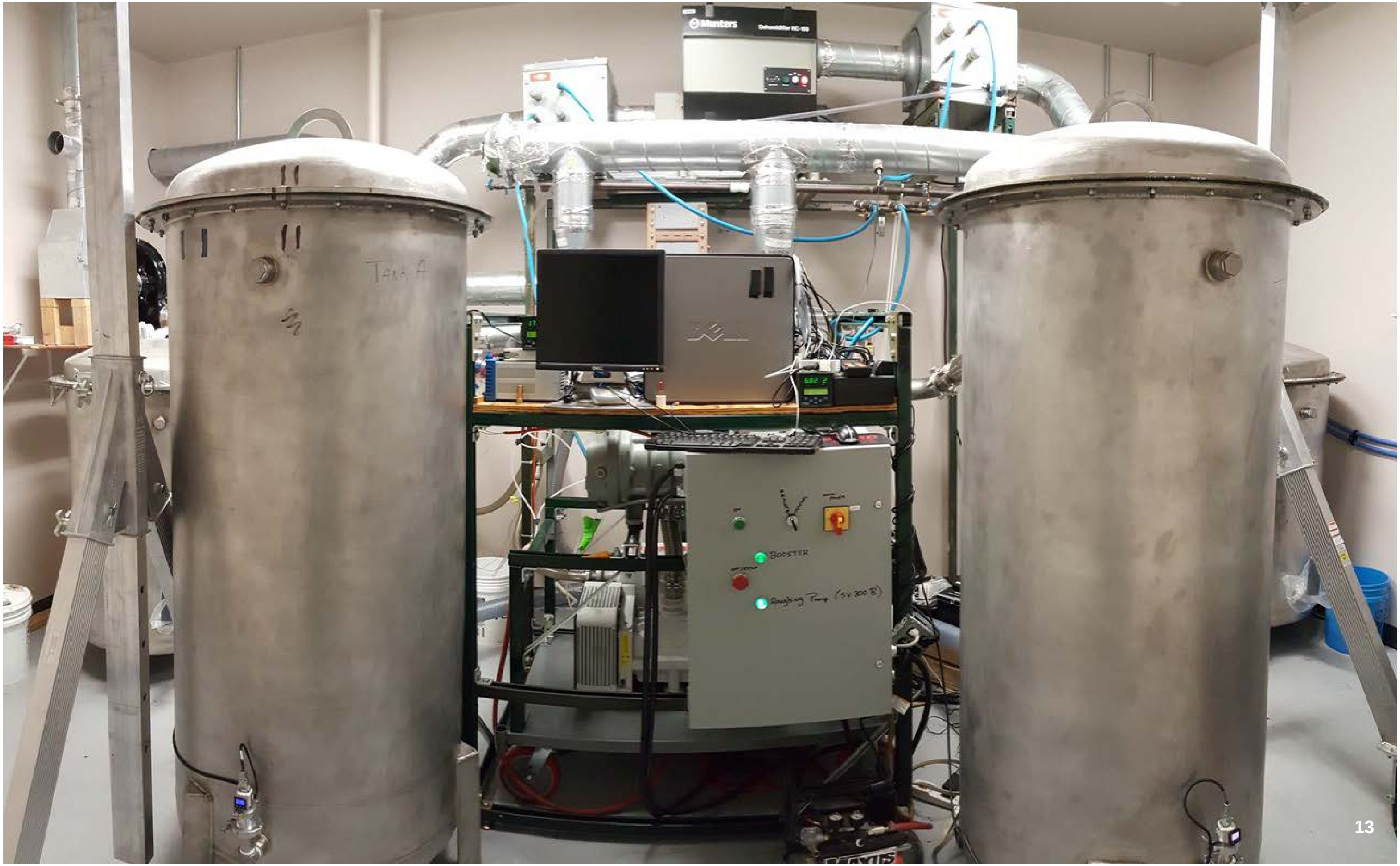

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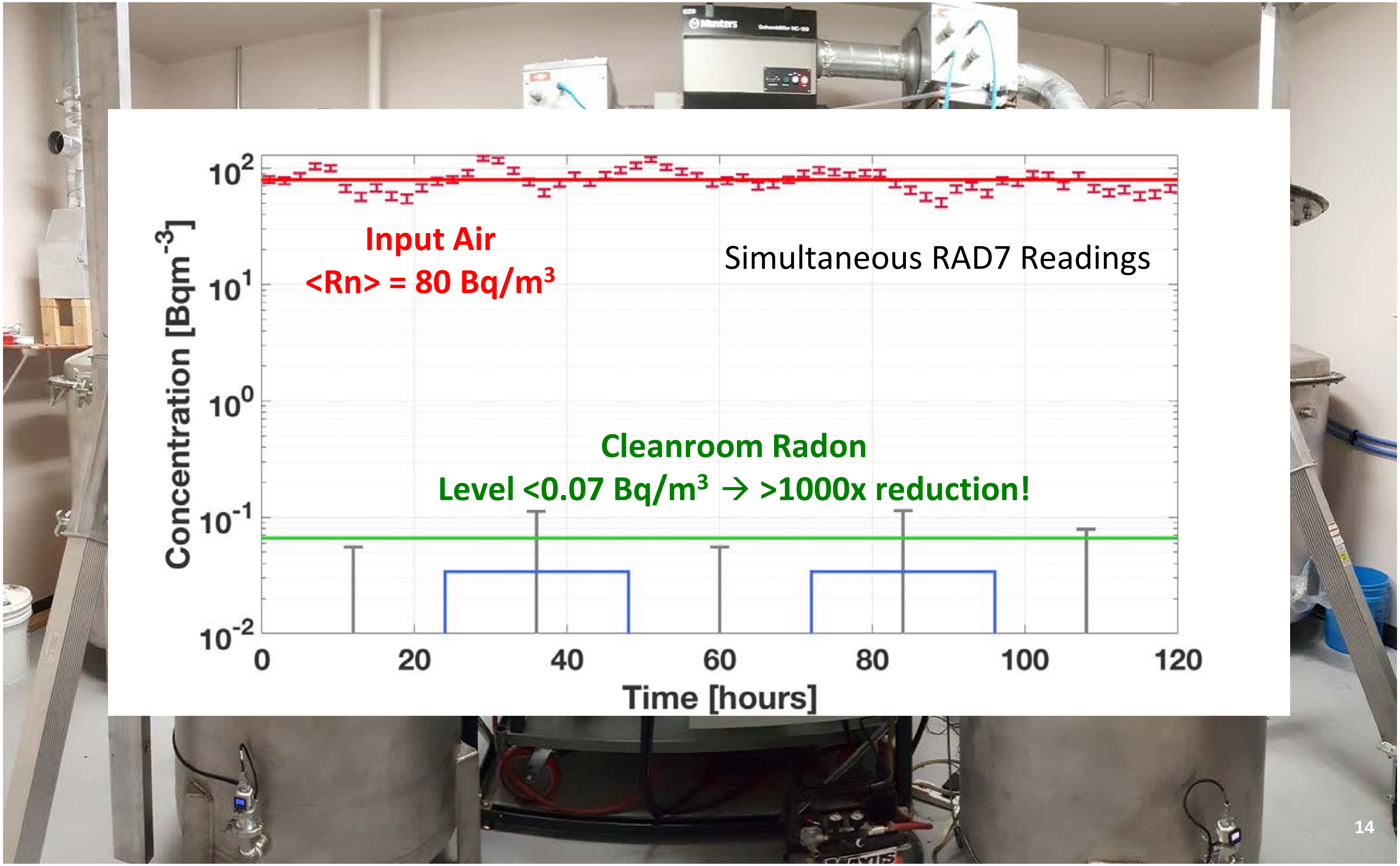

Validation of Critical Processes

Bottom-up estimate of ^{210}Pb plate-out from radon exposure in air: ← Σ

- Detector surfaces: 50/80 nBq/cm^2 for faces/sidewalls
- Tower-copper surfaces: <10 nBq/cm^2

But doesn't include:

- Initial level of surface contamination
  → do surfaces start clean?
- Contamination directly from fabrication processes
  (*e.g.*, chemical contact)

R&D tests to validate critical processes:

- Detector surfaces → crystal polishing & sensor fabrication
- Copper surfaces → cleaning method

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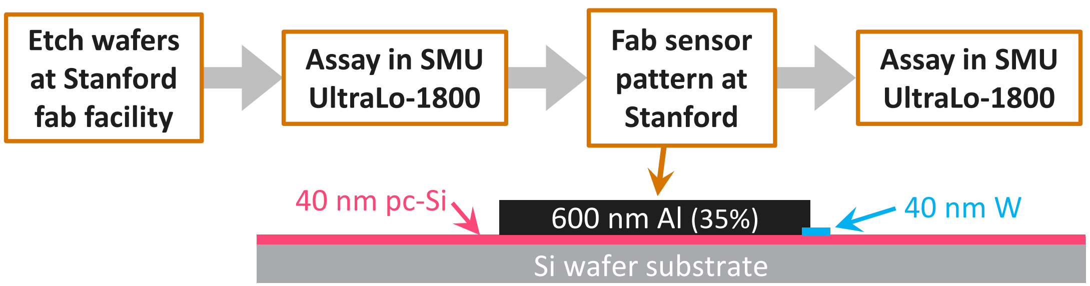
Sensor Fabrication Test

Goals:

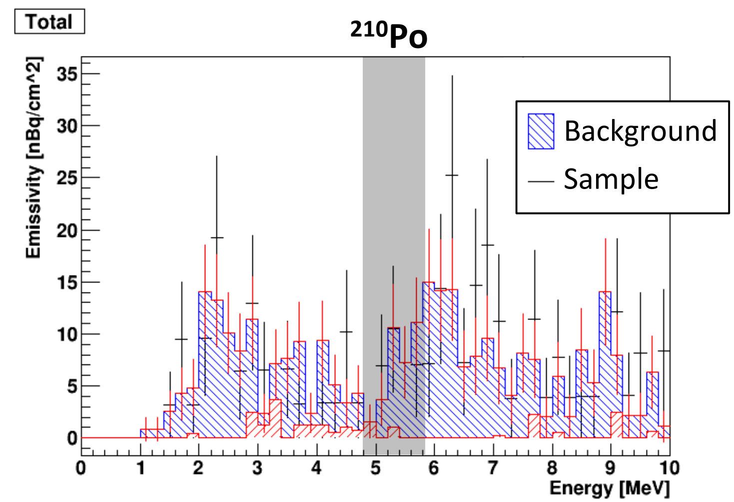
- Validate starting level of ^{210}Pb on detector surfaces
- Validate surface contamination from sensor fabrication

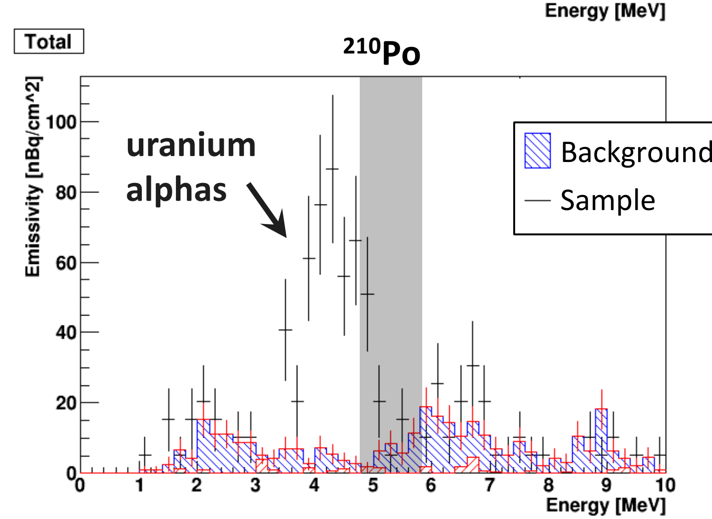


Results:

- Broad 4–5 MeV peak suggests upper-chain ^{238}U alphas
- Precedent from DRIFT → *Battat et al., NIM A794 (2015)*
- Background concern → ^{234}Th daughter beta decay
- Follow-up measurements:
  - Backsides of wafers → no peak
  - ICP-MS of wafers → few Bq/kg of ^{238}U in aluminum

XIA UltraLo-1800 Spectra (SMU)





Sensor Fabrication Test

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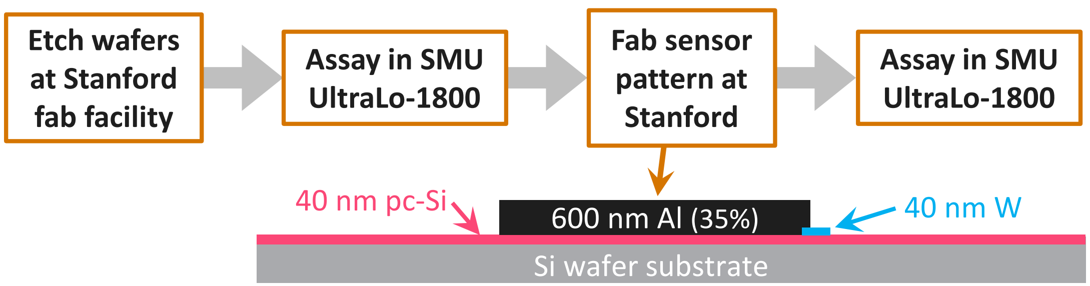

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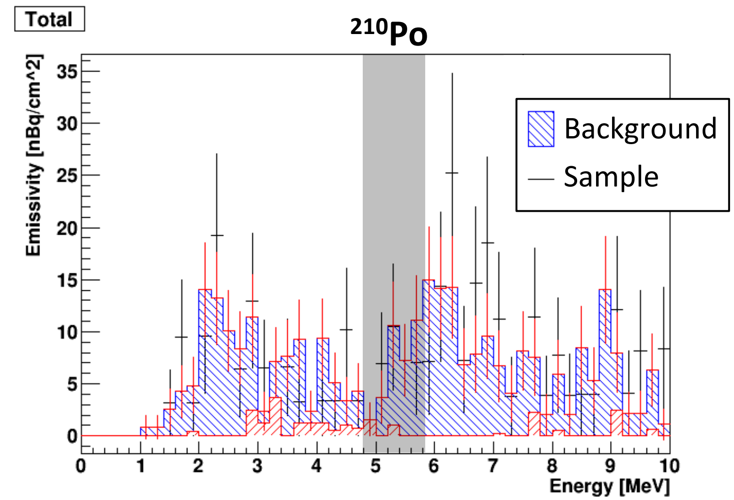
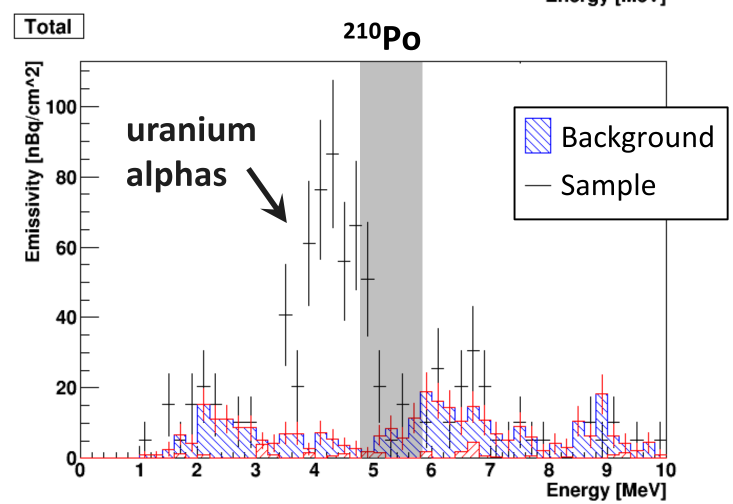
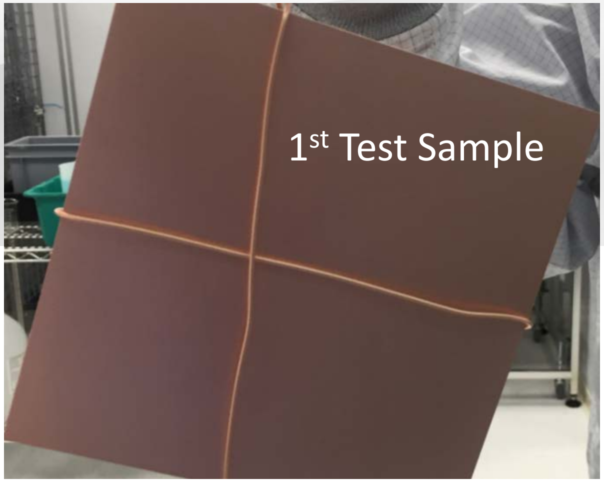
Not seen on SuperCDMS Soudan detectors
Working with vendor to pre-screen aluminum

XIA UltraLo-1800 Spectra (SMU)





Copper Cleaning Test

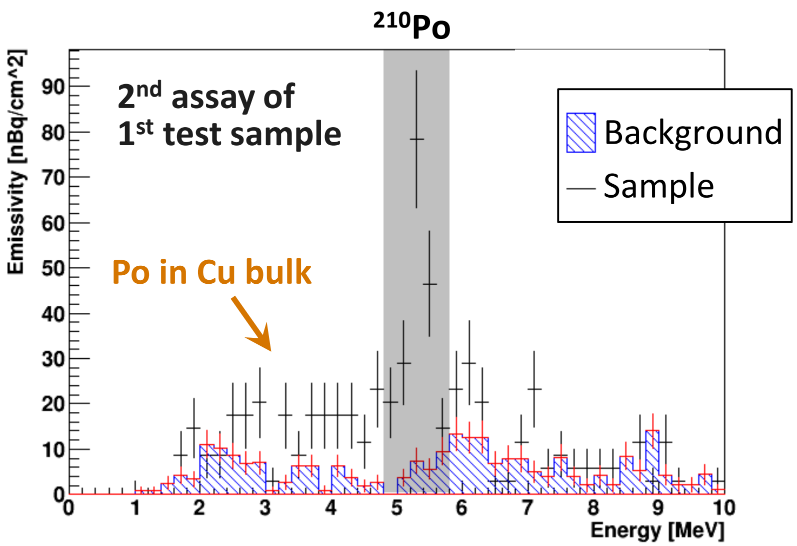


Goal:

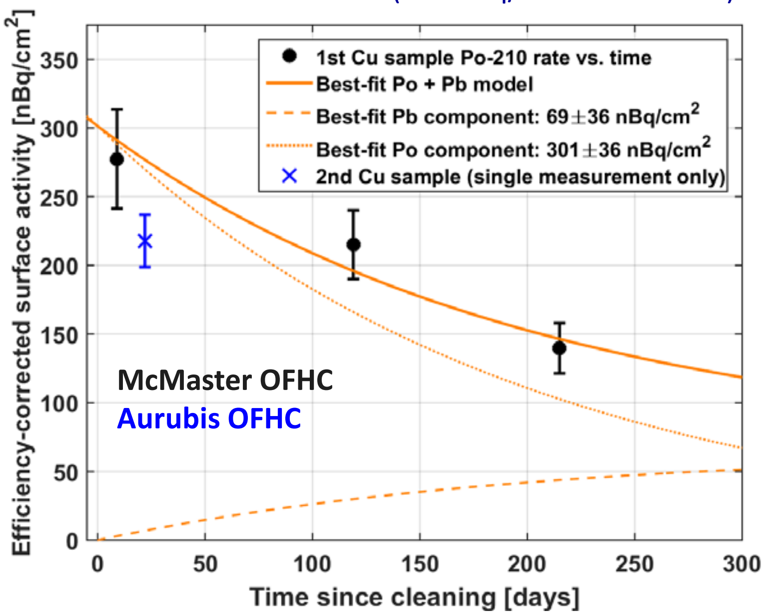
- Validate method for cleaning tower copper parts
  - And thus starting contamination level for detector housings

Methodology:

- Fabricate 2 sets of large-area Cu plates: McMaster & Aurubis OFHC (alloy 101)
- Mill off >1 mm from all surfaces to simulate parts fabrication
- Clean w/ PNNL acidified-peroxide etching recipe
- Use SMU UltraLo-1800 to measure surface alphas



UltraLo-1800 Background not Subtracted (≈25 nBq/cm² in ^{210}Po ROI)



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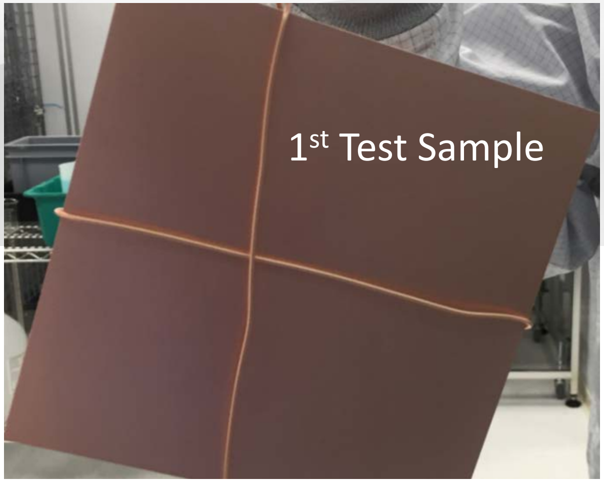

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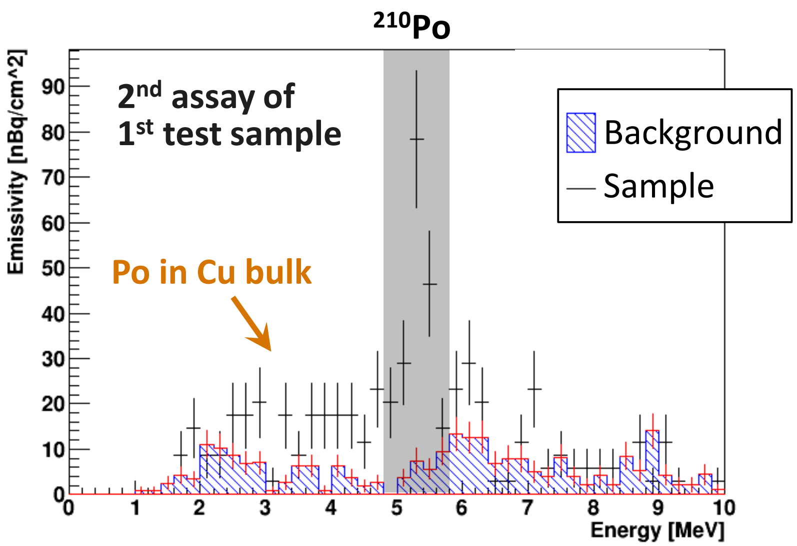

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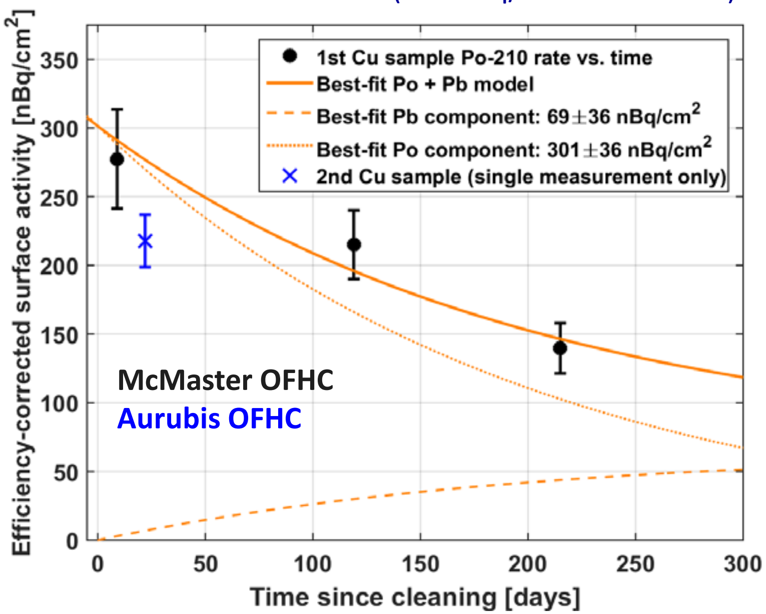

Anticipate <100 nBq/cm^2 ^{210}Pb (>10x better than Soudan)

Summary

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Radon is an important background consideration for SuperCDMS SNOLAB

- ^{210}Pb within line-of-sight of detectors is a potentially dominant background

Estimate of ^{210}Pb from plate-out:

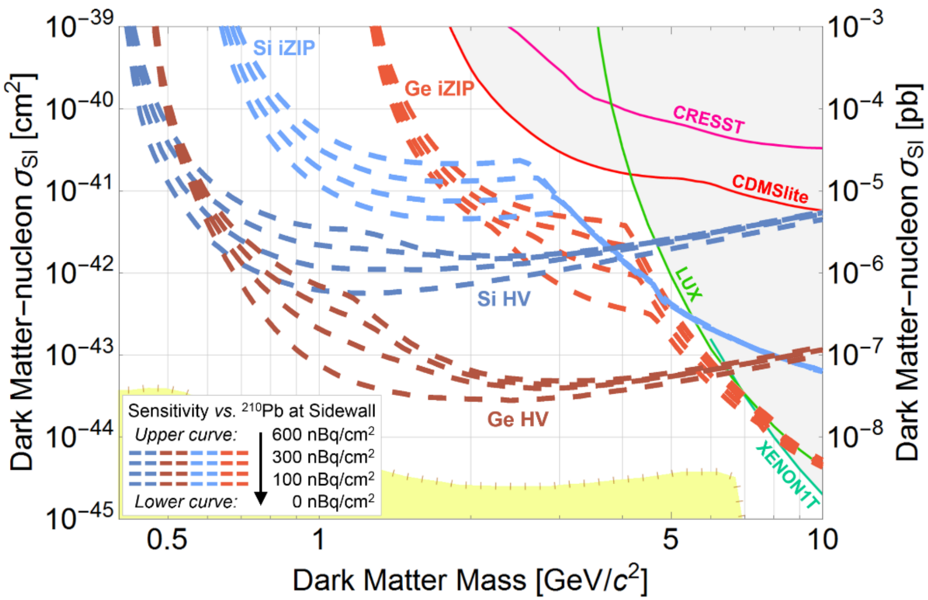
- Detector faces/sidewalls: 50/80 nBq/cm^2
- Copper housings: <10 nBq/cm^2

Low-radon cleanroom for installation at SNOLAB mitigates plate-out by ≈2x

- SDSM&T VSA demonstrates >1000x radon reduction

Validation of critical processes:

- Contamination during crystal polishing negligible
- Discovered uranium in detector-sensor aluminum → working with vendor to eliminate
- Demonstrated copper surfaces with <100 nBq/cm^2 ^{210}Pb via PNNL acidified-peroxide etch



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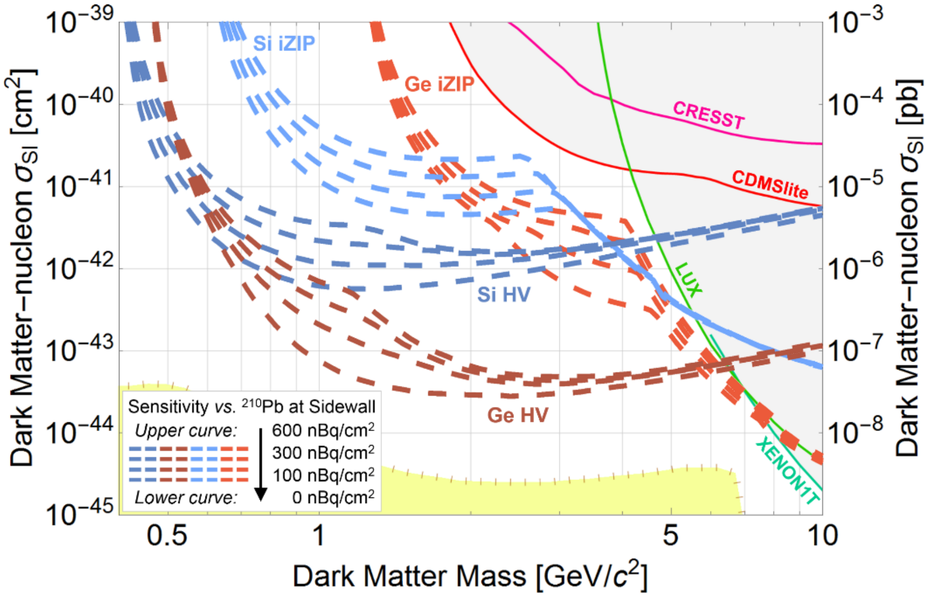


Demonstrated ^{210}Pb at sidewalls: detector + copper <200 nBq/cm^2

Validation of critical processes:

- Contamination during crystal polishing negligible
- Discovered uranium in detector-sensor aluminum → working with vendor to eliminate
- Demonstrated copper surfaces with <100 nBq/cm^2 ^{210}Pb via PNNL acidified-peroxide etch

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. Minnesota
U. South Dakota
U. Toronto

* Associate members

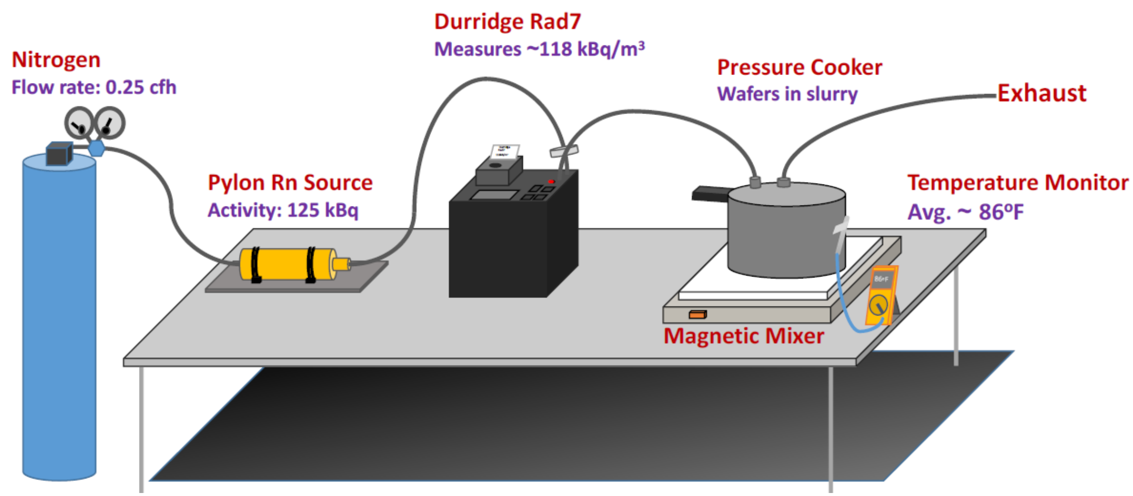
Crystal Polishing Test

Goal:

- Validate ^{210}Pb contamination rate during polishing

Methodology:

- Seven 100 mm Si wafers as proxy for detector surfaces
- UltraLo-1800 to measure surface alphas
- 10,000x radon w/ SDSM&T source to boost sensitivity



^{210}Pb surface contamination during polishing insignificant → <1 nBq/cm^2

XIA UltraLo-1800 Spectra (SMU)