Radon-daughter Plate-out Measurements for SuperCDMS SNOLAB

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Outline

- Project Objectives
- Introduction to SuperCDMS
- SNOLAB and Environmental Conditions
- Experimental Setup
- Model & Analysis
- Results

Objectives

- To develop a ^{210}Pb plate-out model that can:
  - Predict alpha activity over time
  - Inform exposure limits for installation of SuperCDMS SNOLAB
  - Inform future background estimates
  - Be useful for other projects/experiments
- To achieve this through measured samples of high density polyethylene (HDPE) and copper at SNOLAB

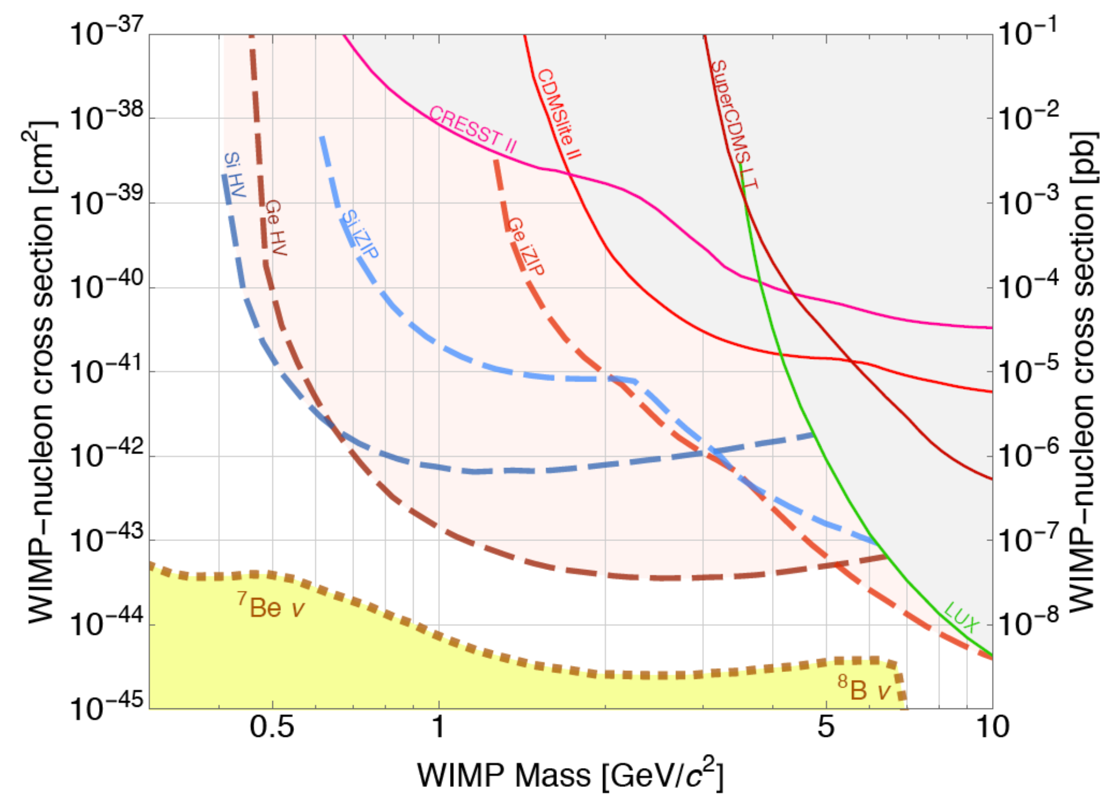
SuperCDMS
(Super Cryogenic Dark Matter Search)

- Cryogenic solid-state detectors to directly detect low-mass WIMPs
- Set world-best low-mass limits with previous-generation SuperCDMS Soudan and CDMSlite
- In the planning and design phase of SuperCDMS SNOLAB (next generation detector)

SuperCDMS SNOLAB

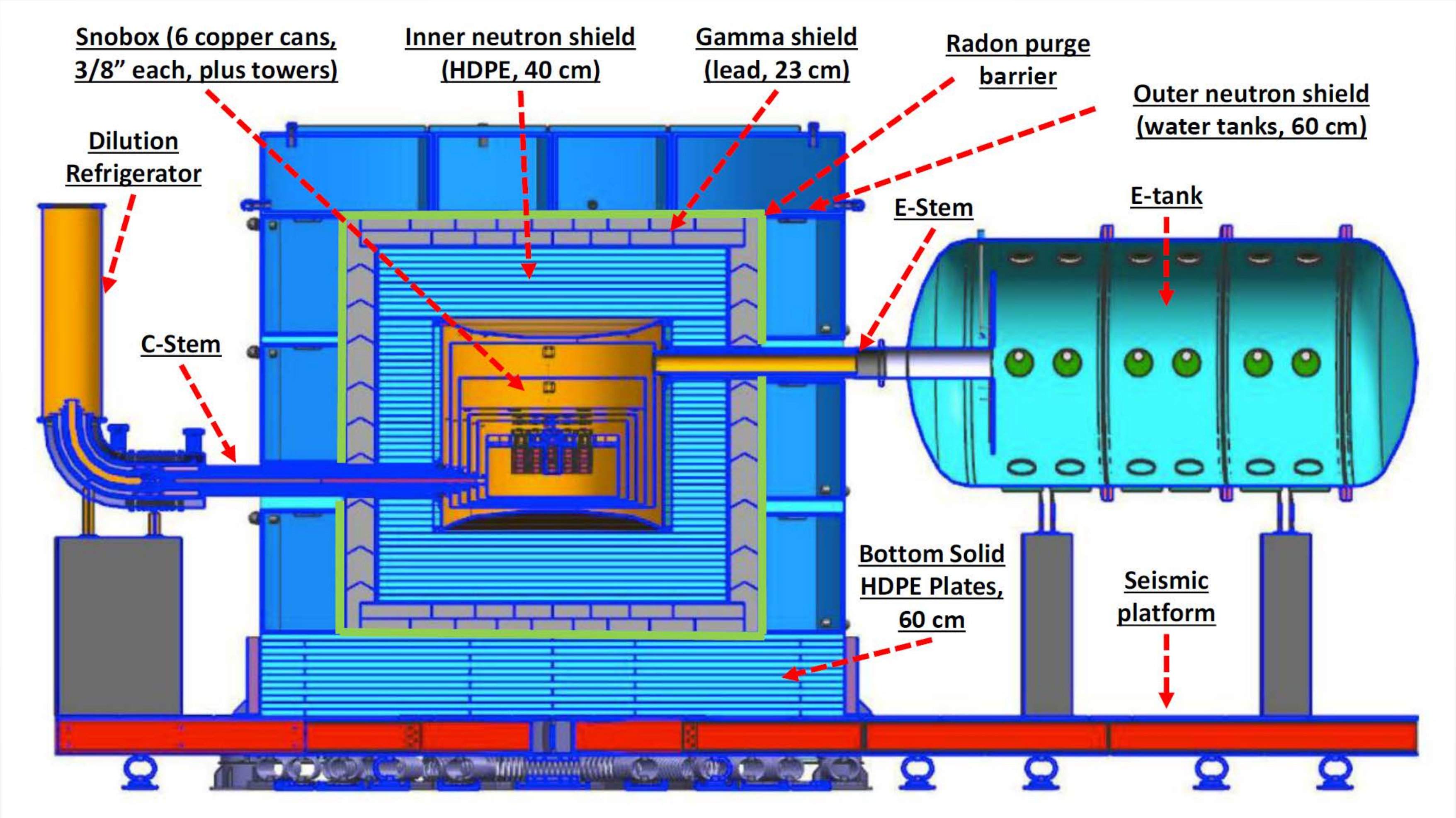
- Total of 24 detectors
- Total of 28.7 kg
  - 25 kg Ge
  - 3.7 kg Si
- Four year exposure

	iZIP		HV	
	Ge	Si	Ge	Si
Number of detectors	10	2	8	4
Total exposure (kg·yr)	56	4.8	44	9.6
Phonon resolution (eV)	50	25	10	5
Ionization resolution (eV)	100	110	–	–
Voltage Bias (V)	6	8	100	100

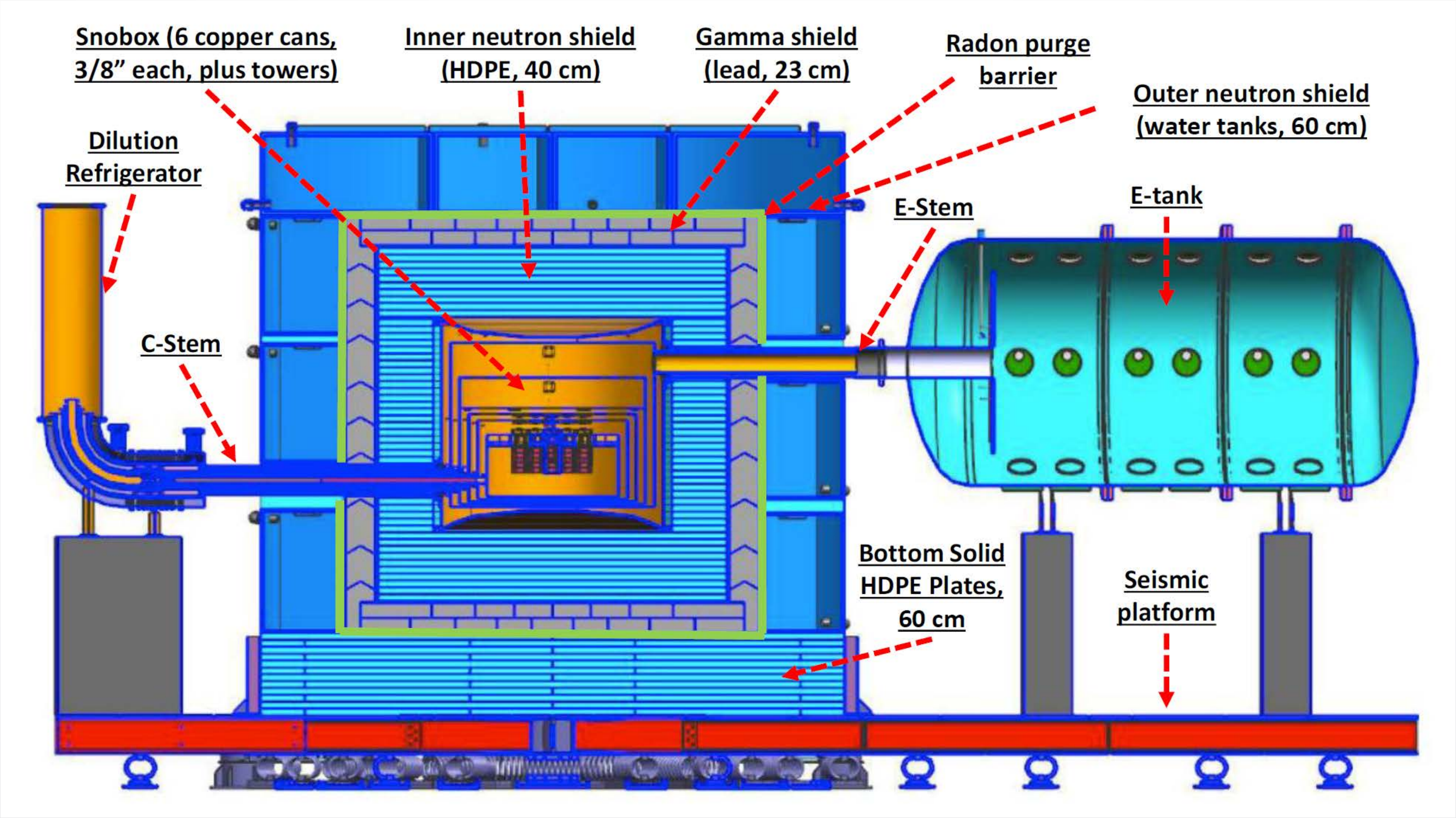


https://journals.aps.org/prd/abstract/10.1103/PhysRevD.95.082002

Shielding Schematic



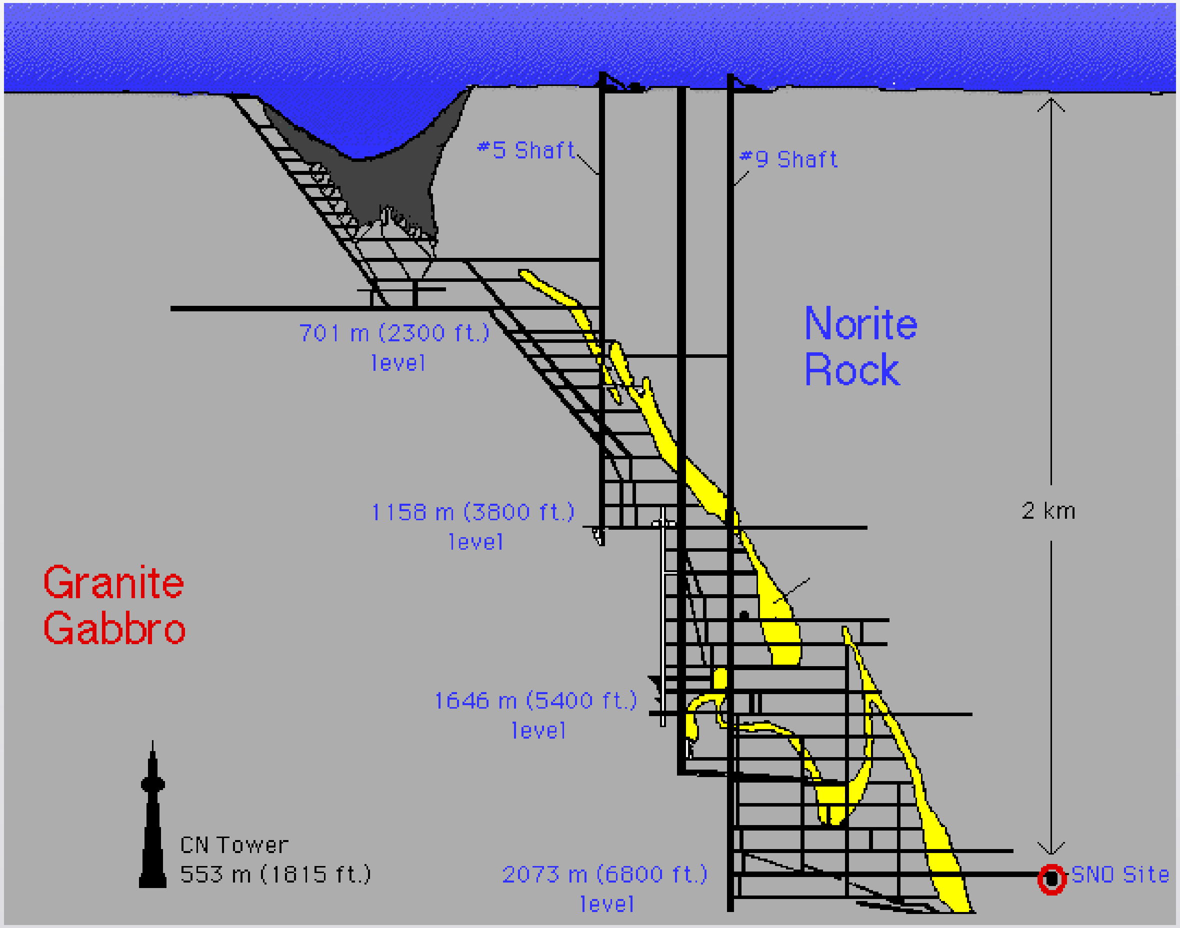
Shielding Schematic



- Sensitivity estimates assume 10 μBq/cm^2 from ^{210}Pb on shield surfaces

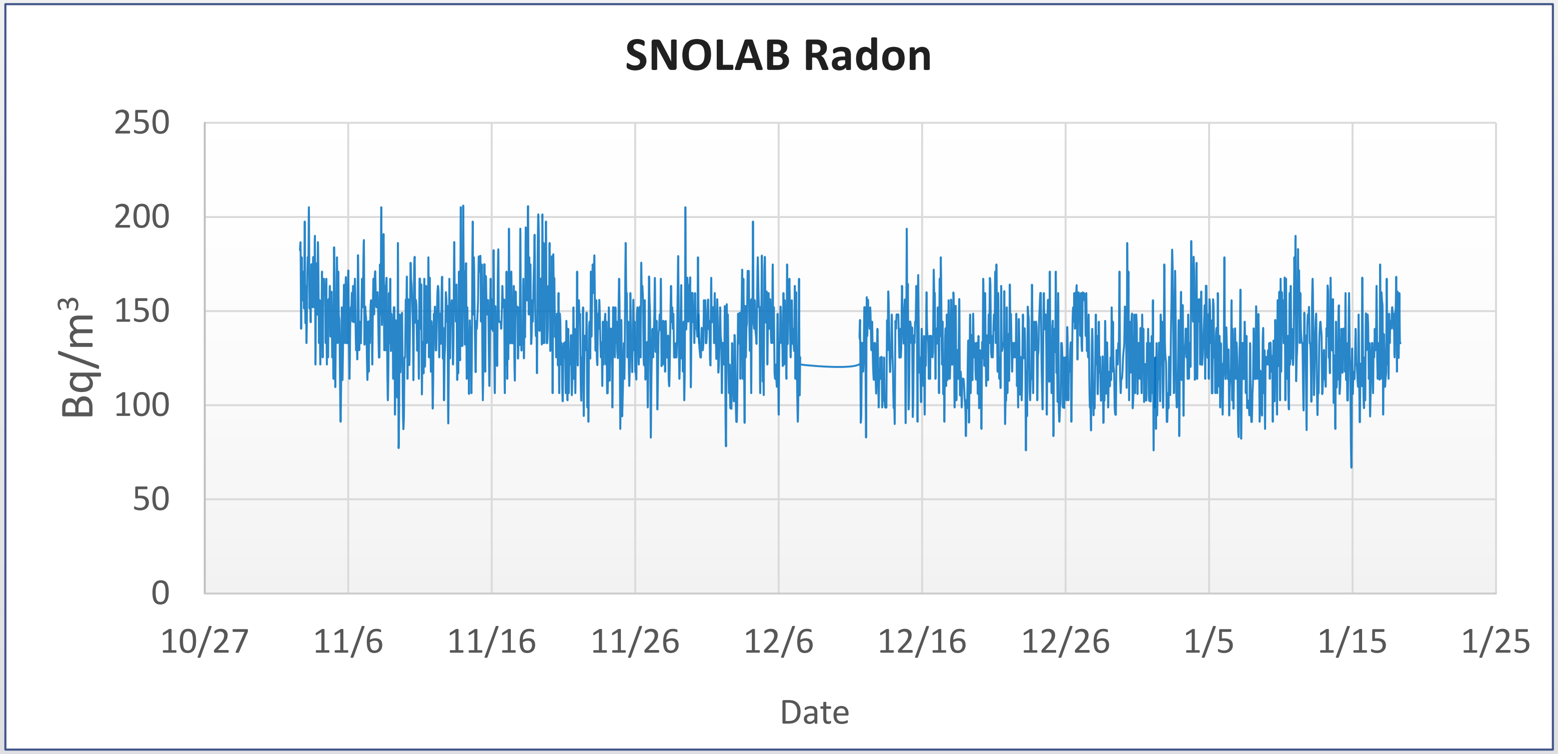
SNOLAB

- Main lab located at 6,800 ft level of operational Vale Creighton nickel mine
- 2,073 m overburden
- 6,010 mwe



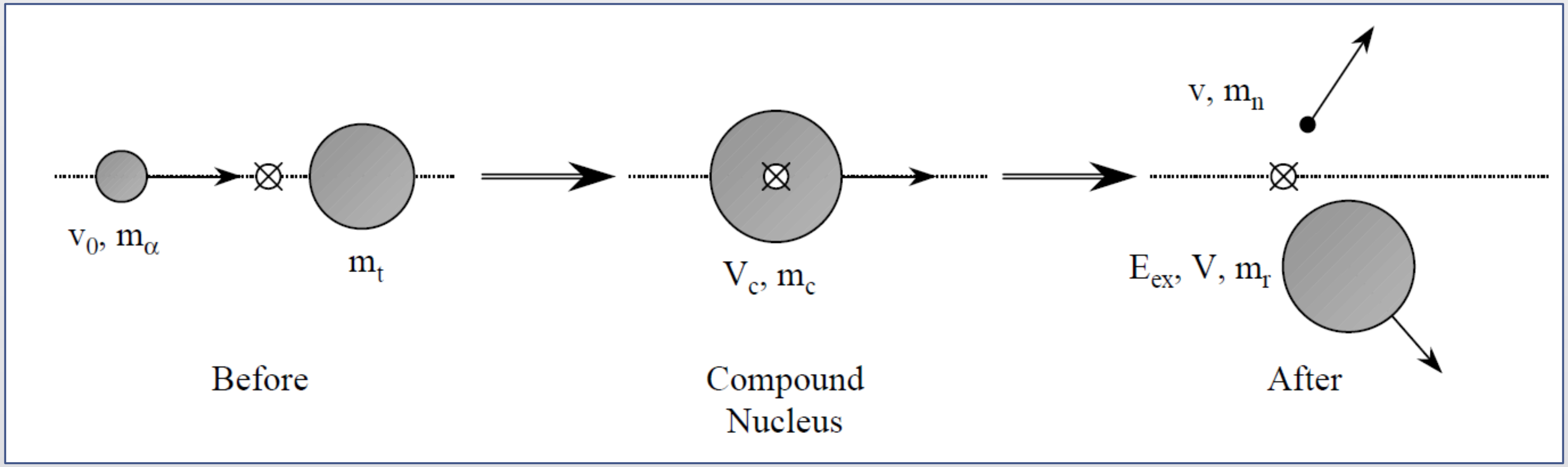
SNOLAB Environment

- Average radon activity ≈ 135 Bq/m³
- ^{210}Pb plate-out is a concern during installation



Neutron Backgrounds

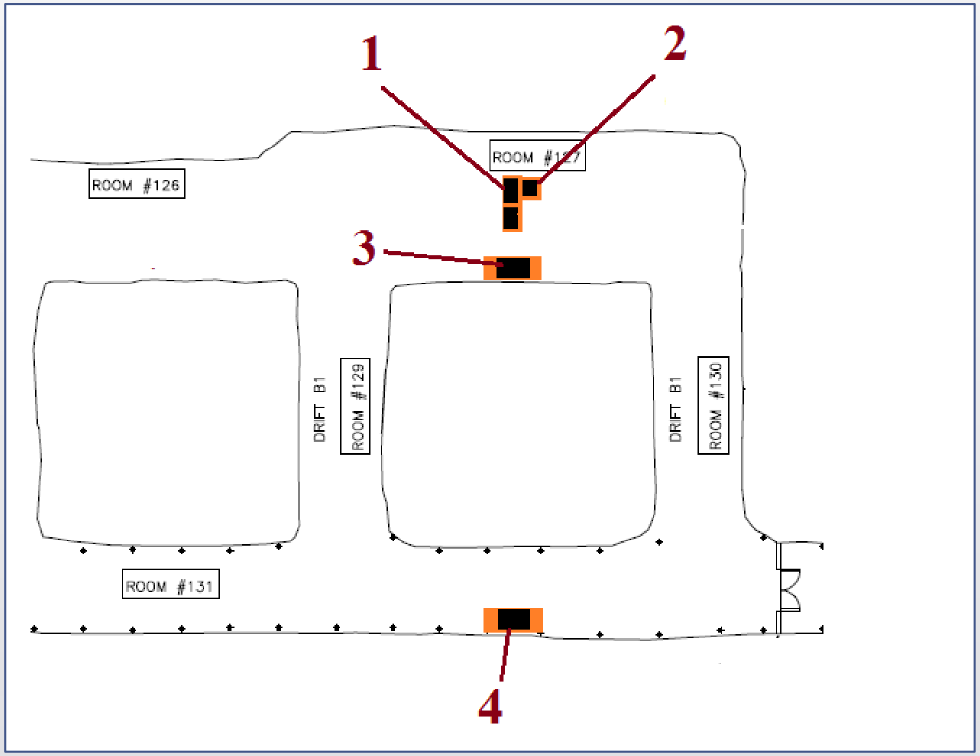
- Neutrons generated through (alpha,n) reactions
  - ^{210}Po alphas – 5.3 MeV
  - ^{13}C isotope in HDPE – $(C_2H_4)_n$
    - 1.1% natural abundance
  - Produce neutrons



Experimental Setup

- Exposed 8 HDPE and 2 Cu samples in 4 locations in lab
- 2 more HDPE control samples left at surface
- Total of 83 days of exposure
- Room 127: Main Site
- Room 131: Staging Area

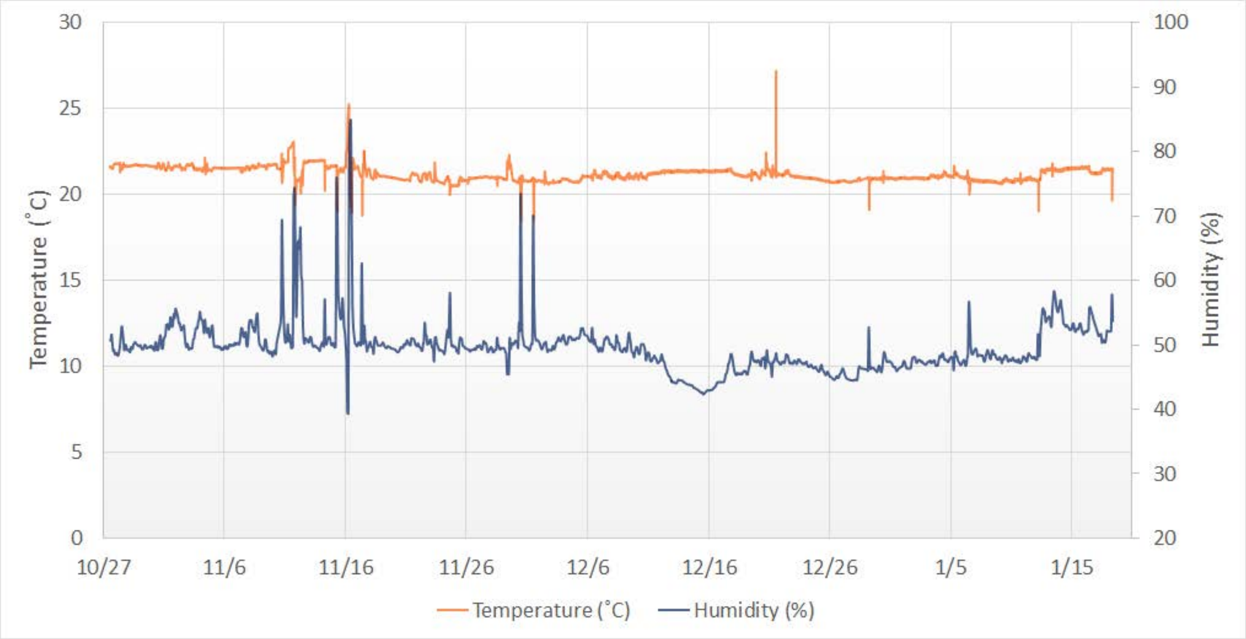
Site Number	Room Number	Nearest Wall (m)	Height (m)
1	127	3.63	0.94
2	127	3.63	2.01
3	127	0.38	0.94
4	131	0.38	0.94



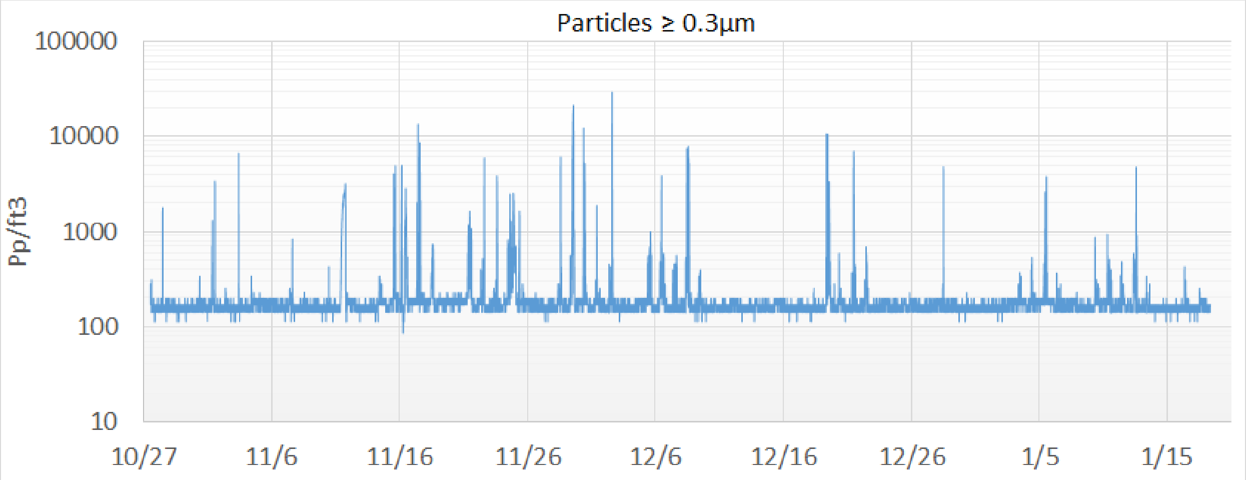
Experimental Setup

- Samples transported in nitrogen flushed nylon bags
- Control samples left in bags

Environmental Data

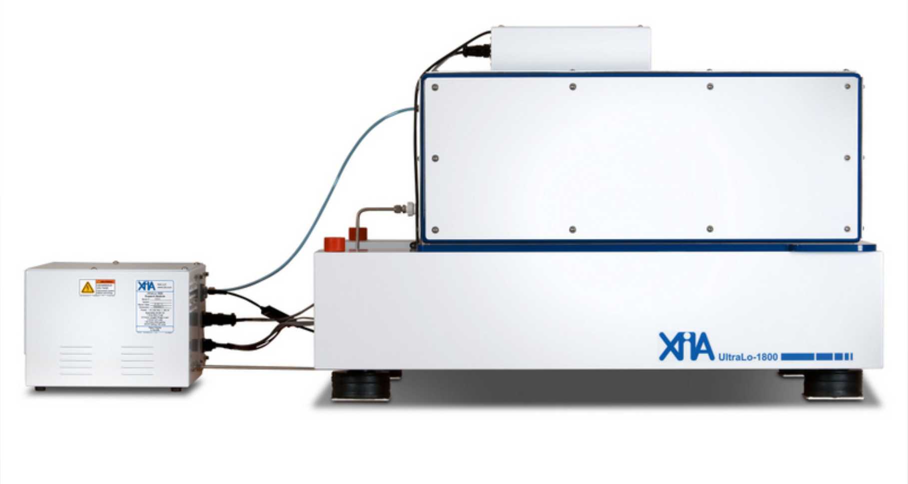


Data	Average	σ
Particles (pp. ft^3)	238.	679.
Radon (Bq/m^3)	135.	22.6
Temperature (°C)	22.5	0.397
Humidity (%)	57.9	1.59

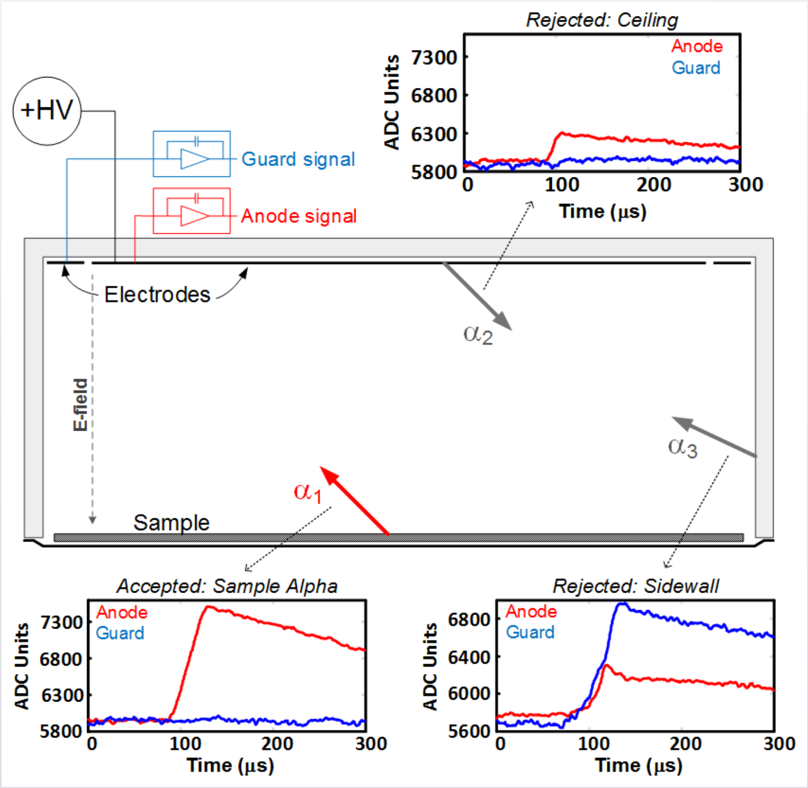


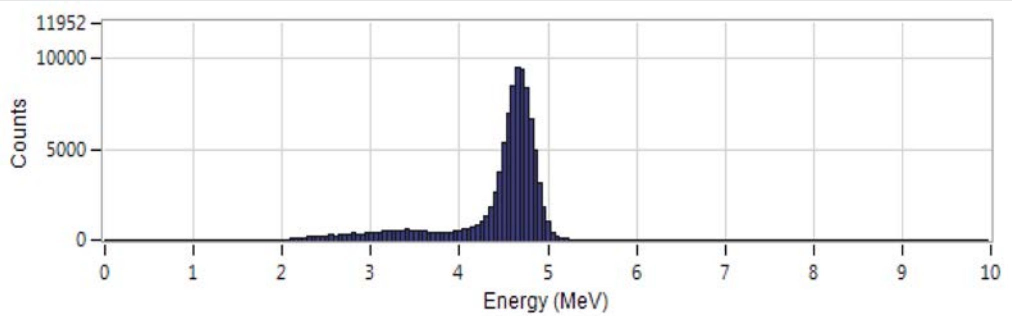
SNOLAB → Class 2000

XIA Ultralo-1800



- Ionization counter
  - Argon counting gas (boil-off)
  - 707 and 1800 cm^2 sample areas
- Dual-channel pulse-shape analysis
  - Sidewall/Ceiling/Mid-air rejection
  - Alpha energy
- Lumina Lab at SMU: Class 100

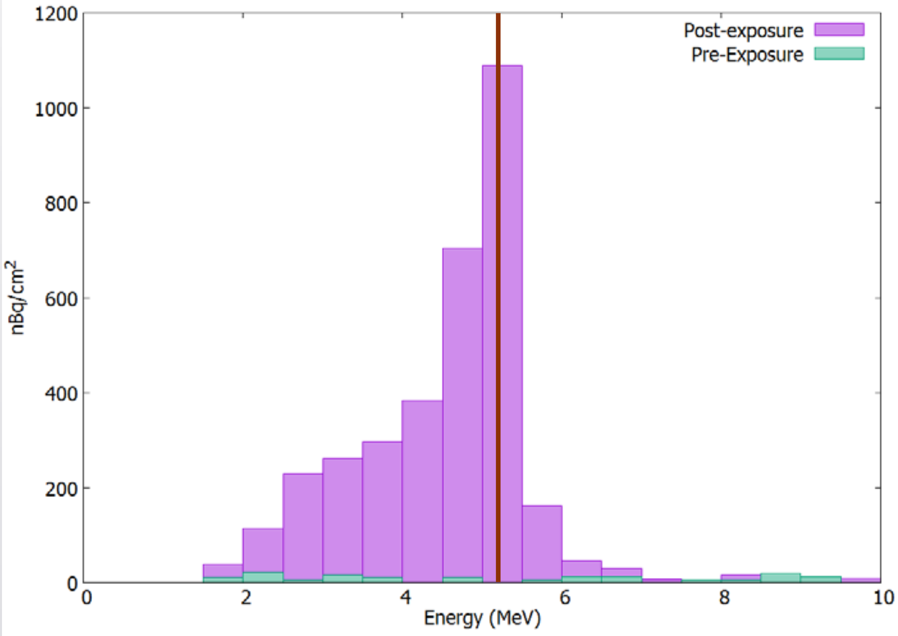




^{230}Th Calibration Source

Data

- XIA UltraLo-1800 Alpha Counter at SMU
  - Focus on 2-5.8 MeV region
- Pre-exposure assays performed
  - **96 ± 18** nBq/cm^2 for HDPE
  - **394 ± 62** nBq/cm^2 for Cu
- 2 post-exposure measurements per sample
  - Separated by ~75 days
- Control Samples, Post-Exposure:
  - **91 ± 22** nBq/cm^2 for HDPE

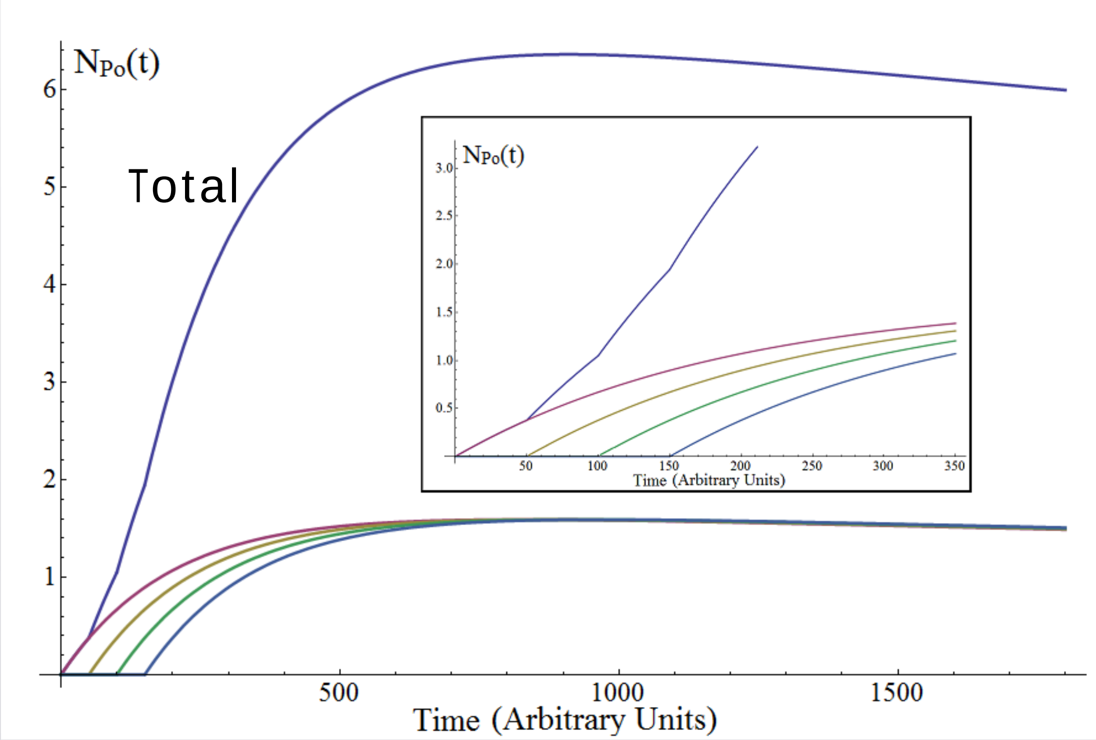


Analytical Model

- Bateman Equation:

$$N_{Po}(t) = N_{Pb}(0)\frac{\lambda_{Pb}}{\lambda_{Po} - \lambda_{Pb}}\left(e^{-\lambda_{Pb}t} - e^{-\lambda_{Po}t}\right)$$

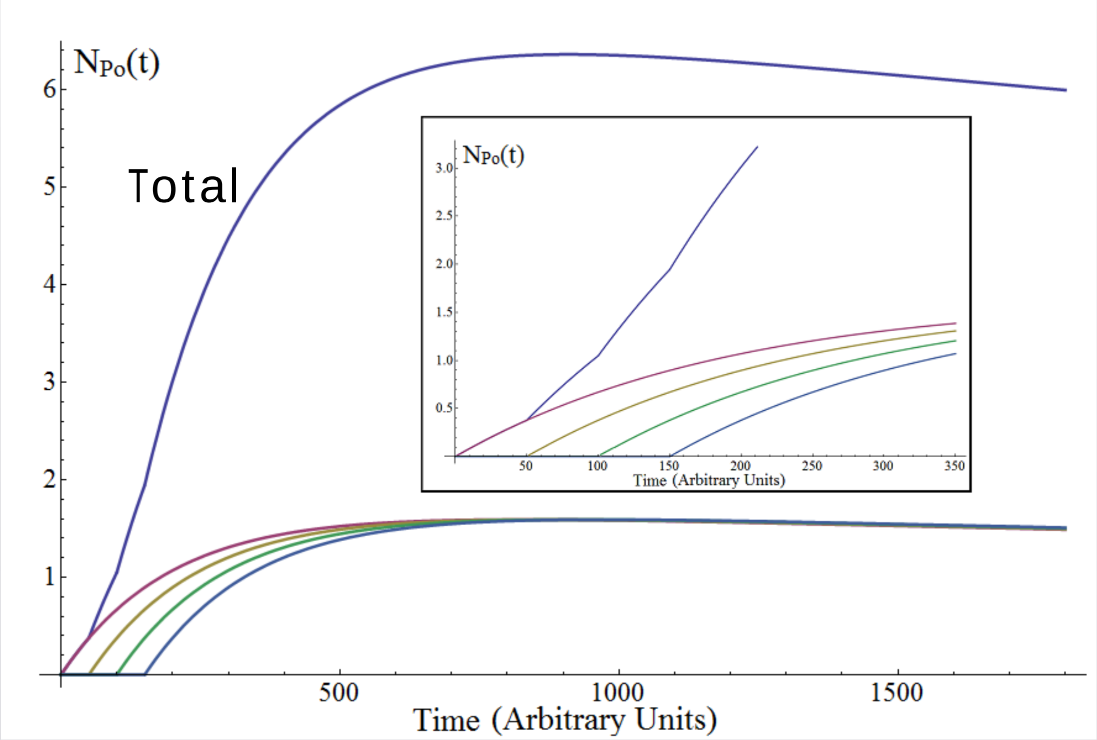
- Add subsequent Bateman models due to continued contamination from ^{210}Pb



- $\lambda_i = \frac{Ln(2)}{t_{1/2,i}}$
- $N_{Po}(0) = 0$

$$N_{Po}(t) = N_{Pb}(0)\frac{\lambda_{Pb}}{\lambda_{Po} - \lambda_{Pb}}\left(e^{-\lambda_{Pb}t} - e^{-\lambda_{Po}t}\right)$$

$$B(t, N_o, t_b) = N_o\frac{\lambda_{Pb}}{\lambda_{Po} - \lambda_{Pb}}\left(e^{-\lambda_{Pb}(t-t_b)} - e^{-\lambda_{Po}(t-t_b)}\right)\Theta(t - t_b)$$



Analytical Model: ^{210}Po Activity

Time of exposure

Smaller is better (but slower)

$$^{210}Po\ Activity = A(t, R_{Pb}) = \lambda_{Po}\left[\sum_{i=1}^{t_{exp}/binSize} B(t, R_{Pb} * binSize, i * binSize)\right]$$

Number of ^{210}Pb atoms plated out per unit time

Number of ^{210}Po atoms at t

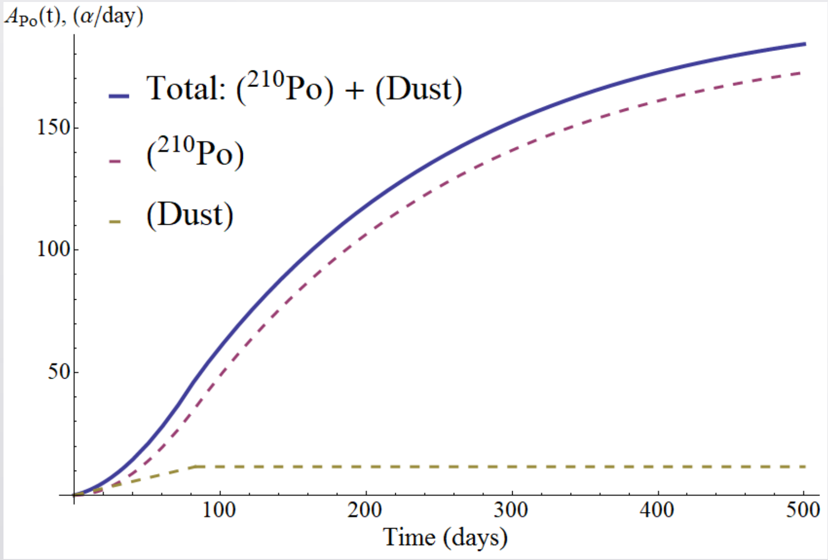
$$B(t, N_o, t_b) = N_o \frac{\lambda_{Pb}}{\lambda_{Po} - \lambda_{Pb}}\left(e^{-\lambda_{Pb}(t-t_b)} - e^{-\lambda_{Po}(t-t_b)}\right)\Theta(t - t_b)$$

Analytical Model: Total Activity

$$Total\ Activity = (^{210}Po\ Activity) + (Dust\ Activity)$$

$$A_{dust}(t, t_{exp}) = (S_{dust}\, t)\Theta(t_{exp} - t) + (t_{exp} S_{dust})\Theta(t - texp)$$

Rate of activity accumulated per unit time from dust (i.e. $\frac{\#\ Bq}{day \cdot cm^2}$)



Analytical Model: Total Activity

$$^{210}Po\ Activity = \lambda_{Po}\left[\sum_{i=1}^{t_{exp}/binSize}(R_{Pb} * binSize)\frac{\lambda_{Pb}}{\lambda_{Po}-\lambda_{Pb}}\right.$$

$$\left.\times\left(e^{-\lambda_{Pb}(t-\{i*binSize\})}-e^{-\lambda_{Po}(t-\{i*binSize\})}\right)\Theta(t-\{i*binSize\})\right]$$

$$+(S_{dust}\,t)\Theta(t_{exp}-t)+(t_{exp}S_{dust})\Theta\left(t-t_{exp}\right)$$

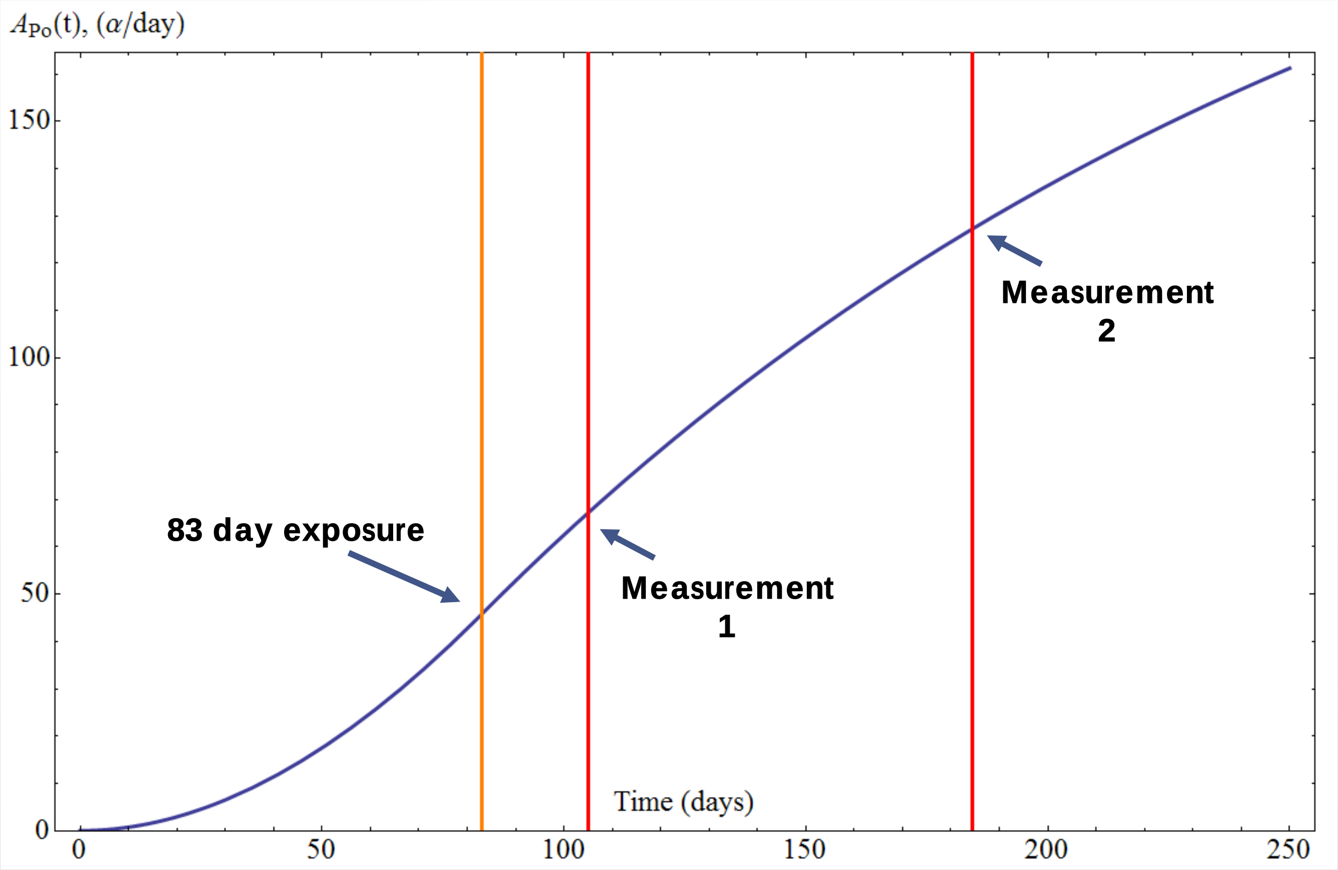
Analytical Model: Total Activity

- Simplifies to: $Total\ Activity = R_{Pb}K_{Pb} + S_{dust}K_{dust}$

  given:
  - $t_{exp} \rightarrow$ Time of exposure
  - $t_m \rightarrow$ Time of measurement
  - Take 2 measurements of activity to solve for remaining variables

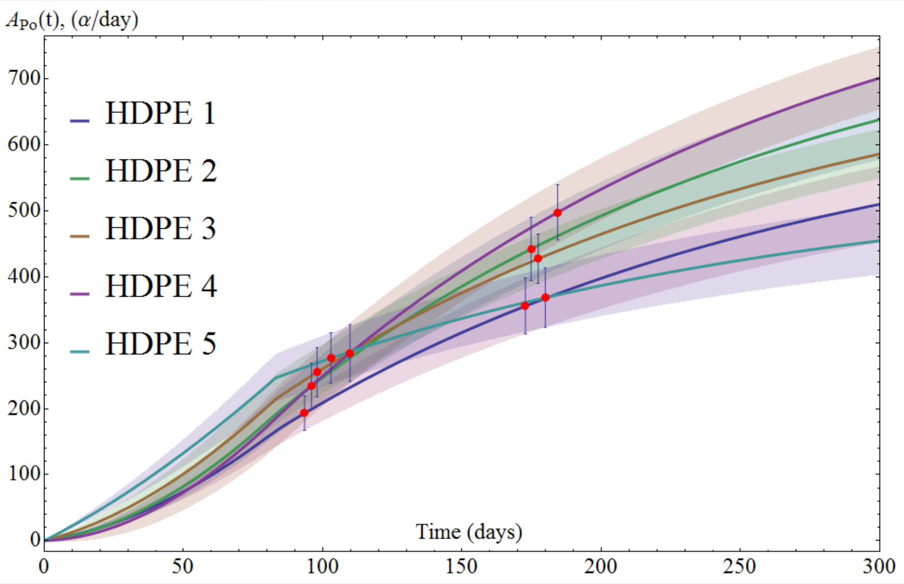
Analytical Model: Total Activity

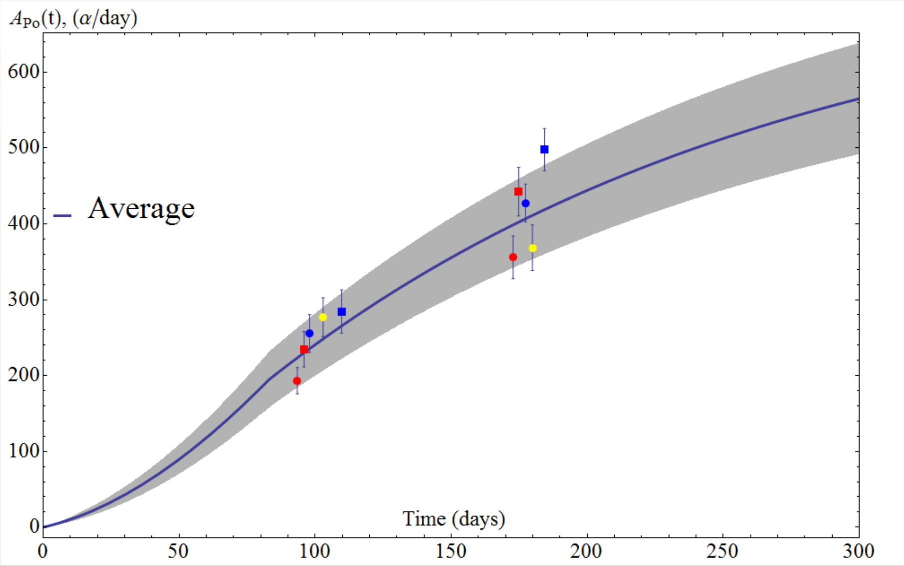
$$\begin{pmatrix} M_1 \\ M_2 \end{pmatrix} = \begin{pmatrix} K_{Pb,1} & K_{dust,1} \\ K_{Pb,2} & K_{dust,2} \end{pmatrix} \begin{pmatrix} R_{Pb} \\ S_{dust} \end{pmatrix}$$



Analysis Results

- Combined result for Room 127 samples:

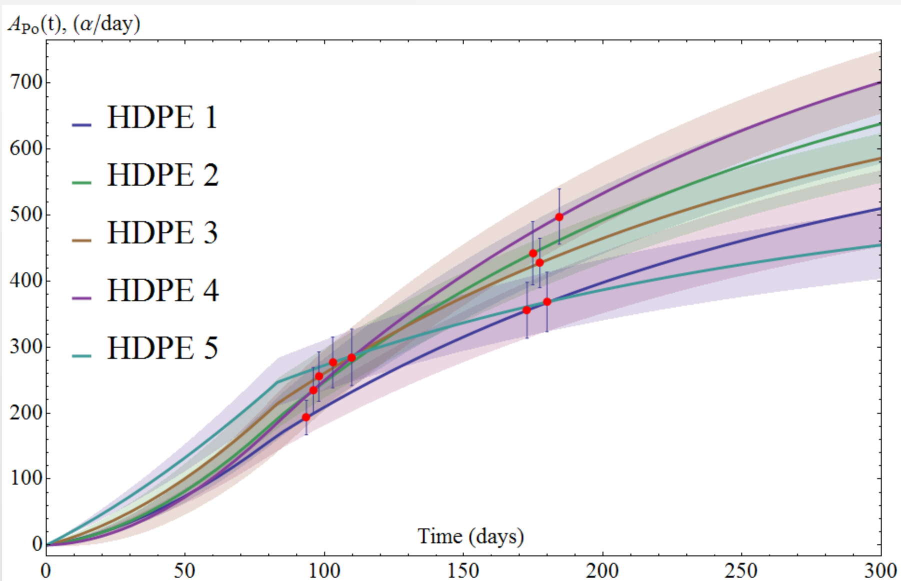


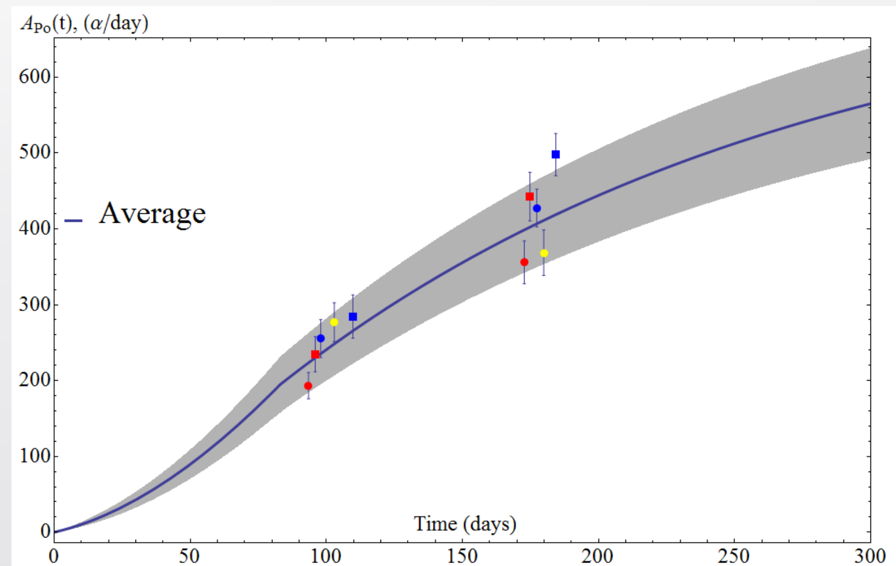


- Determined:
  - $R_{Pb} = 278 \pm 14 \frac{atoms\ of\ Pb}{day \cdot cm^2}$
  - $S_{dust} = 27 \pm 5 \frac{nBq}{day \cdot cm^2}$

Analysis Results

- Combined result for Room 127 samples:





- Determined:
  - $R_{Pb} = 278 \pm 14 \frac{atoms\ of\ Pb}{day \cdot cm^2}$
  - $S_{dust} = 27 \pm 5 \frac{nBq}{day \cdot cm^2}$

Not the same units

Comparisons

- Determined:
  - $S_{dust} = 27 \pm 5 \frac{nBq}{day \cdot cm^2}$
- SNOLAB Technical Report Data:
  - Dust fallout of 1-7 ng/cm^2/hour (SNO-STR-95-050)
  - Activity of ~150 Bq/kg (^{238}U + ^{232}Th chains) (SNOLAB-STR-2007-003)
  - Yields expected value of:
    - $S_{dust} = (3.6 - 28.8) \frac{nBq}{day \cdot cm^2}$

http://sno.phy.queensu.ca/sno/str/

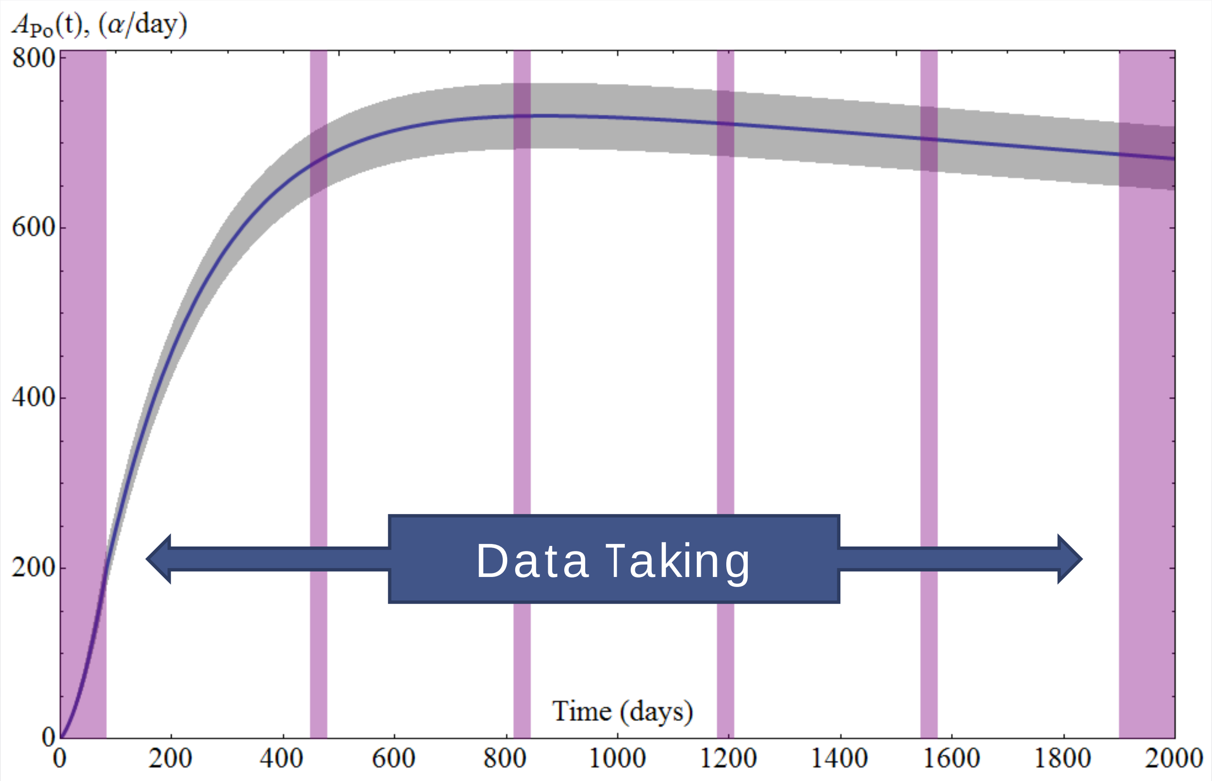
Conclusions

- Developed activity prediction model that accounts for ^{210}Pb and dust:
  - $$Total\ Activity = \lambda_{Po}\left[\sum_{i=1}^{t_{exp}/binSize} B(t, R_{Pb} * binSize, i * binSize)\right] + (S_{dust}\, t)\Theta(t_{exp} - t) + (t_{exp} S_{dust})\Theta(t - texp)$$
- Determined:
  - Plate-out rate: ~278(423) ^{210}Pb atoms per day per cm^2 for HDPE(Cu)
  - Dust activity increases ~27(5) nBq per day per cm^2 for HDPE(Cu)
- Constraint for installation of shielding
  - ~39 days to limit ^{210}Pb to 10 μBq/cm^2
  - ~60 days to limit dust activity

Backup Slides

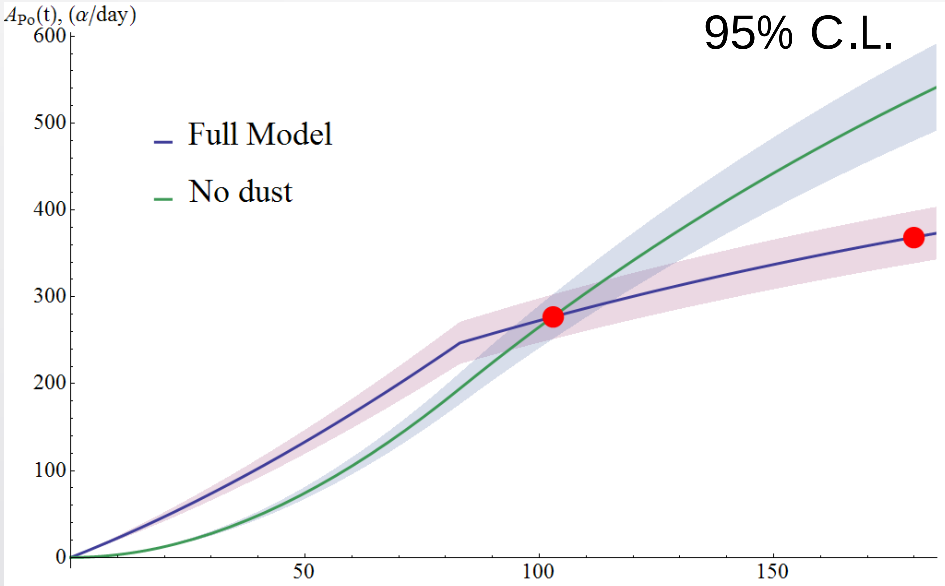
Conclusions

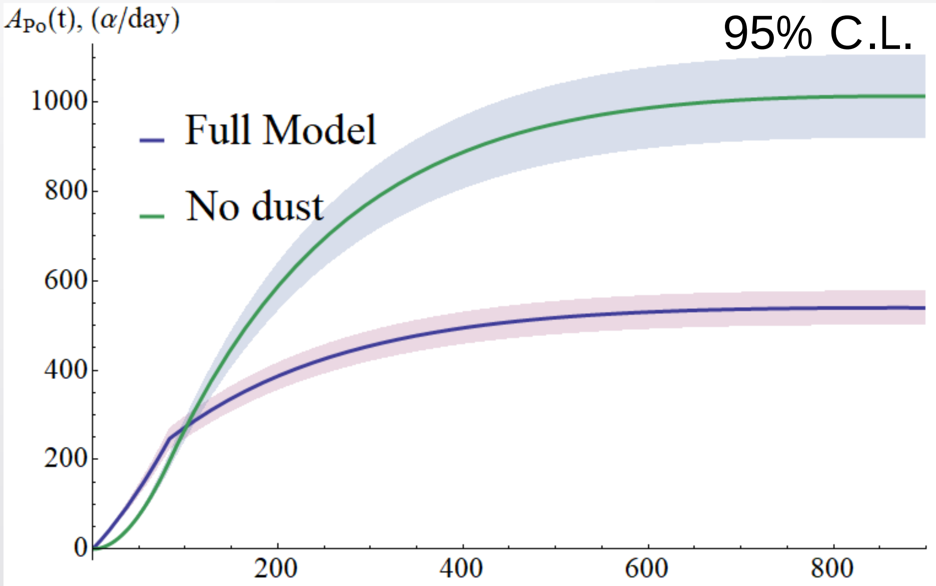
- Model activity over live time of experiment:



Analysis Results

- 2nd measurement shows big adjustment for higher dust contribution (vs single measurement)

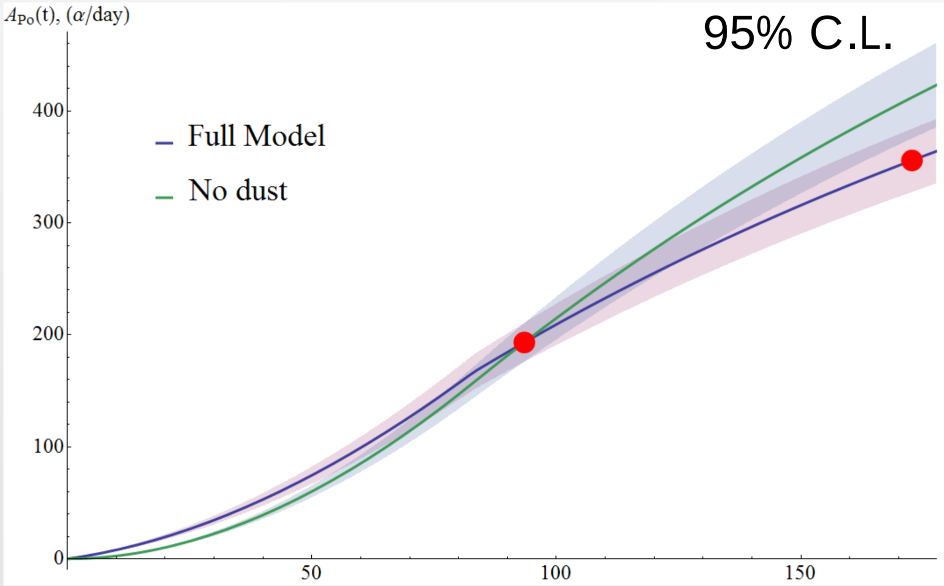


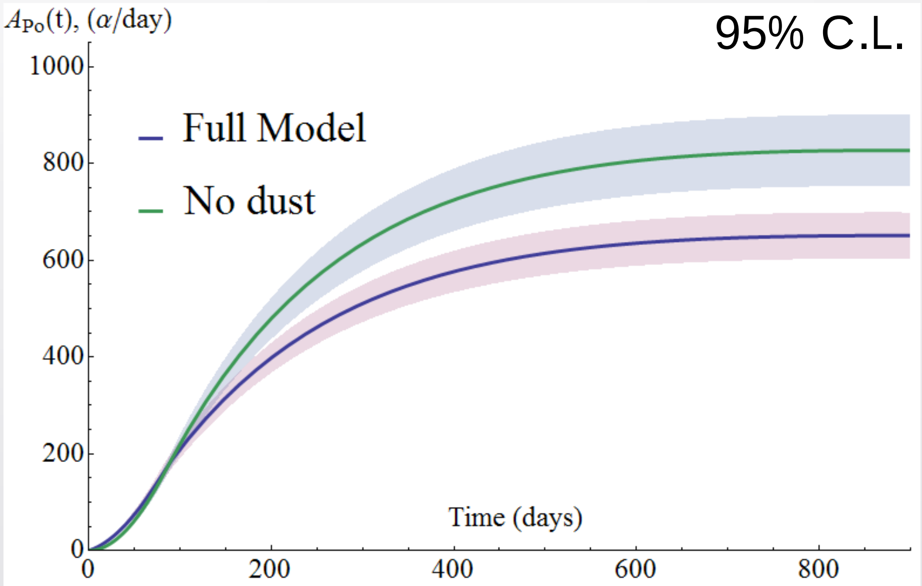


- Example: Site 2, HDPE sample 1
  - $R_{Pb} = 156 \pm 34 \frac{atoms\ of\ Pb}{day \cdot cm^2}$
  - $S_{dust} = 69 \pm 13 \frac{nBq}{day \cdot cm^2}$

Analysis Results

- 2nd measurement shows less adjustment for lower dust contribution (vs single measurement)

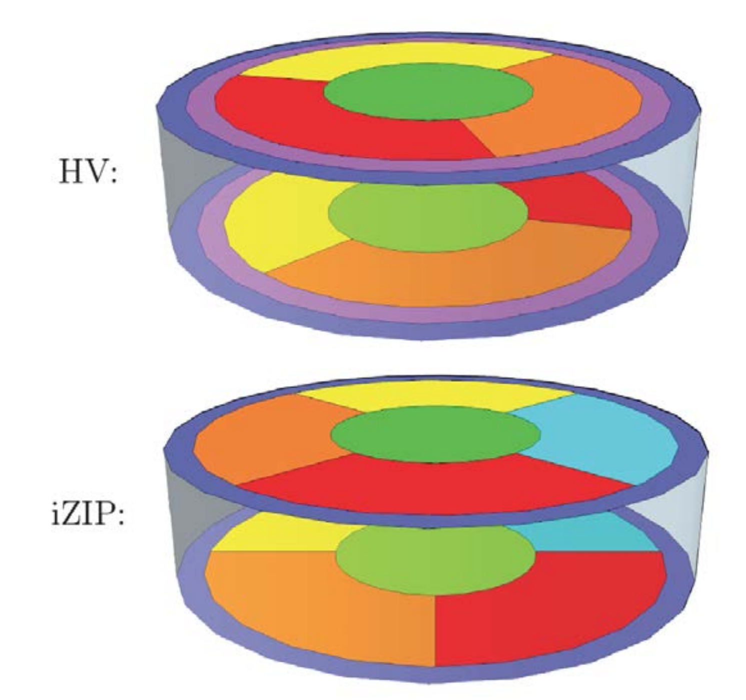


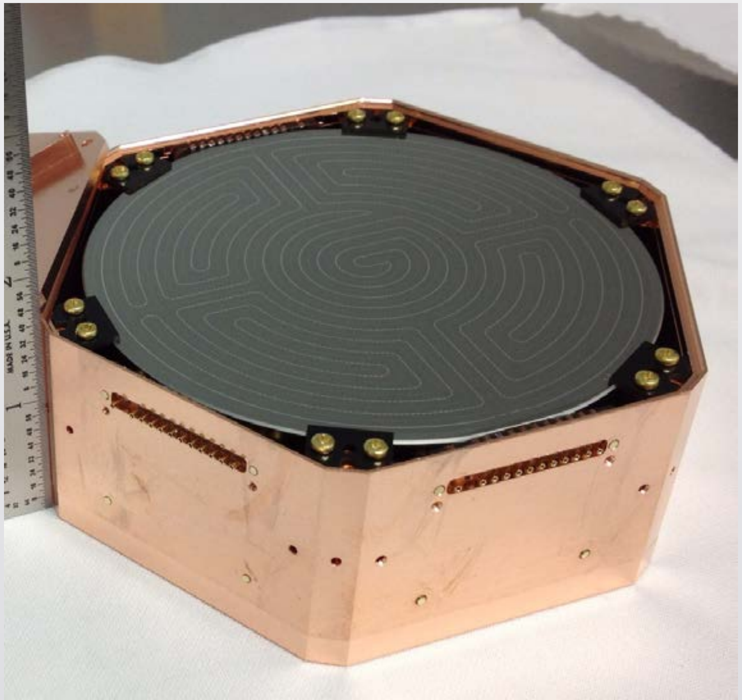


- Example: Site 1, HDPE sample 1
  - $R_{Pb} = 257 \pm 26 \frac{atoms\ of\ Pb}{day \cdot cm^2}$
  - $S_{dust} = 20 \pm 8 \frac{nBq}{day \cdot cm^2}$

SuperCDMS SNOLAB Detectors

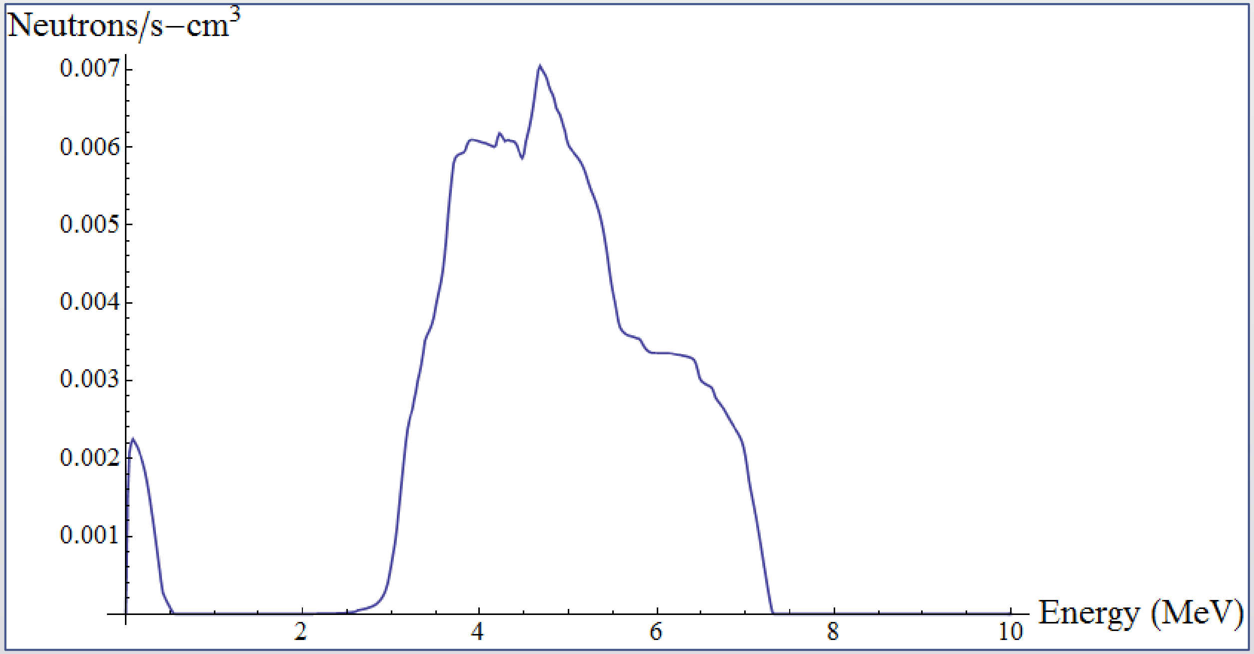
- HV: High Voltage
  - 6 phonon channels each side
- iZip: Interleaved Z-sensitive Ionization and Phonon
  - 6 phonon + 2 ionization channels each side





Neutron Backgrounds

- Neutrons generated through (alpha,n) reactions
  - ^{210}Po alphas – 5.3 MeV
  - ^{13}C isotope in HDPE – $(C_2H_4)_n$
    - 1.1% natural abundance
  - Produce neutrons



References

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- SuperCDMS Soudan (First Results) – 2014: https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.112.241302
- SuperCDMS (CDMSlite) – 2014: https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.112.041302
- CDMS II – 2010: http://science.sciencemag.org/content/327/5973/1619
- SNOLAB Technical Reports: http://sno.phy.queensu.ca/sno/str/