Neutron Calibration Studies for the SuperCDMS SNOLAB Experiment

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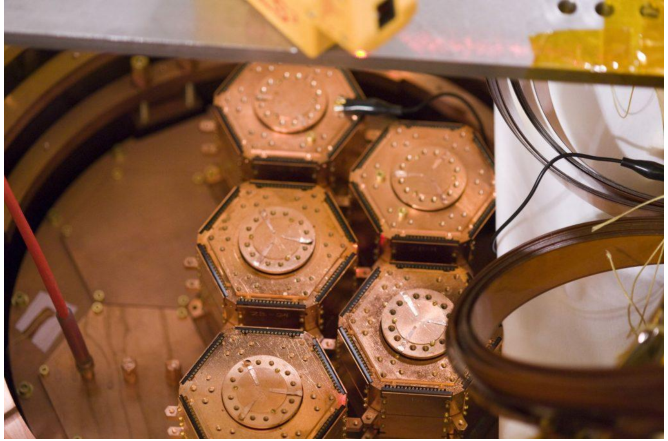
SuperCDMS SNOLAB Experiment

- SuperCDMS is an experiment to probe the subatomic nature of dark matter.
- Dark matter constitutes ~25% of the universe, but we are unsure of its nature.
- Silicon and germanium detectors sit at the heart of the experiment.
- When a theoretical dark matter particle hits the detectors, we expect elastic scatter off the crystal.
- We must check that the detectors respond to a known “billiard” source.



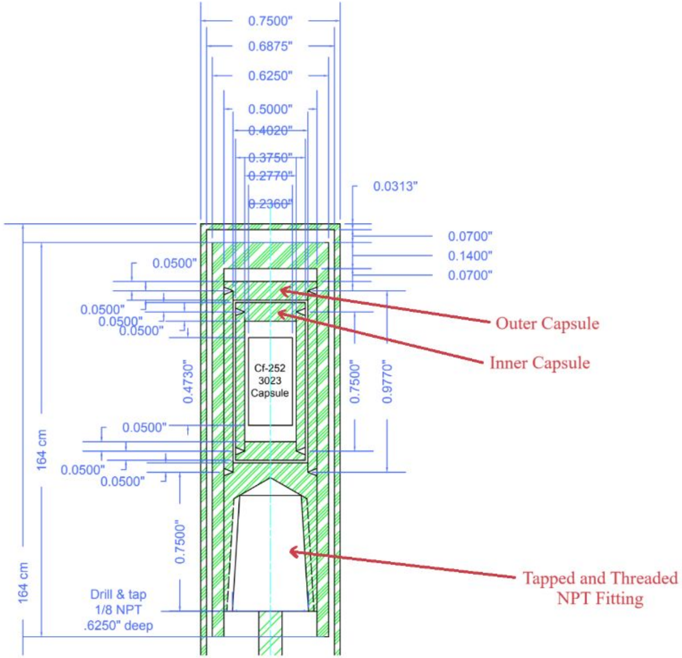
SuperCDMS Detectors (image courtesy of SNOLAB)

“Billiard ball scattering”

Neutron Source Encapsulation

A robust encapsulation method to conform to SNOLAB clean-room and leak-proof standards for a radioactive Cf-252 source is needed.

- Overall system consists of three layers
  - Inner Capsule
  - Outer Capsule
  - Delivery tube
- The delivery tube holds the inner two capsules and the source itself, which is inserted into the experiment when needed.



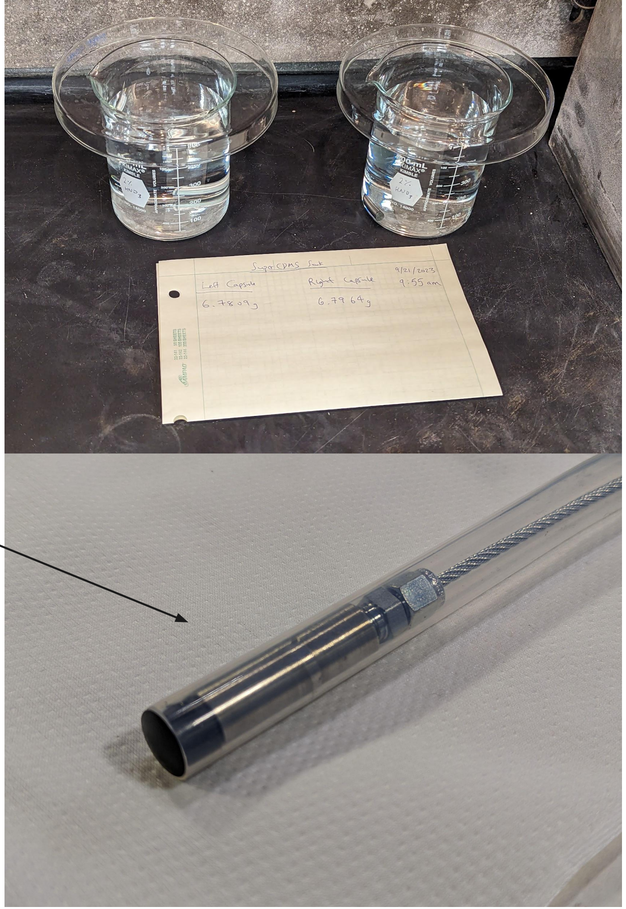
Inner Encapsulation for the Cf-137 Neutron Source

Neutron Source Encapsulation

The source delivery system is nearing completion.

- I robustly leak-tested the epoxy seals.
- I assembled a mockup of the final delivery system.
- I verified that the apparatus fits the SNOLAB experimental dimensions.

Pending acquisition of the Cf-252 source, the delivery system will be ready for deployment at SNOLAB.



Soak test in progress and completed source encapsulation device.

SuperCDMS Detector Calibration

- Just knowing that the detectors work is not good enough.
- We want to discriminate between *low* energy deposit dark matter and *high* energy deposit background radiation.
  - The instrumental response of the detectors is not calibrated.
  - We have to correlate a known energy deposit to some instrumental readout.

How do we know how much energy is deposited in the detector stack?

SuperCDMS Detector Calibration

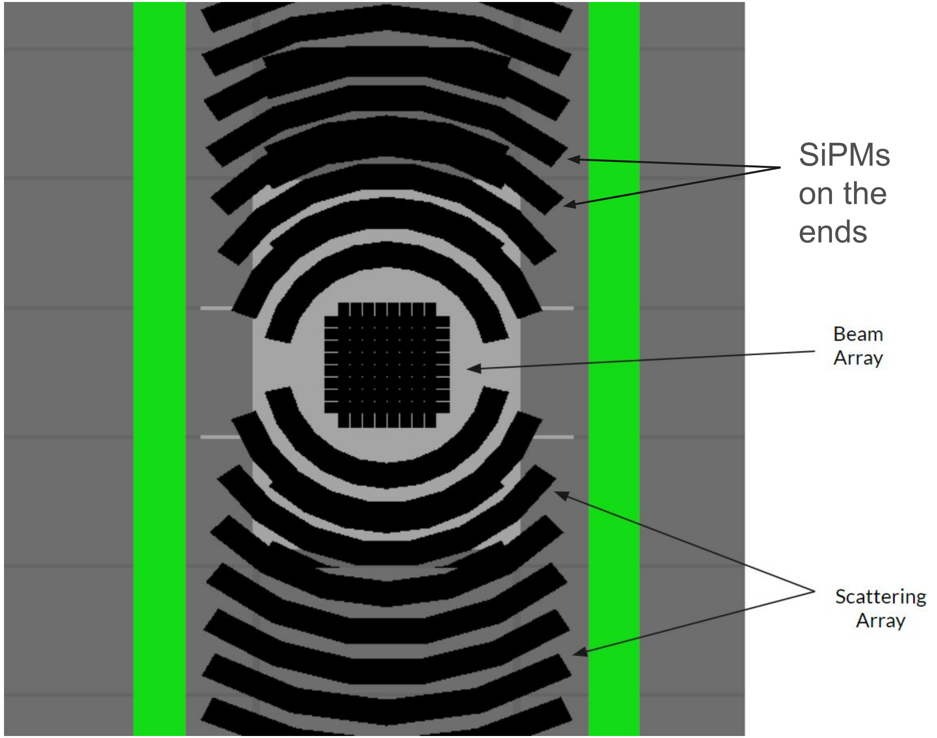
- A **monoenergetic collimated neutron beam** incident on the detectors achieves the elastic collisions we want.
- The scattering angle from neutrons incident on the detector is functionally related to the energy deposit.
  - By measuring the scattering angle, we can solve for the energy deposit based on the instrumental readout.

$$E_T = 2E_i \left(\frac{m_n}{m_n + m_T}\right)^2 \left(\frac{m_T}{m_n} + \sin^2\theta - \cos\theta\sqrt{\frac{m_T^2}{m_n^2} - \sin^2\theta}\right)$$

Exposed view of the NEXUS D-D Generator
(image courtesy of Dylan Temples)

SuperCDMS Detector Calibration

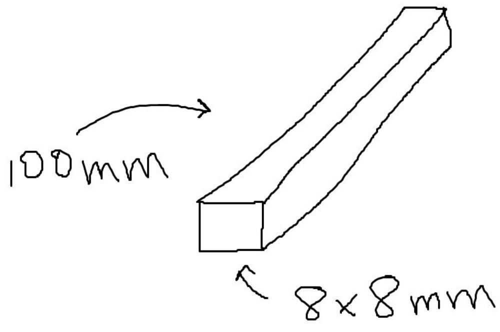
- To measure the scattering angle, we use a **scintillator array**.
  - The “beam array” allows us to align the scintillators to measure the angle correctly.
  - The “scattering array” actually measures the angle.
- Once neutrons hit the scintillators, they generate scintillation photons.
- The scintillation photons propagate through the plastic, and are detected by silicon photomultipliers (SiPMs) on the end.



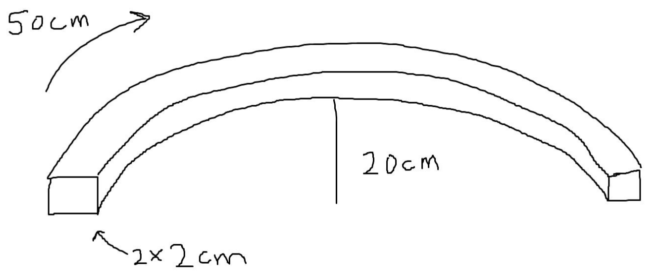
NEXUS neutron detection “backing array” (image courtesy of Patrick Lukens)

SuperCDMS Detector Calibration

- With Geant4, we knew how many scintillation photons were generated, but we did not know how they propagated or how well we could detect them.
- The exact dimensions, number of silicon photomultipliers (SiPMs), and detection threshold was unknown.
- I wrote a **Monte Carlo simulation** to do three things:
  - Simulate the propagation of scintillation photons through the scintillator.
  - Check how many scintillation photons are detected by the SiPMs.
  - Quantify the probability of detecting a neutron hit based on some photoelectron threshold in the SiPMs.



"Beam Counter"



"Scattering Counter"

SuperCDMS Detector Calibration

Step 1	Step 2	Step 3	Step 4	Step 5	Step 6
Generate a bootstrapped sample (N=100,000) from the beam or scattering SiPM photon distribution.	Each entry is assigned a random position based on a Gaussian or uniform distribution in the bar depending on whether it is a beam or a scattering counter.	For each entry in the prior sample, multiply by the optical loss, bending loss, SiPM coverage loss, and SiPM coupling loss.	Round the expected photon count to an integer and draw from a Poisson distribution to convert expected to observed incident photons.	Randomly assign the incident photons from Step 2 to each SiPM on the end of a given scintillator bar.	For the photons randomly assigned to each SiPM, give each photon a 40% chance of being converted to a photoelectron.

Monte Carlo photoelectron framework

Scintillation Photons → SiPM Photoelectrons

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SuperCDMS Detector Calibration

Step 1

After converting to photoelectrons, we are left with N=100,000 lists each with length equal to however many SiPMs we have on the bar in total.

Step 2

Each list entry is the number of observed photoelectrons in each SiPM for that specific neutron hit.

Step 3

For a given photoelectron threshold, calculate the fraction of the N=100,000 lists in which some number of entries are greater than a given threshold.

Step 4

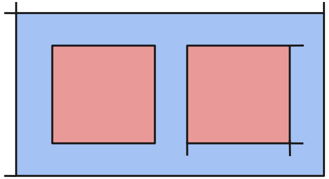
Repeat for arbitrary bar dimensions, simultaneous detections, different thresholds, etc.

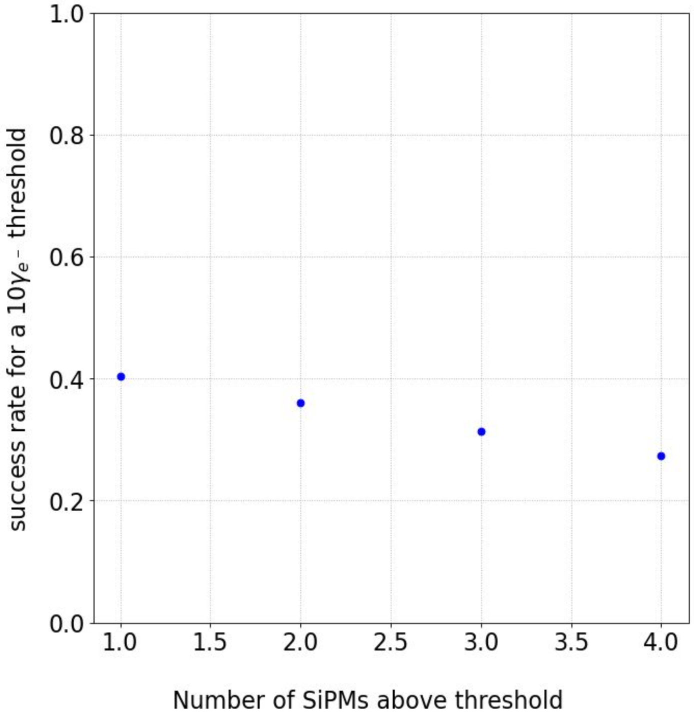
Monte Carlo detection framework

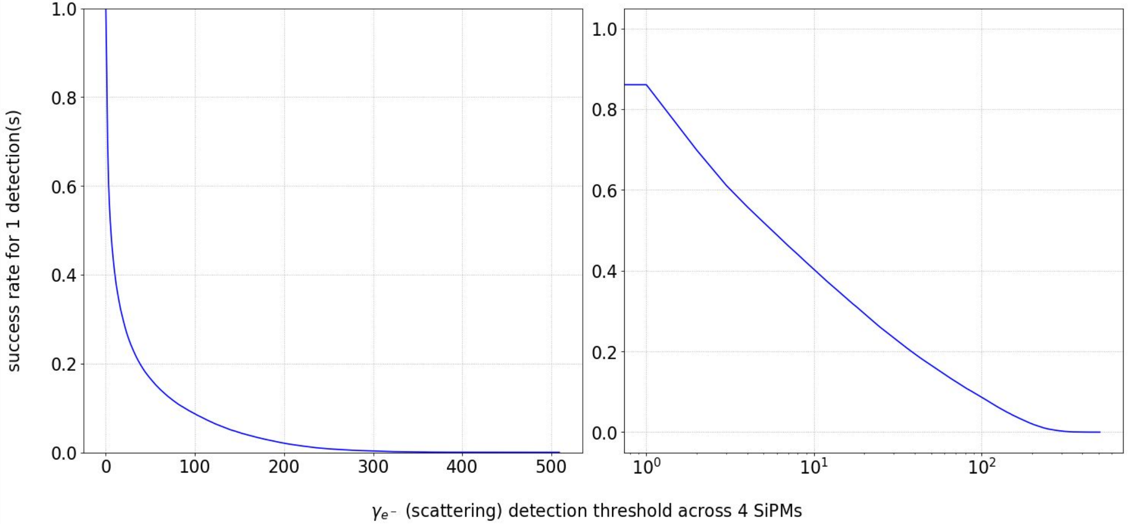
SiPM Photoelectrons → Detection Efficiency

SuperCDMS Detector Calibration

21cm bar
10mm x 18mm cross section

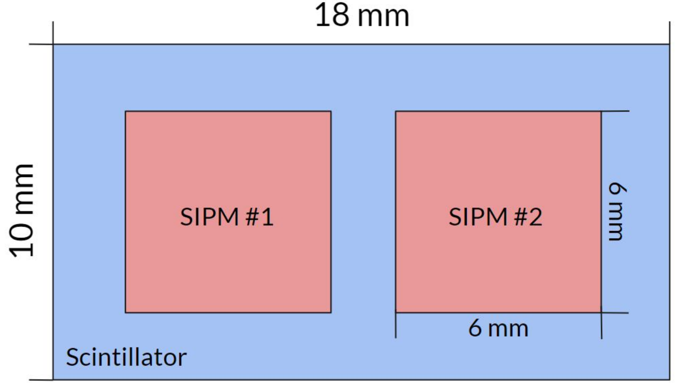






Summary

- I have completed testing and assembling the prototype Cf-252 neutron source delivery system.
- I wrote a Monte Carlo simulation parameterizing neutron detection efficiency in a plastic scintillator backing array as a function of scintillator dimensions and photoelectron detection threshold.
- I arrived at an optimal design for the backing array dimensions, and will help construct the array in the coming months.



(above) Prototype source delivery system and (below) best-fit scintillator and SiPM dimensions.

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