GEANT4 Lucas Cell Simulation

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Motivation

^{222}Rn and its progeny are a problematic source of background for SNO+ and for the other experiments at SNOLAB

As part of SNOLAB's ^{222}Rn testing program, we measure the concentrations of ^{222}Rn for these experiments through Radon Assays.

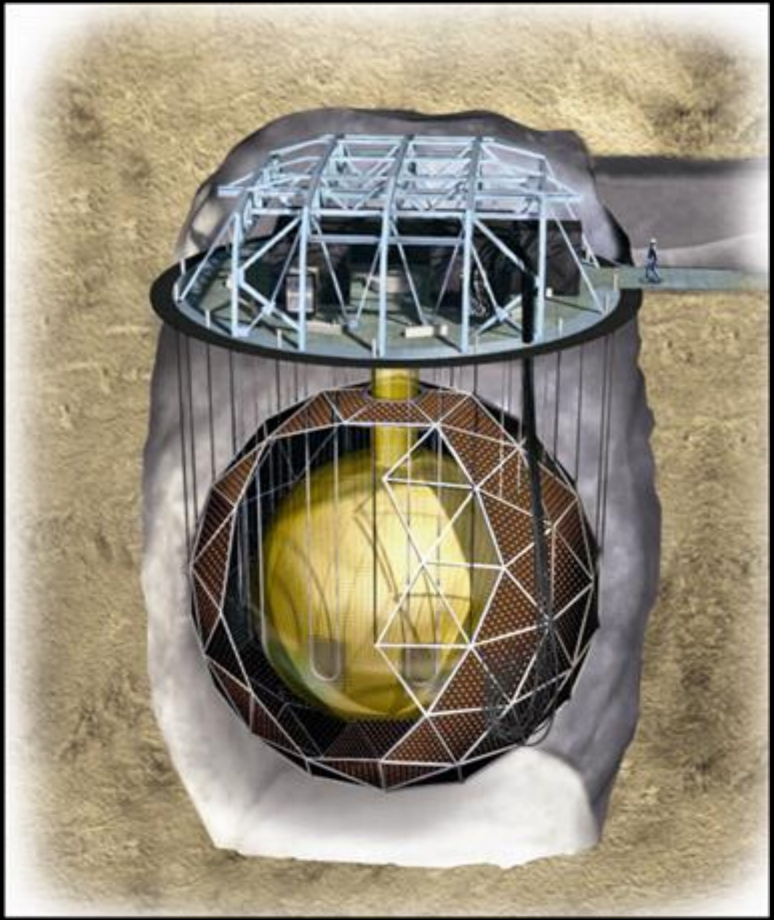
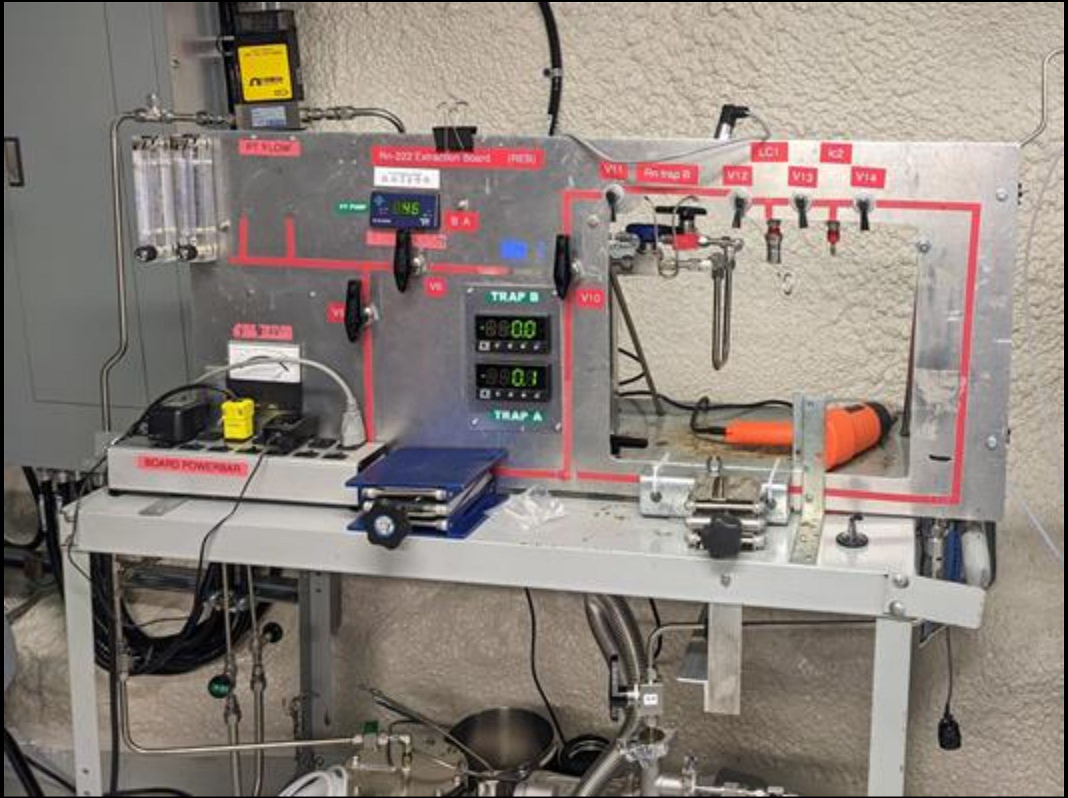


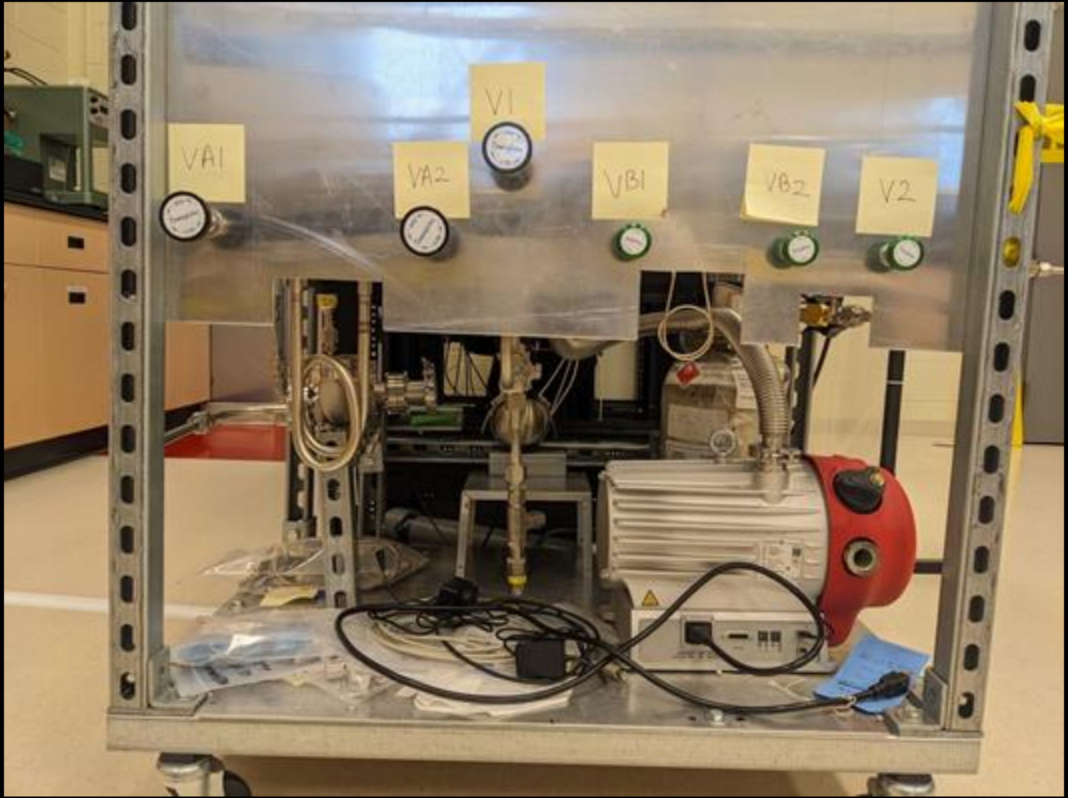
Image provided by SNO

Motivation



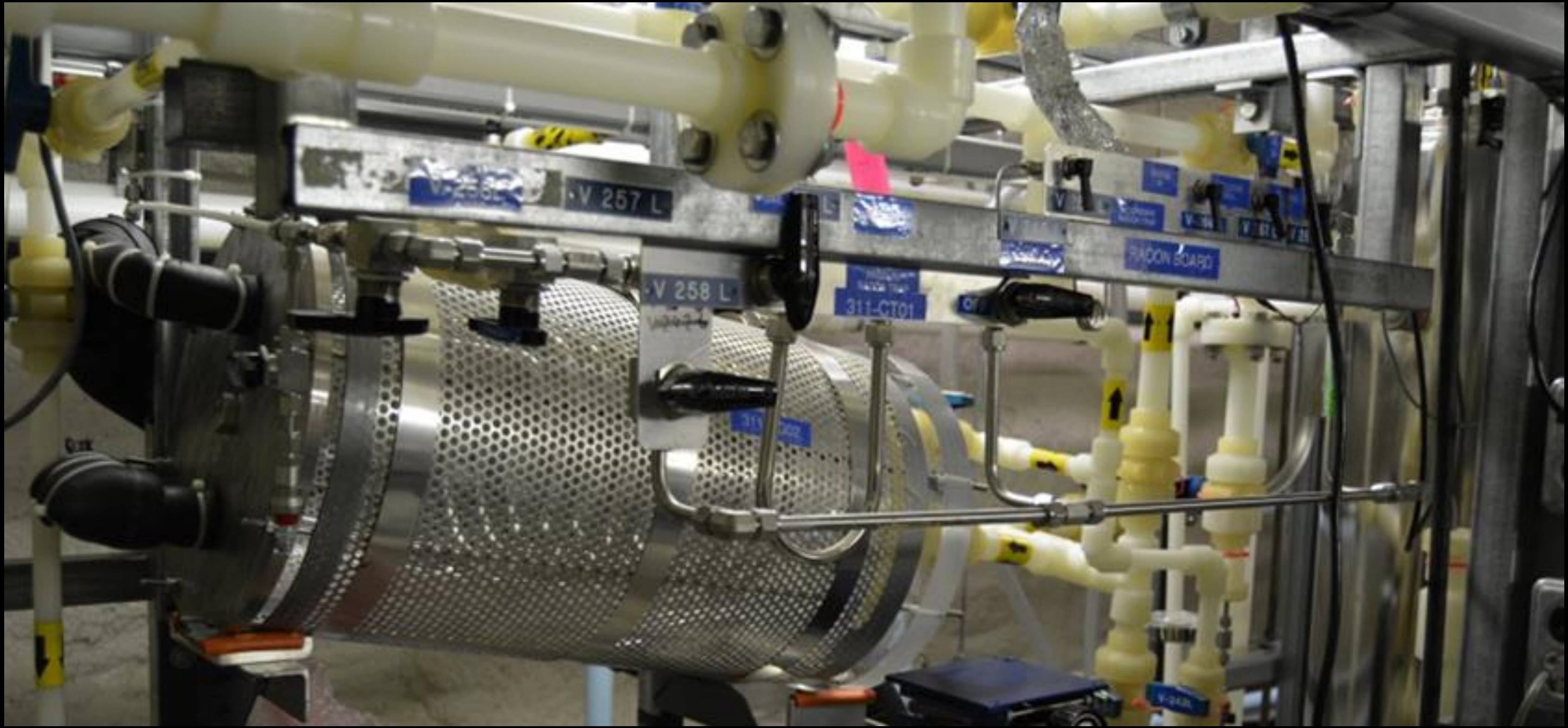
Underground Radon Board

Motivation

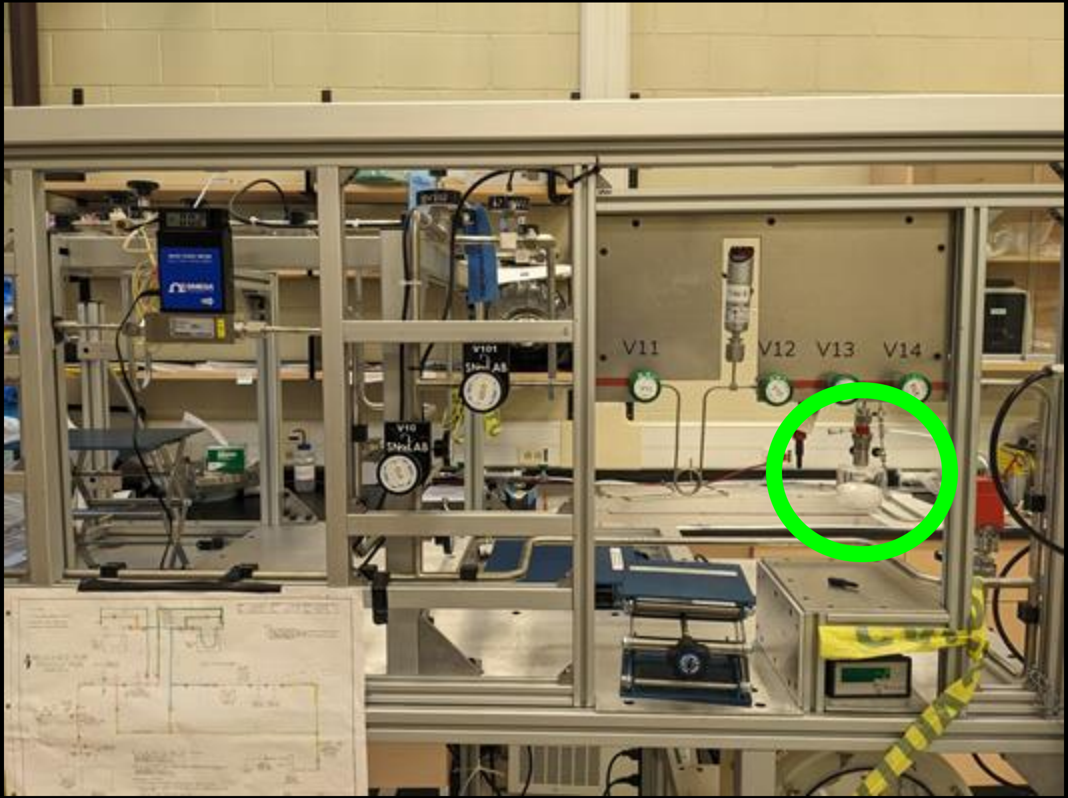


DEAP Radon Board

Motivation



Motivation



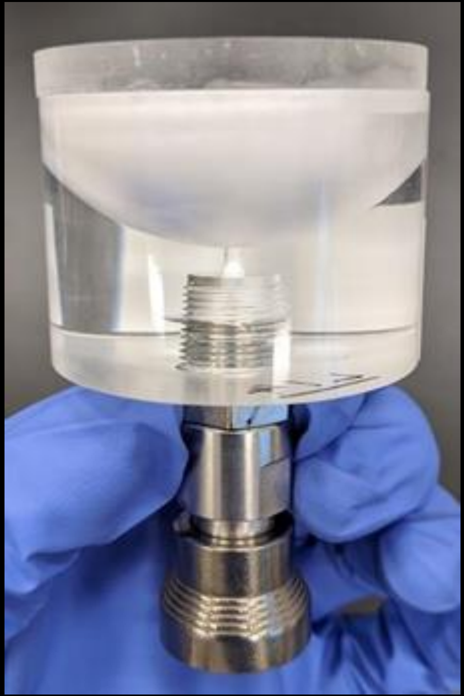
Surface Radon Board

What is a Lucas Cell?

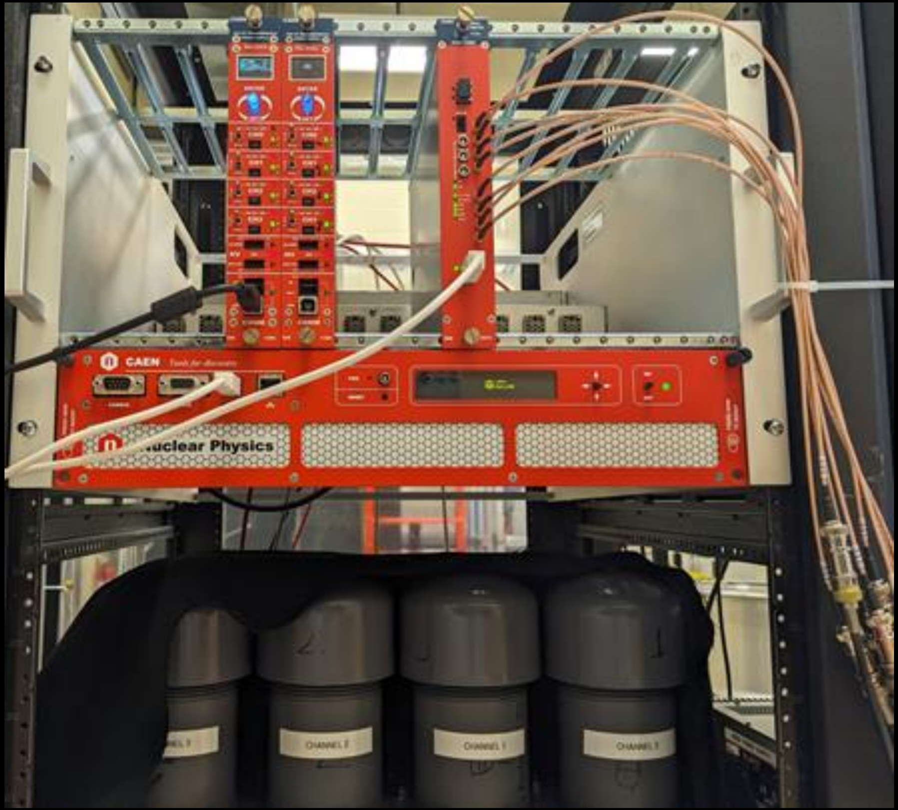
- Scintillation counter sensitive to alpha particles made at SNOLAB

- Individual ^{222}Rn alpha decays can be counted with 2-inch photomultiplier tubes (PMTs) with known quantum efficiencies

- Used to quantify the amount of ^{222}Rn for the four systems presented

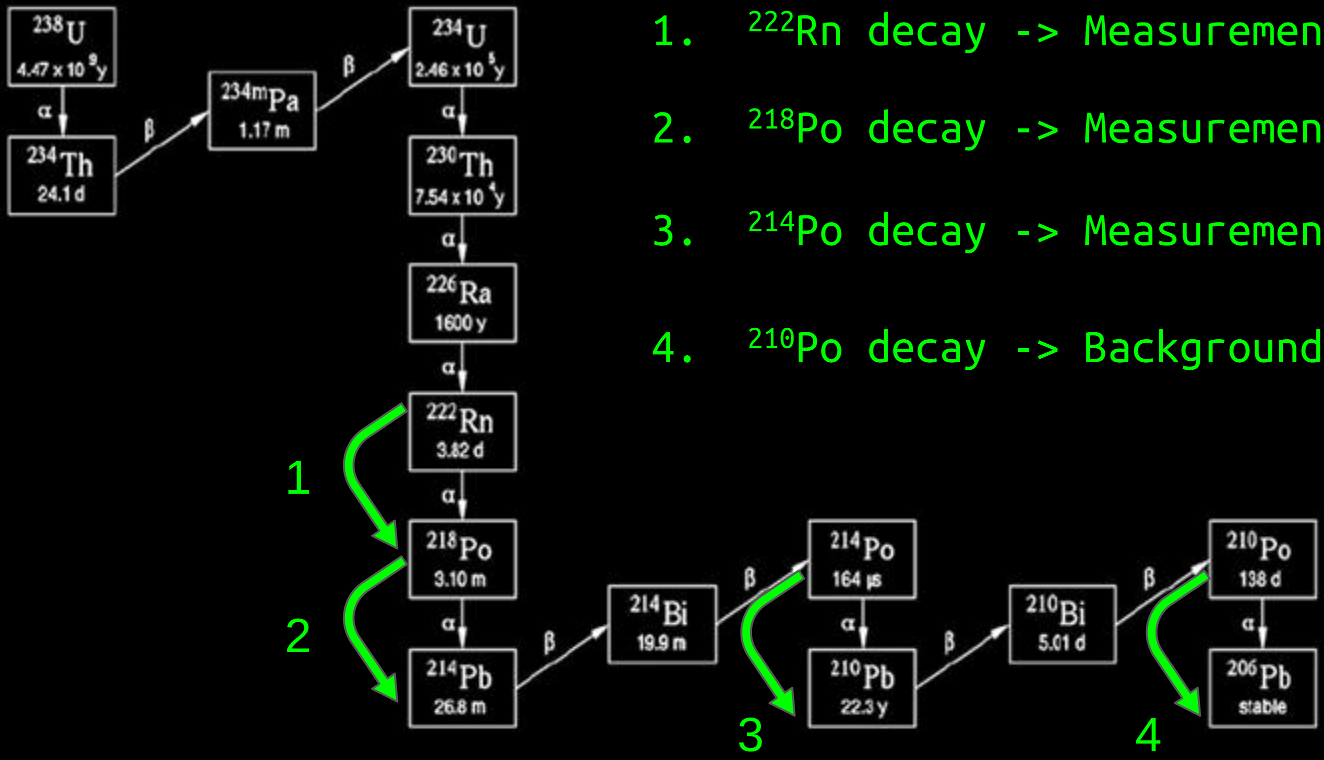


Data Acquisition System (DAQ)



Power supply unit (Above), PMT channels (Below)

Measured Alpha Decays



1. ^{222}Rn decay -> Measurement
2. ^{218}Po decay -> Measurement Verification
3. ^{214}Po decay -> Measurement Verification
4. ^{210}Po decay -> Background

Image provided by IAEA

Why simulate Lucas Cells?

Radon in Lucas Cell

$$\eta_T = \frac{\text{Number of detected Radon Decays}}{\text{Total Number of Radon Decays}}$$

Detected Radon

Why simulate Lucas Cells?

The focus of my presentation is understanding this counting efficiency

$$\eta_T = \eta_{LC}\eta_{QE}\eta_{DAQ}$$

$$\eta_T = 74 \pm 7\%$$

Source : ^{222}Rn emanation into vacuum(1993) [3]

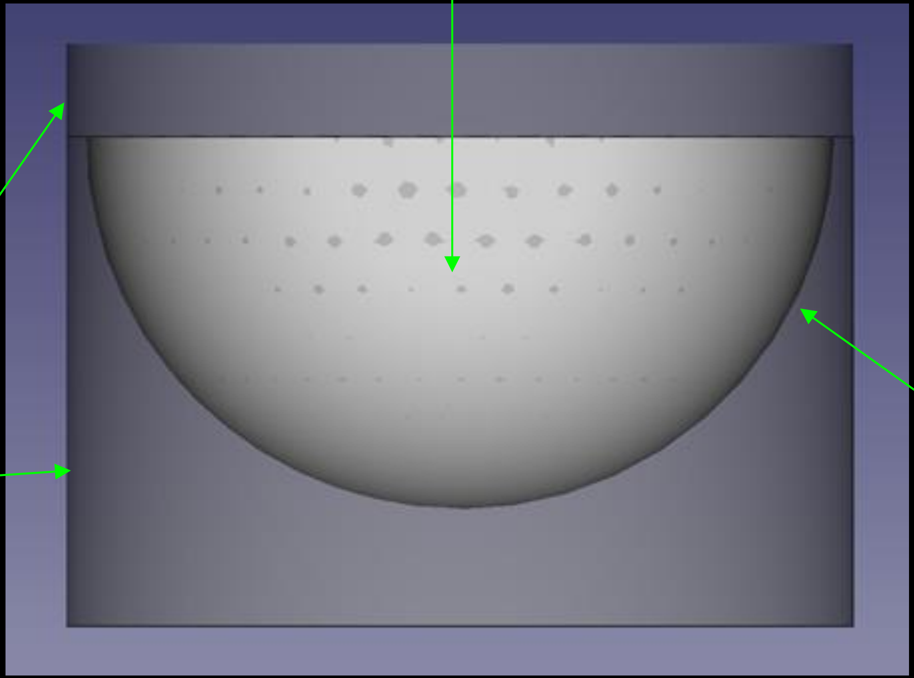
$$\eta_T = 62 \pm 3\%$$

Source : Measurement of ^{222}Rn dissolved in water at the Sudbury Neutrino Observatory(2004) [1]

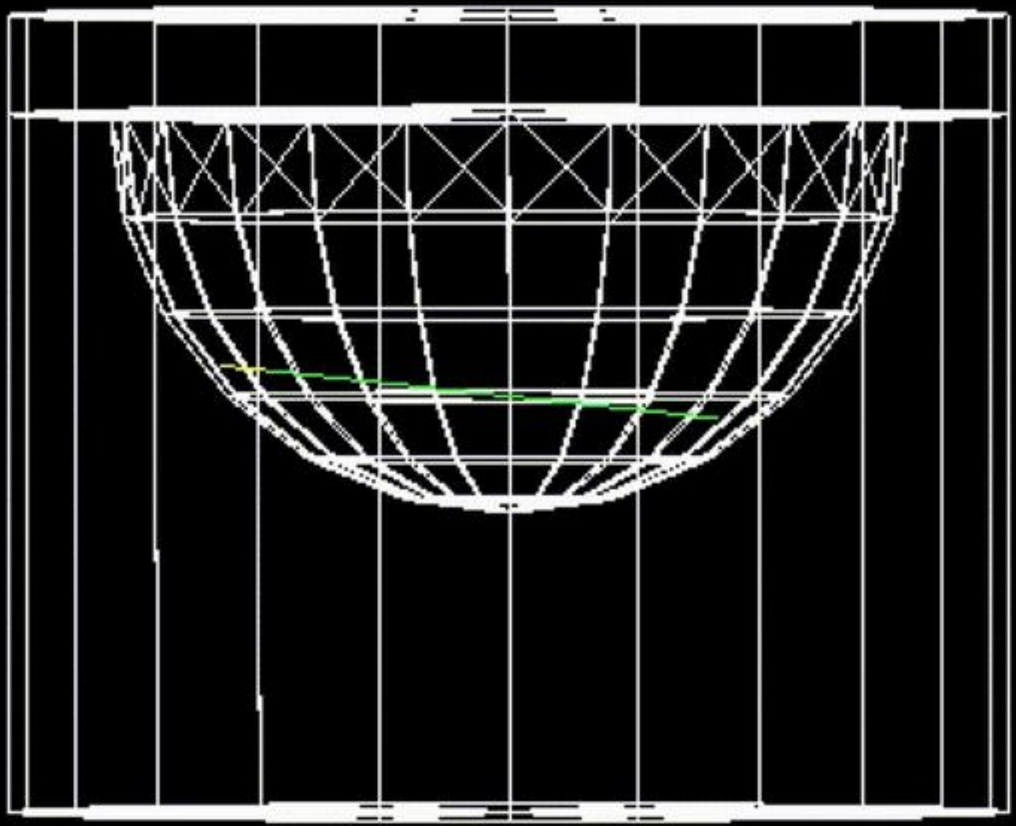
Why simulate Lucas Cells?

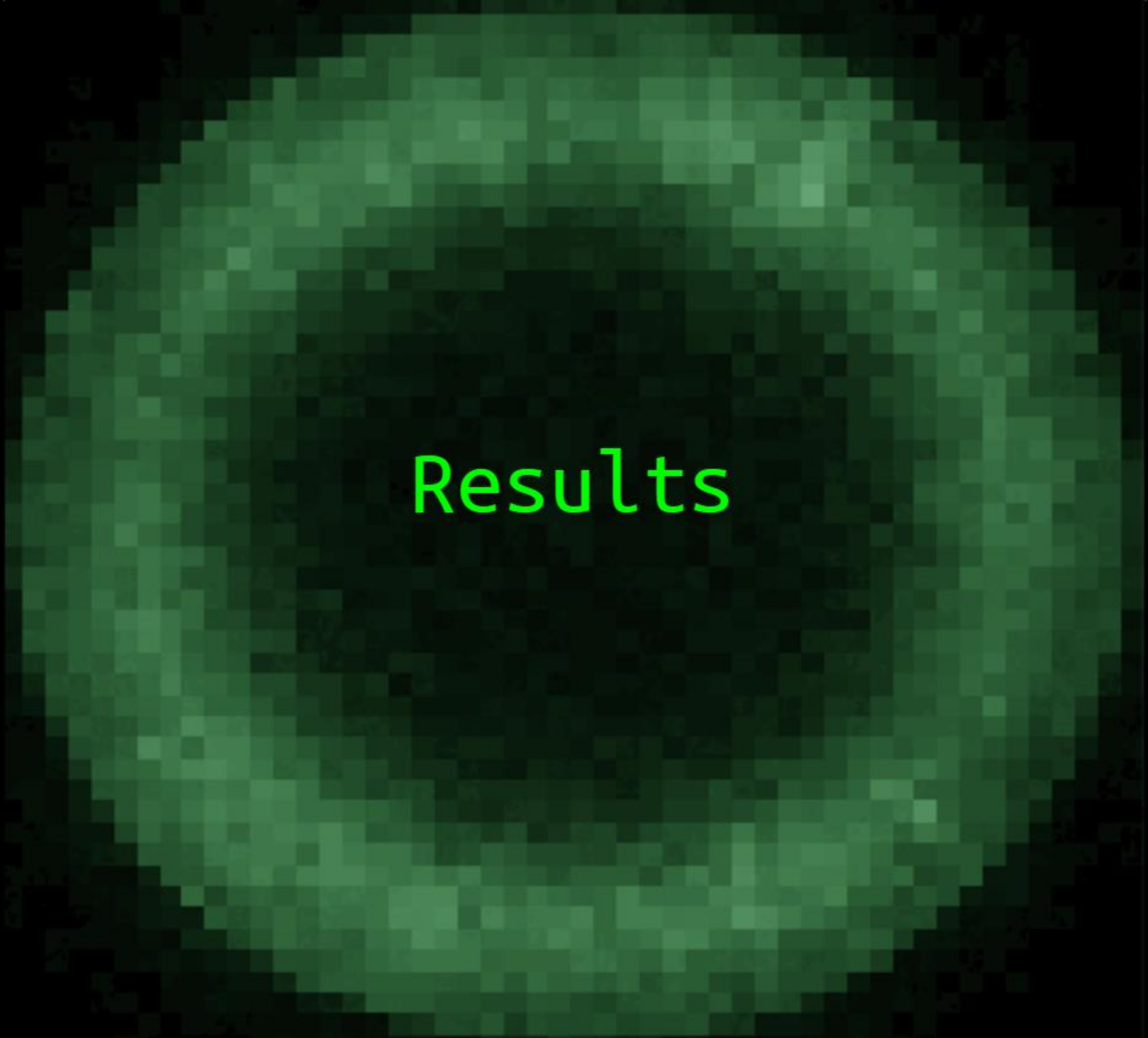
To give us a better understanding of the underlying processes at play during radon assays at SNOLAB

Lucas Cell Geometry



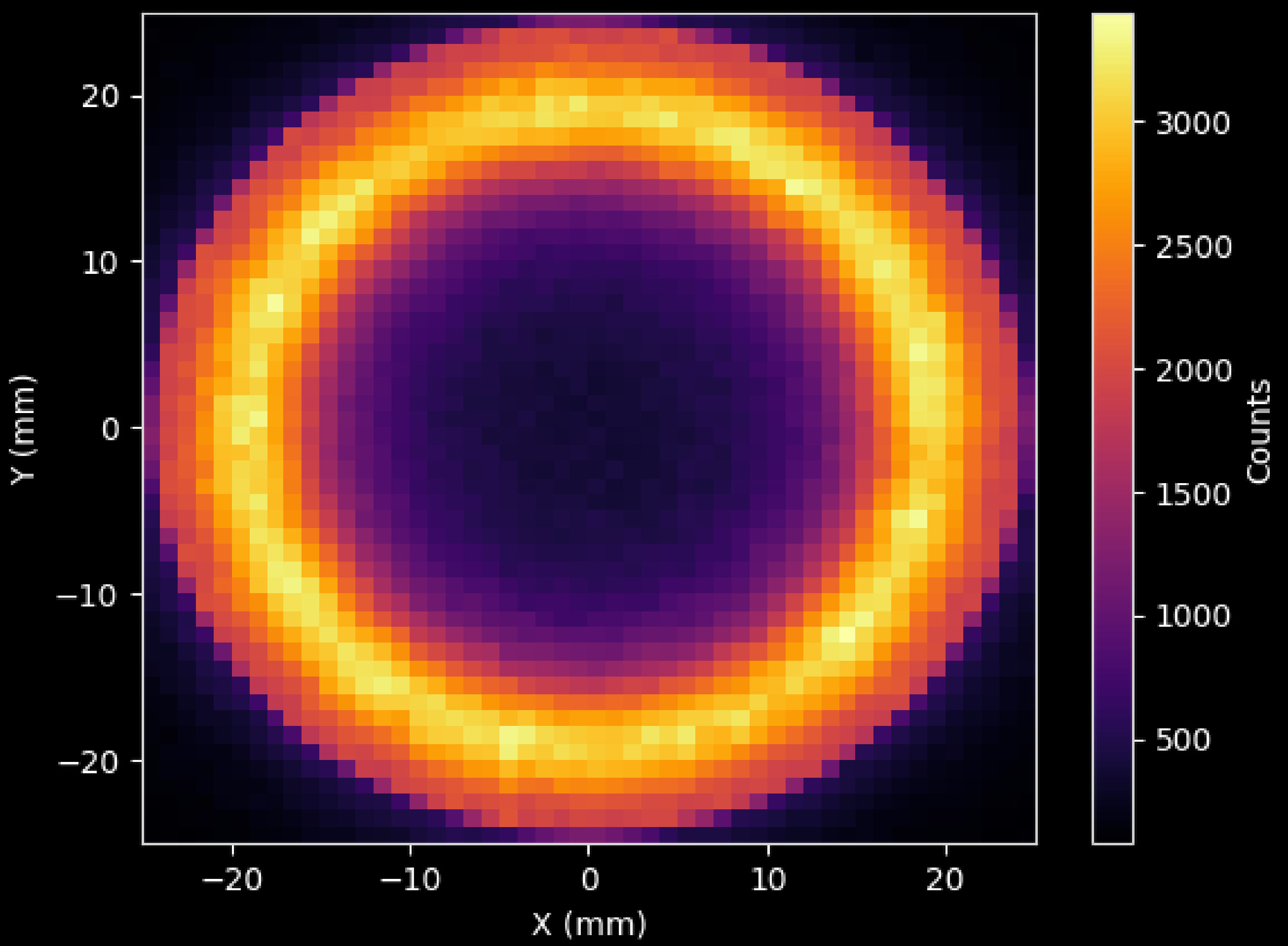
Lucas Cell Geometry



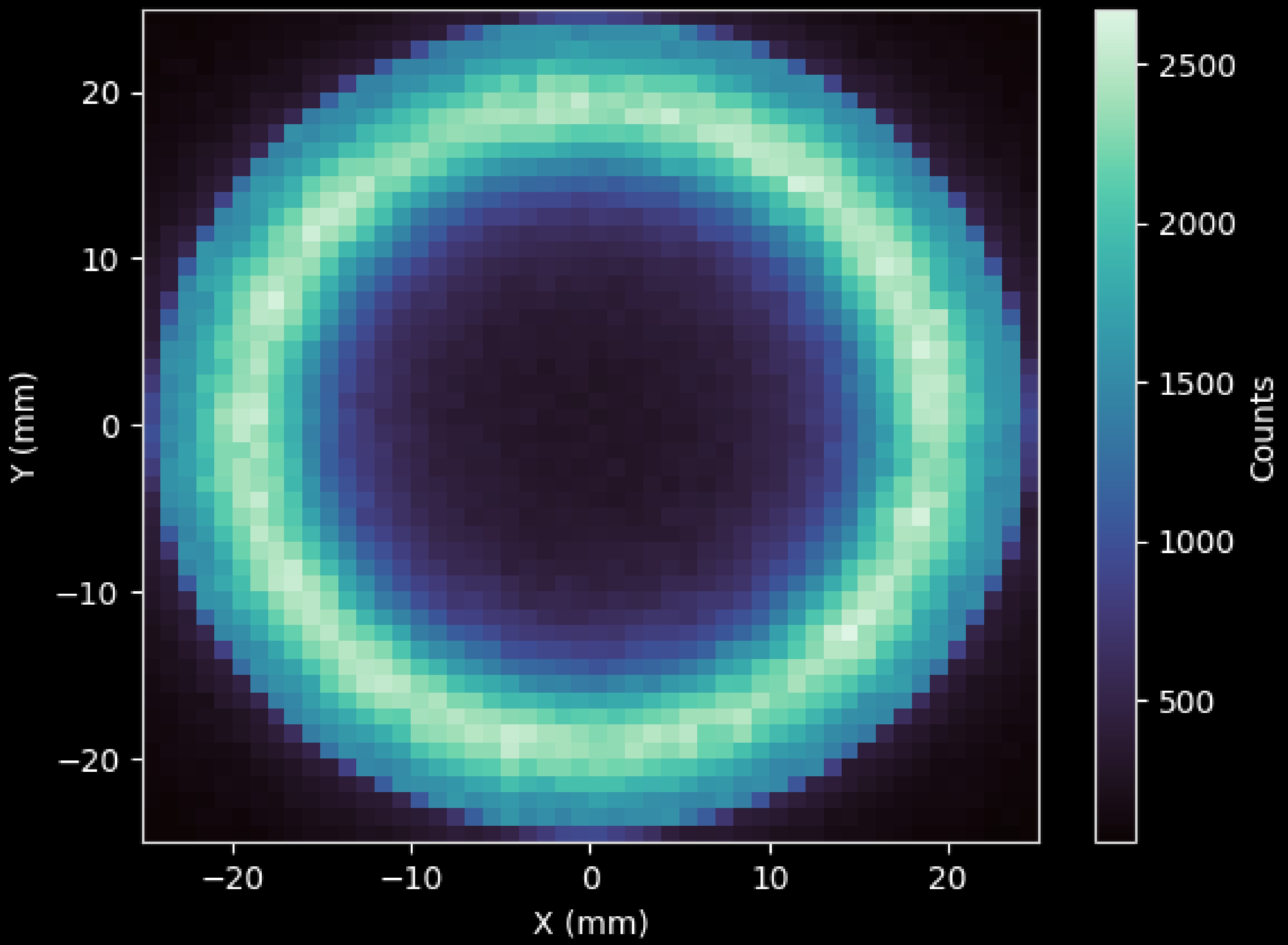


Results

Positional Frequency of Optical Photons on PMT surface



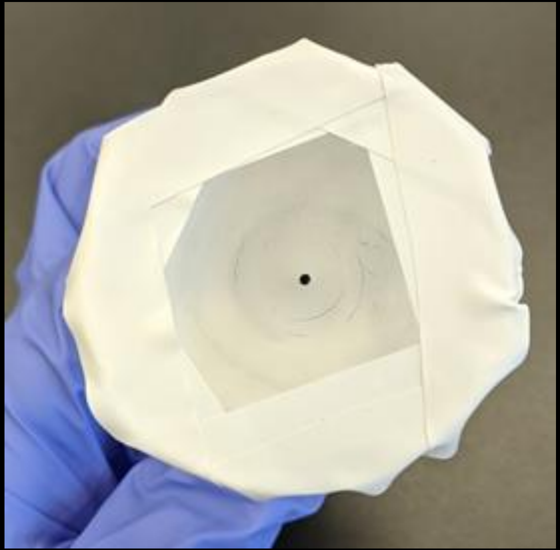
Positional Frequency of Optical Photons Yielding Photoelectrons



Photon Distribution Testing

Expectation: ~90% less counts

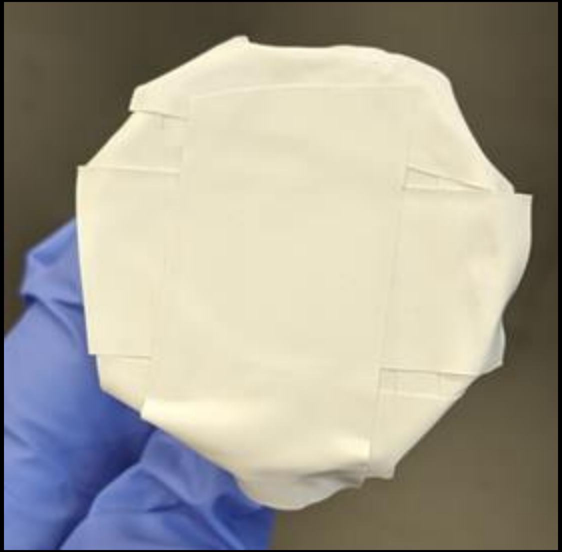
Result: No reduction



Tape : Partial Coverage

Expectation: No counts

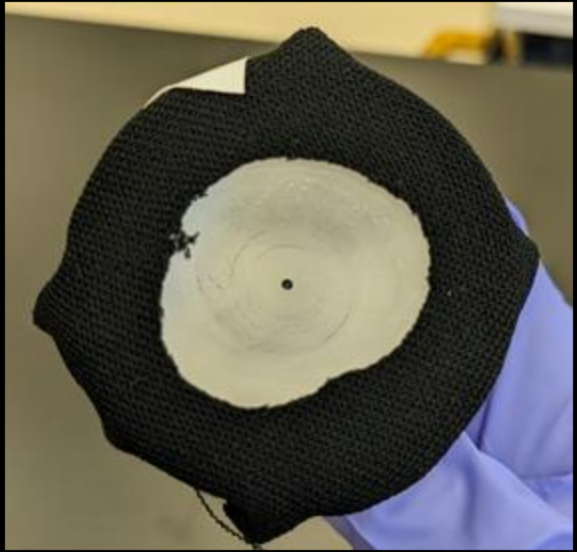
Result: No counts



Tape : Full Coverage

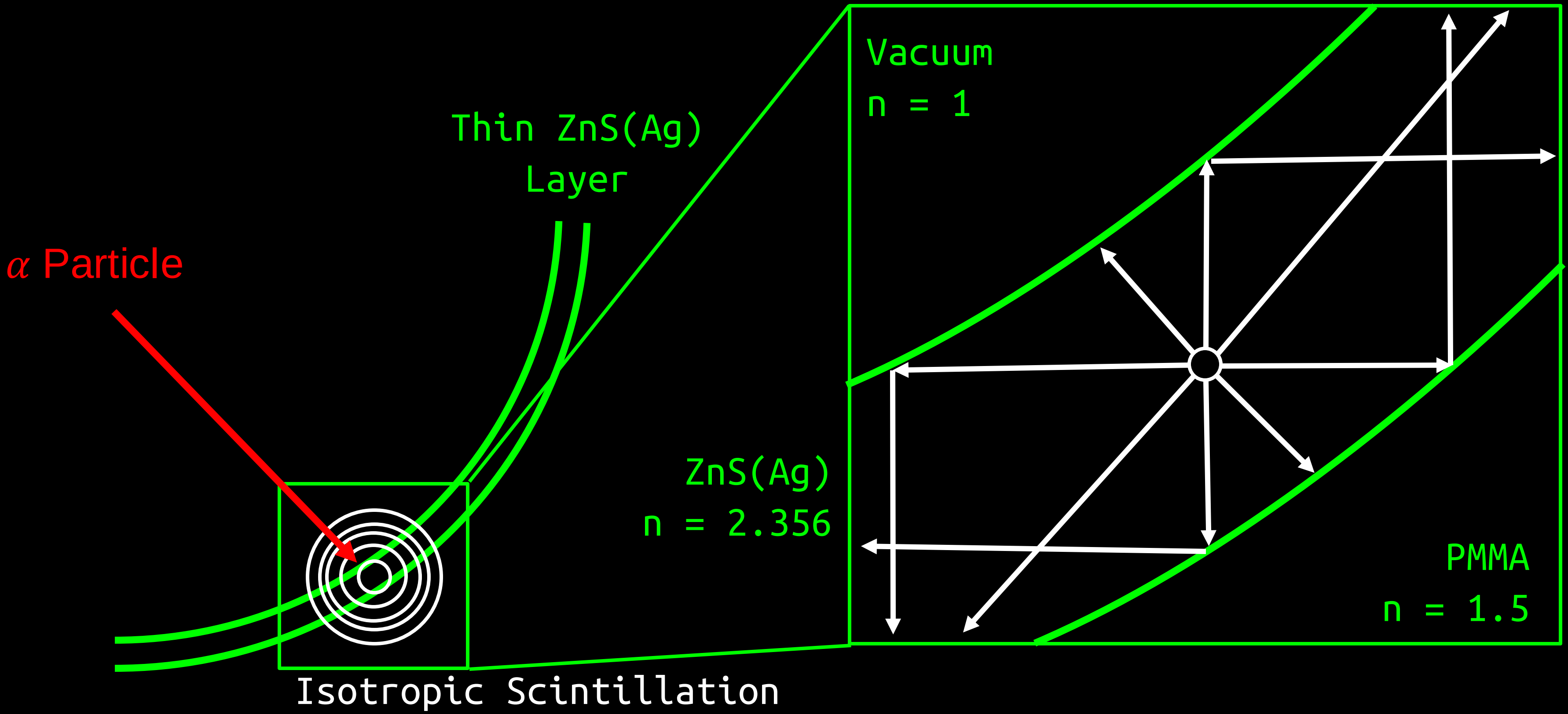
Expectation: ~90% less counts

Result: No reduction

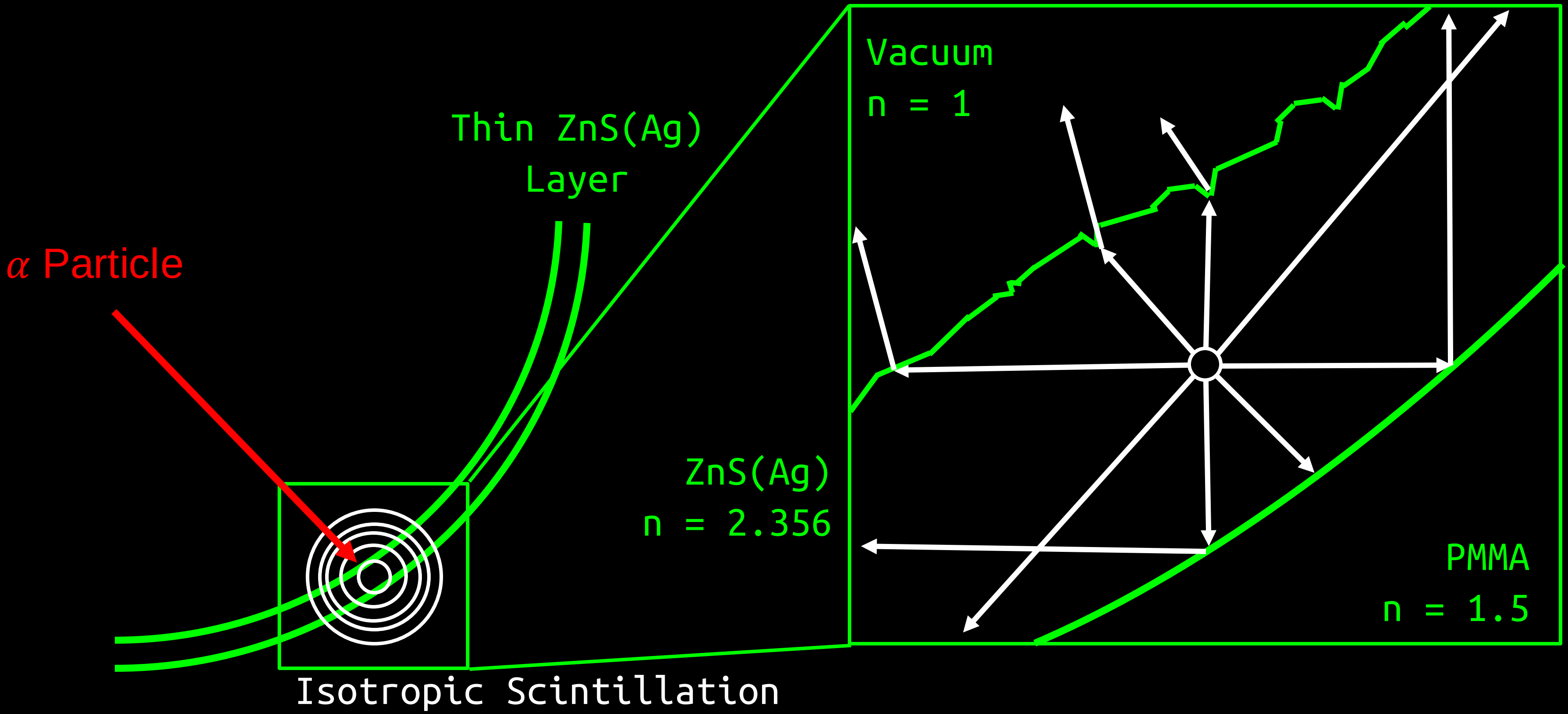


Cloth : Partial Coverage

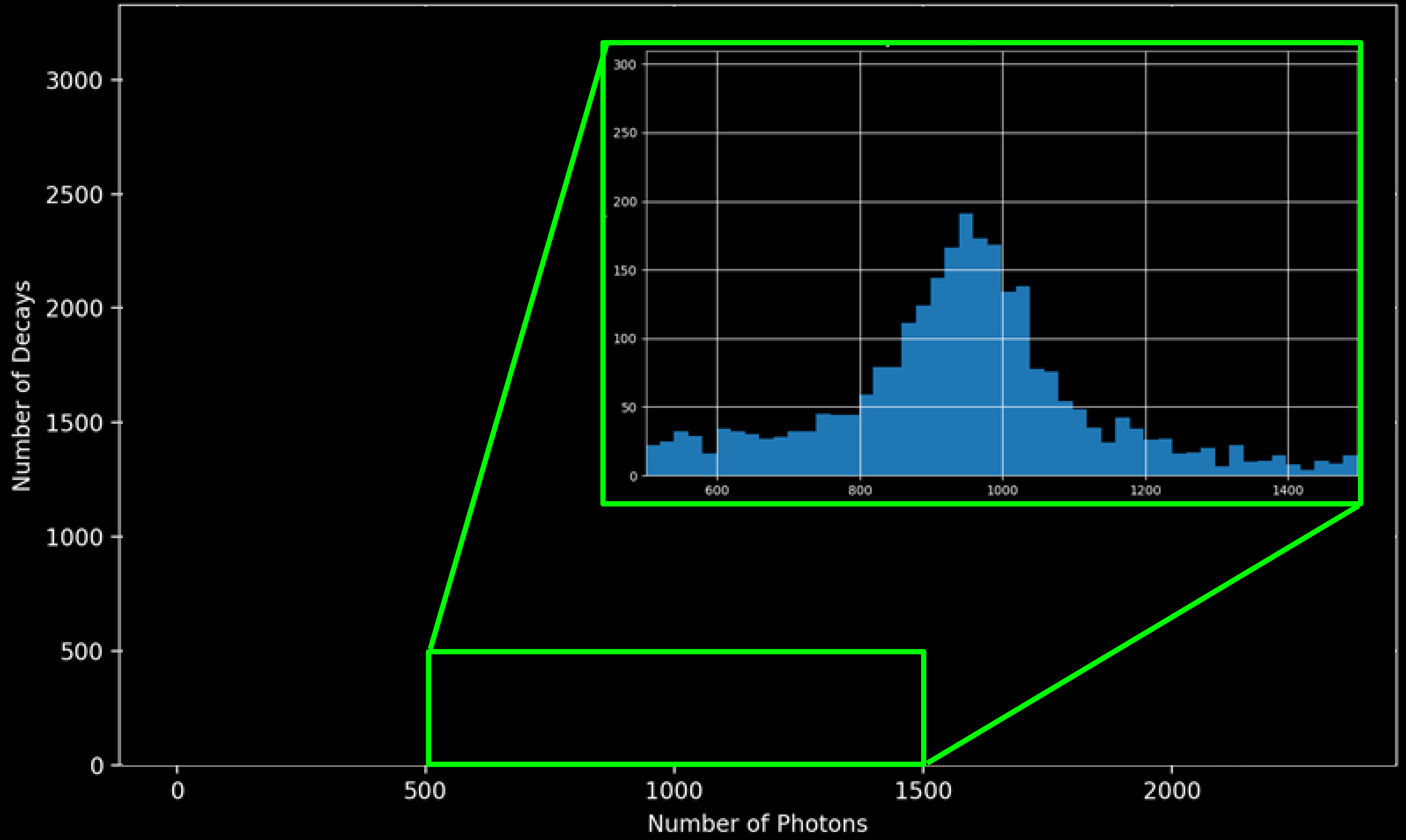
Total Internal Reflection



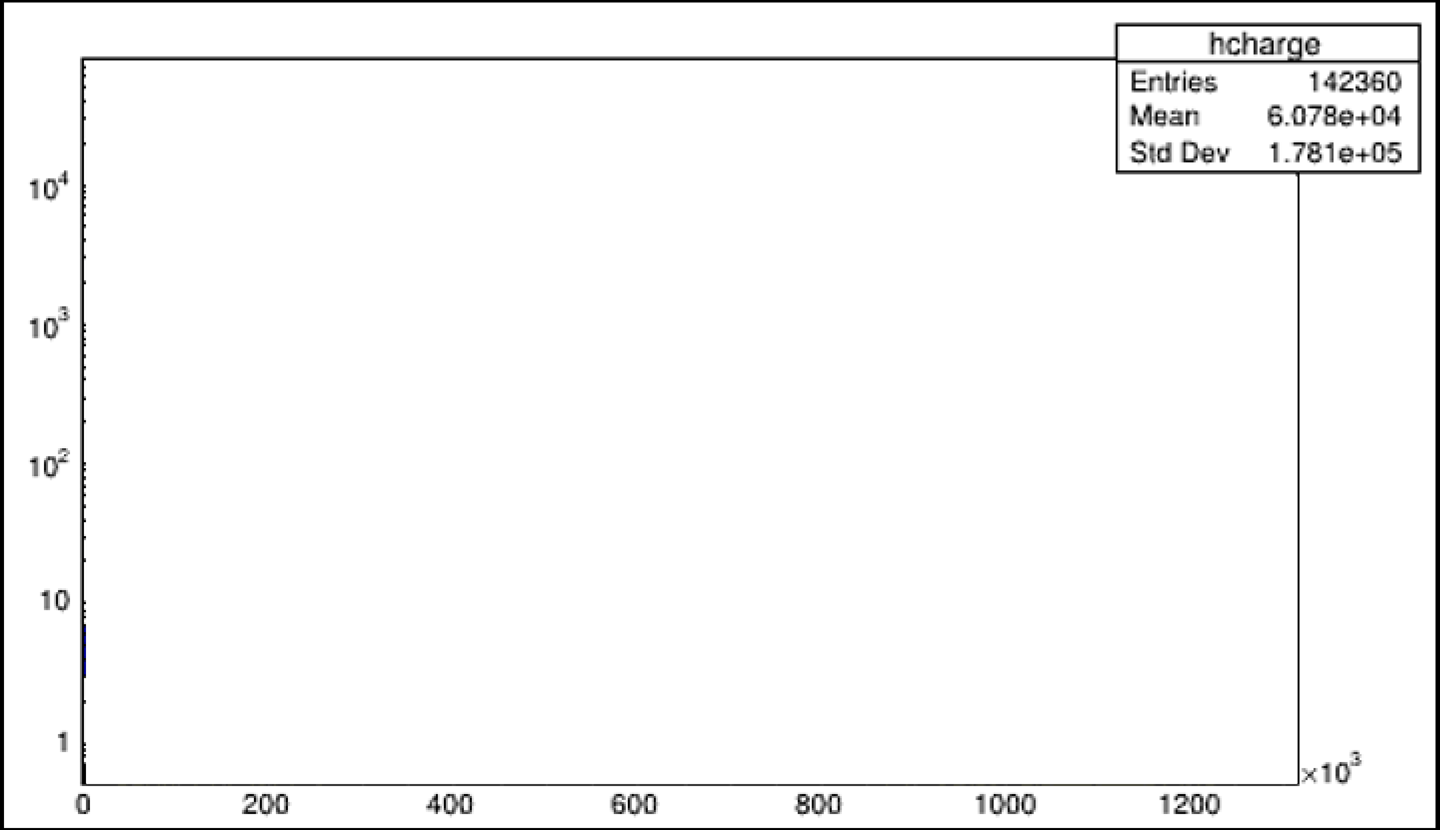
Total Internal Reflection



Number of Decays with a Given Number of Photons Detected



Integrated PMT Charge Distribution



Number of Decays

Energy (A.U.)

GEANT4 Simulation Milestones

- Stochastic Decay Timing Model implemented for the relevant isotopes

- GDML functionality for different Lucas Cell dimensions

- Value for $\eta_{QE,Rn222} = \frac{2848542}{3678865} = 0.7743$ photoelectrons/photon

- GUI to facilitate graphing and knowledge transfer

Future Work

- Implementing the ZnS(Ag) surface roughness***
- Transfer simulation to computer cluster
- Measuring the spatial distribution of ^{222}Rn daughters
- Enhancing GUI and uploading code to Github

Thank you!

Nasim Fatemighomi

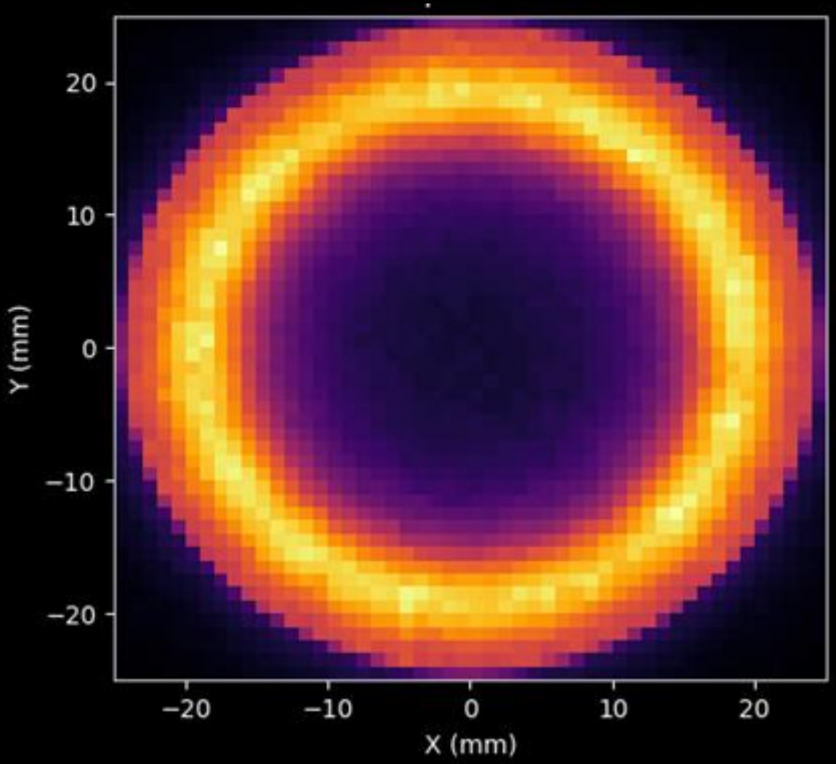
Keegan Paleshi

Mark Ward

Ryan Bayes

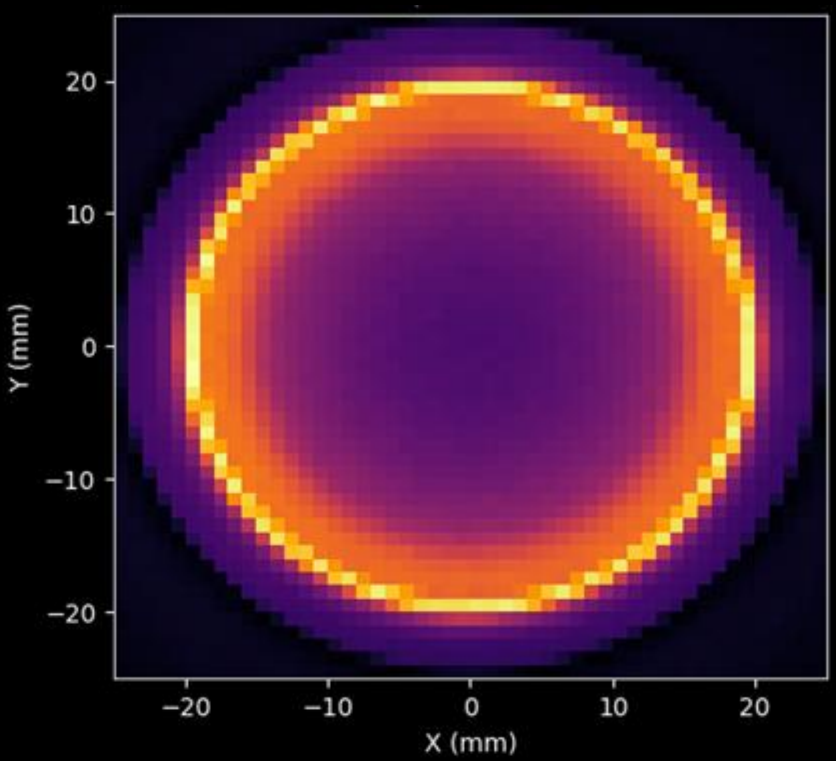
Lina Anselmo

Smooth Scintillator Surface



Not Realistic

Rough Scintillator Surface



More Realistic

Backup - QE calculation

Positional Frequency of Optical Photons Yielding Photoelectrons

Total Number of Optical Photons : 2848542

Positional Frequency of Optical Photons on PMT surface

Total Number of Optical Photons : 3678865

$$\eta_{QE,Rn222} = \frac{2848542 \text{ photoelectrons}}{3678865 \text{ photons}} = 0.7743 \text{ photoelectrons/photon}$$

References

[1] Blevis, I., Boger, J., Bonvin, E., Cleveland, B. T., Dai, X., Dalnoki-Veress, F., Doucas, G., Farine, J., Fergani, H., Grant, D., Hahn, R. L., Hamer, A. S., Hargrove, C. K., Heron, H., Jagam, P., Jelley, N. A., Jillings, C., Knox, A. B., Lee, H. W., … Zhu, X. (2004). Measurement of 222 Rn dissolved in water at the Sudbury Neutrino Observatory. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, *517*(1–3), 139–153. https://doi.org/10.1016/j.nima.2003.10.103

[2] IAEA. (2010). Analytical Methodology for the Determination of Radium Isotopes in Environmental Samples. https://www-pub.iaea.org/MTCD/publications/PDF/IAEA-AQ-19_web.pdf

[3] Liu, M., Lee, H. W., & McDonald, A. B. (1993). 222rn emanation into vacuum. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, *329*(1–2), 291–298. https://doi.org/10.1016/0168-9002(93)90948-h