

# Geant4 Lucas Cell Simulation

By Justin Suys

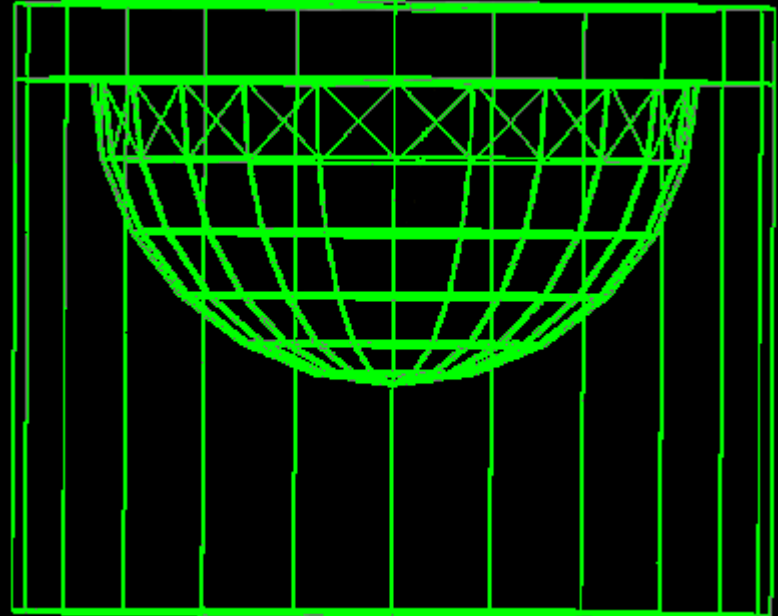
# Outline

## 1. Motivation and Background



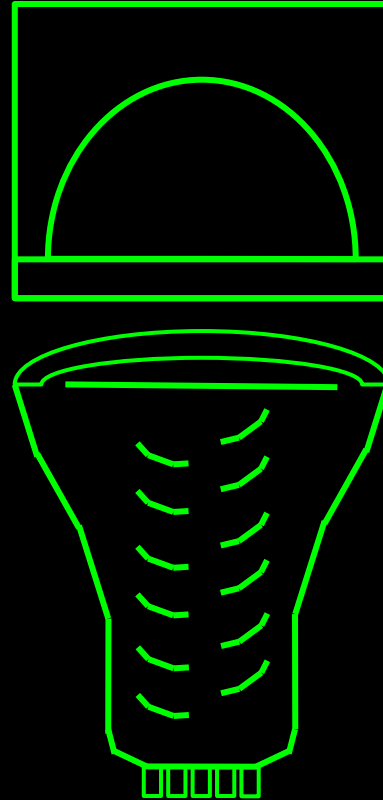
# Outline

1. Motivation and Background
2. Geant4 and Python Simulations



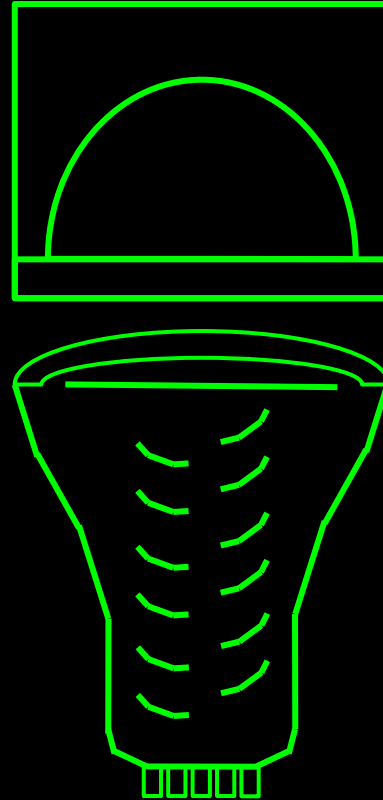
# Outline

1. Motivation and Background
2. Geant4 and Python Simulations
3. Results and Analysis



# Outline

1. Motivation and Background
2. Geant4 and Python Simulations
3. Results and Analysis
4. Further Steps

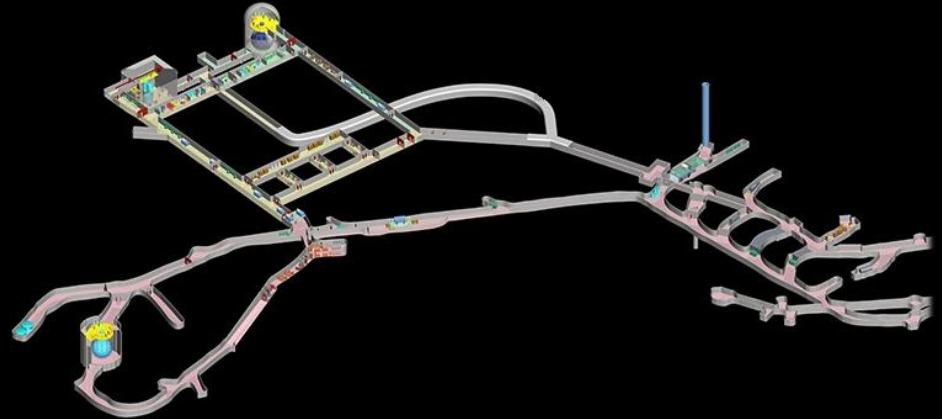




Motivation

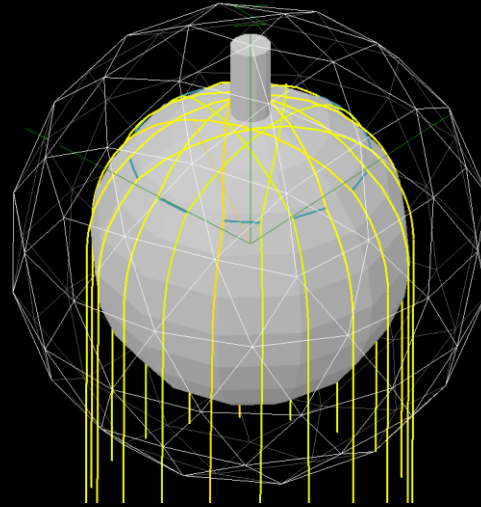
# Motivation

- SNOLAB is situated 2.1 km below ground in Creighton Mine located in Lively, ON

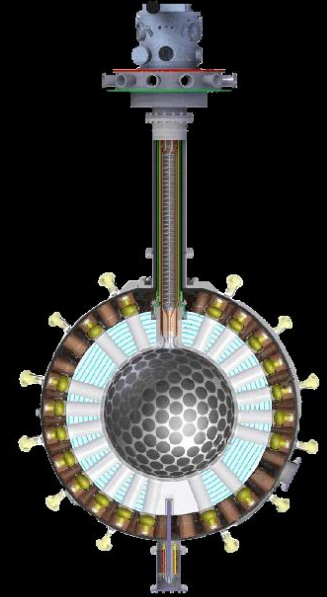


# Motivation

- SNOLAB is situated 2.1 km below ground in Creighton Mine located in Lively, ON
- The rock overburden shields astro-particle physics experiment from cosmic rays



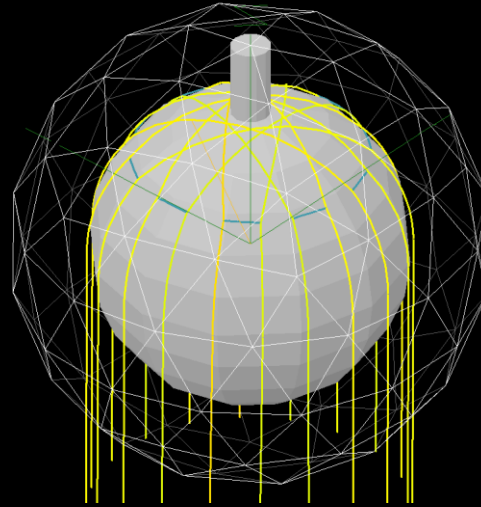
SNO+  
 $0\nu\beta\beta$



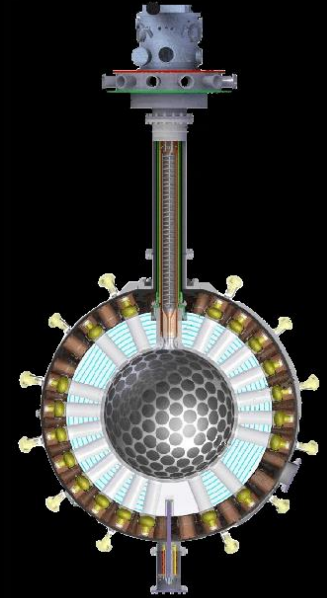
DEAP-3600  
Dark Matter

# Motivation

- SNOLAB is situated 2.1 km below ground in Creighton Mine located in Lively, ON
- The rock overburden shields astro-particle physics experiment from cosmic rays
- Experiments at SNOLAB also require isolation from radioisotopes



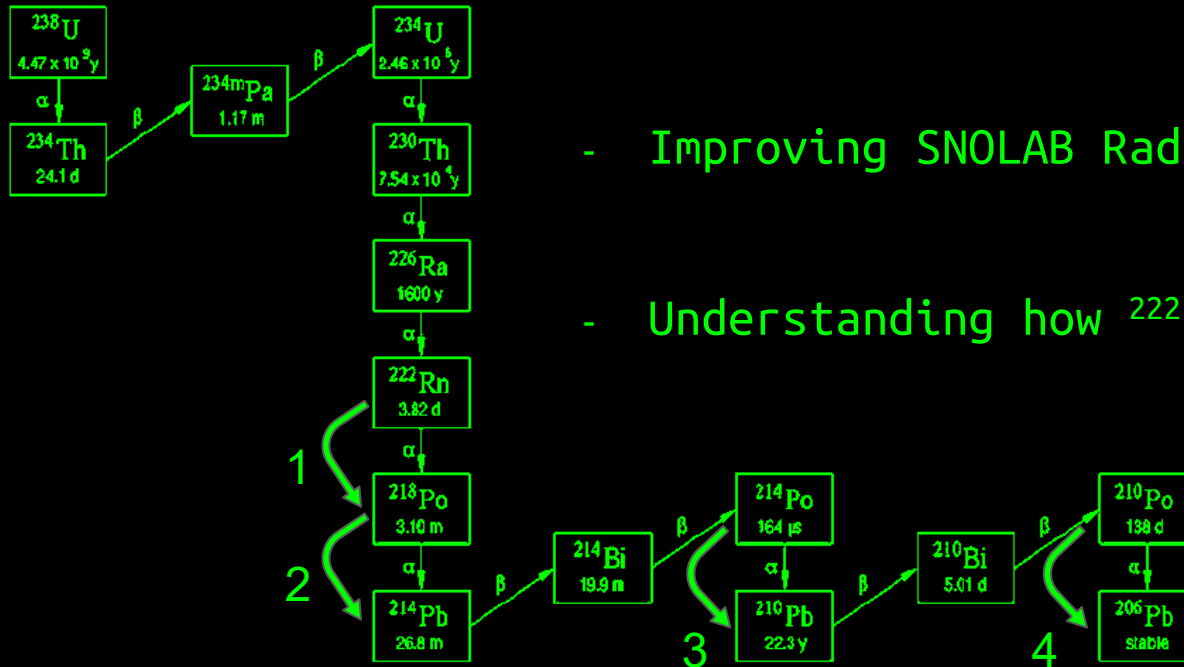
SNO+  
 $0\nu\beta\beta$



DEAP-3600  
Dark Matter

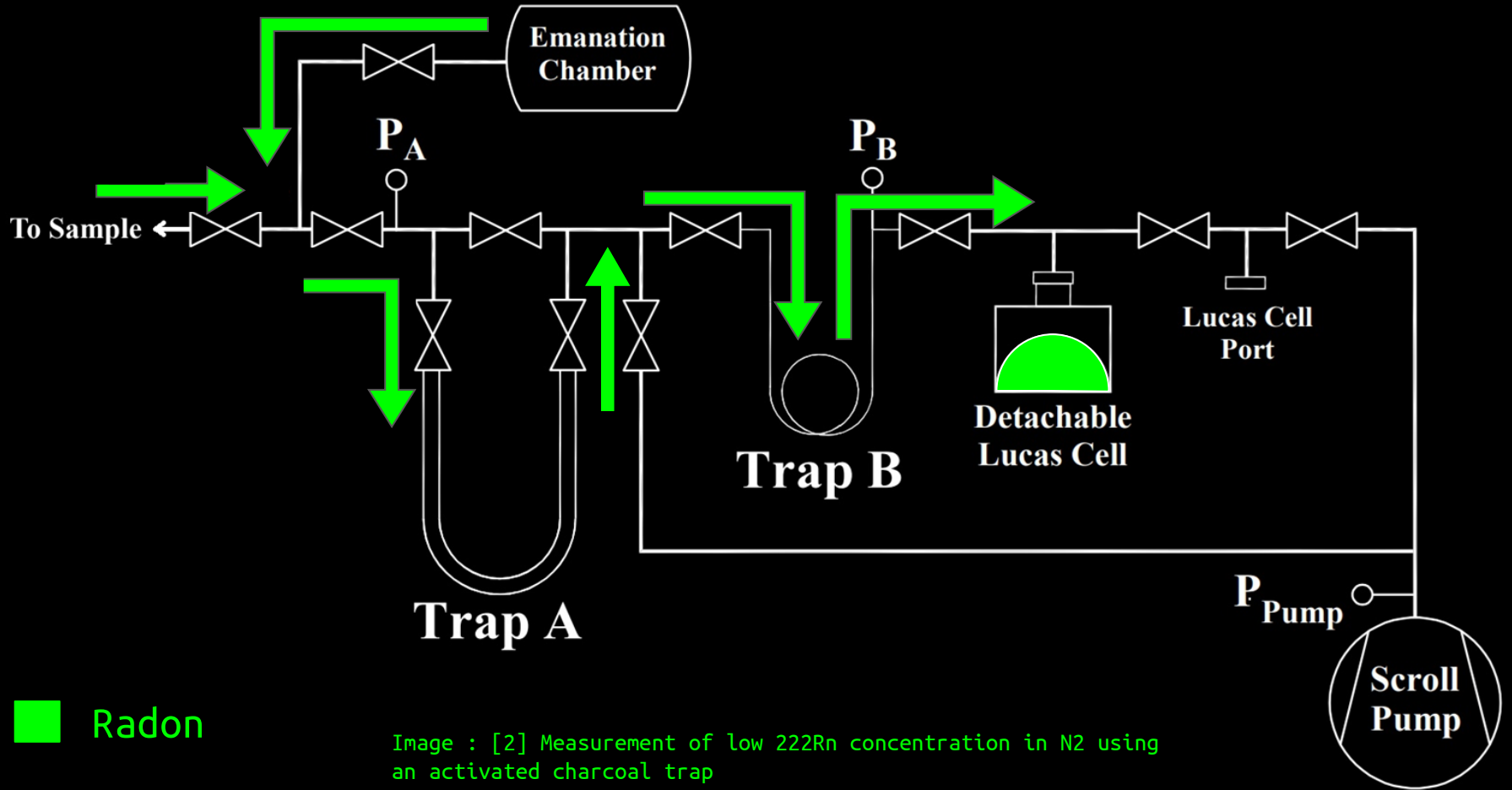
# Motivation

- $^{222}\text{Rn}$  is a source of radioactive background
- Improving SNOLAB Radon Assay Systems
- Understanding how  $^{222}\text{Rn}$  is measured





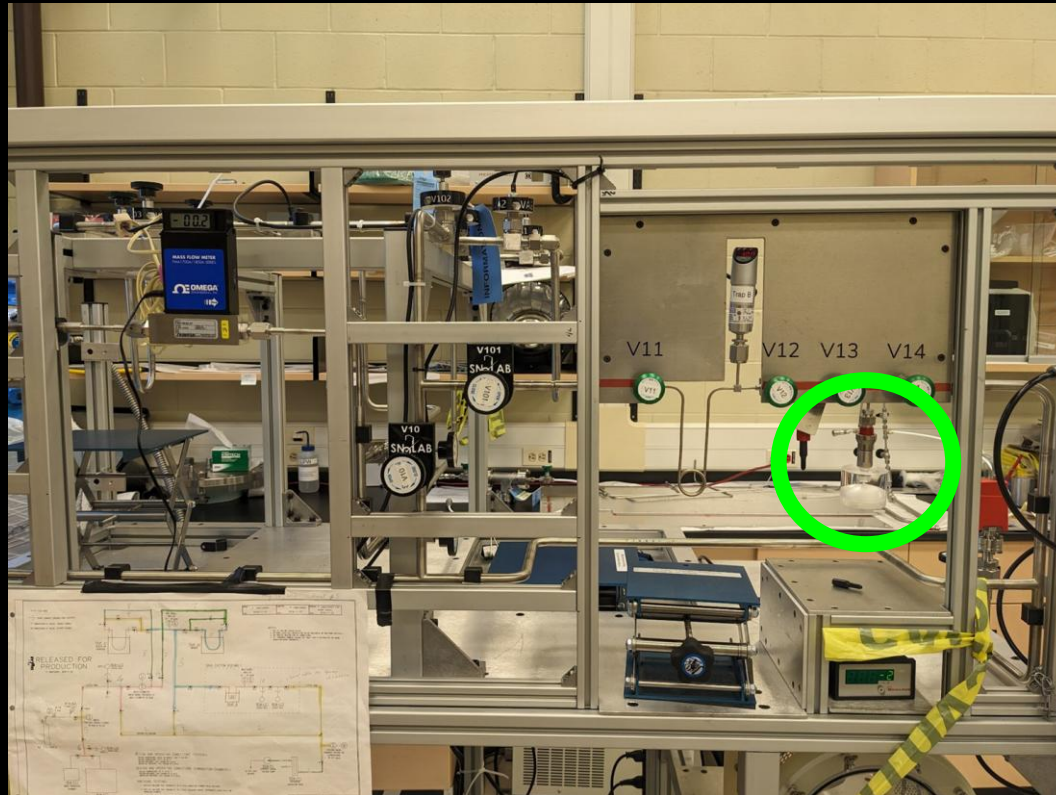
Background



■ Radon

Image : [2] Measurement of low  $^{222}\text{Rn}$  concentration in  $\text{N}_2$  using an activated charcoal trap

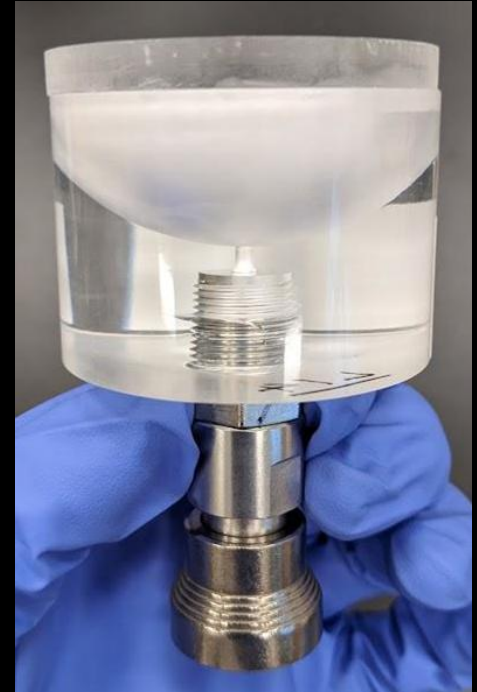
# Motivation



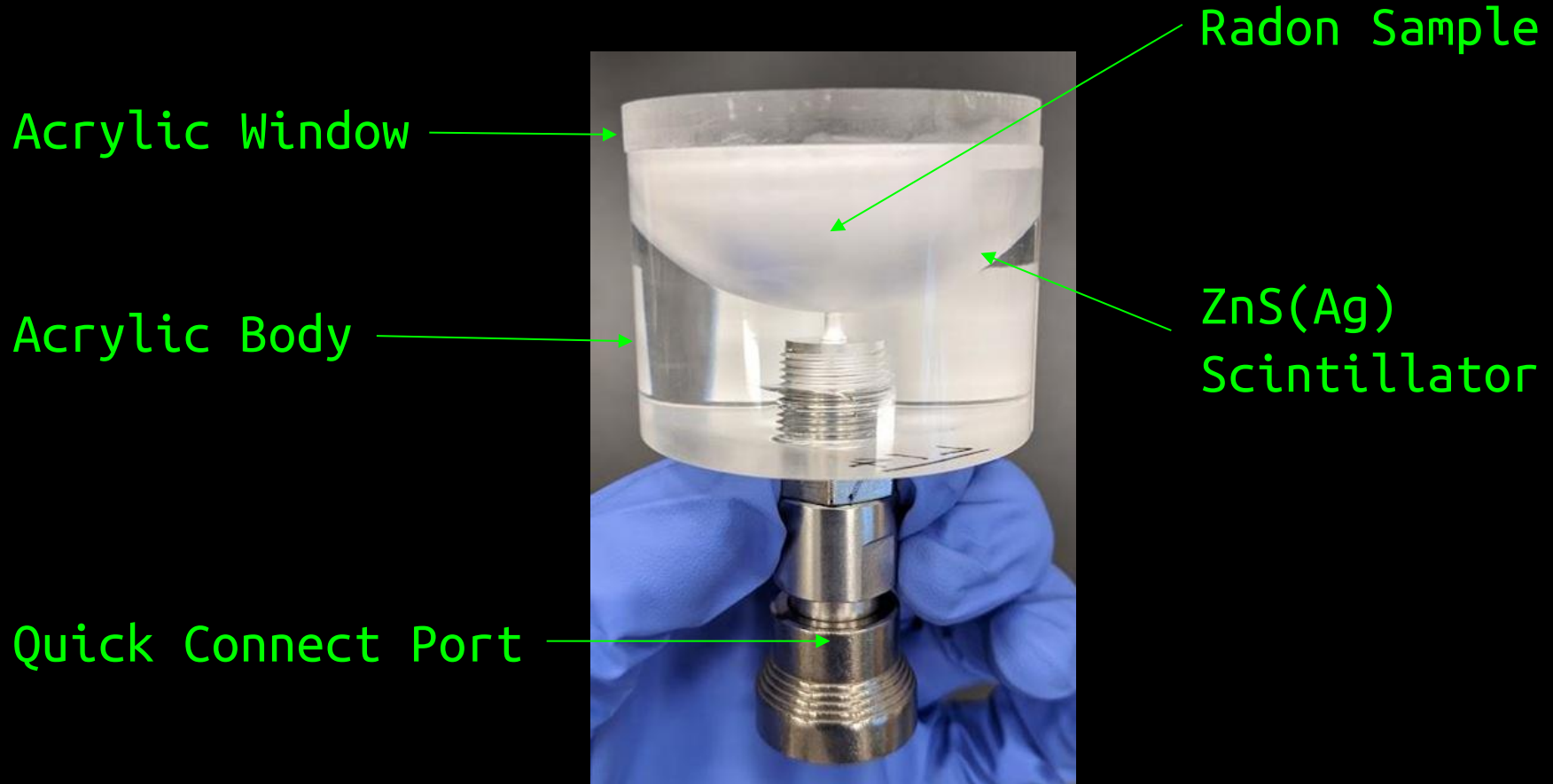
Surface Radon Board

# What is a Lucas Cell?

- Scintillation counter sensitive to alpha particles made at SNOLAB
- Used to quantify the amount of  $^{222}\text{Rn}$  in SNOLAB's radon assay systems
- Individual alpha decays are counted with PMTs



# What is a Lucas Cell?



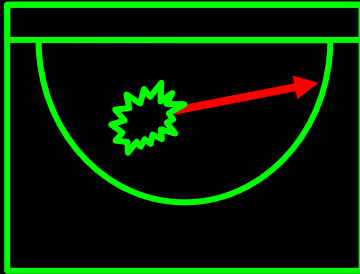
# Why simulate Lucas Cells?

To understand their effectiveness and  
optimize their design.

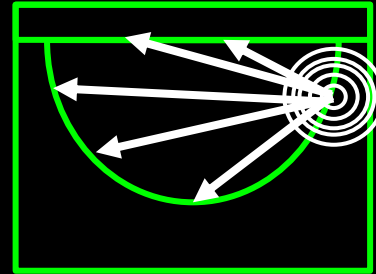
# LC Measurements

- Simulation results should coincide with laboratory measurements

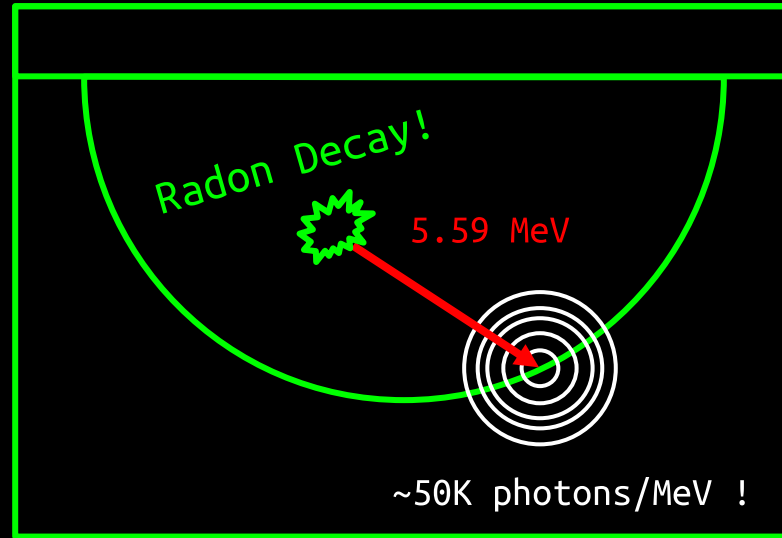
## 1. Geometrical Efficiency



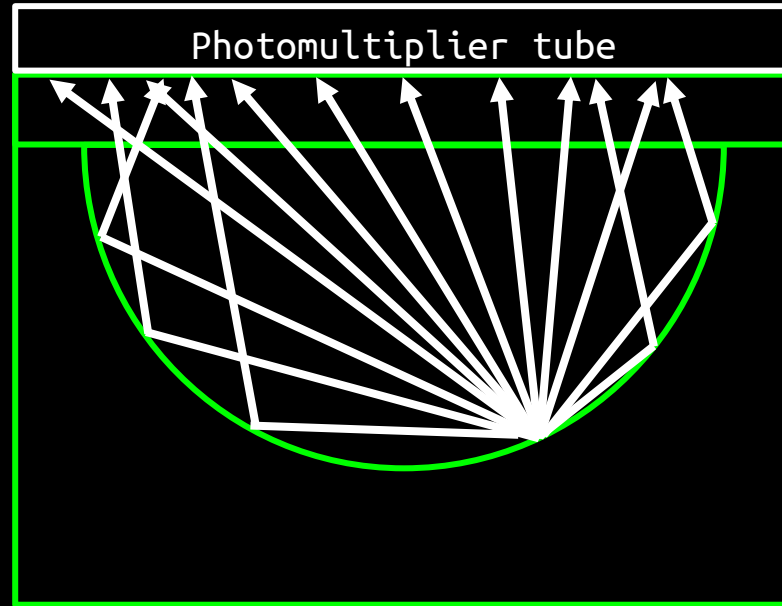
## 2. Scintillation optical model



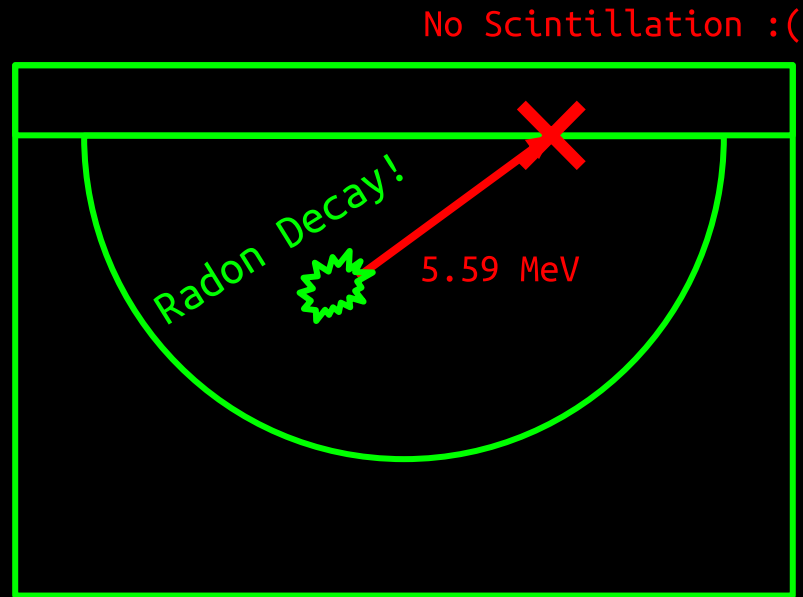
# Scintillation Events



# Scintillation Events



# Window Events



# Geometric Efficiency

- Geometric Efficiency is denoted  $\eta_{LC}$

$$\eta_{LC} = \frac{\text{Number of Scintillation Events}}{\text{Total Number of Events}}$$

- Reported values of  $\eta_{LC}$  is inconsistent between studies

$$\eta_{LC} = 74 \pm 7\%$$

$$\eta_{LC} = 62 \pm 3\%$$

Source :  $^{222}\text{Rn}$  emanation into vacuum(1993) [4]

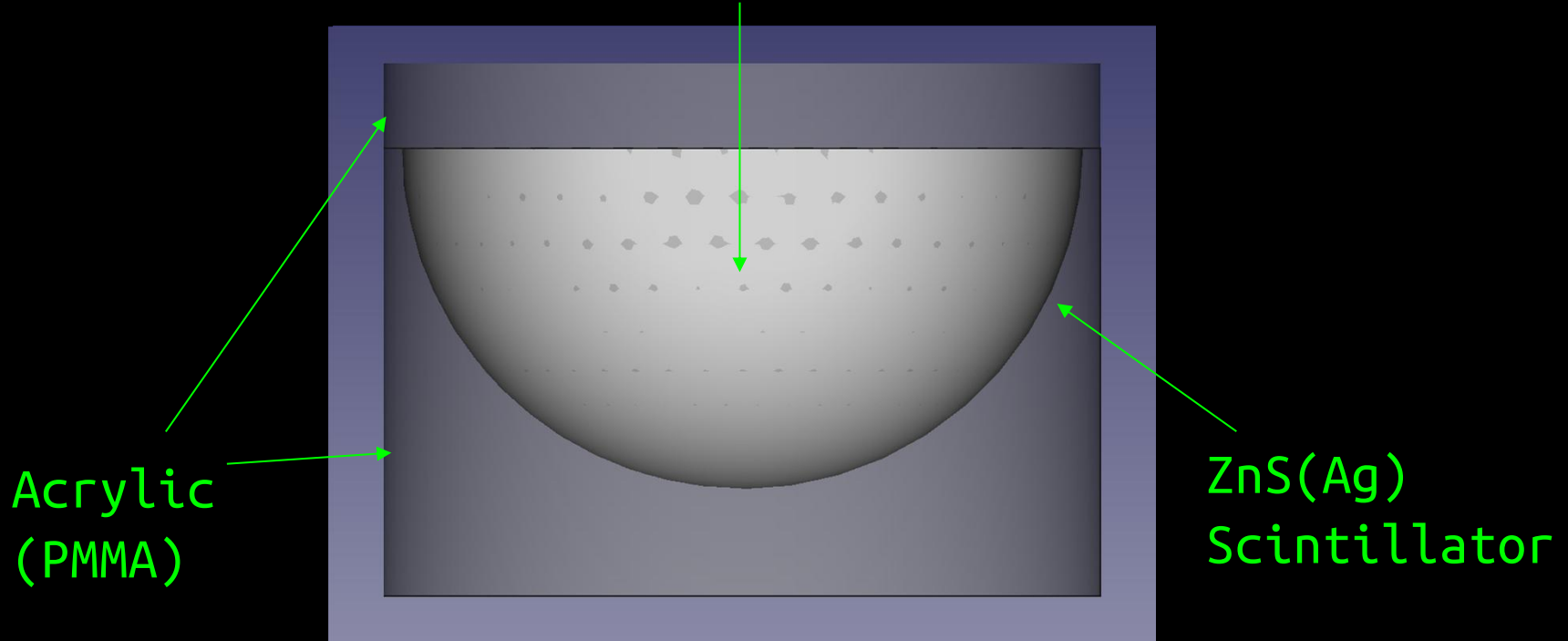
Source : Measurement of  $^{222}\text{Rn}$  dissolved in water at the Sudbury Neutrino Observatory(2004) [1]



Geant4

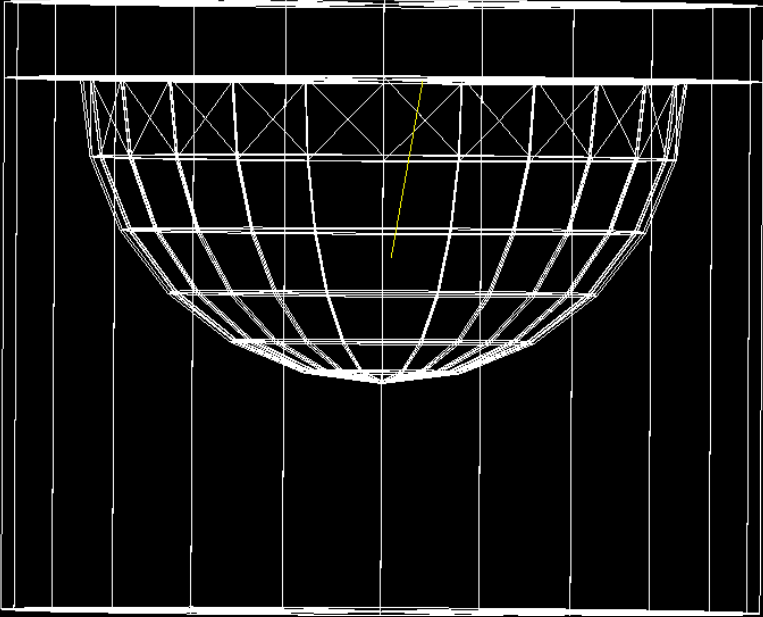
# Lucas Cell Geometry

Radon Sample (Inside hemisphere)

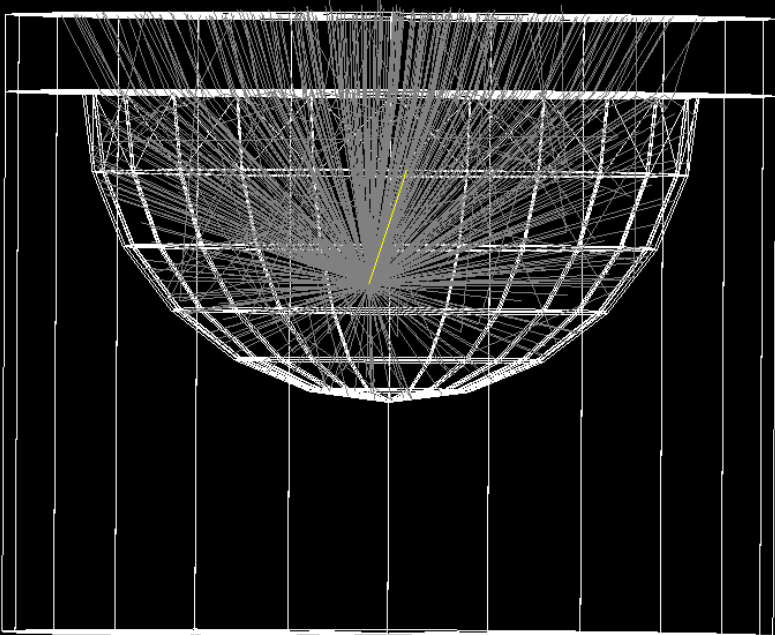


# Lucas Cell Geometry

Window Event



Scintillation Event



Alpha

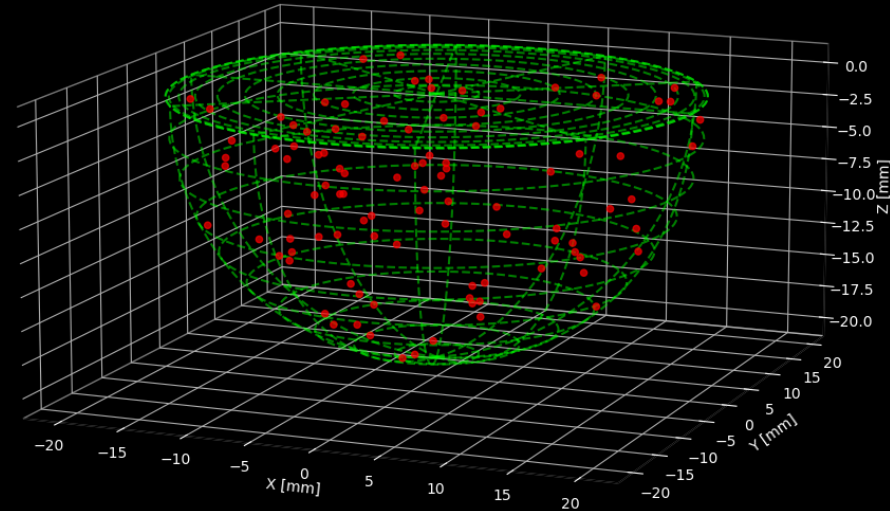
Optical Photon



Python

# Python Simulation Comparison

- Python application provides cross-check with the Geant4 simulation
- $^{222}\text{Rn}$  decays can be simulated faster
- More precise measurement for  $\eta_{\text{LC}}$

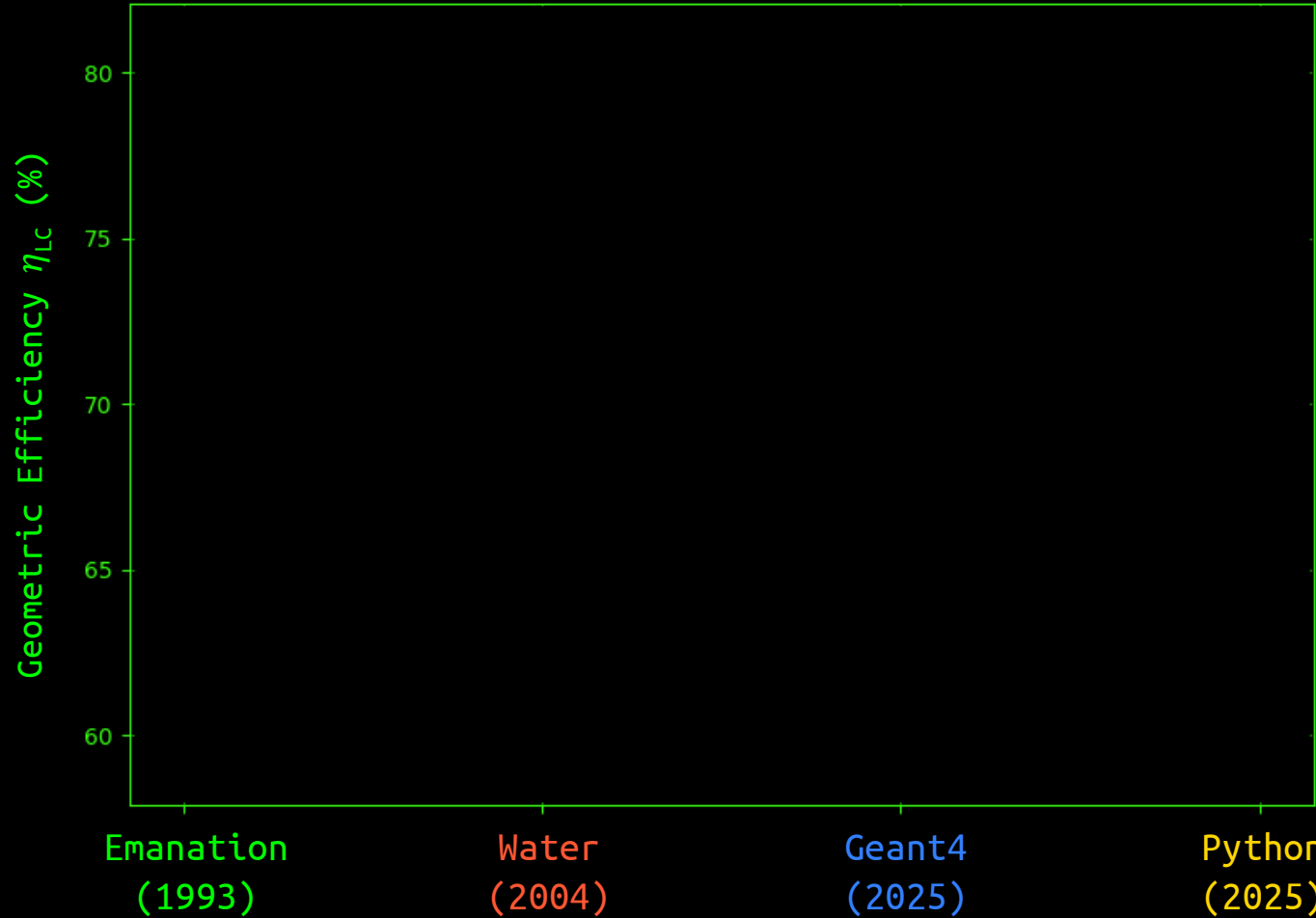


$^{222}\text{Rn}$  Decay Positions Plotted in Python

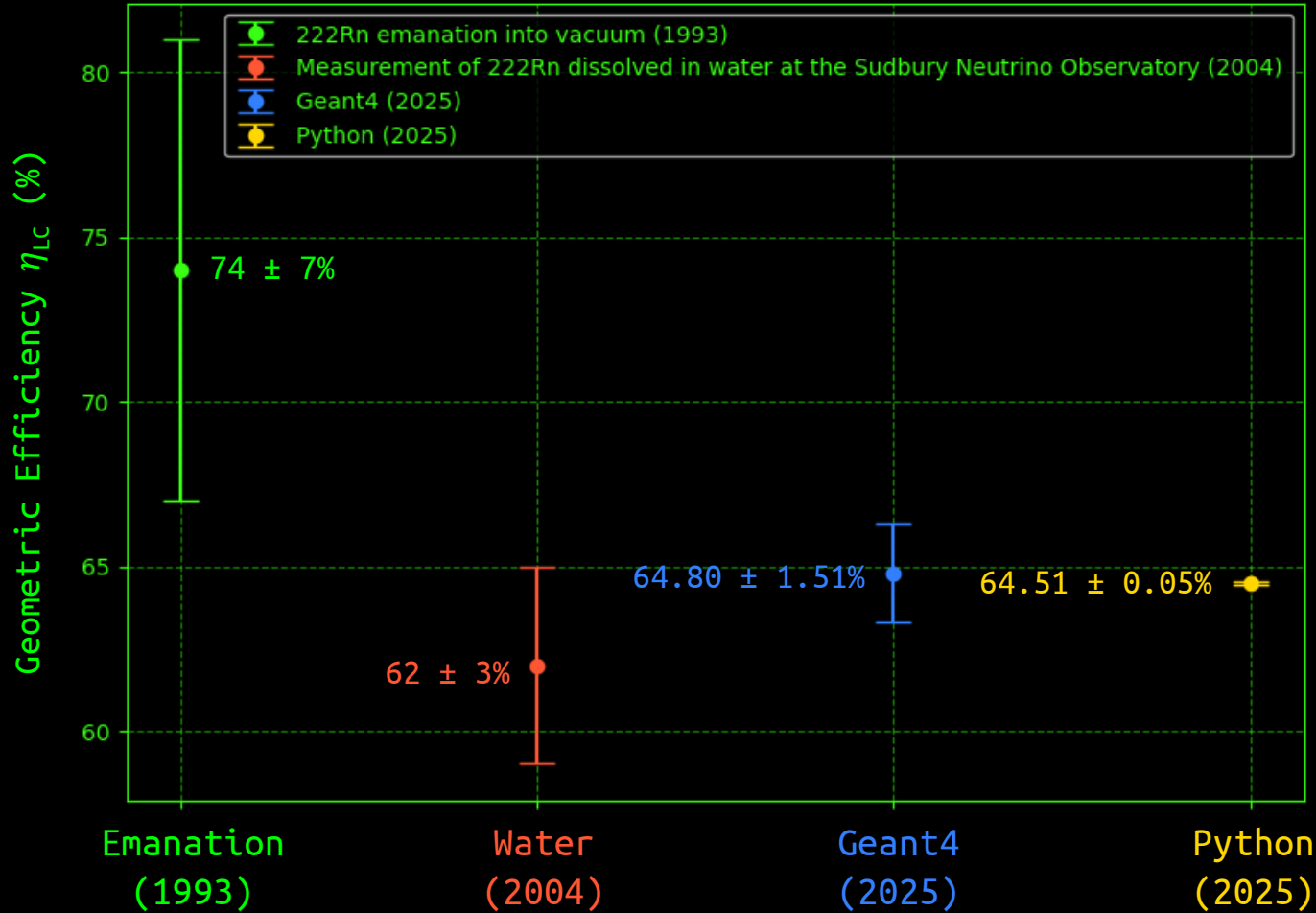


Results

# Geometric Efficiency Comparison



# Geometric Efficiency Comparison

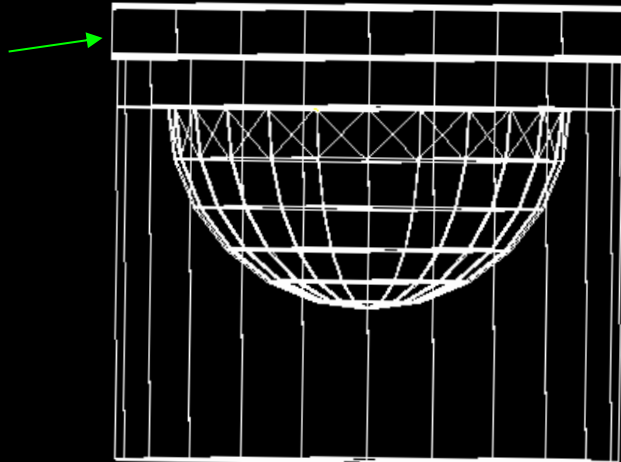


# Geant4 Optical Model

1. Scintillation yield distributions

2. Scintillation photon positional distribution

2D Sensitive  
detector grid

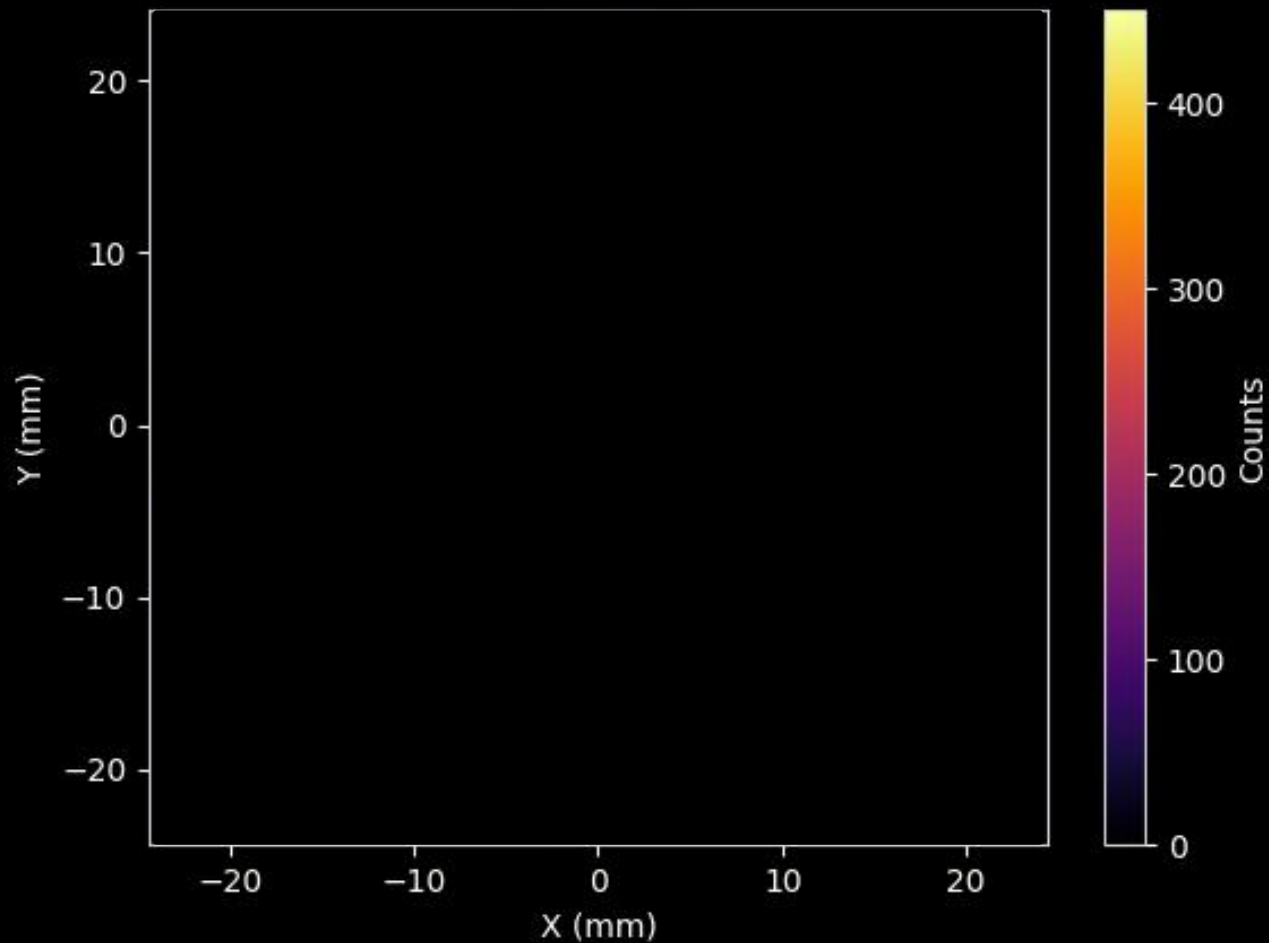


Sensitive detector volumes store the information of particles that interact with them!

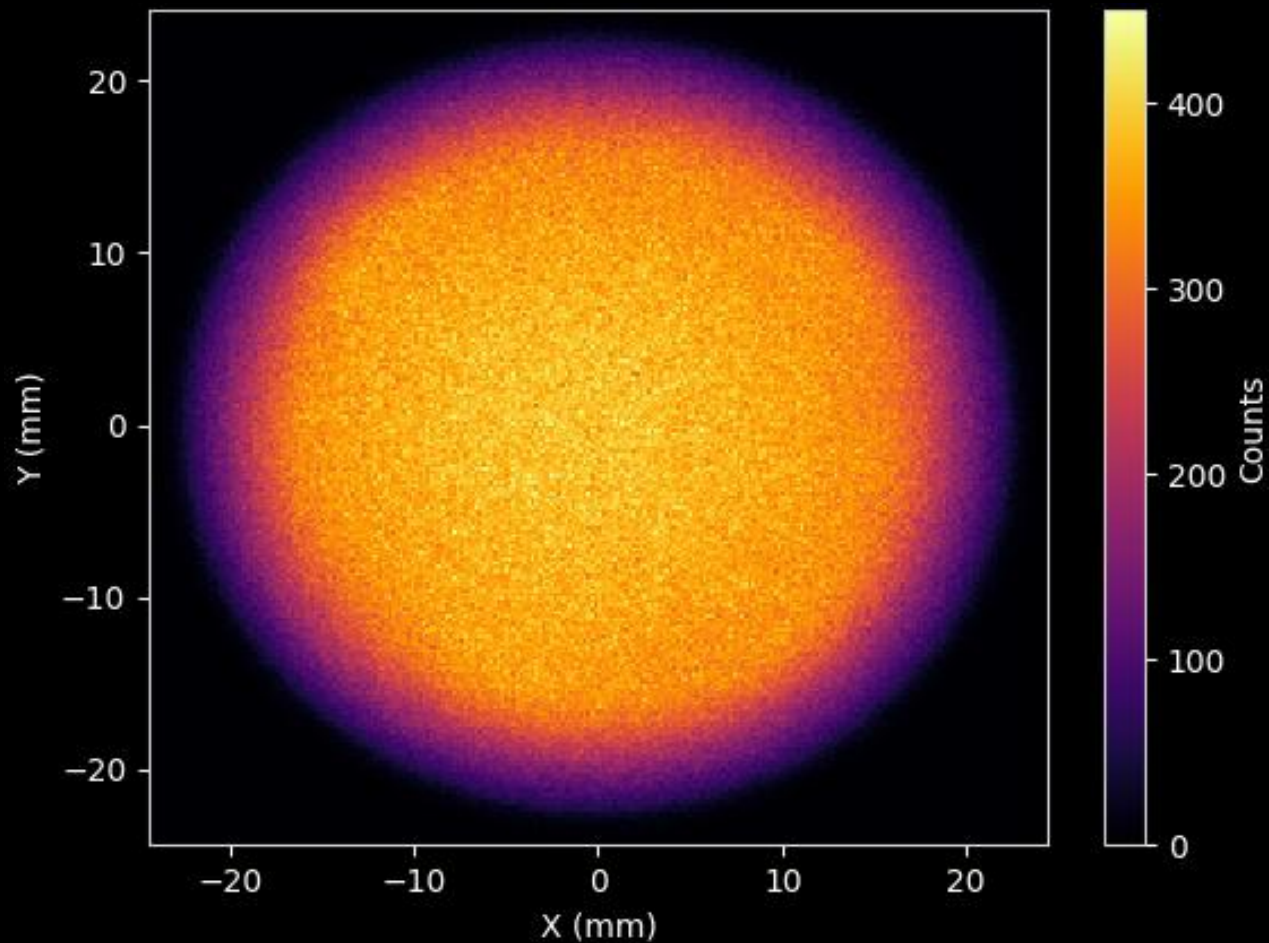
a) Number of Photons

b) Position of Photons on the detector

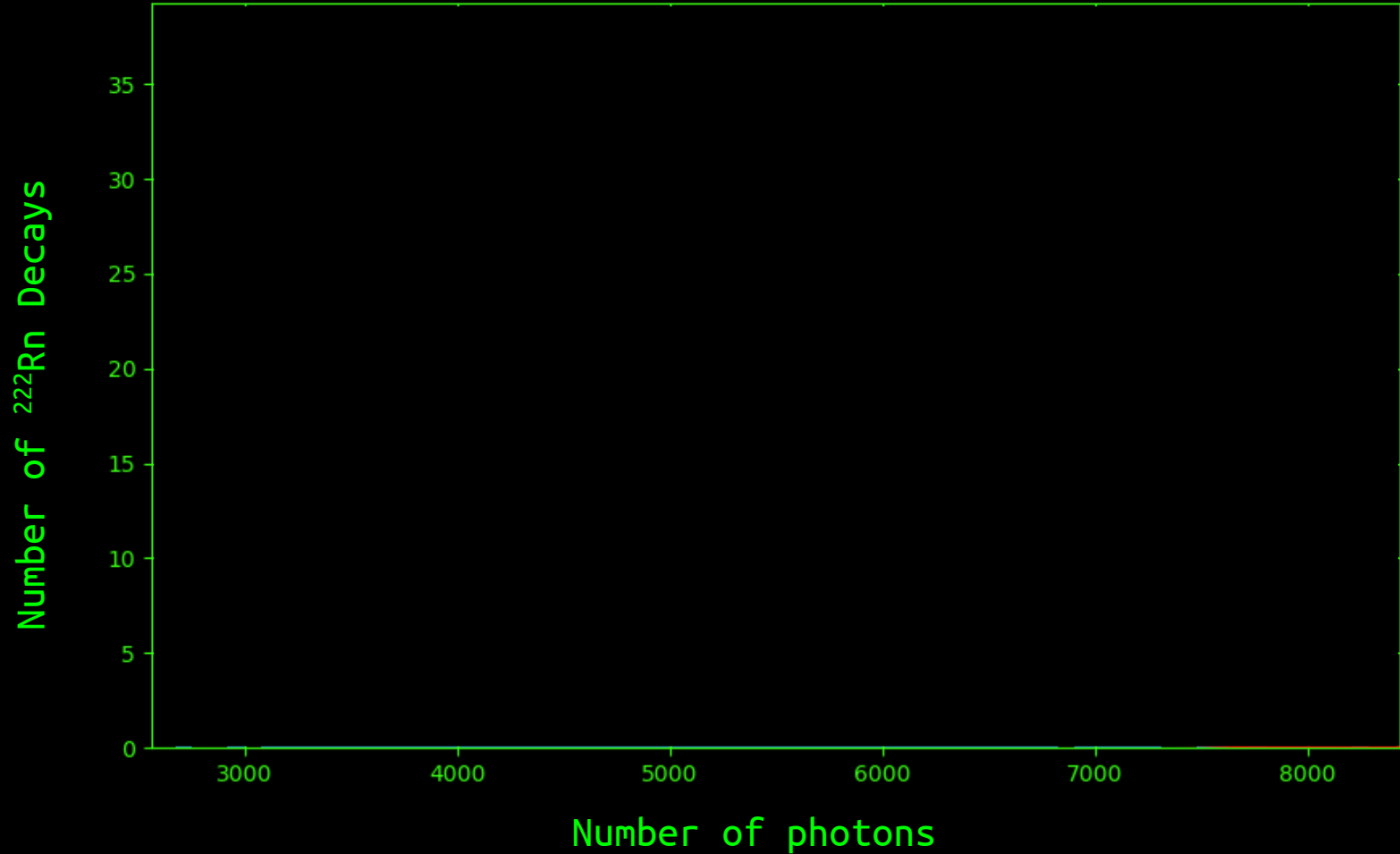
# Scintillation photon positional frequency at the surface of the PMT



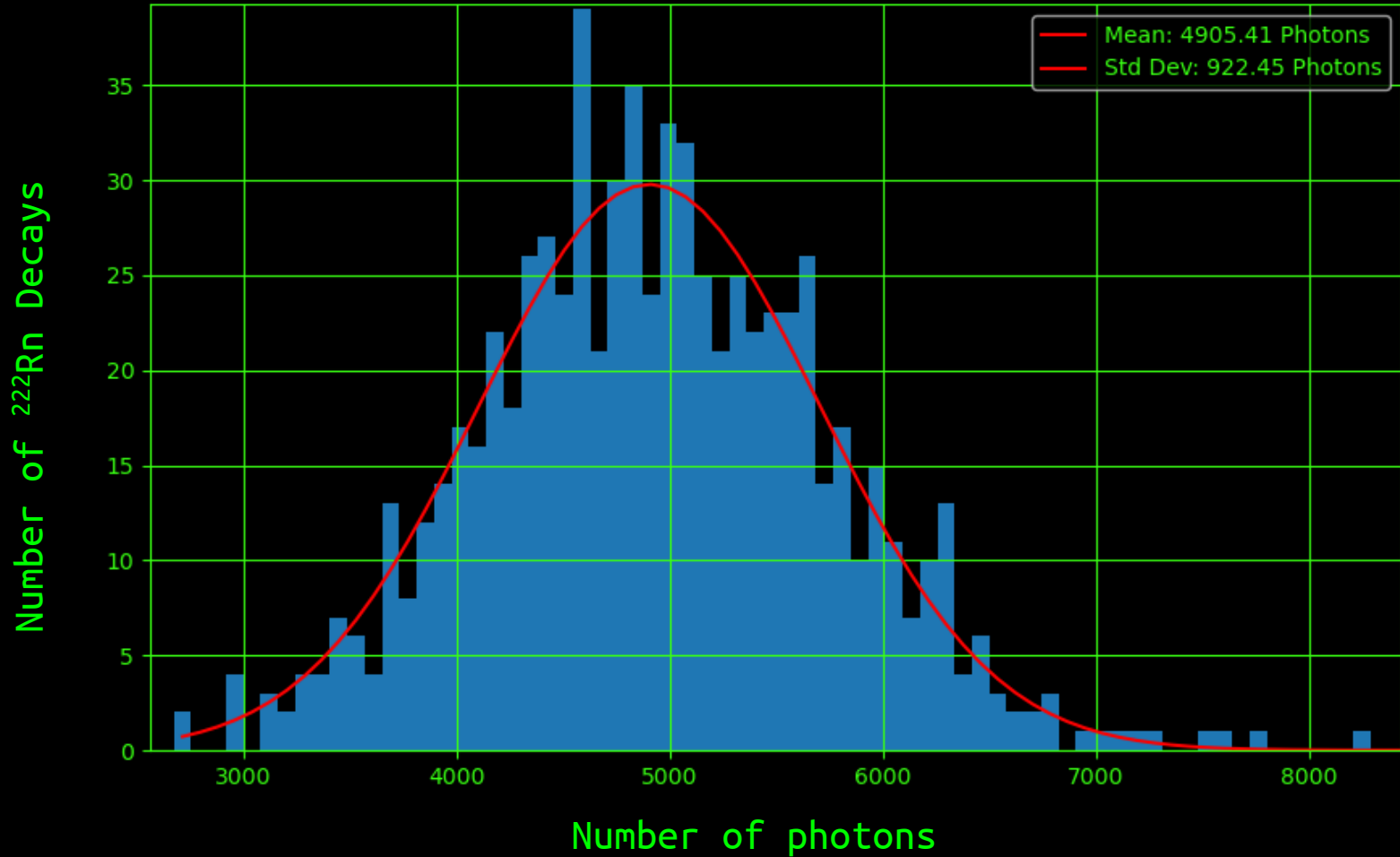
# Scintillation photon positional frequency at the surface of the PMT




# Frequency of total light yield per $^{222}\text{Rn}$ Decay



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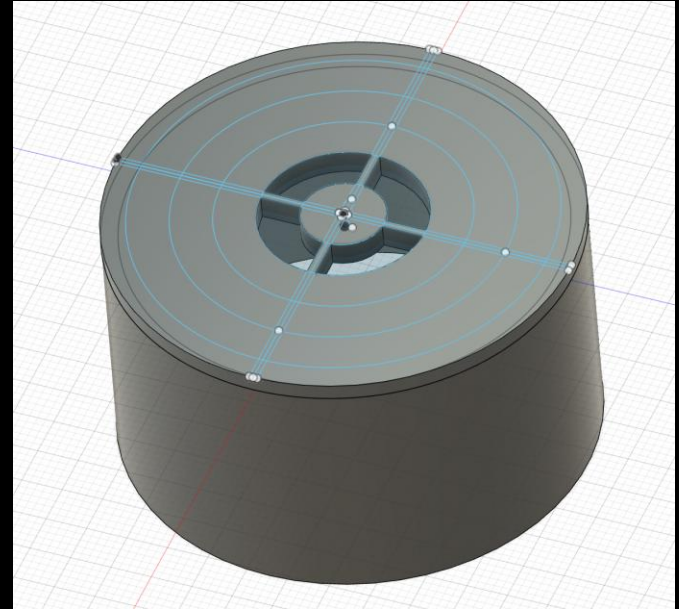




Further  
Steps

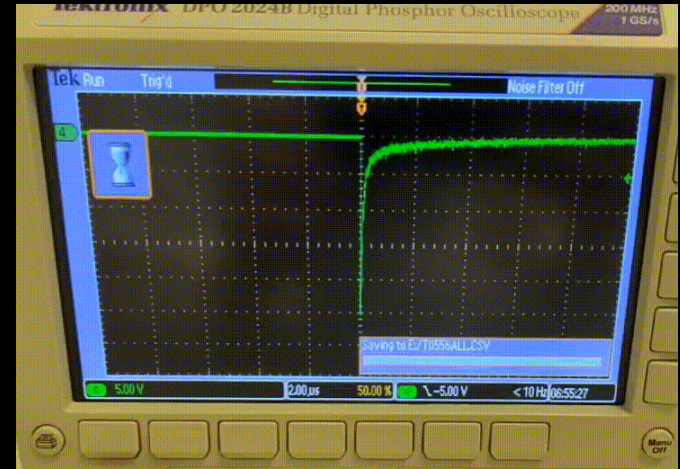
# Further Steps

- Scintillation photon positional distribution using 3D printed covers



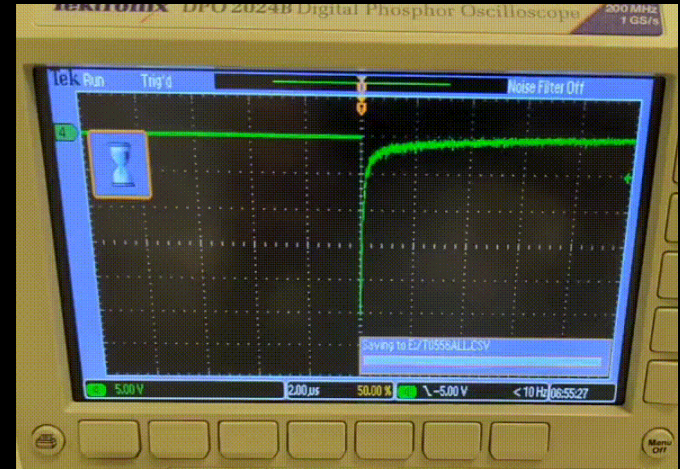
# Further Steps

- Scintillation photon positional distribution using 3D printed covers
- Scintillation yield distribution with an Oscilloscope



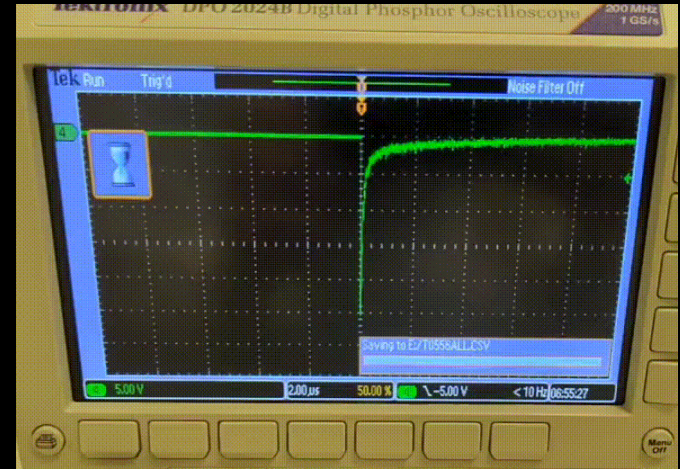
# Further Steps

- Scintillation photon positional distribution using 3D printed covers
- Scintillation yield distribution with an Oscilloscope
- Add inhomogeneity to the scintillator thickness model



# Further Steps

- Scintillation photon positional distribution using 3D printed covers
- Scintillation yield distribution with an Oscilloscope
- Add inhomogeneity to the scintillator thickness model
- Design a testing application to simulate new geometries



Thank you!

Nasim Fatemighomi

Christine Kraus

Keegan Paleshi

Mark Ward

Lina Anselmo

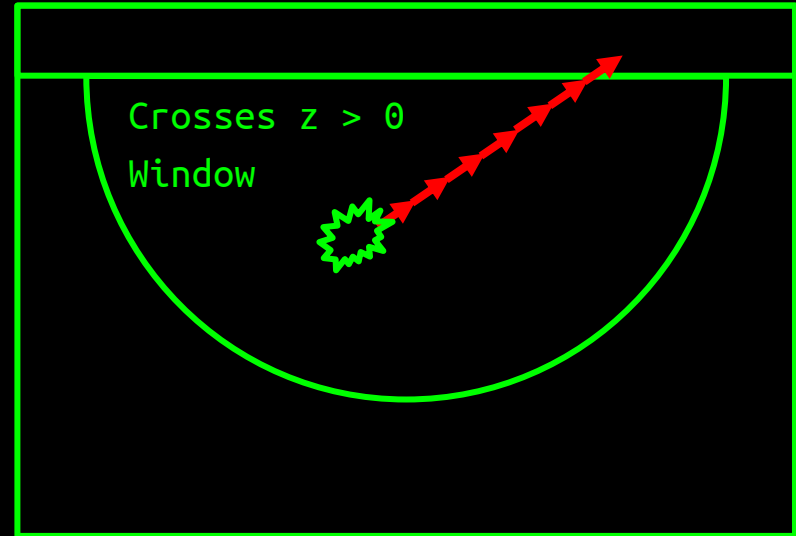
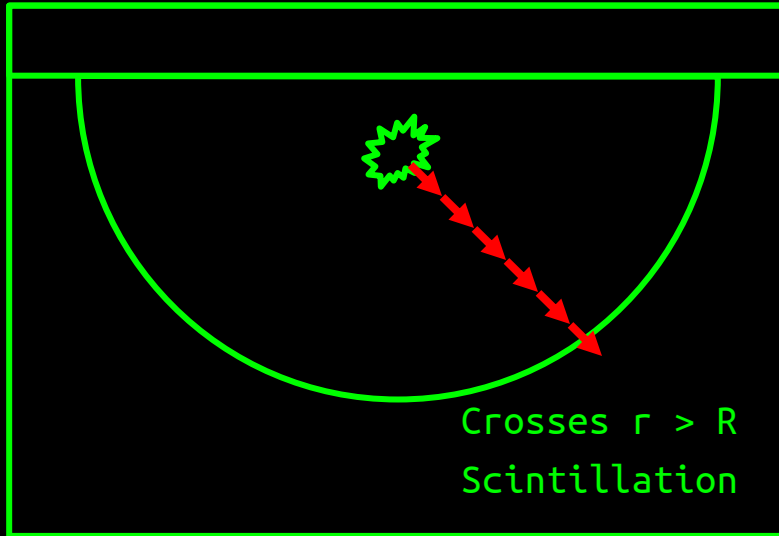
Tom Sonley

# 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  $^{222}\text{Rn}$  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] Fatemighomi, N., Ahmed, Y., Hussain, S. M. A., Lu, J., Pearson, A., & Suys, J. (2025). Measurement of low  $^{222}\text{Rn}$  concentration in  $\text{N}_2$  using an activated charcoal trap. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 1076, 170422. doi:10.1016/j.nima.2025.170422
- [3] 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](https://www-pub.iaea.org/MTCD/publications/PDF/IAEA-AQ-19_web.pdf)
- [4] Liu, M., Lee, H. W., & McDonald, A. B. (1993).  $^{222}\text{Rn}$  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](https://doi.org/10.1016/0168-9002(93)90948-h)

# Python Application Algorithm (Bonus)

1. Choose random decay position and direction
2. Slightly extend vector in the chosen direction
3. Assign scintillation to  $r > R$  and window event to  $z > 0$  if possible
4. If neither condition is met, repeat steps 2 and 3



## More about me



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Electrical Engineering Graduate

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Github

<https://github.com/Swizzle-dev>

Lucas Cell code available on request !