Unfolding the fast neutron spectra with the thermal neutron component using Polysiloxane scintillators via neutron unfolding algorithms

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2023 LANNS Symposium-2

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Current Laboratory Overview

- Completed laboratory work
  - Clown Computer has been wiped and installed in 3-68
    - Currently has VS Code and Python for all users
    - Working on Geant4
  - Cleaned out the shop, there is now space for workstations
  - All the 3D printers are refilled
  - New Blackbox completed just needs BNC and SHV hardware
- Ongoing laboratory work
  - COMET 225kV X-Ray Generator is waiting on installation quote from Marietta NDT\
    - Just received the manipulator quote
  - Varian X-Ray Generator is being retired and replaced with the 225kV Hamamatsu
  - Installation of new monitors and computer for 3-12
  - Inventory RSEL/3-12/3-19

Neutron Spectroscopy

- Neutron spectroscopy is a tooled used to determine the energy spectra of neutrons emitted from a neutron source using either a detector or multiple detectors.
- Knowing the neutron spectra for a given source is of interest for various communities including reactor design, warhead verification, and radiation dosimetry
- Current methods for neutron spectroscopy include using neutron scattering kinematics and time of flight measurements
- This work focuses on unfolding the neutron spectra using algorithms and detector response functions for organic scintillators

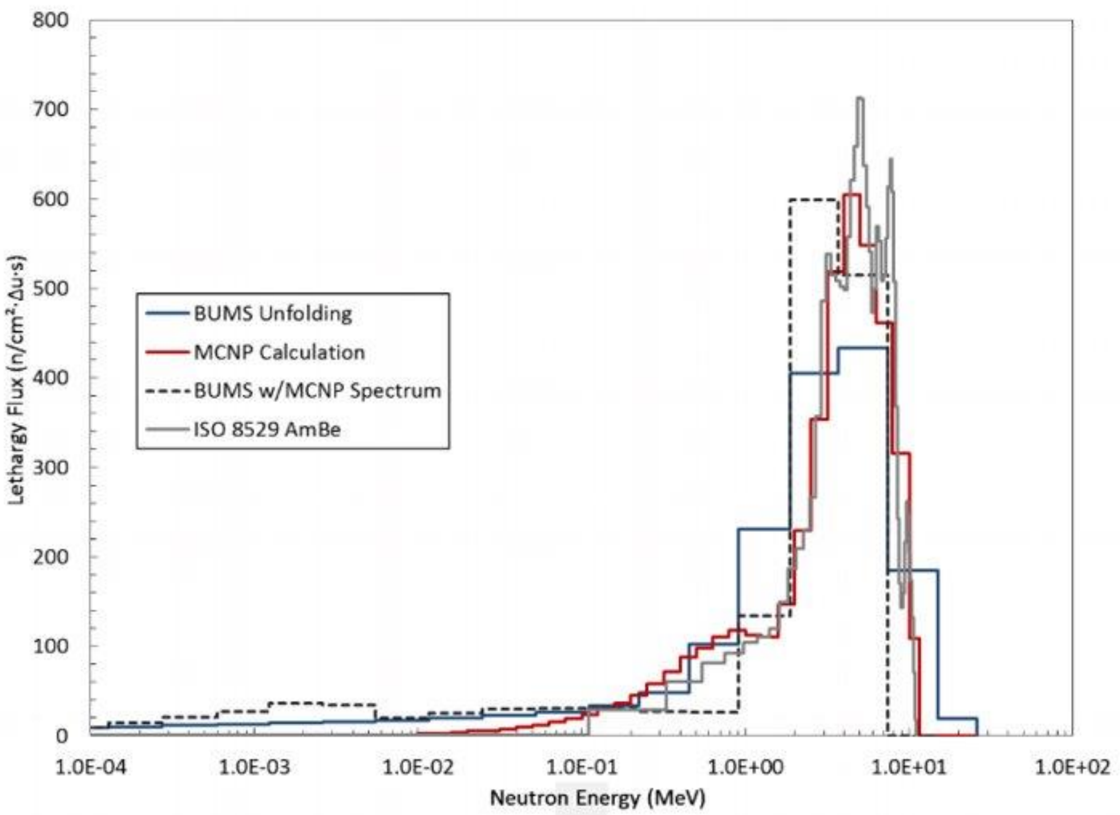
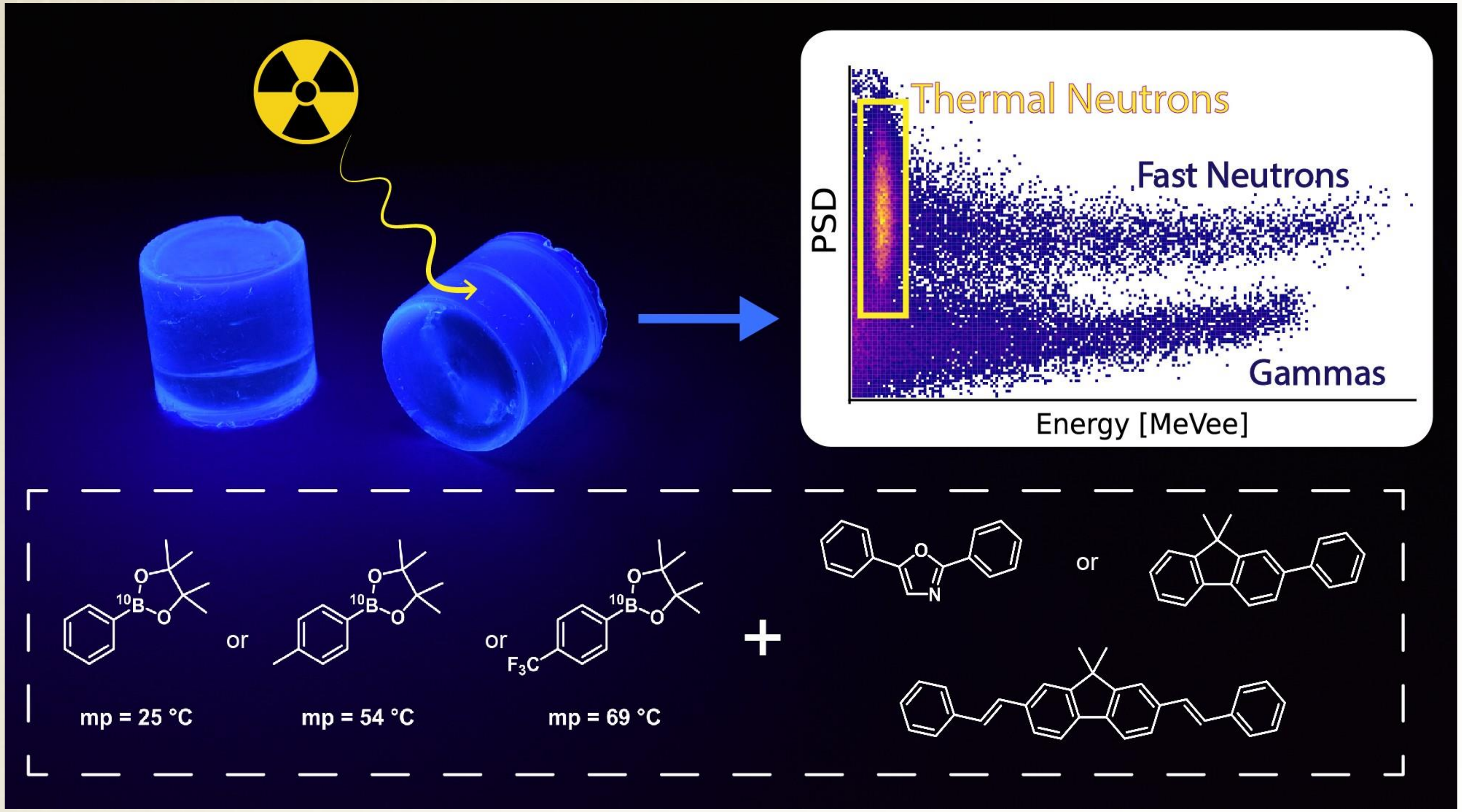


Figure 4.3.5.2. AmBe Bare Spectra

Exeline, P; CHARACTERIZATION OF MODIFIED NEUTRON FIELDS WITH AMERICIUM-BERYLLIUM AND CALIFORNIUM-252 SOURCES

Polysiloxane Plastic Scintillators

- Polysiloxane plastic scintillators are organic scintillators capable of discriminating thermal and fast neutrons and gamma-rays in a mixed radiation field.
- The scintillators are also boron doped to capture thermal neutrons and produce the thermal neutron island shown on the figure below



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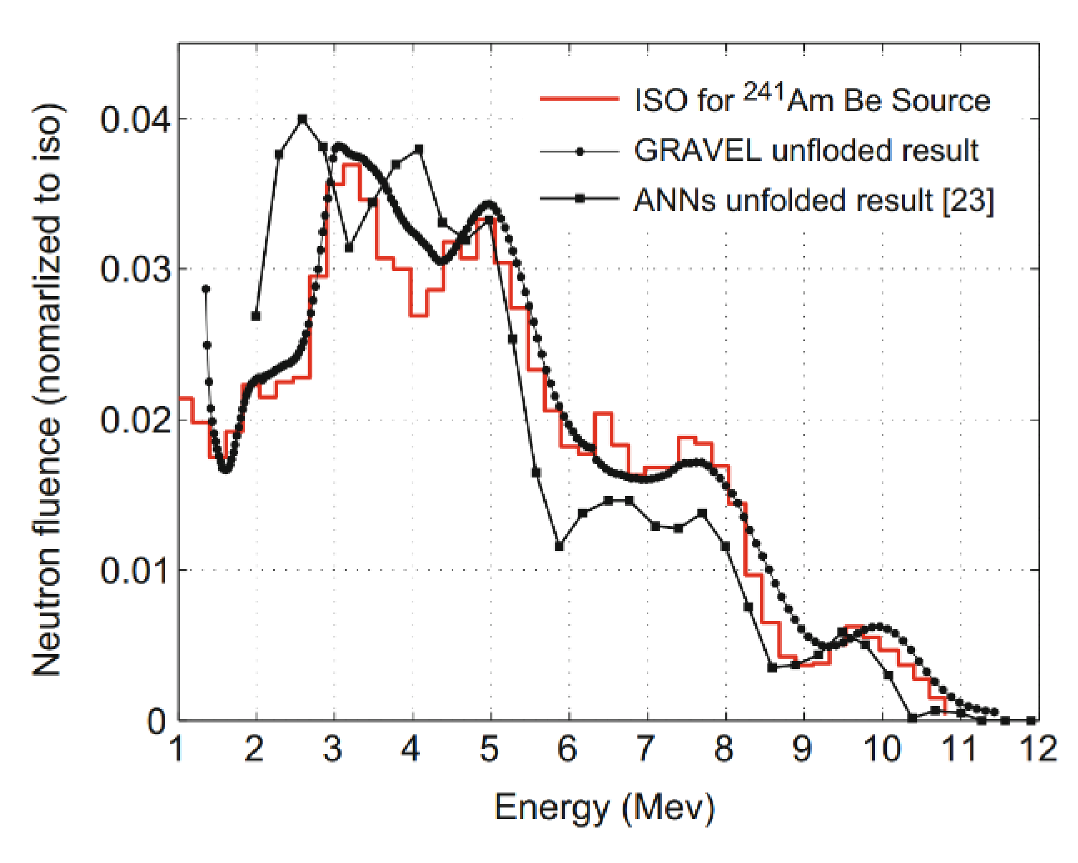
Neutron Spectrum Unfolding

- Neutron spectra unfolding methods have been developed for organic scintillators using techniques that determine the relationship between incident neutron energy and non-linear light output response called the detector response function
- Gamma-ray spectroscopy relies on the same methodology although the light yield response function is linear
- Several unfolding algorithms have been developed using this method including GRAVEL, MLEM, PRIP, and Tikhonov Iterative Regularization



Chen Y H, Chen X M, Lei J R, et al. Unfolding the fast neutron spectra of a BC501A liquid scintillation detector using GRAVEL method. Sci China-Phys Mech Astron, 2014, 57: 1885–1890, doi: 10.1007/s11433-014-5553-7

Light Yield Function

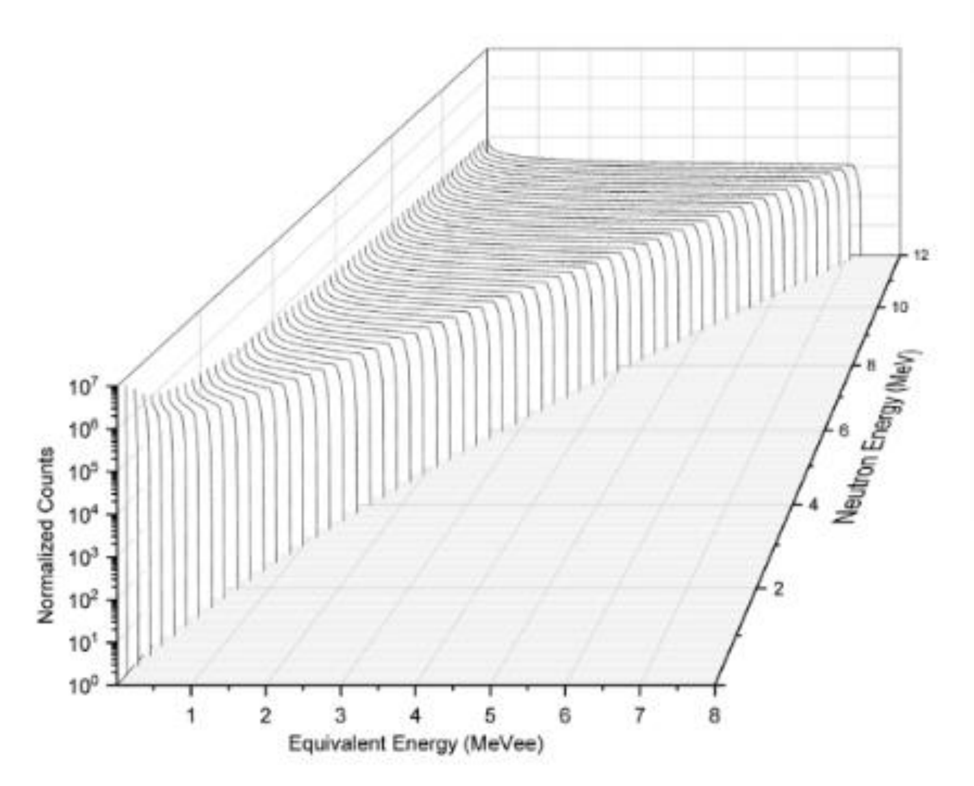
The relationship between light yield and incident neutron energy is given by the first Fredholm integral

$$N(L) = \int R(L, E_n)\phi(E_n)dE_n$$

Where the number of photons produced is based on the light output as a function of energy and the neutron energy spectra

The light output function used is non-linearly due to the energy redistribution after the neutron collision with the proton

$$L(E_p) = aE_p - b\left(1 - \exp\left(-cE_p^d\right)\right)$$



Example Neutron Response function

Quang, N. D., Kim, H., Vuong, P. Q., Ton, N. D., Nam, U.-W., Park, W.-K., Sohn, J., Choi, Y.-J., Kim, S., Youn, S., & Ye, S.-J. (2023). Measuring and unfolding fast neutron spectra using solution-grown trans-stilbene scintillation detector. *Nuclear Engineering and Technology*, *55*(3), 1021–1030. https://doi.org/https://doi.org/10.1016/j.net.2022.10.041

Unfolding Methods

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GRAVEL

- Considered the most used method
- Initial "guess" neutron spectra is needed
- Requires an extra weight function calculated each iteration

MLEM

- Computationally taxing and difficult
- Requires a divergence criteria to finish the iteration process
- Provides best results on mono-energetic sources

Tikhonov Iterative Regularization

- Enhanced accuracy and speed during lead up to convergence
- Produces results with better agreement to standardized spectra

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Polysiloxane Neutron Spectroscopy (PSiNS) Code

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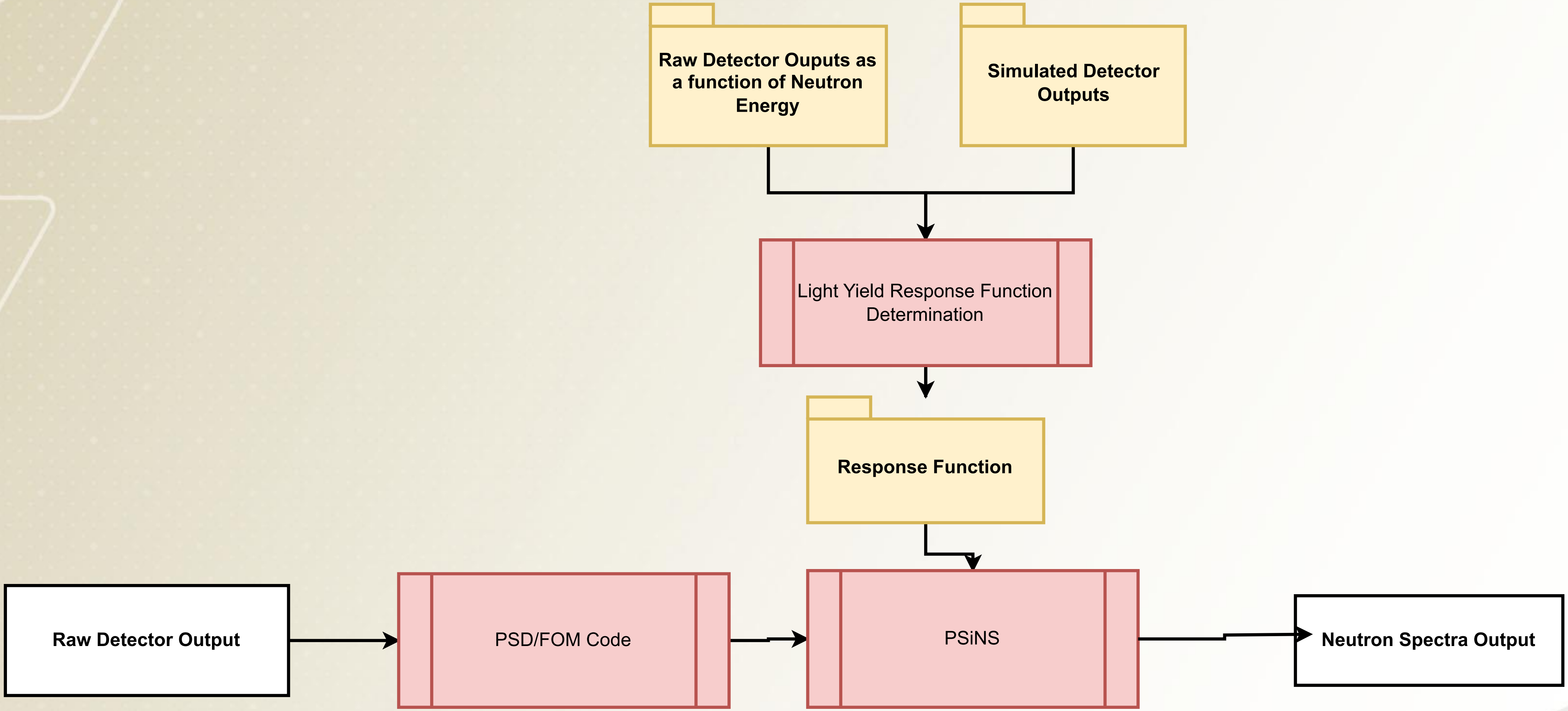

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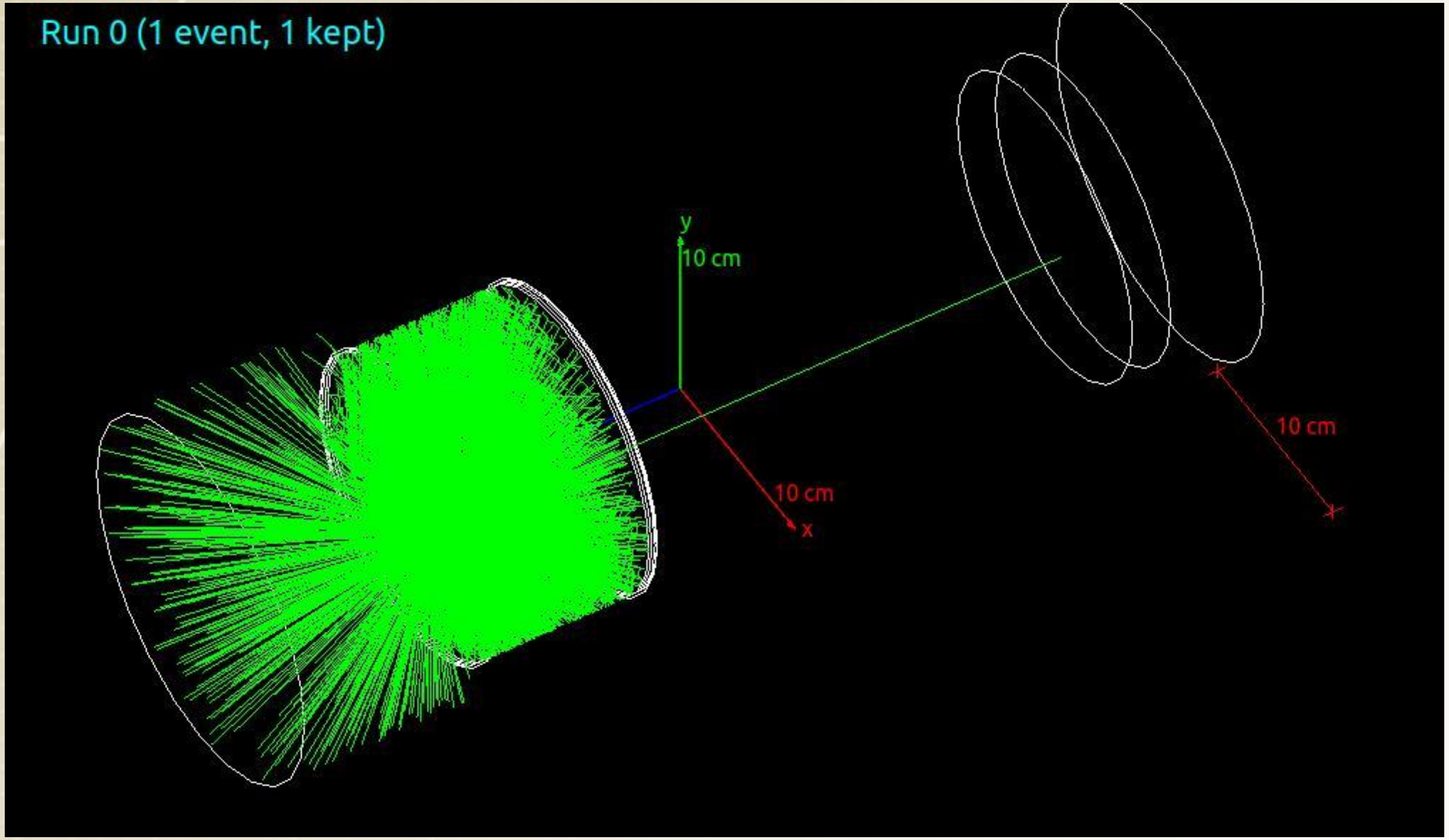
Geant4 Simulation



- The goal is to model the Polysiloxane scintillators that dumps out waveforms for each event
  - Will take user arguments for the Polysiloxane recipe
  - Have different sources that are user defined
  - Data output will be similar to real data outputs
- Current Status
  - Have a geometry model for the scintillator and the user arguments
  - Need the optical properties
  - Need tallies for saving data
  - Thermal Neutron Physics List and Fast neutron physics list
  - Energy Deposition in Scintillator

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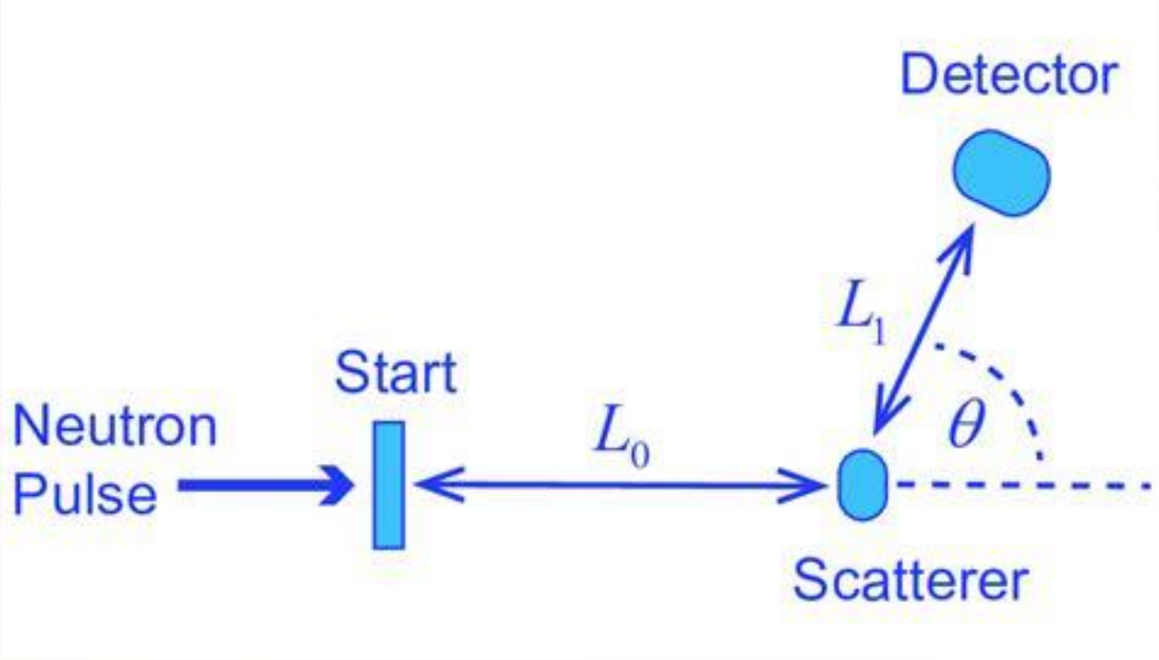
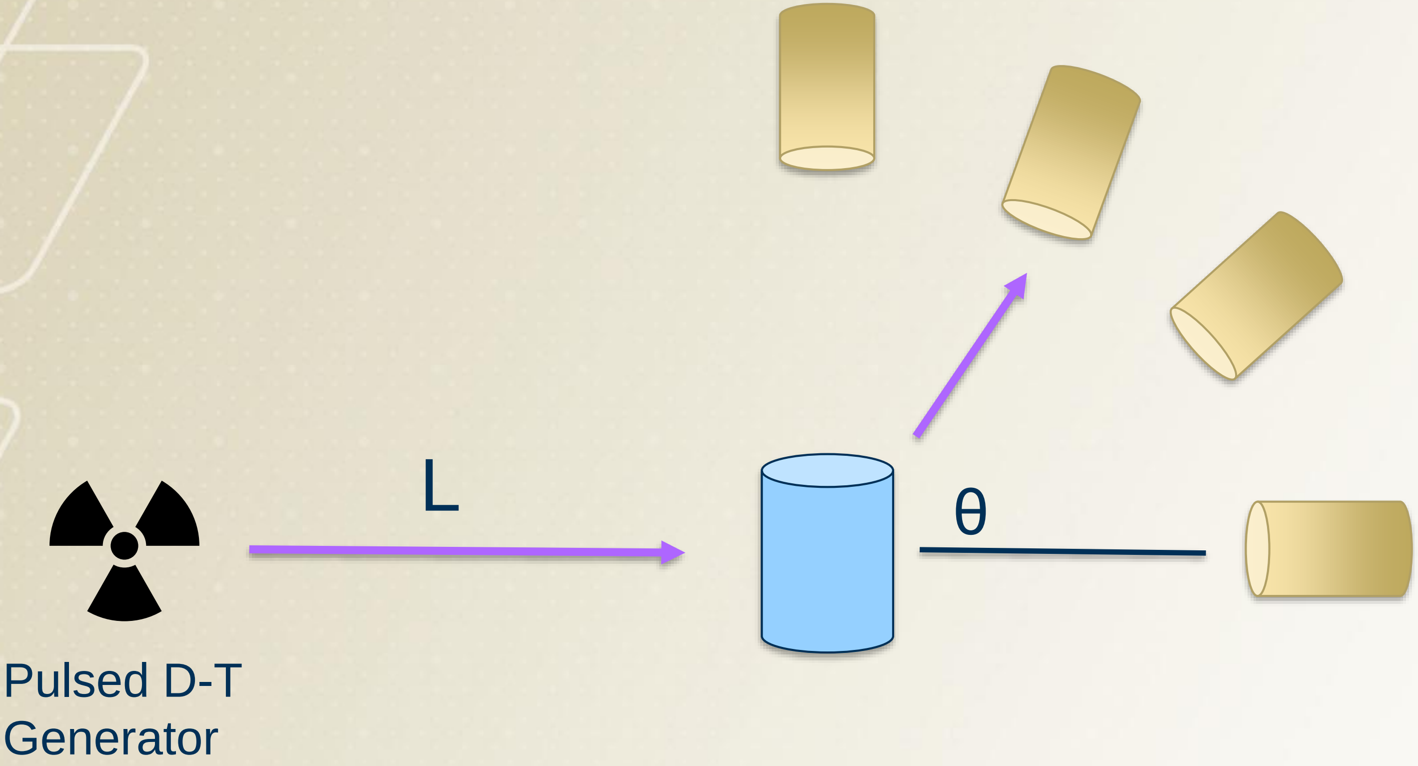
Experimental Methods

- Time of Flight measurements to determine incoming neutron energy from different source setups
  - D-D and D-T
- Proton recoil measurements for light yield as a function of incoming neutron energy
- Am-Be, Pu-Be, and Cf-252 measurements
- Thermalizing the D-T Neutron generator



Experimental Implications of Negative Quantum Conditional Entropy----H2 Mobility in Nanoporous Materials - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/Figure-A1-Scheme-of-a-time-of-flight-neutron-scattering-setup-Taken-from-26-with_fig5_346081439 [accessed 25 Oct, 2023]

Light Yield Response Function



1. Determine the incident neutron energy (E_n) using time of flight
2. Neutron strikes proton creating recoil proton and scattered neutron
3. EJ309 detects scattered neutron
4. Back calculate recoil proton energy as a function of scattered neutron energy and incident neutron energy

$$E_n=(72.3L/TOF)^2 \qquad E_p=E_n\sin^2\theta$$

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