SAND2015-4653C

Characterization of an Optically Segmented Single Volume Neutron Scatter Camera

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Introduction

- Neutron scatter cameras allow for reconstruction of incident neutron direction using neutron kinematics
- Low detection efficiency of the neutron scatter camera (NSC) motivated the creation of the single volume scatter camera (SVSC)
- To reconstruct incident neutron direction, the neutron must scatter twice in the scintillator volume
- Advances in pixelated photodetector and microchannel plate (MCP) technology allow for accurate position and timing reconstruction

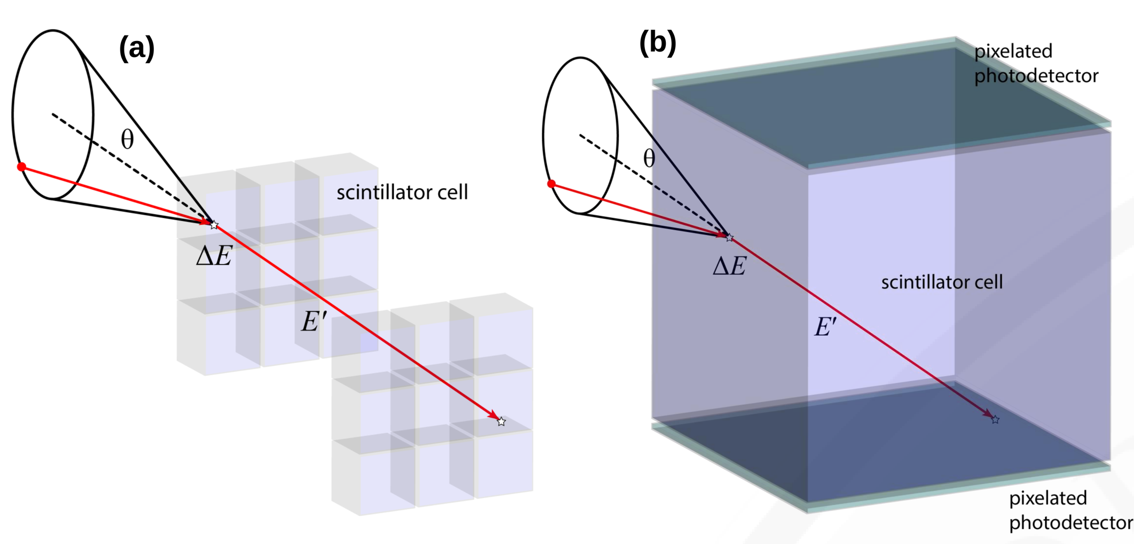

Figure 1(a): Neutron scatter camera design consisting of two separate planes of detectors
Figure 1(b): SVSC design with photodetectors on two opposing faces

- To substantially improve on the NSC efficiency using the SVSC, the minimum distinguishable separation distance for two events would be approximately 2 cm

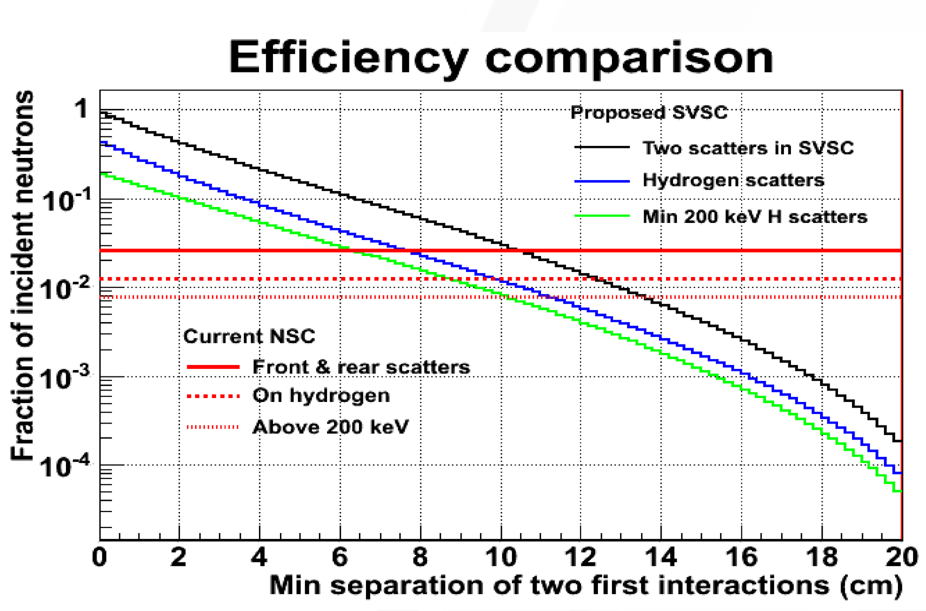

Figure 2: MCNP simulation of a pencil beam of fission spectrum neutrons fired at center of 20 cm cube SVSC and at center detector of NSC.

Optically Segmented SVSC

- One challenge of the SVSC is the electronics needed to digitize all MCP pixels
- An optically segmented single volume neutron scatter camera reduces the number of channels digitized to the 4 optical channels that emit scintillation light
- Each channel consists of a plastic scintillator surrounded by a small air gap to allow total internal reflection of optical photons
- If an optical photon escapes the scintillator, it is reflected back by an enhanced specular reflector lining the channel walls
- The overall volume of the optically segmented SVSC is currently estimated to be between 2000 cm^3 and 8000 cm^3

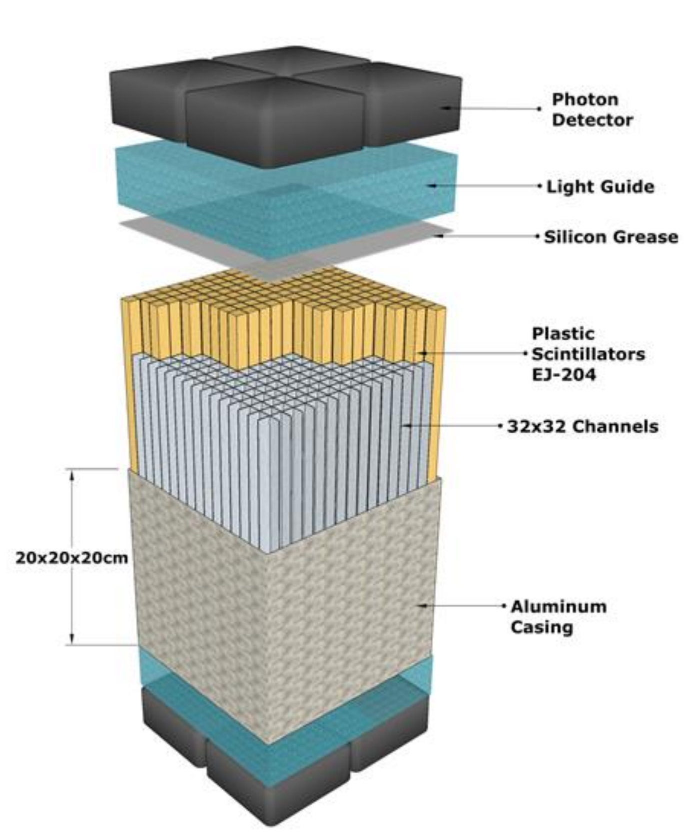

Figure 3: Optically Segmented Neutron Scatter Camera Design

Geant4 Optical Light Simulations

- Geant4 is a simulation tool that provides the transportation of optical photons where custom reflectors can be specified by the user
- Optical photons can…
  - Total internal reflect
  - Fresnel reflect
  - Fresnel refract
  - Specular reflect (off of enhanced specular reflector)
  - Bulk absorption in scintillator
  - Absorb in channel wall

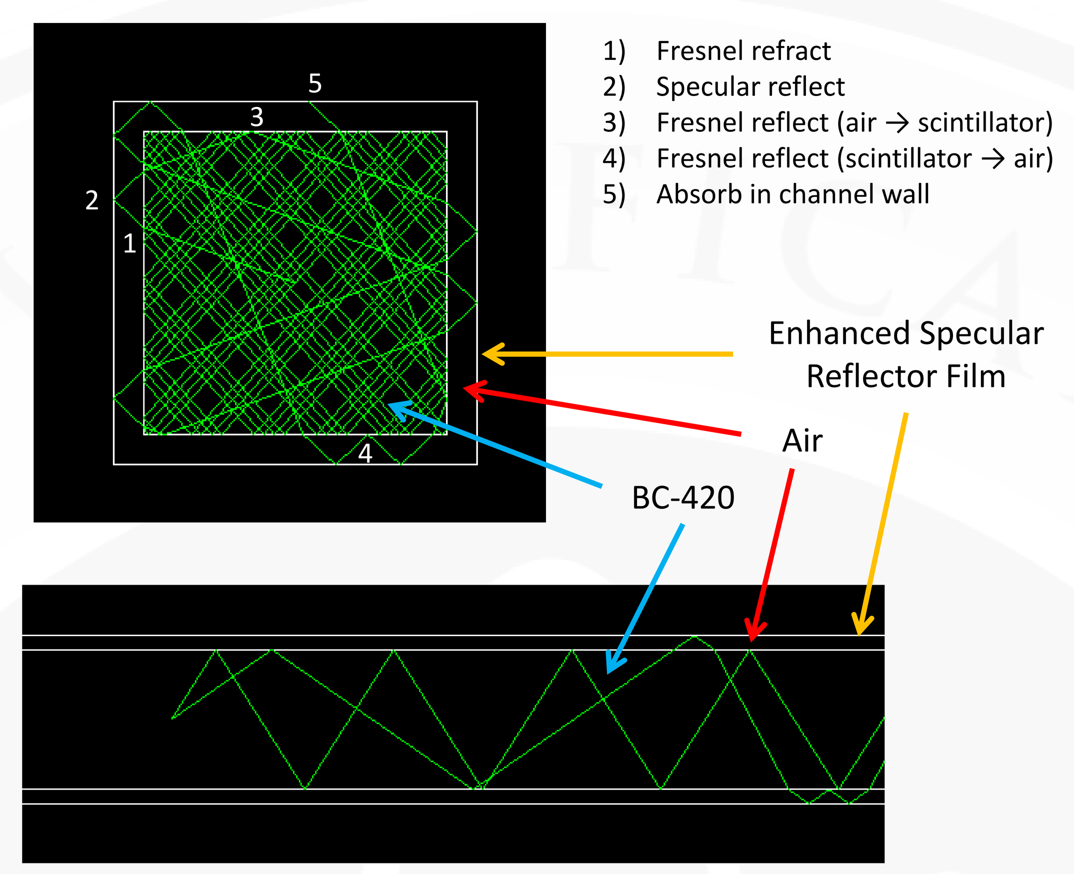

Figure 4: Geant4 optical photon visualization through plastic scintillator channel and air gap

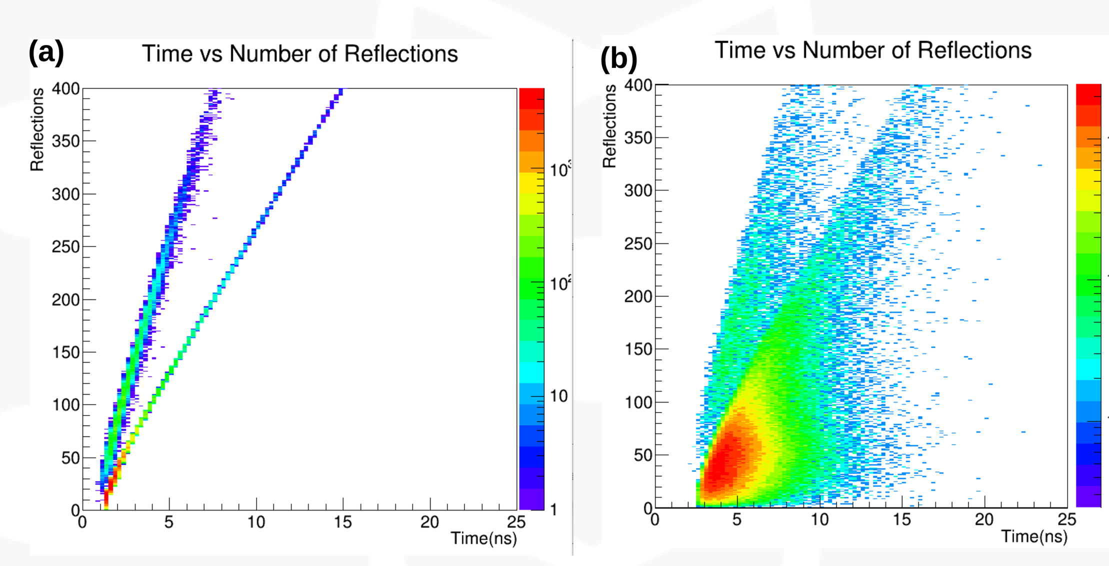

Figure 4(a): Delta pulse of optical photons simulated at center of 50 cm bar. Plot of time of arrival time and number of reflections upon hitting PMT
Figure 4(b): BC-420 pulse of optical photons simulated at center of 50 cm bar. Plot of time of arrival time and number of reflections upon hitting PMT

- Two distinct lines form in Figure 4(a)
  - Left: Fresnel reflection into air gap
  - Right: Total internal reflection within scintillator

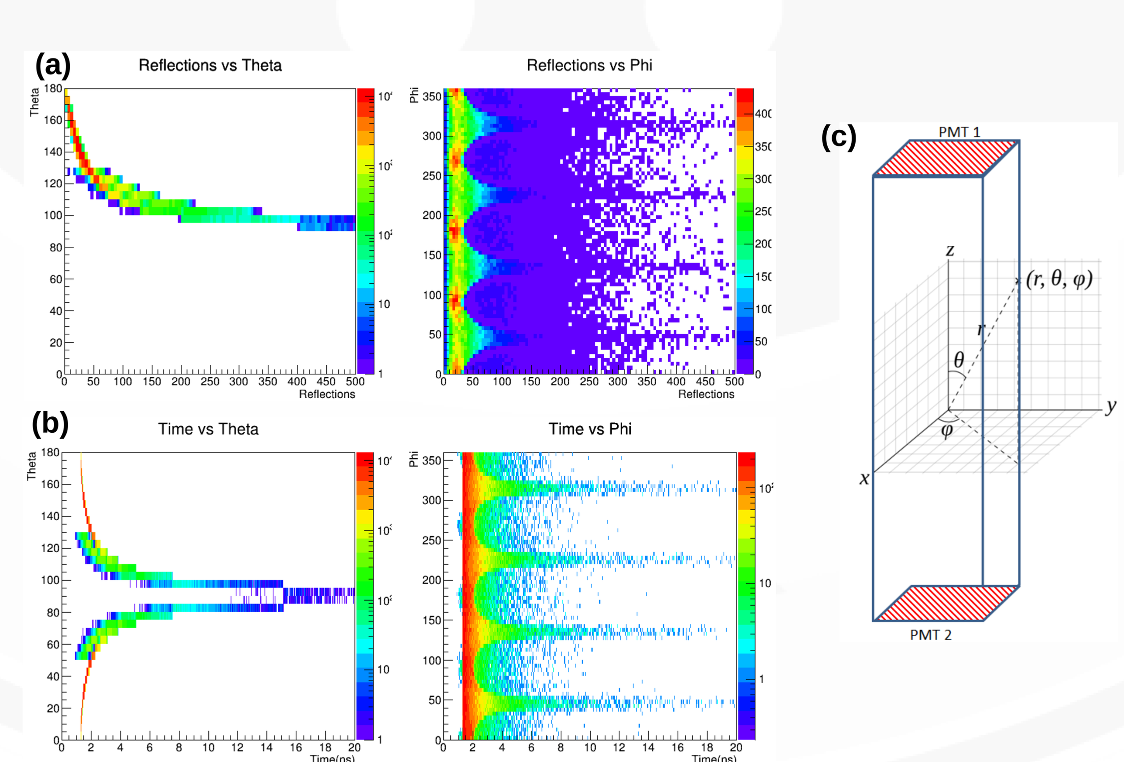

Figure 5(a): Delta pulse of optical photons simulated at center of 50 cm bar. Plot of number of reflections upon hitting PMT vs. the direction θ and ϕ the optical photon was emitted
Figure 5(b): Delta pulse of optical photons simulated at center of 50 cm bar. Plot of time hitting PMT vs. the direction θ and ϕ the optical photon was emitted
Figure 5(c): Geometry of scintillator channel

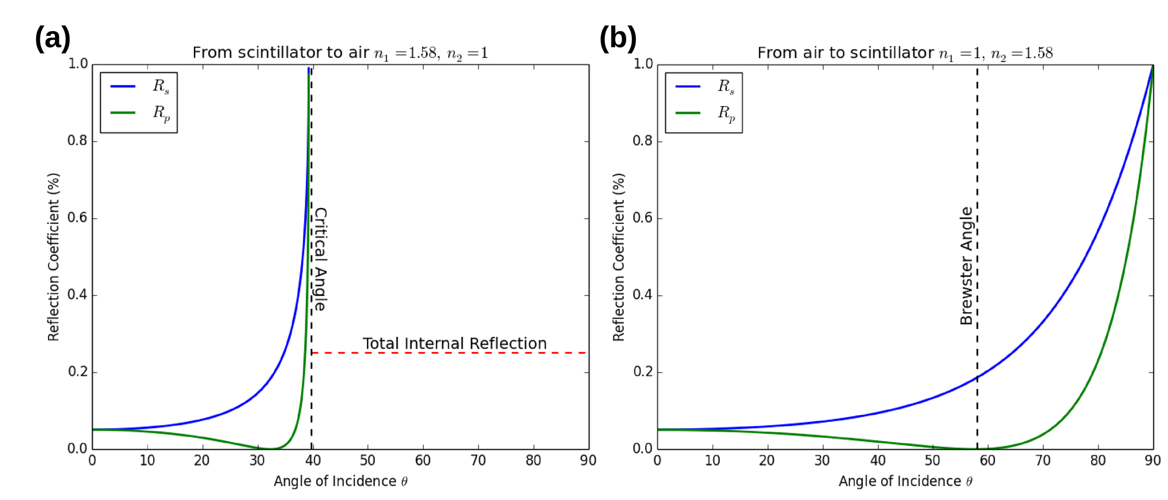

Figure 6(a): Fresnel reflection probability when optical photon travels from scintillator to air.
Figure 6(b): Fresnel reflection probability when optical photon travels from air to scintillator.

- Any photon with incident angle greater than the critical angle, with respect to the surface normal, will undergo total internal reflection down the channel to the PMT
- Any photon with incident angle less than the critical angle has a probability to Fresnel reflect depended upon the polarity of the photon

Optical Photon Reflector Study

- Low light collection efficiency makes it difficult to reconstruct axial scatter position within the scintillator channel
- Three different common light reflector types were studied

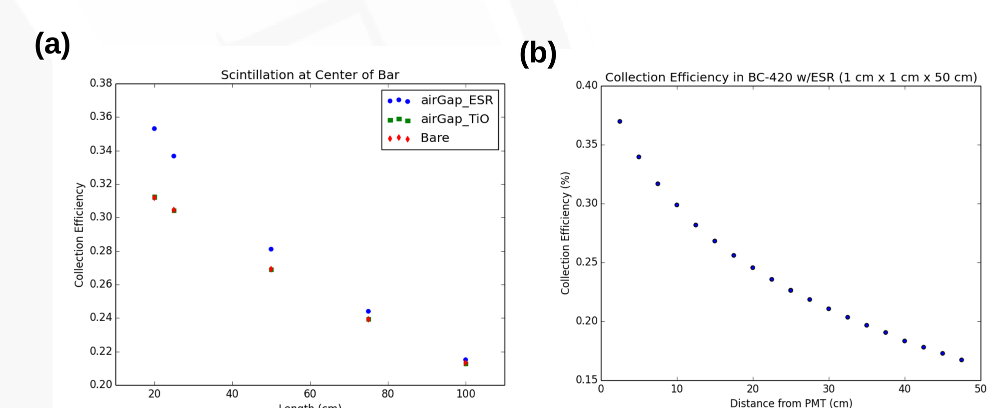

Figure 7(a): Light collection efficiency for various lengths of channel and reflectors for 10^7 emitted neutrons. Scintillation occurred at center of channel.
Figure 7(b): Collection efficiency for an enhanced specular reflector with a 1 cm x 1 cm x 50 cm BC-420 scintillator

Same Cell 2nd Interaction Study

- Neutron double scatter events that occur within the same channel do not allow for axial position reconstruction
- An MCNP-PoliMi study allowed us to determine what percentage of interactions took place in the same cell as the first

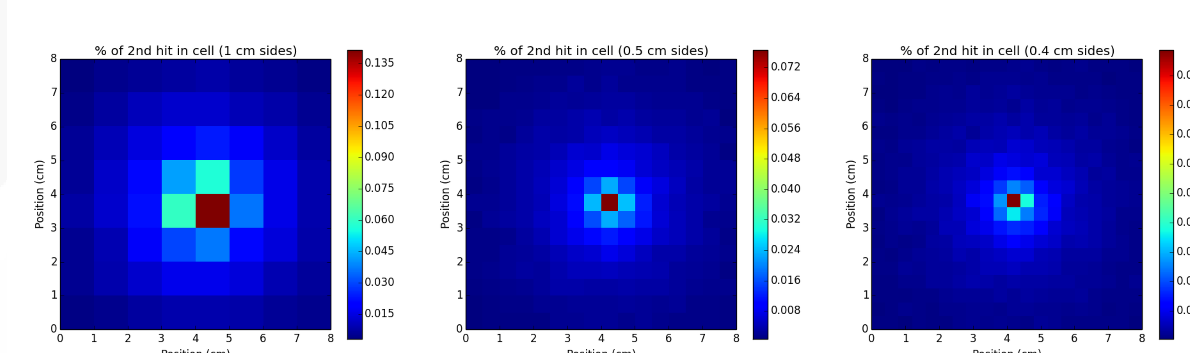

Figure 8: Percentage of second scatter in same cell. Data obtained using a pencil beam of Cf-252 neutrons directed at the center of the scatter camera. The center (red) channel is where the first interaction occurred.

Future Work

- Determine optimal channel dimensions for best estimate of the axial scintillation position
- Characterize effect of axial scintillation position error on pointing vector of incident neutron direction
- Validate simulations with experimental results
- Determine optimal dimensions of camera to obtain the maximum number of double scatter events from neutrons in fission energy spectrum

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