Simulation of concept for compact single volume neutron scatter camera with simplified readout

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Introduction, Motivation, and Mission Relevance

- **Fast neutron scatter cameras can be used to localize fast neutron sources for safeguards or verification purposes.**
  They work by determining the interaction location of correlated neutrons and constructing a trajectory of the incident neutron

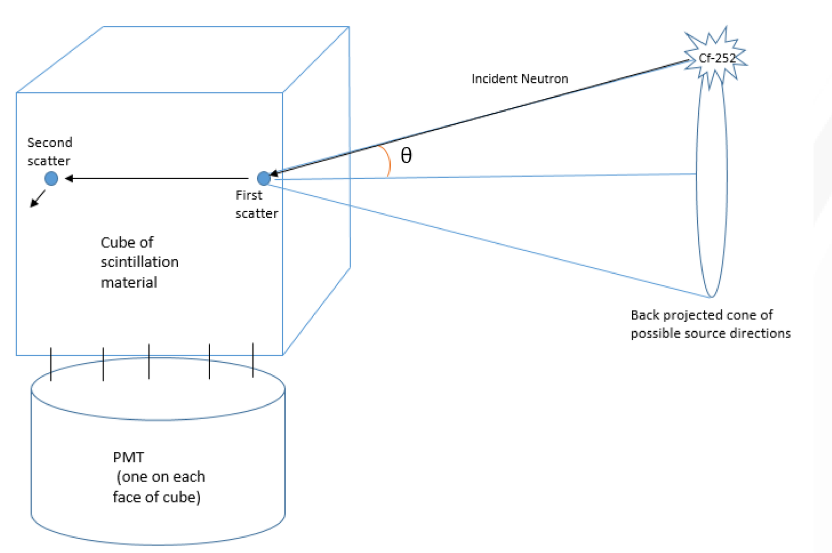


Figure 1. Compact neutron scatter camera operational principle [1]

- **Compact, single detector-volume design reduces the size and weight of detection system by several orders of magnitude**
  Both neutron scatters take place inside same detection volume, requiring fast scintillation material and electronics for resolution of separate scatters
- **Simplified design presented here eschews optical segmentation and arrays of multi-channel plates used in other designs**
  Neutron interaction positions reconstructed by analyzing ratios of light incident on entire surface of opposing PMT-MCPs
  Smaller size and less complex electronics allows for more widespread deployment options in verification and safeguards

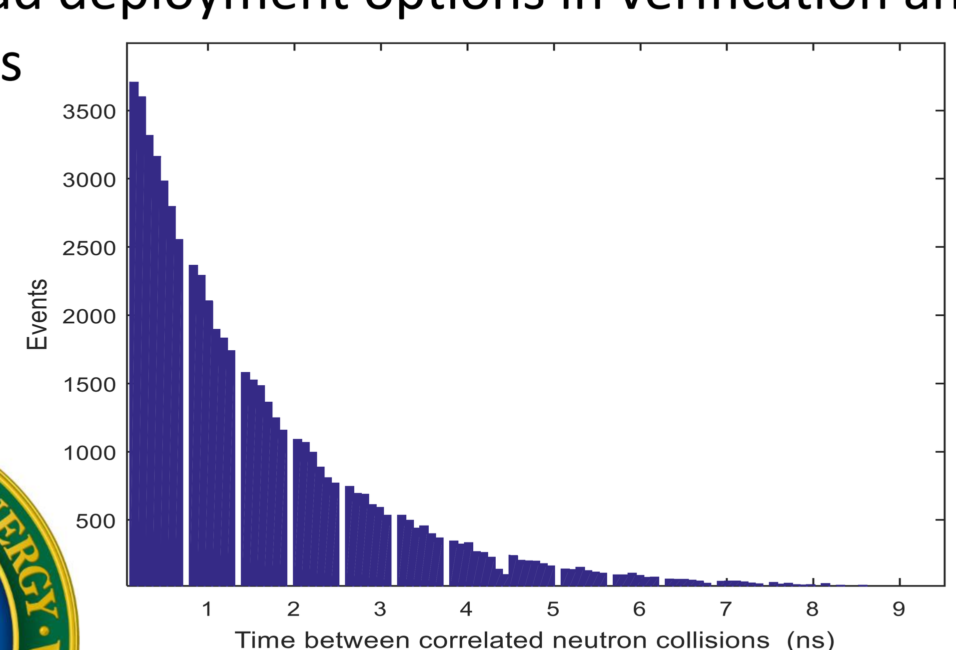


Figure 2. Data from MCNPX-Polimi Histogram showing that a sizable proportion of correlated neutron scatters can be resolved in time with sufficiently fast scintillator material and electronics

Technical Work and Results

- **MCNPX-Polimi simulations of 3-6 inch cube of EJ-232Q fast plastic scintillator material**
  Sizes chosen as intermediate between compactness and efficiency

Side Length (cm)	x-error (mm)	x %	y-error (mm)	y %	z-error (mm)	z %	total error (mm)	percent total
7.6	1.65	2.2	1.67	2.2	1.96	2.6	3.97	4.7
10.2	2.14	2.1	2.15	2.1	2.53	2.5	5.09	4.6
12.7	2.63	2.1	2.6	2.1	3.22	2.5	6.28	4.6
15.2	3.16	2.1	3.08	2	3.95	2.6	7.51	4.6

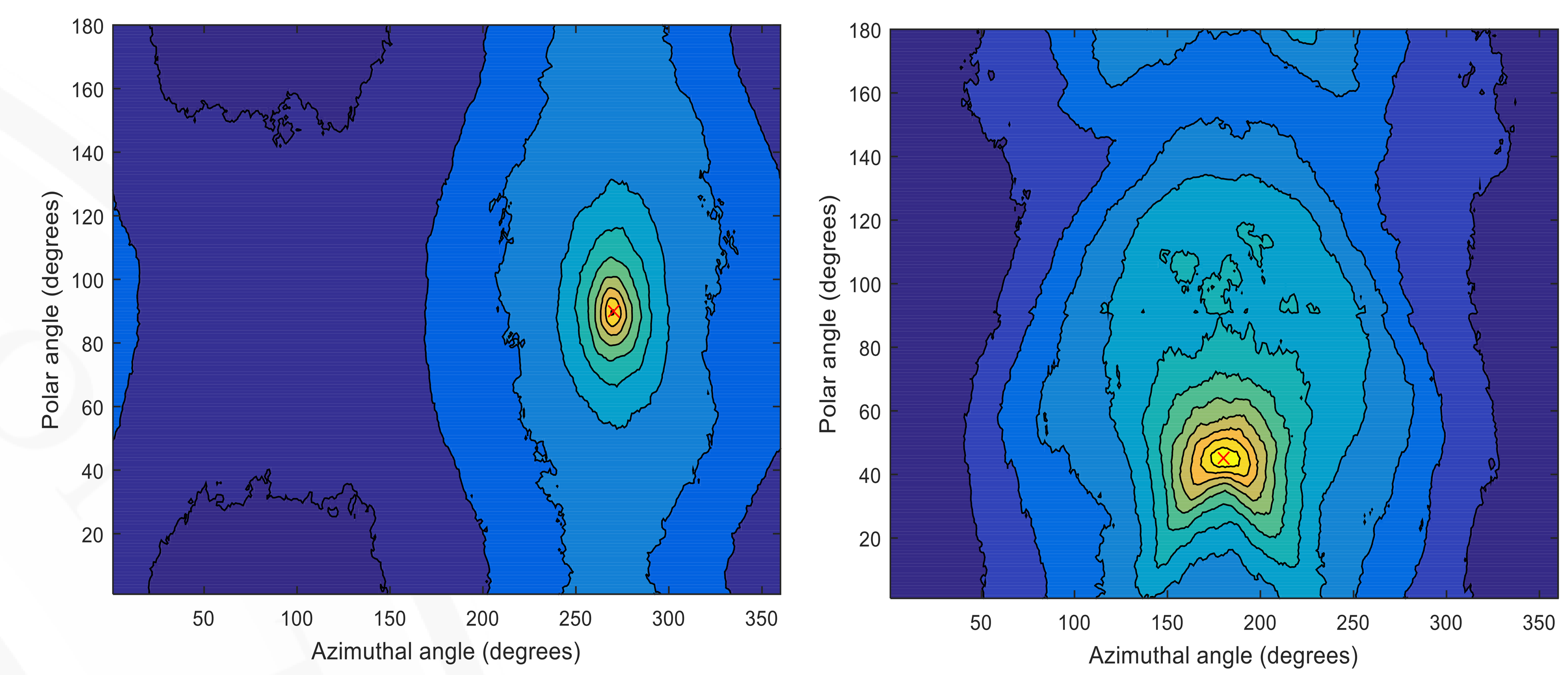
- **Position of each interaction "reconstructed" by comparing ratio of light reaching PMTs on opposite ends of detector volume**
  Reconstructed positions compared to actual interaction positions used to find if resolution of separate interaction in space is tenable
- **Cutoffs in energy deposition and distance between scatters applied to simulation data improves localization accuracy and reduces uncertainty**
  The same could be done in real detection environment with pulse height and shape discrimination

Statistical proton recoil error at various energy cutoffs		
Energy cutoff (MeV)	Energy Error (keV)	Percent Error
0.5	64.9	5.5
1	71.9	4.1
2	81.7	2.9
3	87	2.2

- **A "cone of uncertainty", theta, can be constructed from the kinematics of the neutron's energy deposition at two points**
  The overlap of a set of back projected cones is used to localize the source in the azimuthal and polar directions

$$\theta_N = \sin^{-1}\sqrt{E_{D1,N}/E_{I,N}}.$$

- **Back propagated cones are impinged upon sphere surrounding detector, and most likely direction of source can be found by making contour map of cone overlap**



Figures 3 . Contour map of back propagated cone overlap, indicating likely direction of original source neutrons. The red x's are the simulation-space location of the source

Conclusion and CVT Impact

- **The neutron impinging on the face, edge, or corner of the detector effects the shape and accuracy of the source-localization contour map**
  This detector design can only localize the direction of the source, but not the distance to it
- Simplified scatter camera concept using a single detector volume and PMTs for charge conversion is possible
- Detector design provides RMS error of **1.04 cm** for reconstruction of neutron scatter position and RMS error of **71.9 keV** for reconstruction of energy deposition with 1 MeV cutoff
- Simulation of detector concept able locate source direction at several distances and counting rates using only PMT light collection ratios to pinpoint interaction locations
- CVT Undergraduate Fellow, early research experience helped with transition into graduate school
- Lab internship at LANL, also working on neutron detection

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