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Time-Encoded Neutron Imaging for a Rotational Detector System

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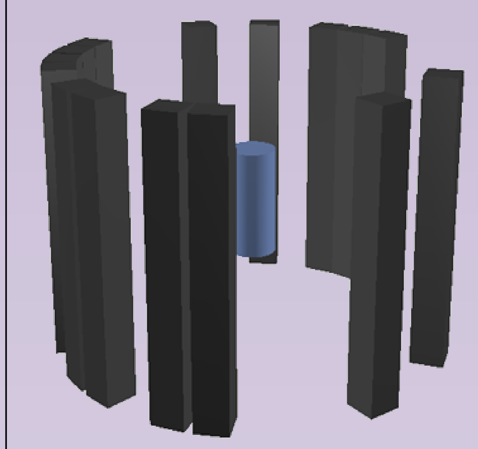
Abstract

There is an urgent need for systems that can detect special nuclear material (SNM) at large distances and/or obscured by shielding. Detecting fast neutrons from SNM offers the greatest advantage due to their great penetrating power and low occurrence in natural background. We have investigated a new fast-neutron imaging system that incorporates Time Encoded Imaging and the Neutron Scatter Camera for dual-mode imaging to achieve high detection efficiency.

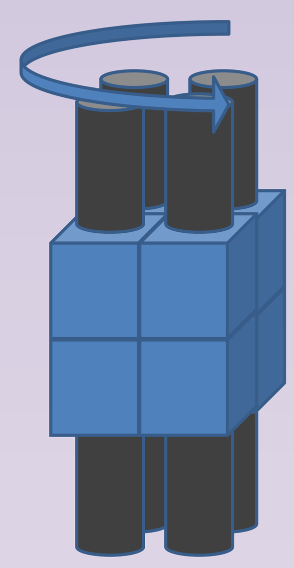
Time Encoded Imaging



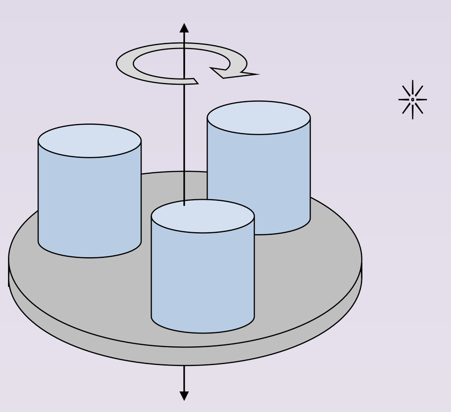
In Time Encoded Imaging systems, the detector configuration moves, creating a time sensitive signal. These systems offer high precision in constructing neutron images. The rotating mask system, shown left, is a proven example of time encoded imaging. Using a mask array of opaque and transparent elements set between the field of view and the detector, it can reconstruct the location of a neutron source.

A disadvantage to the rotating mask is the fundamental concept that the mask must block source particles from reaching the detector, thereby lowering the source signal. This decreases the efficiency of the system and increases the count time to adequately locate the source.

We have chosen a different approach that offers increased efficiency is a fully active, self-masking detector system (shown right). The signal to each detector is sensitive to the time pattern of each detector being shielded by the others. Since all of the detectors are active volumes, any source particle that reaches the system will contribute, allowing for maximum detection efficiency for a given active volume.

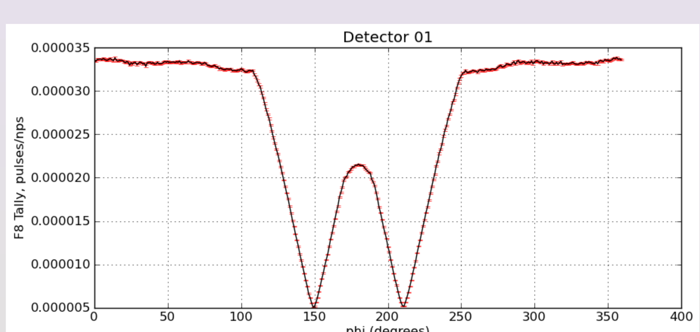


PRISM Detector Setup



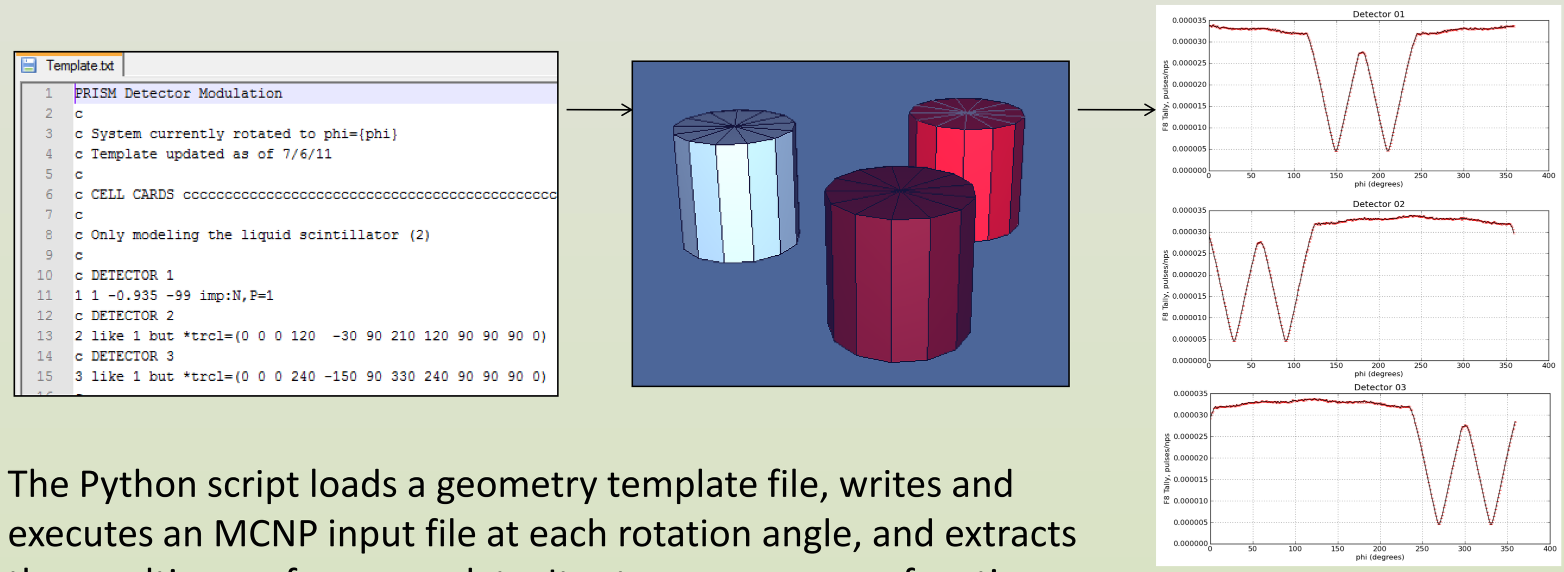
We have focused on the fully active, self-masking detector system, known as PRISM (Portable Rotating Imager using Self Modulation). This system uses liquid organic scintillator cells that rotate around a central axis. The basic mode of operation counts the rate of neutron collisions in each detector as a function of rotation angle, displayed in a detector response function, shown below.

This setup offers a simplistic self-shielding setup that allows us to study the basic principles and best detector configurations. By adjusting the size and spread of the detectors, we can modify the detector response to optimize the system.



Design Tools

In order to calculate the expected detector response, we have created a system that uses a Python script to write and execute an MCNP (Monte Carlo N-Particle), a validated physics code widely used for radiation transport. Using MCNPX-Polimi, a version specially tailored to detector response, we count the number of neutrons that interact in each of the detectors as a function of rotation angle.

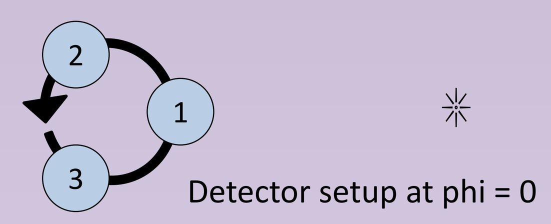


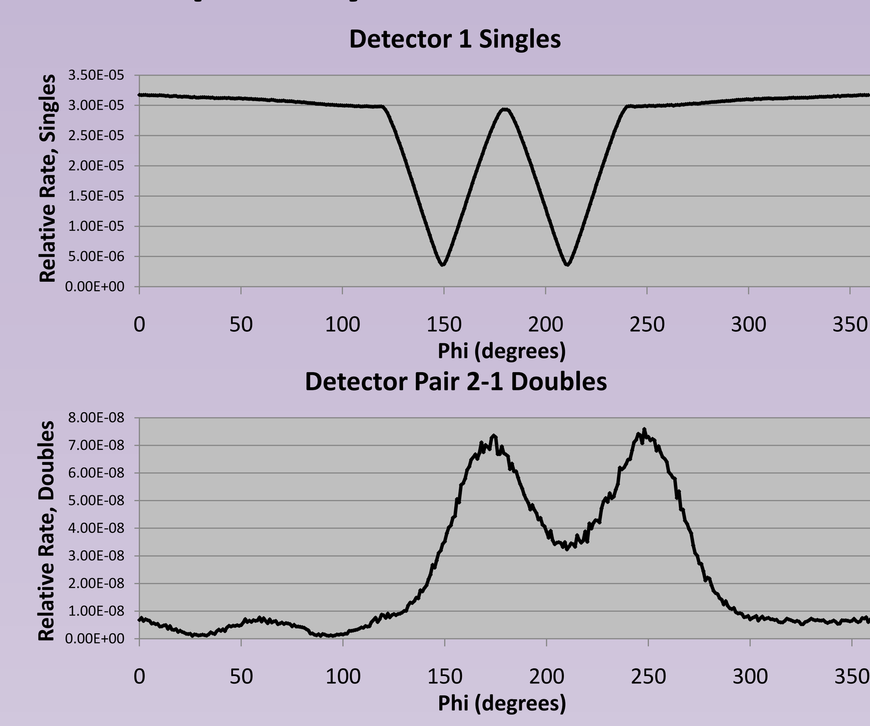
The Python script loads a geometry template file, writes and executes an MCNP input file at each rotation angle, and extracts the resulting performance data. It returns a response function, shown right, for each detector.

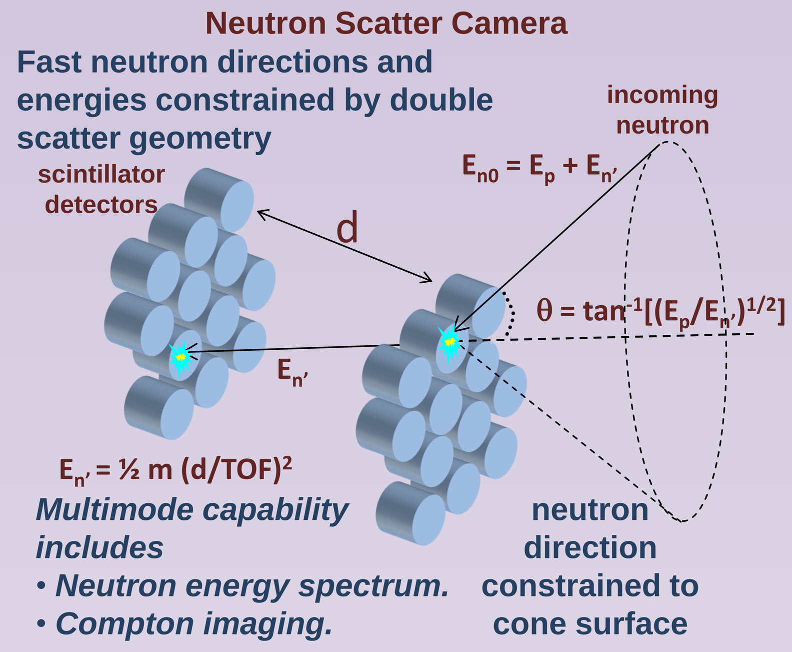
The Python script streamlines the process by automating every aspect of the simulation from creating the geometry to organizing the data. The next step in polishing the process is to build the performance analysis into the Python script, making it a one step process to create and compare new detector configurations.

Dual Mode Capability

PRISM can also operate in dual mode, in which it records neutrons that interact in one detector, "singles," and neutrons that interact in two detectors, "doubles." This creates a unique observation map for each detector and for each detector pair, shown right for the configuration below (not to scale).





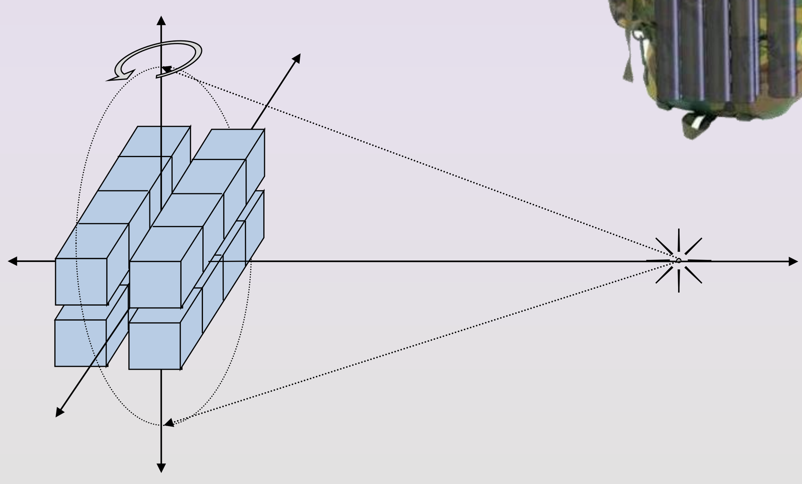


A stretch goal for the doubles mode is to incorporate the concepts of the Neutron Scatter Camera (NSC). The NSC is a proven system that uses neutron double scatters between two detector planes to find the direction of the incoming neutron. With many interactions, the source location can be identified with great accuracy. PRISM could be configured to record the positions of each detector pair during a double scatter to calculate this direction for an added precision.

BINGS Wearable Detector System

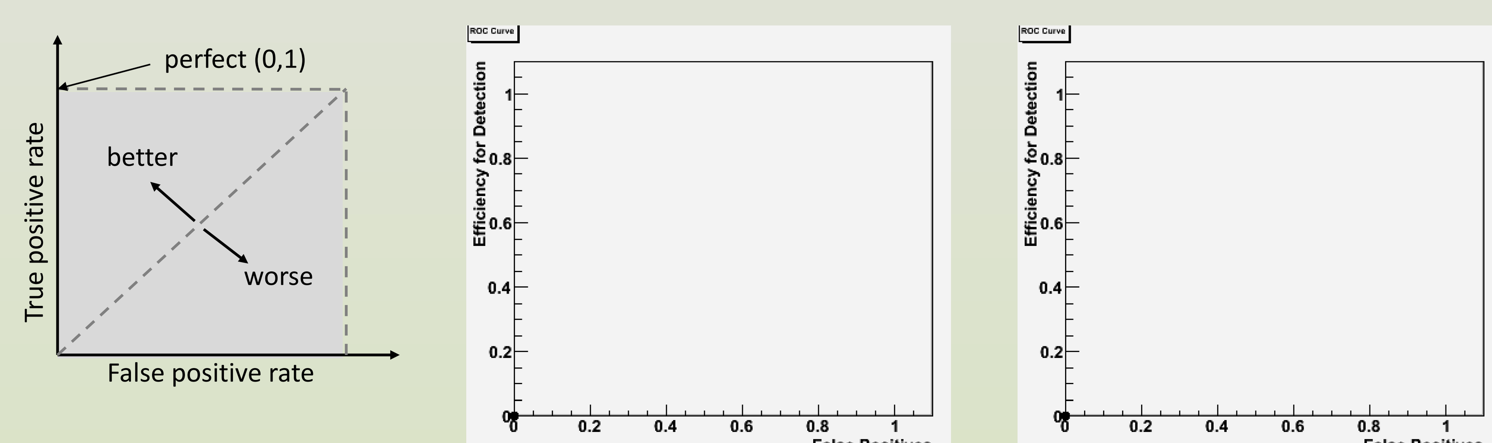
The BINGS (Backpack Imaging Neutron and Gamma Spectrometer) system is a wearable neutron detection system for emergency responders. It makes use of the Neutron Scatter Camera technology in two planes of small 3" cube liquid scintillator cells. This allows for imaging and classifying neutron sources, but has a low efficiency.

Rotating the detectors around a central axis to create a PRISM systems would allow for use of single scatter events that do not contribute to the NSC mode, increasing the efficiency greatly. In the case of emergency responders, reducing the necessary measurement time in this way is extremely advantageous.



ROC Curve Analysis

In order to assess how well a given detector configuration works, we have made use of ROC curves. These are graphical plots of sensitivity, or true positive rate vs. false positive rate. A perfect system would have 100% true positive rate and 0% false positive rate. By comparing the ROC curve of various detector systems in singles, doubles, or both modes, we can determine which configuration is best and how to make improvements.



These ROC curves show that the added double mode improves system sensitivity.

Conclusions and Future Work

We have begun the process of designing, modeling, and analyzing a self-masking detector system that has the capability to image and classify neutron sources at great distances. By operating the system in singles and doubles modes, we have increased the efficiency with respect to previous detector systems.

In the next weeks, we will continue to improve the analysis process in order to better evaluate and optimize the detector system. We will record data with our experimental setup on a small laboratory scale and in a large stand off measurement. Later work includes implementing the Neutron Scatter Camera method to increase the accuracy of the system.

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