



Time-Encoded Imagers

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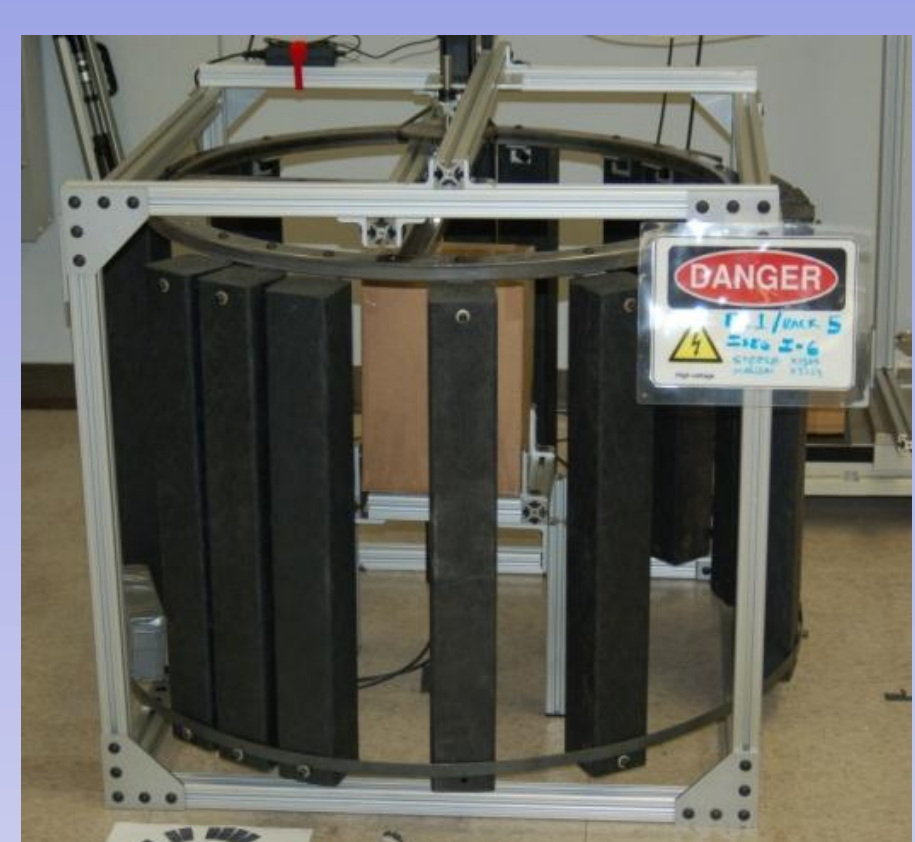
SL11-TimImager-PD03

Goals and Objectives

- Develop the technique of time-encoded imaging to enable a new class of simple, robust, scalable radiation detection systems.
- Build and demonstrate a large 1-D directional fission-energy neutron detector optimized for large standoff SNM detection applications.
- Create a conceptual design and prototype system for high-resolution two-dimensional imaging of fission-energy neutrons for treaty verification and related applications.

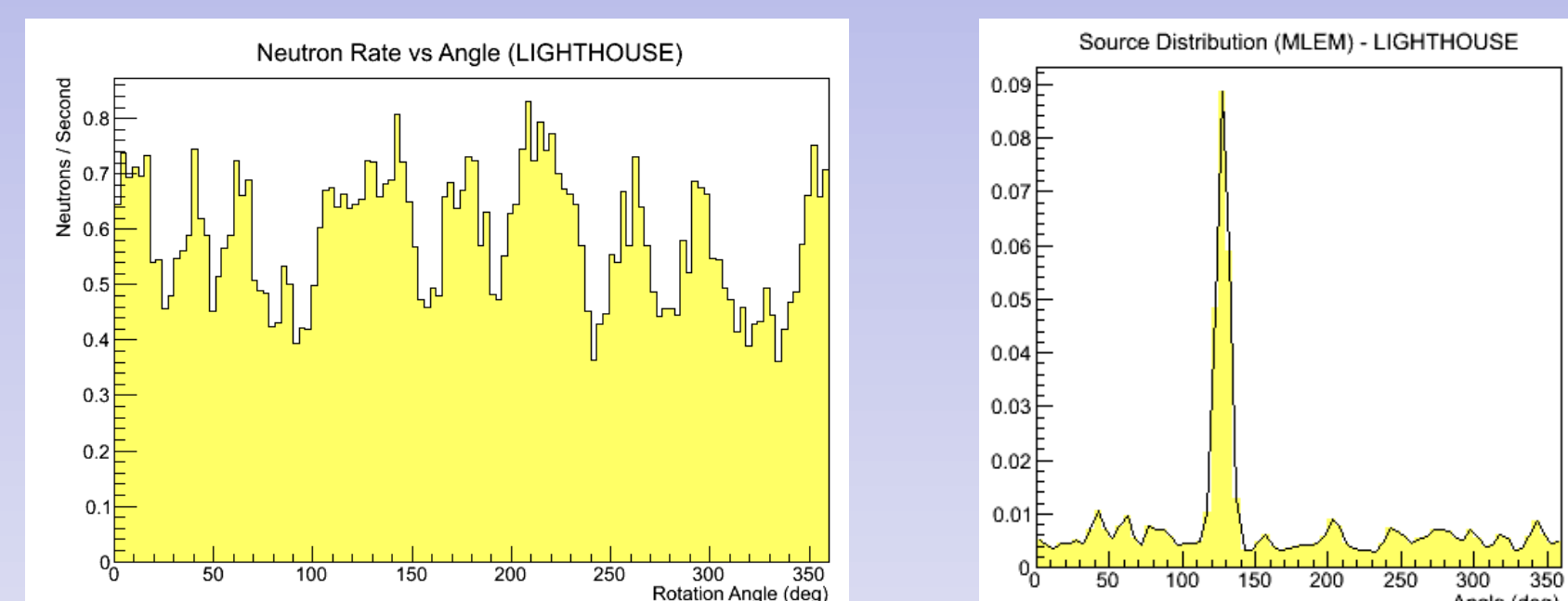
Prototype 1-D Detector Designs

Two prototypes were developed for comparisons based on distinct detector designs. Both image in the azimuthal dimension, for e.g. standoff source detection. Lab and field studies of the prototypes resulted in the choice of a PRISM design for a demonstration system to be built.



'LIGHHOUSE' Design

- Direct time-domain analog of 1-D coded aperture
- Mask of 3.5" x 3.5" x 27" HDPE bars in a URA pattern
- 5"D x 5" liquid scintillator cell w/ 5" PMT
- Motor drives mask rotation at O(1 rpm)
- Passive mask decouples imaging performance from detection

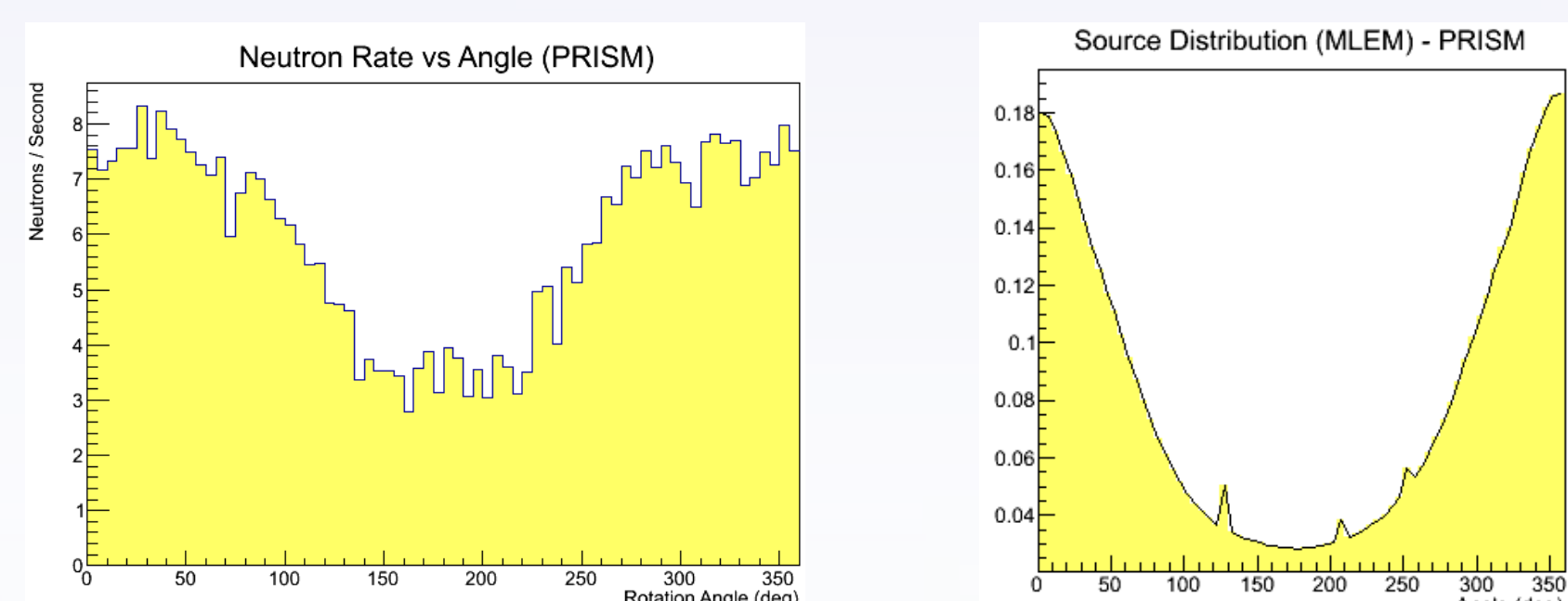


Above: LIGHHOUSE, a prototype TEI based detector, is composed of a rotating mask surrounding a 5" PMT. Right: Detected neutron rate vs rotation angle for a weak Cf-252 source at 5 m; reconstructed source distribution.



'PRISM' Design

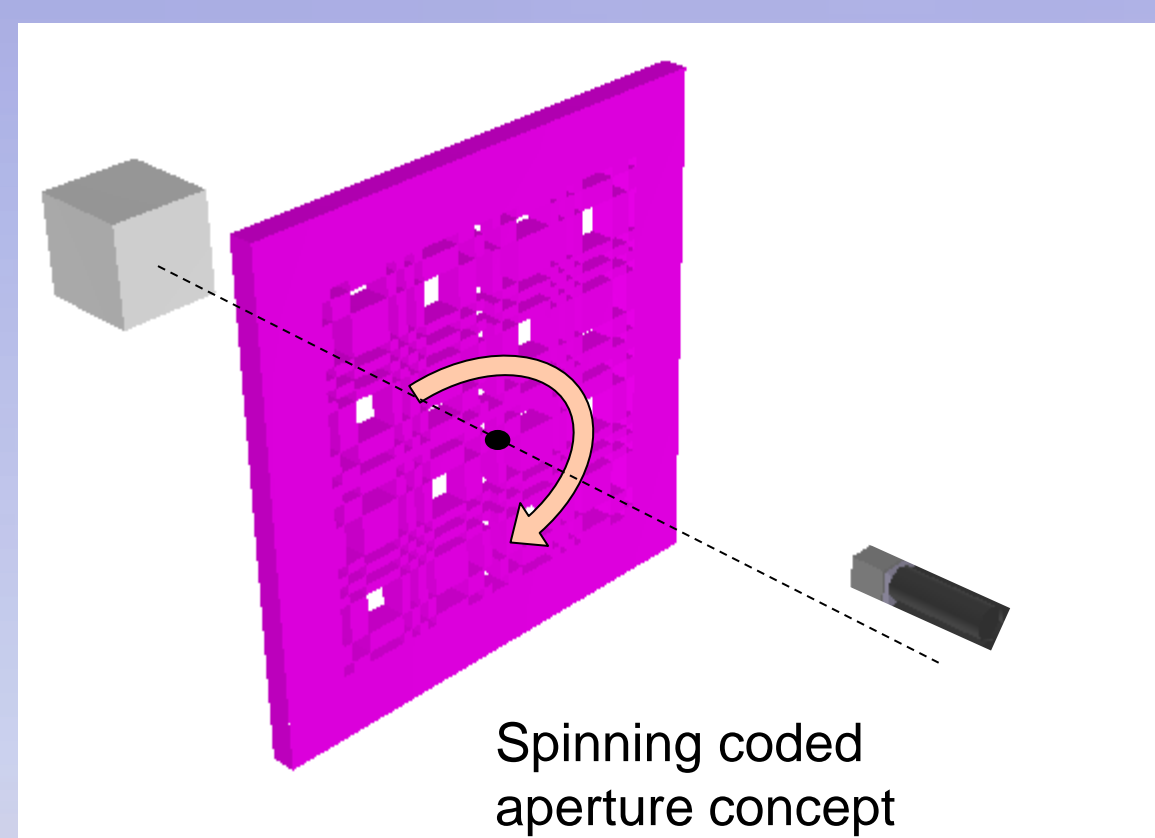
- Fully active system → compact, scalable, high effective area
- Three liquid scintillator cells, each 27 L w/ 9" PMT
- Only one cell instrumented for prototype
- Motor rotates platform with all three detectors, each cell modulates the signal to its neighbors
- Downside of large cell/PMT is higher threshold for good PSD
- Both prototypes read out with 500 MS/s waveform digitizer



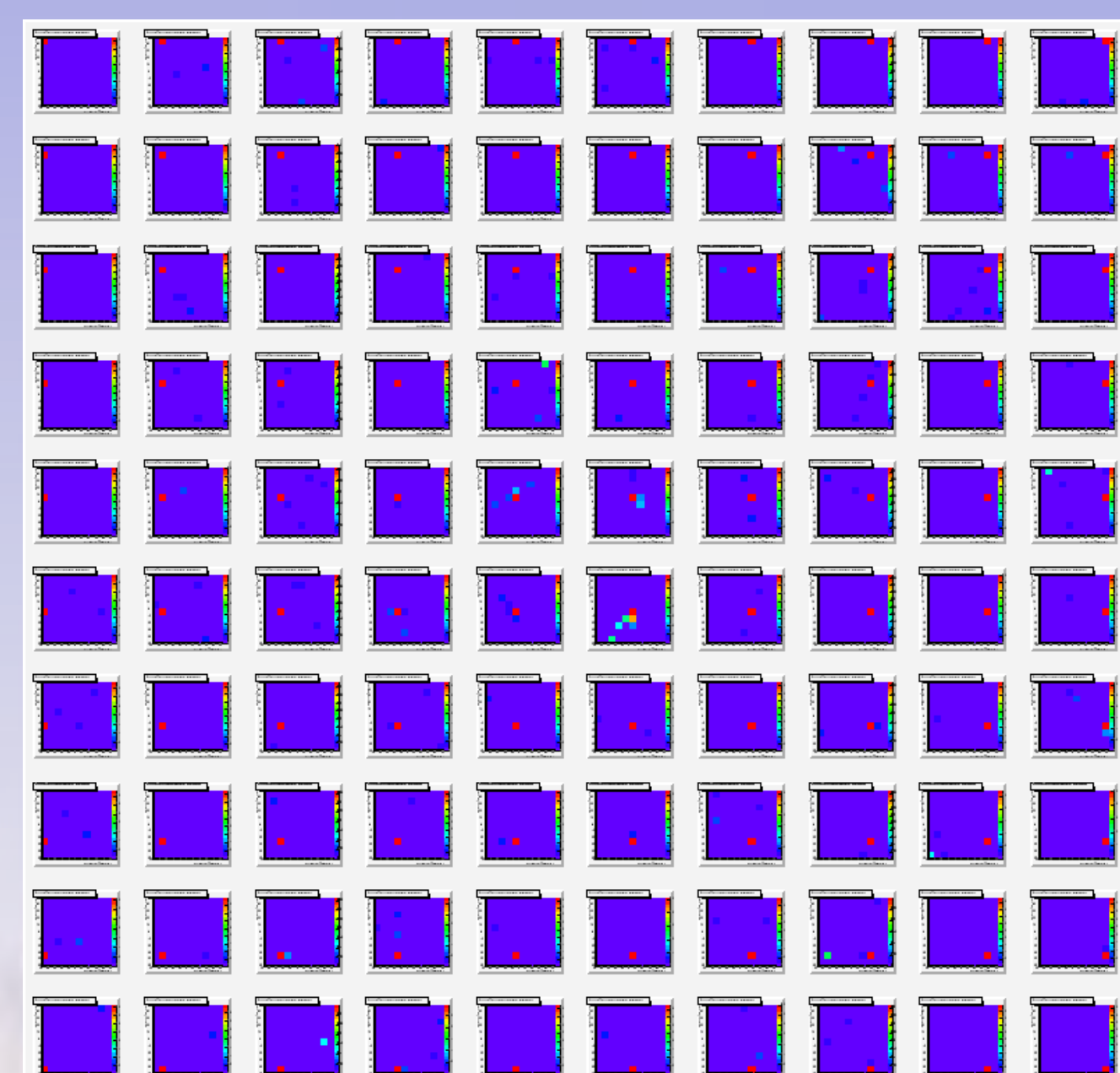
Above: Another TEI prototype, dubbed PRISM, comprises three large cells rotating together, each cell modulating the signal arriving at the others. Right: Detected neutron rate in one cell vs rotation angle for a weak Cf-252 source at 5 m for 1 hr; reconstructed source distribution.

2-D High-Resolution Time-Encoded Imager Studies

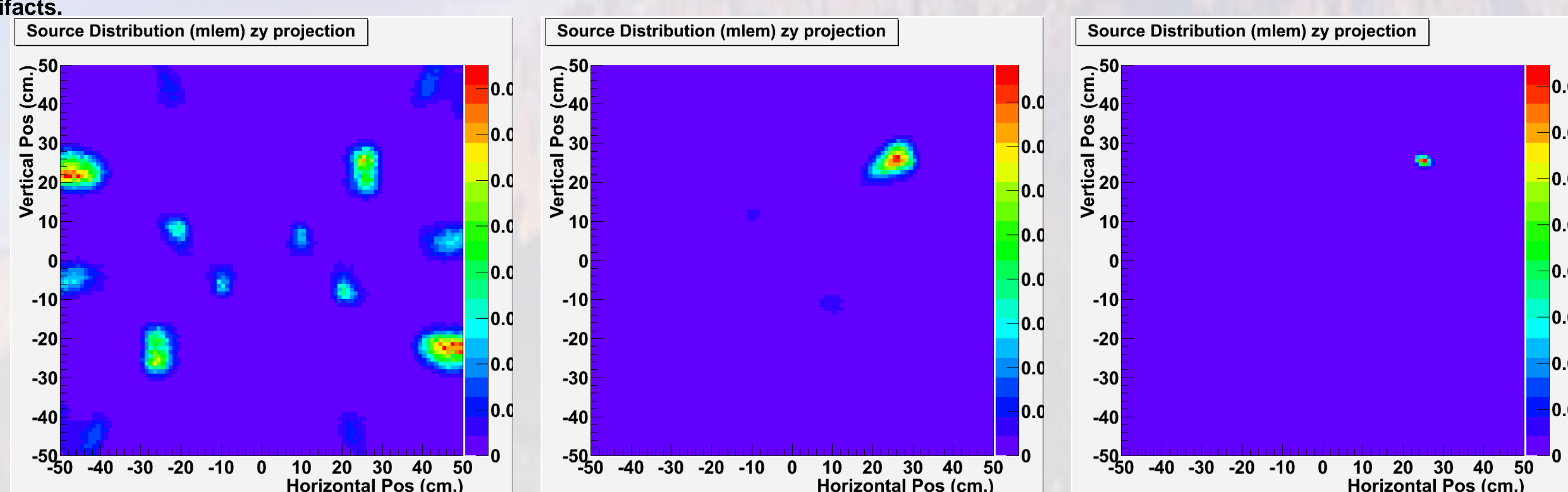
- Various designs under consideration: spinning coded aperture, 2-D LIGHHOUSE, etc.
- Conceptually, spatial → temporal analogy with coded aperture technique extends to high-resolution two-dimensional imaging.
- Practically, two issues arise.
 - Difficult to achieve the modulation as a function of position for a mechanically moving mask.
 - Size of detector element, and thus system effective area, is limited by desired imaging resolution.
- Studies of point source imaging are successful; extended sources will pose greater challenge.



Spinning coded aperture concept



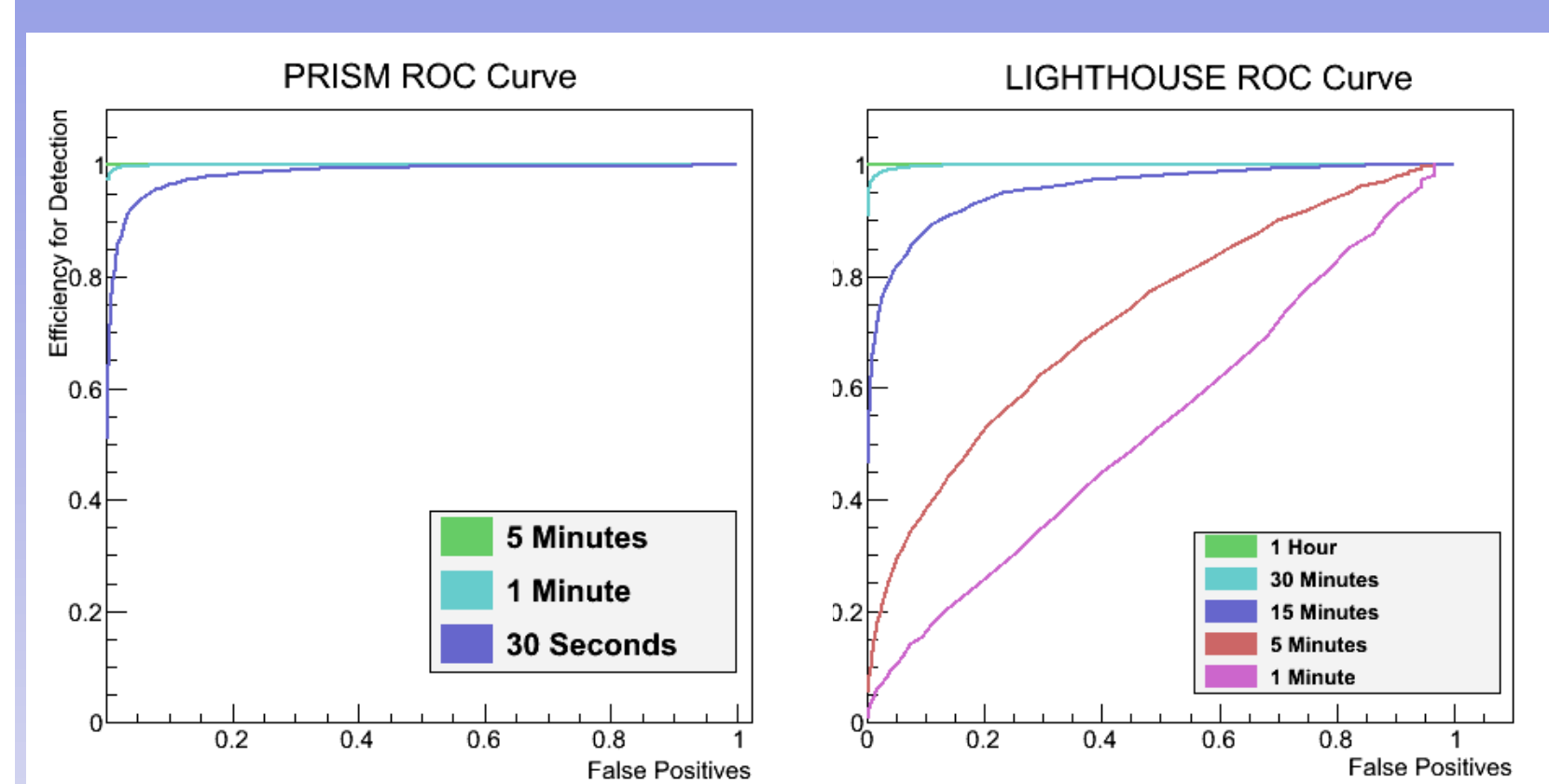
Above: In the spinning coded aperture concept, a 2d coded aperture mask spins on its axis, producing a different time modulation in the detector as a function of source position. Right: point source imaging over a coarsely pixelated source space, demonstrating successful reconstructions over the full space for a random mask spinning coded aperture. Below: Point source reconstruction for spinning coded aperture in three configurations. Left: 19x19 URA mask pattern, detector on axis. Middle: 19x19 URA mask pattern, detector off axis. Right: Random mask pattern. For time-encoded imaging, the near-symmetry of URA patterns results in undesirable artifacts.



Introduction

Time encoded imaging (TEI) is a new approach that produces images by inducing a time-dependent modulation of detected particles. TEI-based detectors use single-scatter events and have a low channel count, reducing complexity and cost while maintaining high efficiency with respect to other radiation imaging techniques such as double-scatter or coded aperture imaging. The scalability of TEI systems makes them a very promising detector class for weak source detection. Extension of the technique to high-resolution imaging is under study.

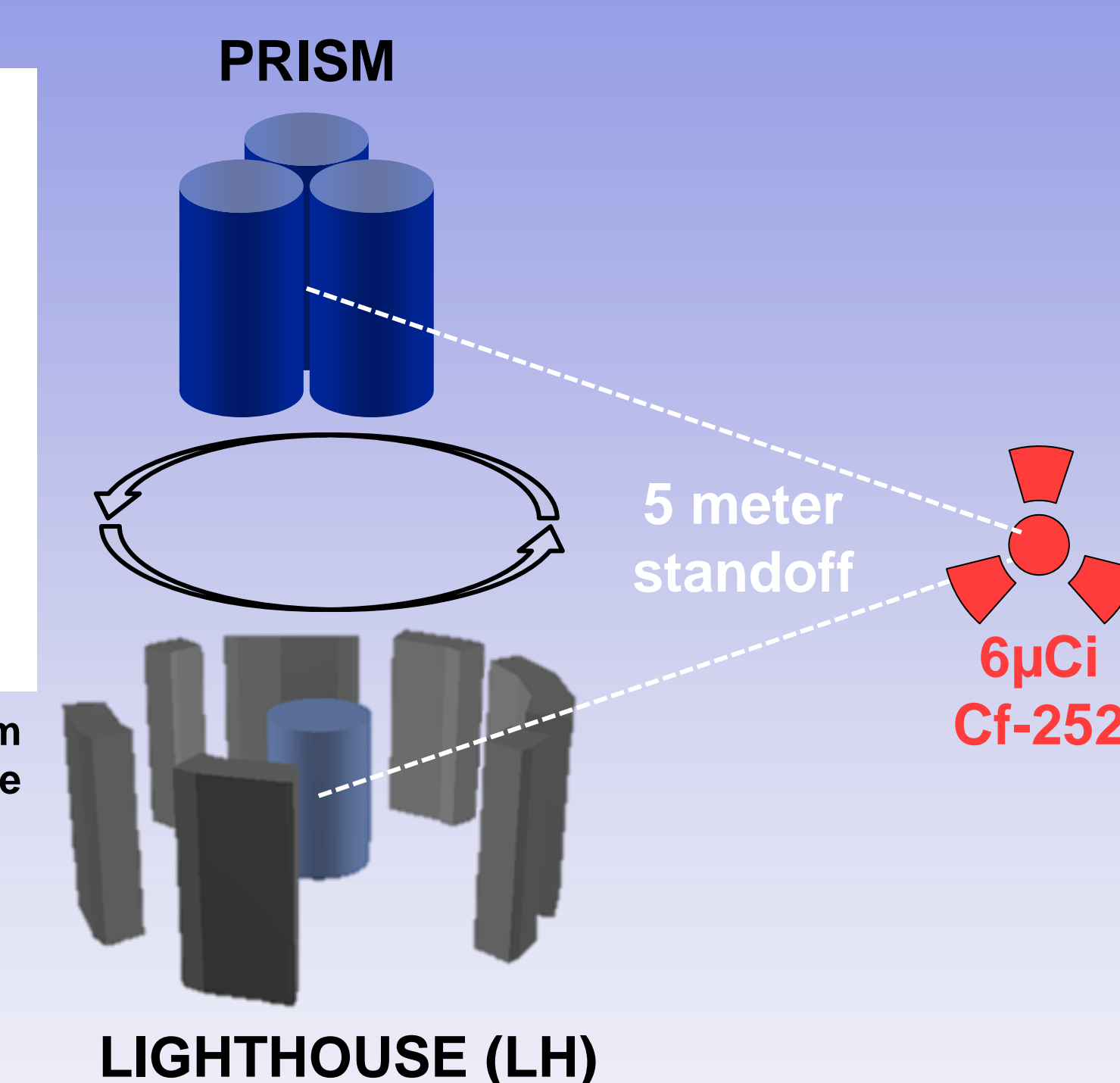
1-D Detector Analysis & Results



Above: ROC curves for source detection in the lab at 5 m standoff. Roughly a factor of 10 is attributable to larger effective area of the PRISM cell.

$$LLR = \ln \frac{L(\text{data} | s + b)}{L(\text{data} | b)}$$

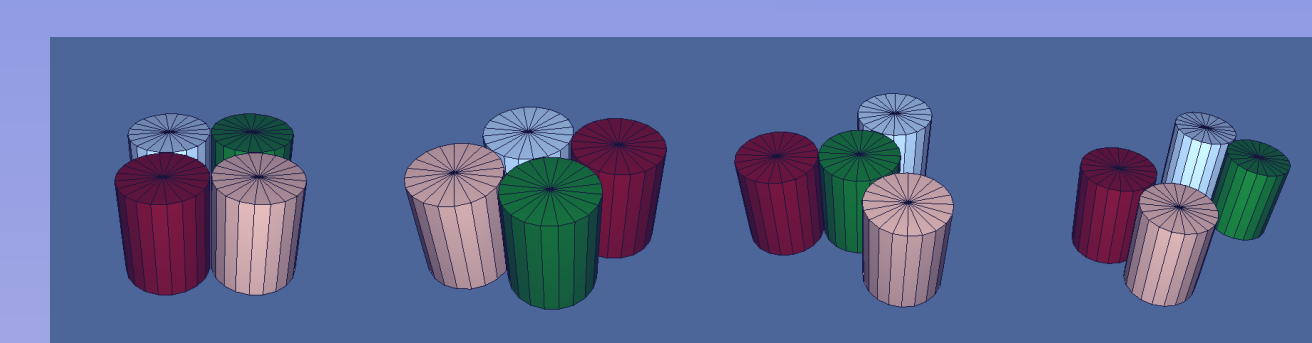
- Data is analyzed using a hypothesis test based on log-likelihood ratio (LLR) for presence of a point source over uniform background.
- Large datasets were acquired with & without source present; by sampling shorter sets of data ROC curves can be constructed.



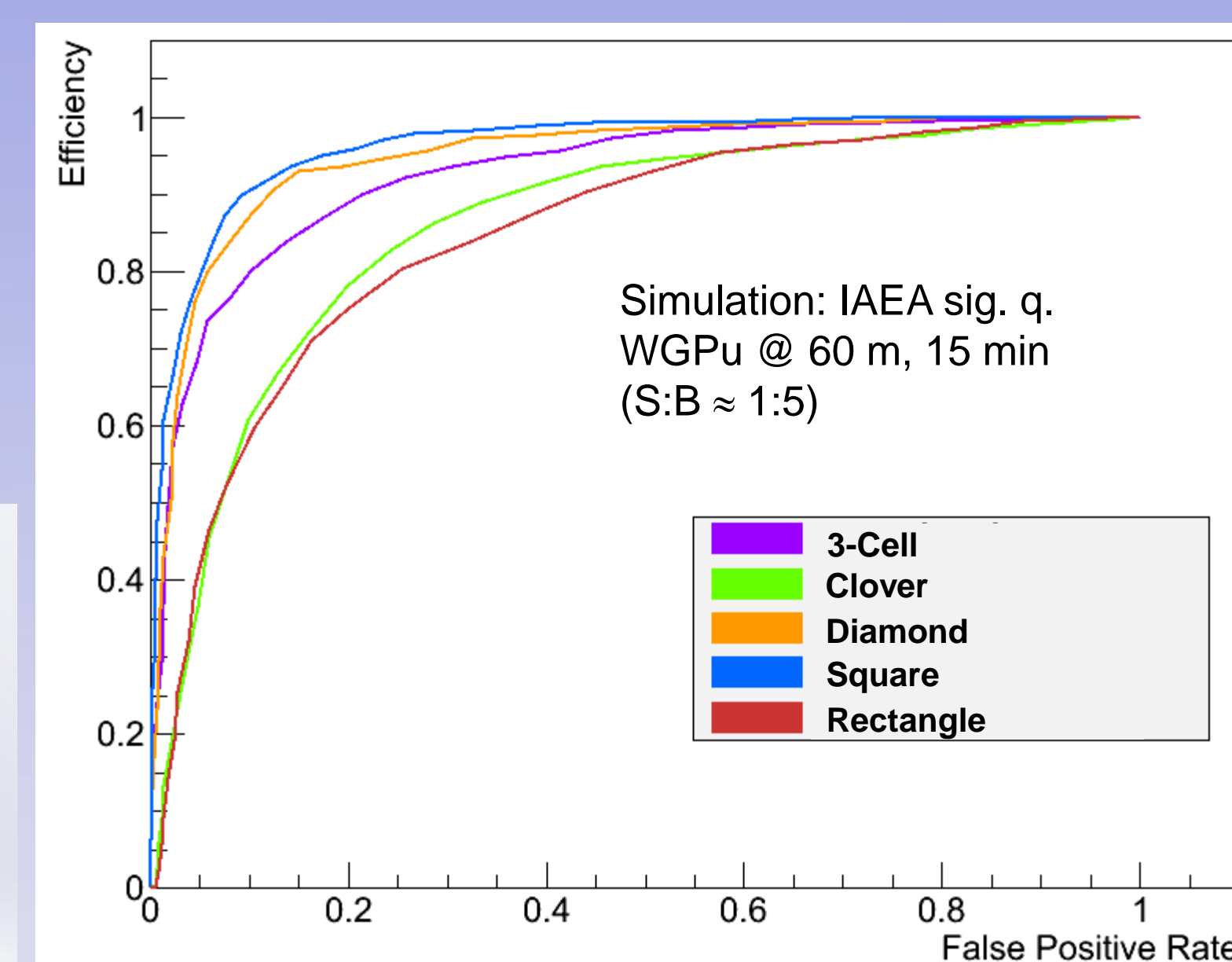
- PRISM cell has ~10x greater sensitivity than LH cell, due to larger volume partially offset by higher threshold.
- Analysis indicates 30 s PRISM run roughly equivalent to 1200 s LH.
- Conclusion: PRISM is both more scalable and provides more optimal pattern for source detection.

1-D Demonstration Detector Design

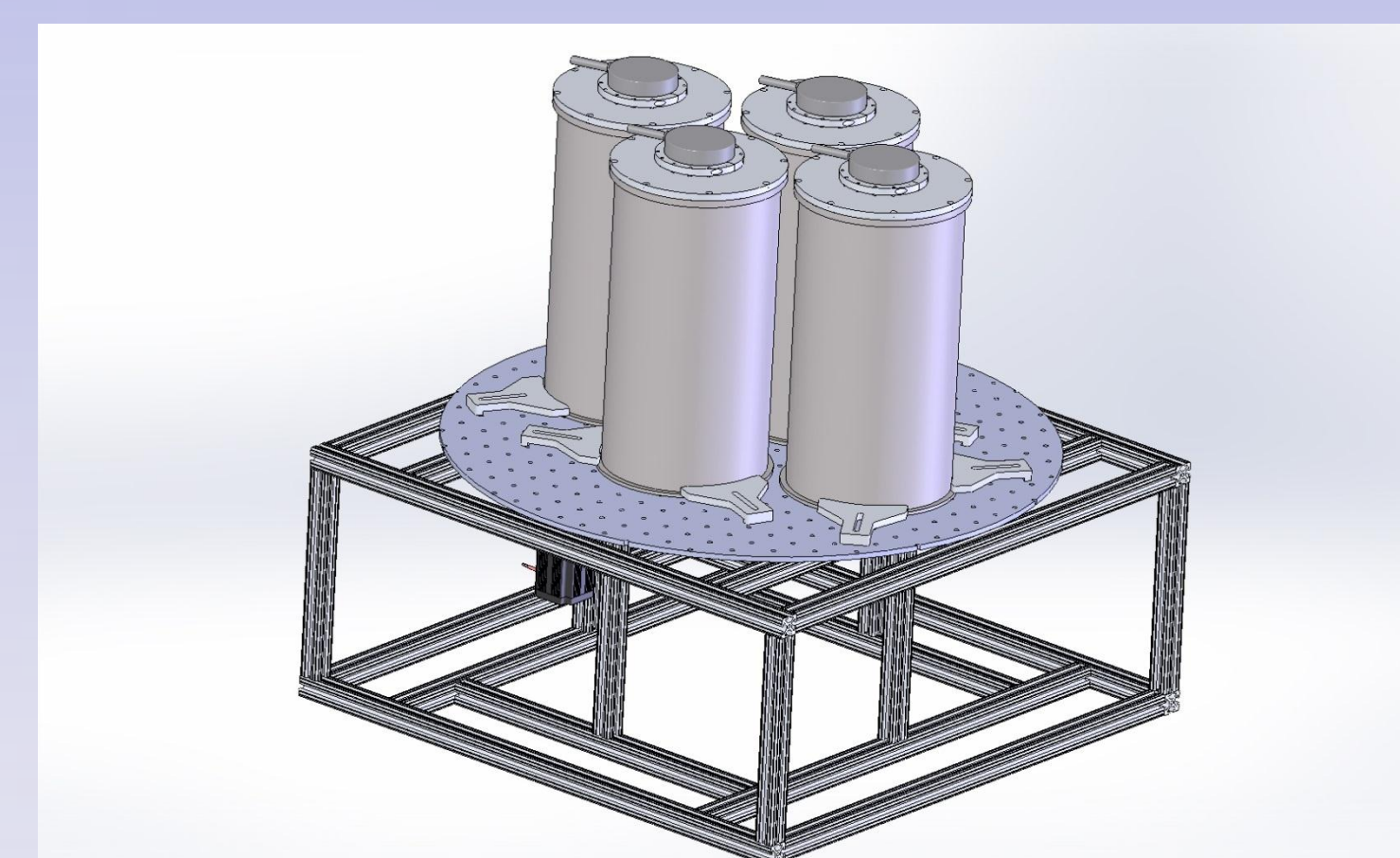
- Based on the results of prototype testing, we developed a demonstration detector design (below) using the PRISM concept with four channels.
- PMT choice is essential to maintain low thresholds with good PSD; testing of alternatives is underway.
- Various cell placement geometries have been considered; results of simulation studies are not intuitive! Close-packed arrangements have best performance.



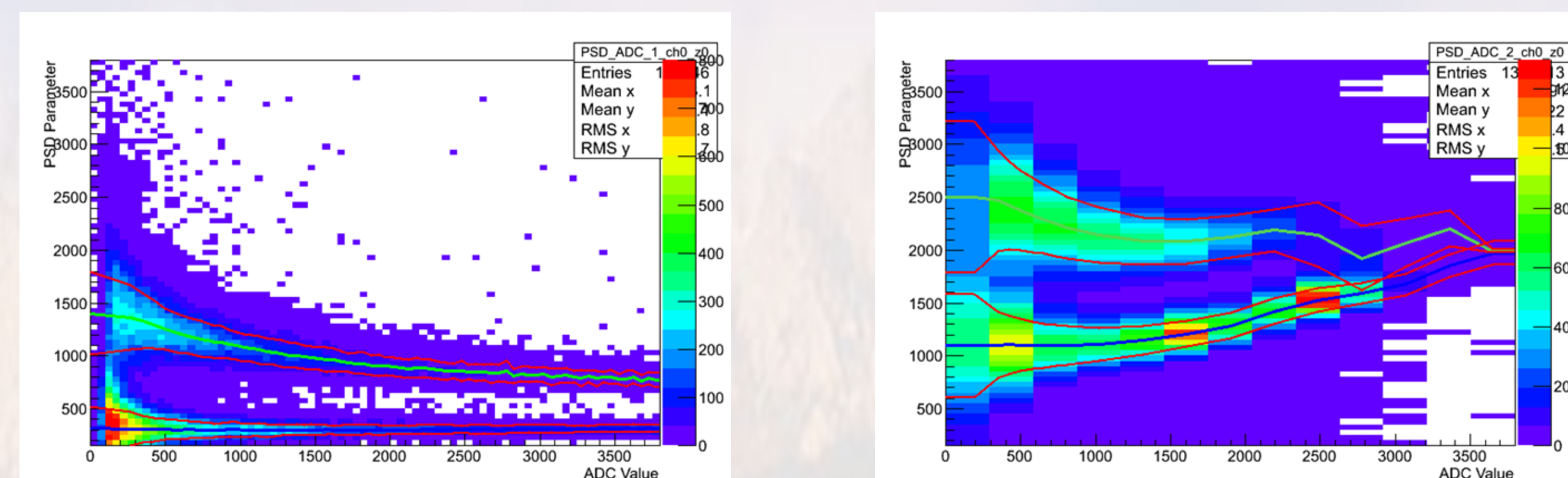
Square Diamond Clover Rectangle



Top: Possible configurations for a demonstration TEI detector based on PRISM. Bottom: These were simulated with MCNP and evaluated using ROC curve comparisons



PSD plot for 5" LS cell with 5" PMT (left) and 12" LS cell with 9" PMT (right). Poor gamma/neutron separation at low energies in large cells/PMTs results in a higher effective energy threshold, cutting into the fission spectrum. PSD performance is thus an important consideration for PMT selection for the demonstration detector.



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