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Fast-Neutron Time-Encoded Imaging with an Asymmetric Mask

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Overview

High resolution neutron imaging is a valuable capability for nuclear non-proliferation and international safeguards. A potential application in treaty verification is measuring the extent of a warhead. One of the challenges facing high-resolution neutron imaging is the size, weight, and complexity of the imaging systems. Fast-neutron time-encoded imaging utilizes a single non-position sensitive detector at the center of a rotating, HDPE mask to image fast neutron sources. In this work, we test offsetting the detector from the rotational axis hence imaging with an asymmetric mask. Along the imaging axis, the mask to detector distance increases leading to better angular resolution for the same mask, or conversely, one can achieve the same angular resolution in a limited field of view with a smaller, lighter mask. Here are some preliminary experimental results for fast-neutron time-encoded imaging with an asymmetric mask.

Experimental Setup

Two sets of experimental data were collected:

A. 1 inch Stilbene detector placed at the rotational axis (not presented here)

B. 2 inch EJ309 detector placed ~40 cm offset from the rotational axis

- Goal: Compare a system designed for a detector on axis against a system designed for a detector offset from the axis.
- 10 μCi Cf-252 sources were placed 1m from the rotational axis. The azimuthal angle is defined from the rotational axis.

Figure 1: A 2 inch EJ309 detector is placed ~40 cm off axis inside a ~1 m diameter mask. The mask is randomly coded with 4 inches of HDPE. Elements are 2.09 cm by 1.81 cm.

System Response

Challenges to generating the system response for an asymmetric mask:

A. Scatter from the mask is shift variant, not DC – ray tracing is inaccurate

B. Limited rotational symmetry – need response from every mask rotation angle and source position.

Solution: Multigroup, adjoint option in MCNP – 1000 times faster!

A. Particle is born in the detector from the detector response distribution

B. Particle is transported through geometry and gains energy during scatter

C. Particle weight is multiplied by the source emission probability and tallied

Variance reduction methods were also implemented.

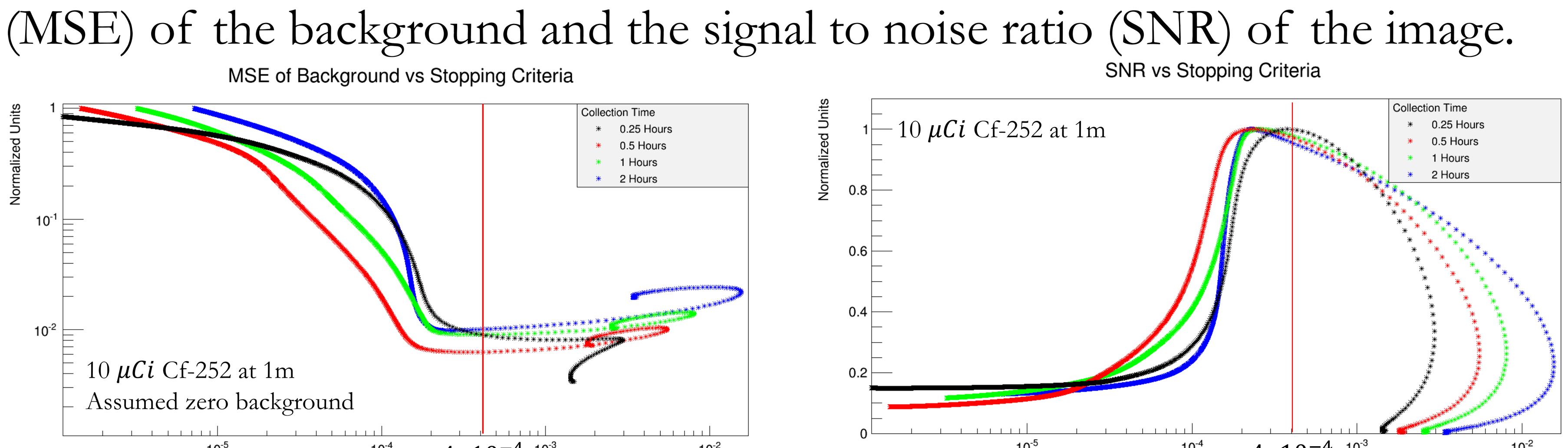
MLEM Stopping Condition

An automatic stopping condition was employed for MLEM.

$$r^{(k)} = x - \hat{x}^{(k)};\ \delta^{(k)} = \frac{var(r^{(k-1)}) - var(r^{(k)})}{var(r^{(k)})} < 4x10^{-4}$$

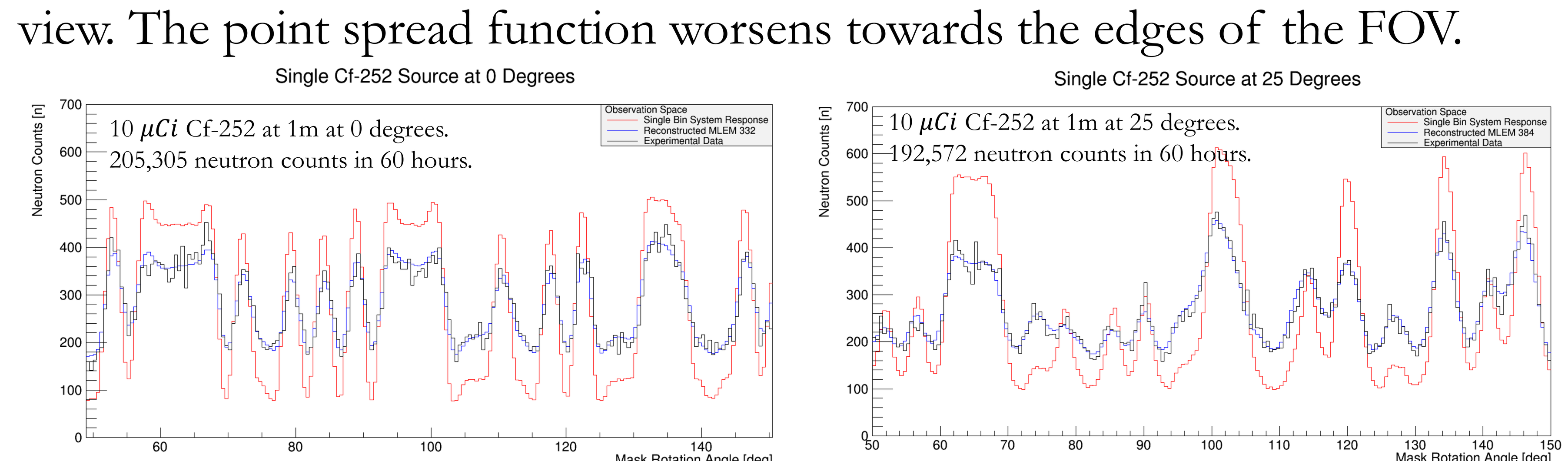
x is the observation vector, $\hat{x}^{(k)}$ is the forward projected observation vector for iteration k, $r^{(k)}$ is the observation residual for iteration k, $var()$ is the variance function, thus $\delta^{(k)}$ is the percent change in the variance of the observation residual for iteration k.

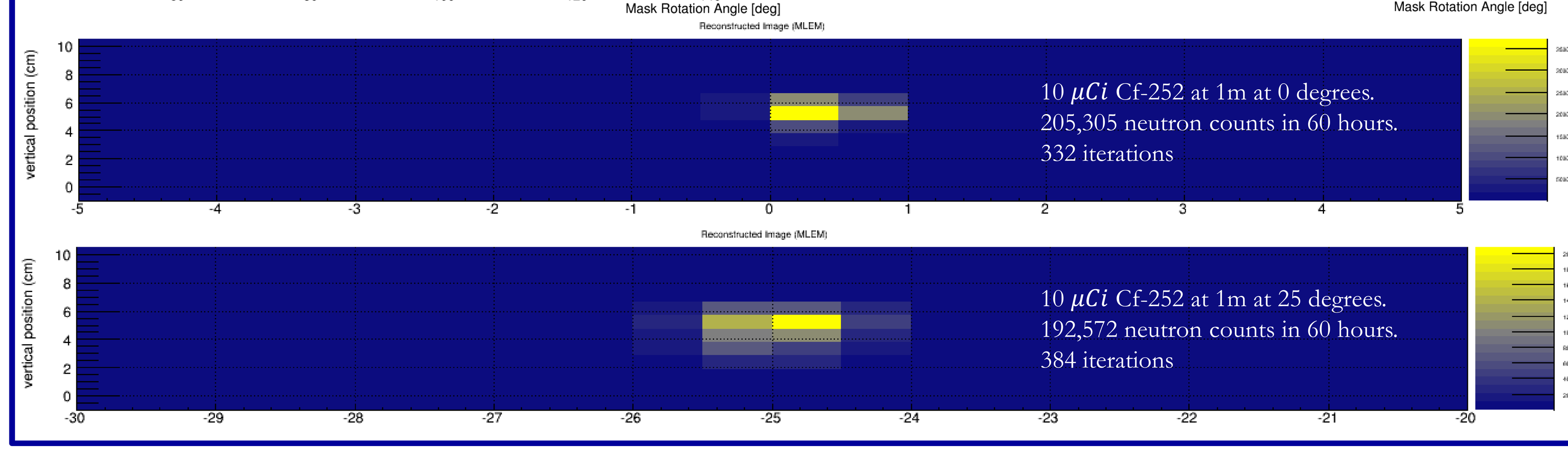
A stopping point of $4x10^{-4}$ was chosen based on the mean squared error (MSE) of the background and the signal to noise ratio (SNR) of the image.



Field of View

Due to the thickness of the mask, an asymmetric TEI has a limited field of view. The point spread function worsens towards the edges of the FOV.





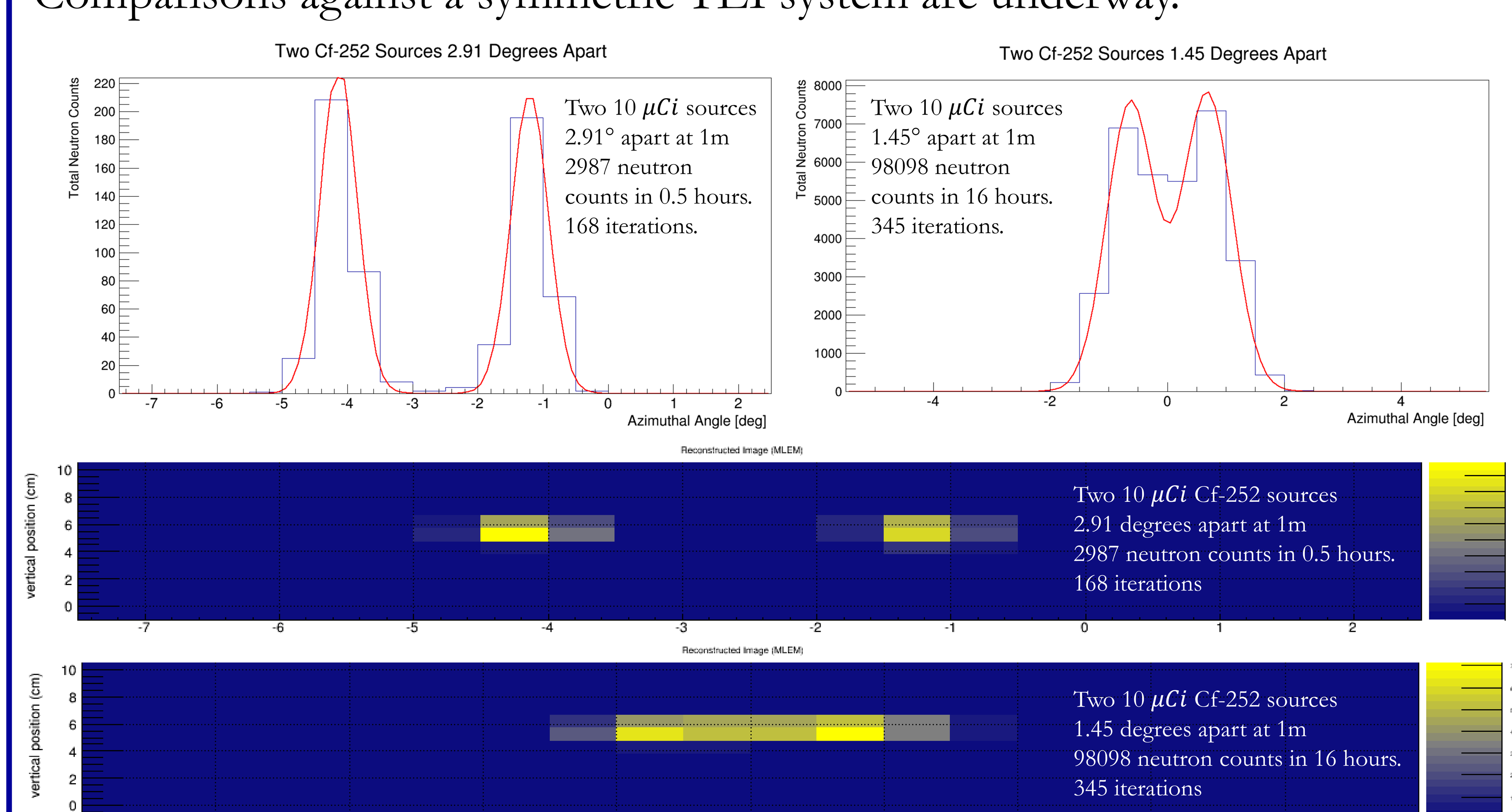
Angular Resolution

Two 10 μCi Cf-252 sources at 1m were measured at various separations to estimate angular resolution. The asymmetric TEI can resolve:

two sources 2.91° apart in 0.5 hours (2987 neutron counts), and

two sources 1.45° apart in 16 hours (98098 neutron counts).

Comparisons against a symmetric TEI system are underway.



Future Work

A. Compare symmetric vs asymmetric TEI system - continuing this work

B. Explore the benefit of moving the same detector within a mask.

C. Design an adaptive imaging protocol to leverage the advantages of a moving detector within the TEI mask.

References

[1] J. Brennan, et. al., "Demonstration of two-dimensional time-encoded imaging of fast neutrons," Nucl. Instruments Methods Phys. Res. Sect. A Accel. Spectrometers, Detect. Assoc. Equip., vol. 802, pp. 75–81, 2015.

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