LANTERN: A Cylindrical Time-Encoded Dual Particle Imager

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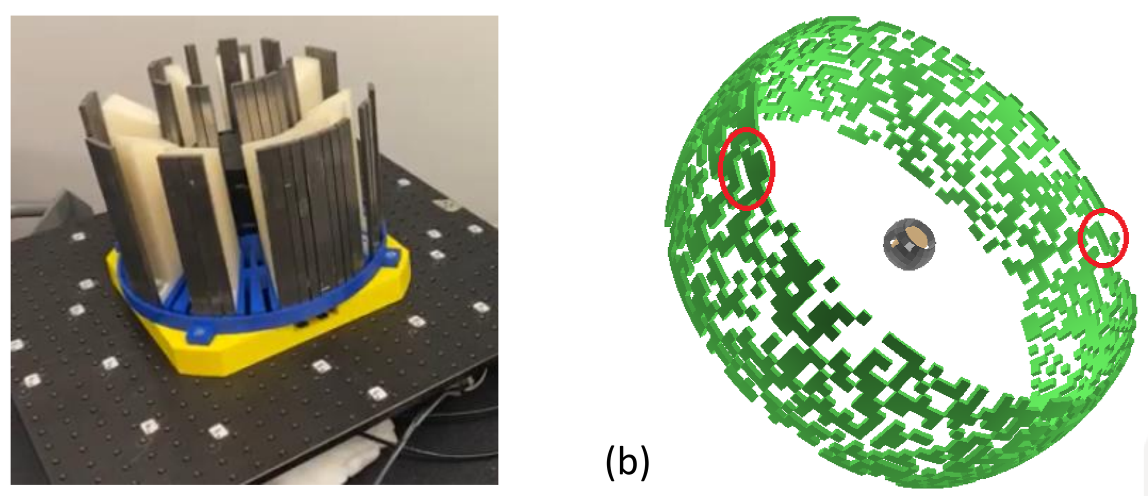
Introduction and Motivation

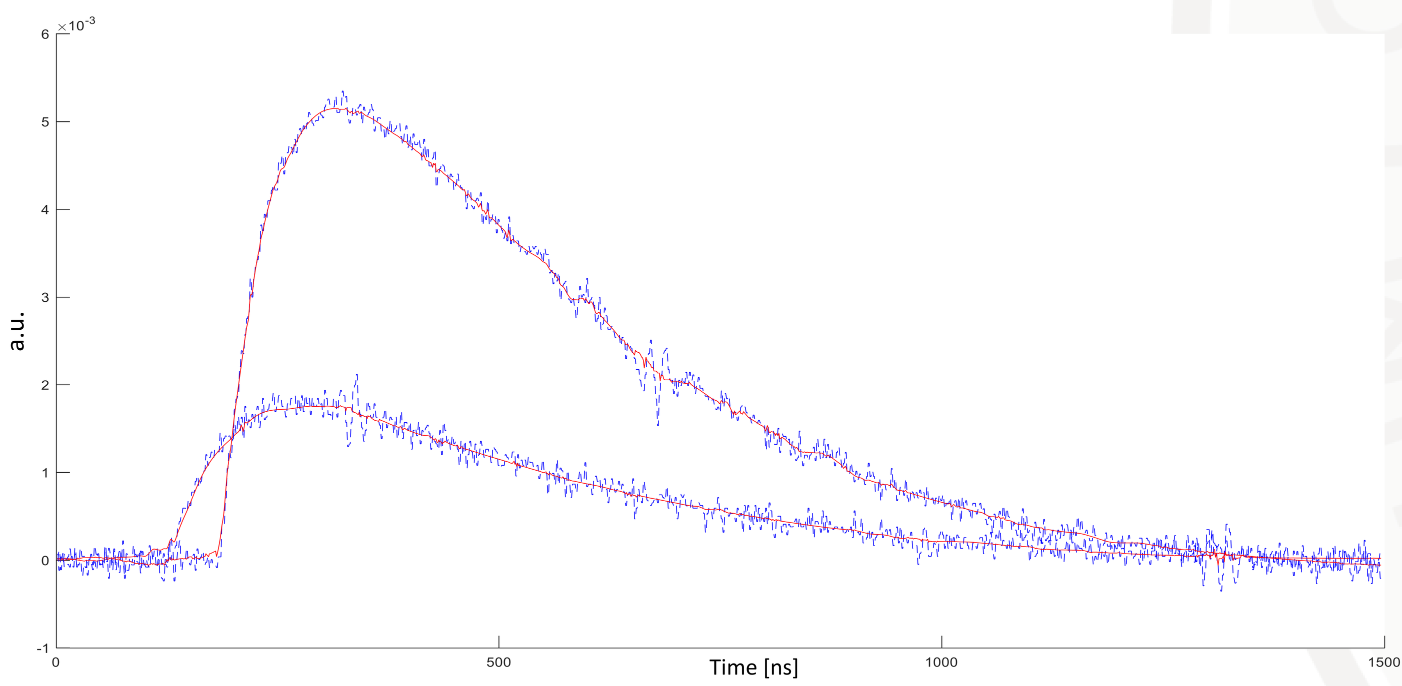
- A 1D, man-portable, dual particle cTEI imaging system is desirable for nuclear nonproliferation applications. The SolidWorks model and first implementation of LANTERN are shown in Figure 1a.
- A larger 2D system is being developed by SNL in collaboration, see Figure 1b.
- Overall Goal: Retain image quality when transitioning from a large- to small-diameter time-encoded mask.



▲ Fig. 1: (a) LANTERN implemented 3-layered mask. (b) GDA optimized random mask-antimask coded aperture (green) with the configuration of the 2D SNL COGNIZANT system, highlighting two noticeable mirror matches (red rings).

Technical Approach

- Electrical grounding was improved by covering all cables and connections with copper tape, and a Hempel filter was applied to reduce noise in waveforms, as seen in Figure 2.



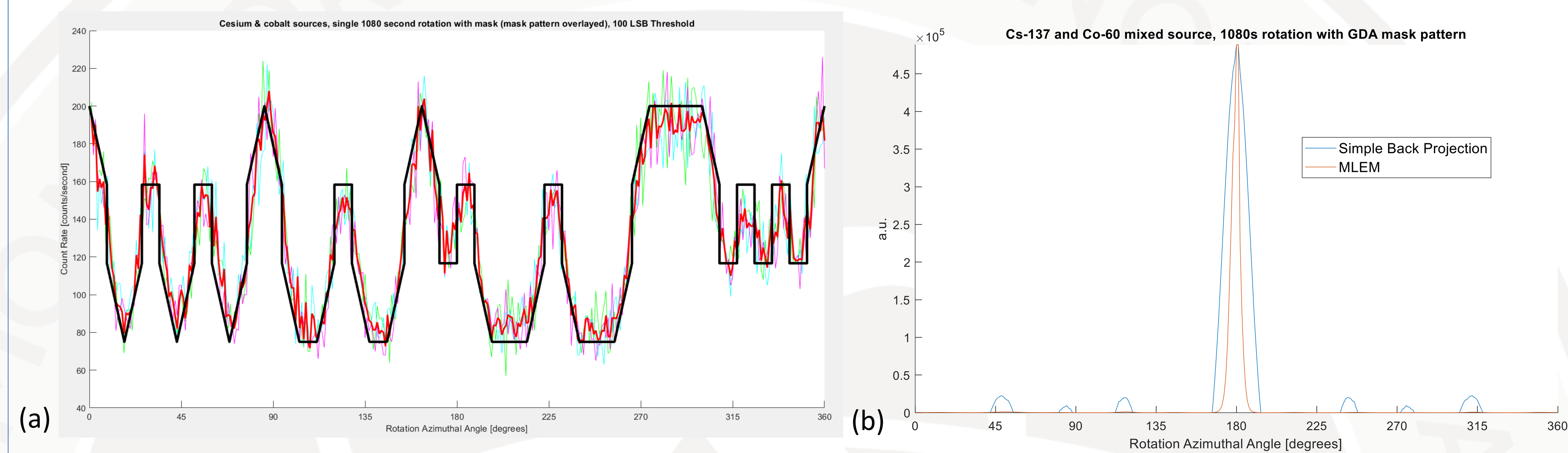
▲ Fig. 2: Examples of recurring noise in all waveforms that partially originates from the LV supply. Pre-digital filtering waveform (blue) and cleaned waveform (red).

$$Q = \left[\left(\left[\frac{1}{NxNy} * \sum_{i,j} a(i,j)\right] + \frac{b}{I_T}\right)\frac{1}{NxNy} * \sum_{i,j}\frac{1}{|A(i,j)|^2}\right]^{-1}$$

- An optimized random mask pattern was implemented for LANTERN which was created using variations of the Great Deluge Algorithm (GDA) (below) where Nx and Ny are the dimensions of the pattern and a and A are the pattern and the Fast Fourier Transform of the pattern, respectively.
- This was condensed to 1D and was implemented into the LANTERN mask pattern optimization; while the 2D version is being implemented for Sandia's COGNIZANT mask pattern optimization.

LANTERN (U of M) Methods & Results

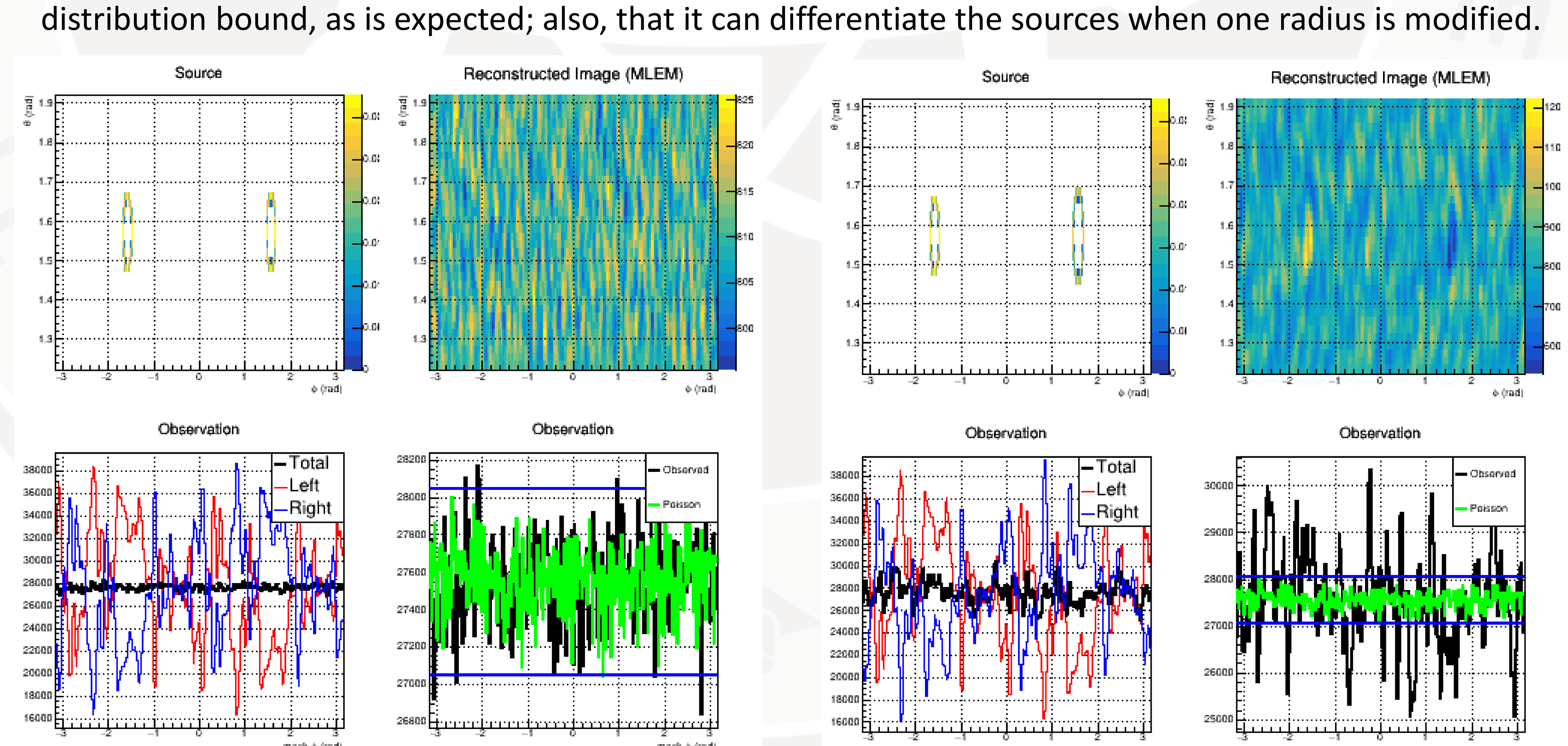
- The LANTERN system was tested using a two-layer mask (polycarbonate-tungsten) using a pattern that was optimized using the GDA. A strong, mixed source of Cs-137 and Co-60 was measured and the source modulation over time is shown in Figure 3a. The measurement was conducted three times and averaged for better statistics. The averaged data matches the approximated ideal point response quite well.
- Image reconstruction was then conducted on the above measurement (Figure 3b), and the maximum likelihood estimation maximization (MLEM) resulted in better image resolution than the simple back projection (SBP). The reconstructions codes are not optimized, but the current FWHM for SBP and MLEM of this experiment are ~15° and ~5°, respectively.



▲ Fig. 3: (a) Source modulation over time of Cs-137 and Co-60 measured with a 1" CLLBC crystal and a GDA mask pattern. Three measurements (green, pink, blue) and average (red). Approximated ideal point response (black). (b) MLEM and SBP reconstructions with side lobe subtraction for normalized comparison.

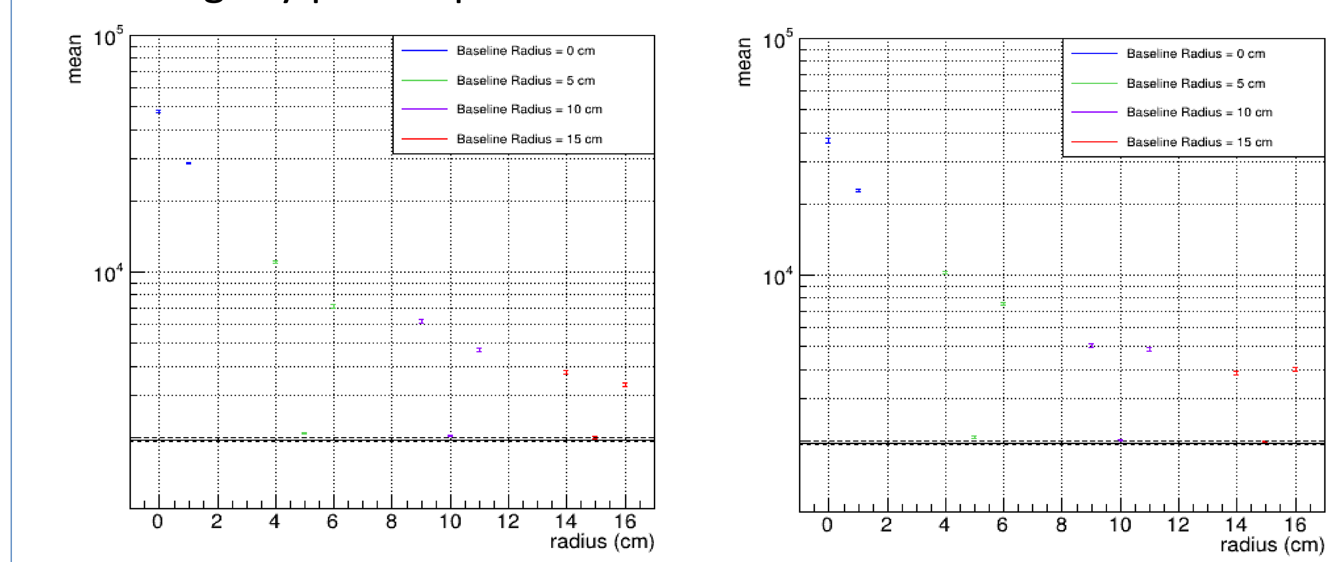
COGNIZANT (SNL) Methods & Results

- A 2D GDA optimized mask-antimask pattern was tested using simulations with two sources at 180-degree separation. The source sizes started as point sources and moved to extended sources up to a radius of 15 cm. Each of the setups included a simulation with one of the sources being modified to test the mask's ability to differentiate between two identical sources and two non-identical sources.
- Figure 4 shows that the GDA pattern sees two identical sources as being within the Poisson noise distribution bound, as is expected; also, that it can differentiate the sources when one radius is modified.



▲ Fig. 4: GDA mask pattern: Identical 5 cm radius extended sources (left) and a 5 cm radius with one modified 6 cm radius (right). Each side: source configuration (top left), MLEM reconstruction (top right), observation from each half of mask with black subtraction line (bottom left), observation overlayed with Poisson distribution bounds (blue lines) (bottom right).

- The mean of the negative log-likelihood (NLL) was calculated for each of the double source experiments for the 2D GDA pattern and for the current COGNIZANT mask pattern.
- Figure 5 shows that the GDA pattern has comparable performance as COGNIZANT, as they both see identical sources as Poisson. While the GDA pattern does slightly better for larger extended sources, it has slightly poorer performance for smaller sources.



▲ Fig. 5: The mean of the negative log-likelihood (NLL) for comparison between the COGNIZANT mask-antimask pattern (left) and the GDA randomly optimized mask-antimask pattern (right). All the points on the plots have one standard deviation bars. Points at 5 cm, 10 cm and 15 cm are identical extended sources that fall into the ideal Poisson noise bands (3 std. dev black dashed bands).

MTV Impact

- Personnel transitions: John Kuchta is a year-round intern at Sandia National Laboratories to explore unconventional mask optimizations for the 2D COGNIZANT system.
- This work has been in collaboration with the Radiation and Nuclear Detection Systems group at Sandia National Laboratories.

Mission Relevance

- **Nonproliferation applications**: source verification and search operations.
- Need for a compact, cost-effective fast neutron imager.

  NNSA Mission: https://www.energy.gov/nnsa/missions/nonproliferation

Conclusion

- Variations of the GDA produced a fairly optimal mask pattern for 1D time encoded imaging of Cs-137 gamma rays.
- Further work must be done on mask optimizations to produce all around improvement of the COGNIZANT mask.
- The first 2-layered LANTERN system matches expected source modulation from the ideal point response.

Next Steps

- Test the neutron imaging capabilities of LANTERN.
- Test more mask patterns for LANTERN and for SNL to improve validation of modified ring source differentiation.
- Finalize the MLEM stop criterion for image reconstruction as it was likely over-iterated.

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