SAND2022-6513C

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Defense Nuclear Nonproliferation Research and Development

University Program Review (UPR) 2022 Meeting

Time-Encoded Dual Particle Imager (LANTERN)

Consortium for Monitoring, Technology, and Verification (MTV)

Presenter: John (Jack) Kuchta[1,2]
Lead Investigator: David Wehe[1]
Peter Marleau[2], Melinda Sweany[2]
1) University of Michigan, 2) Sandia National Laboratories

June 7 - 9, 2022

Defense Nuclear Nonproliferation Research & Development Program

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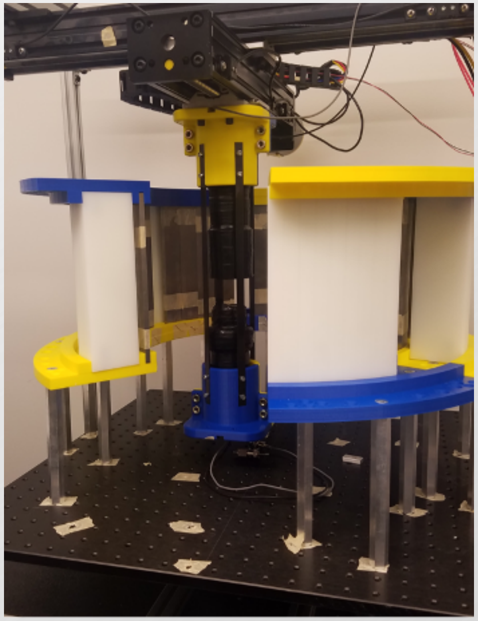
System Comparisons

MATADOR (Michigan)

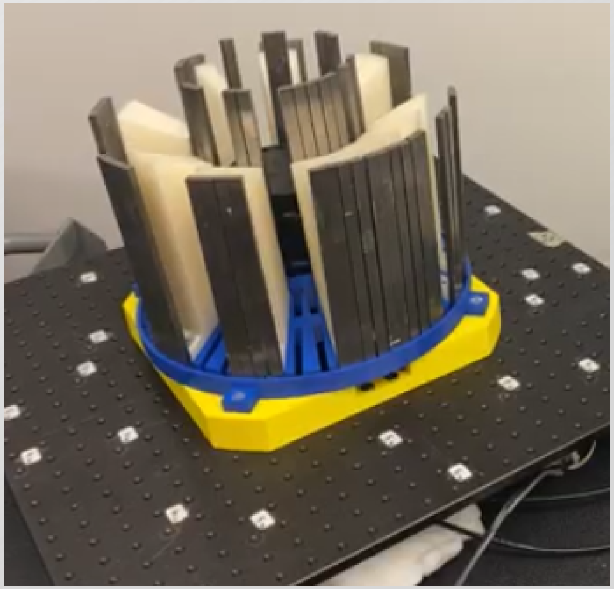
LANTERN (Michigan)

CONFIDANTE (Sandia)

Outer Diameter: 66.6 cm
Inner Diameter: 56.6 cm



Outer Diameter: 51.4 cm
Inner Diameter: ~25 cm

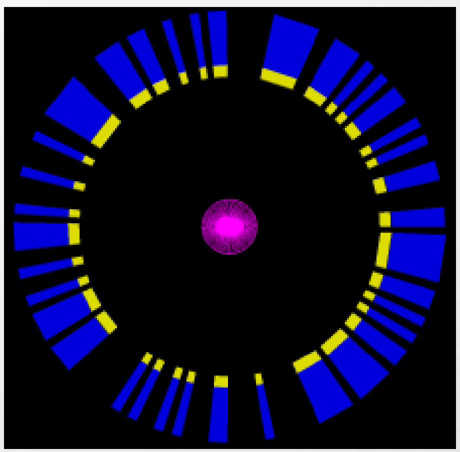


Outer Diameter: 30.635 cm
Inner Diameter: ~12 cm

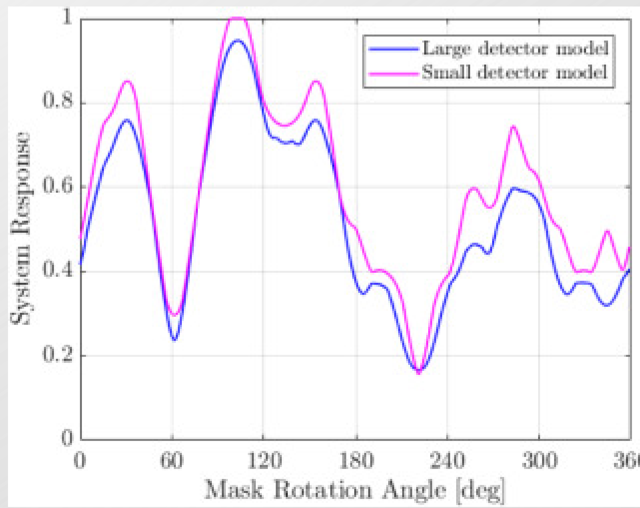
Cylindrical Time-Encoded Imaging

- A rotating coded mask modulates a static source, producing a detector count rate over time that resembles the mask pattern.

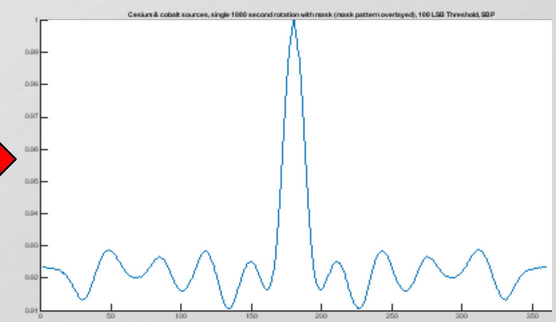
Top View



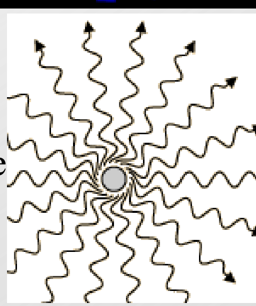
Collect Count Rate



Deconvolved Image



n,γ source



Shah N.P, Vanderzanden J., Wehe D.K.
Nuclear Inst. and Methods in Physics Research, A Design and construction of a 1-D, cylindrical, dual-particle, time-encoded imaging system
Nucl. Instrum. Methods Phys. Res. A (2019), pp. 1-7, 10.1016/j.nima.2019.01.012

- The size of the detector compared to the distance to the inner layer of the mask dictates the count rate over time.

Motivation

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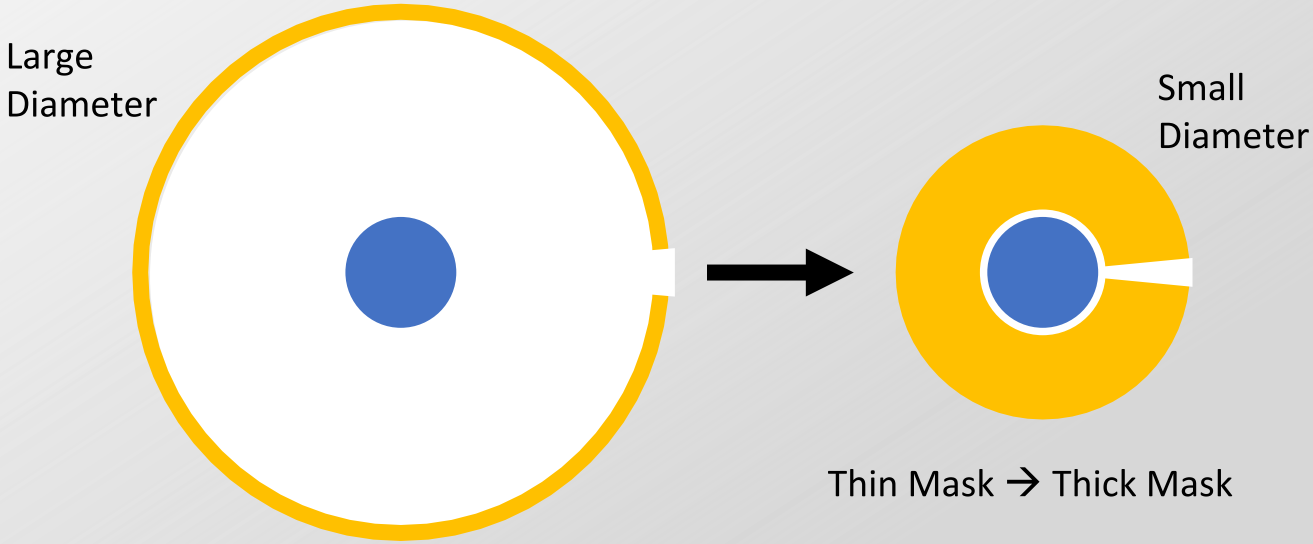
- 1D, man-portable, dual particle cTEI imaging system is desirable for nuclear nonproliferation
- Overall Goal: Retain image quality when transitioning from a large to small diameter coded mask.



Mission Relevance

Nuclear Nonproliferation

Preventing nuclear weapons proliferation and reducing the threat of nuclear and radiological terrorism around the world are key U.S national security strategic objectives that require constant vigilance. NNSA's Office of Defense Nuclear Nonproliferation works globally to prevent state and non-state actors from developing nuclear weapons or acquiring weapons-usable nuclear or radiological materials, equipment, technology, and expertise.

- **Nonproliferation applications: source verification and search operations, forensics, post-event operations (deterrent capability)**
- **Effective Fieldable Instrument: Compact, cost-effective fast neutron/gamma imagers**

PROJECT PLAN

- PHASE 1: design and implement initial system
  - design mask bed
  - compare coded aperture patterns
  - implement 1-3 layered designs
- PHASE 2: simulate and implement design refinements
  - use MCNP for tungsten side wall effectiveness
  - Evaluate tradeoffs for weight, size, SNR, and image resolution
  - Compare LANTERN designs for specific applications
- PHASE 3: project validation and advancement
  - measurement campaigns
  - more sophisticated imaging and coded aperture techniques

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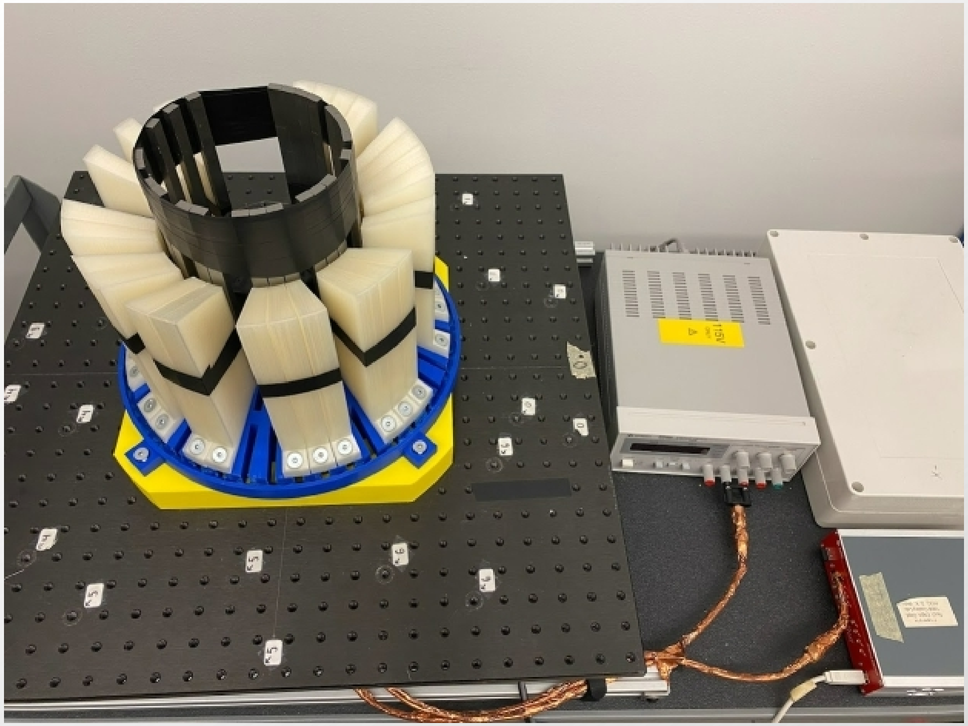
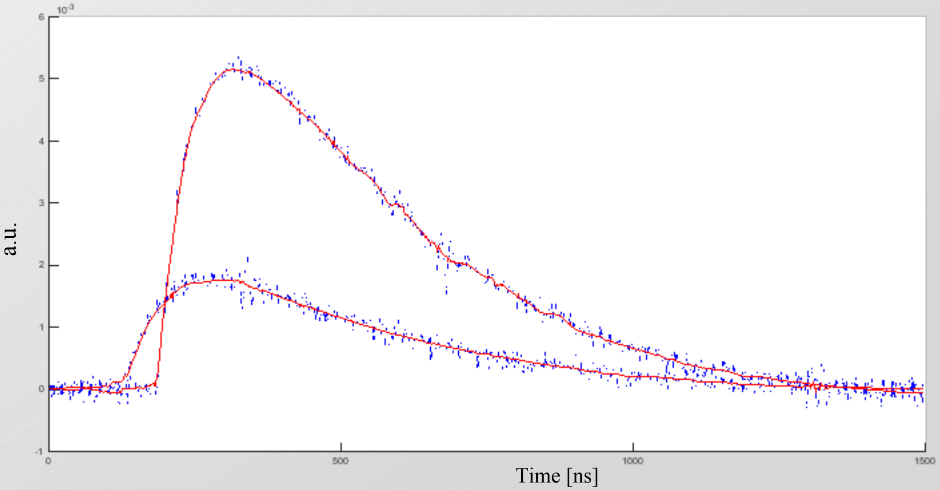
Current System Status





- Grounding issues resolved. Digital processing applied to improve first experimental results.
- Completed gamma-ray experiments for some of the initial designs

First Experimental Results

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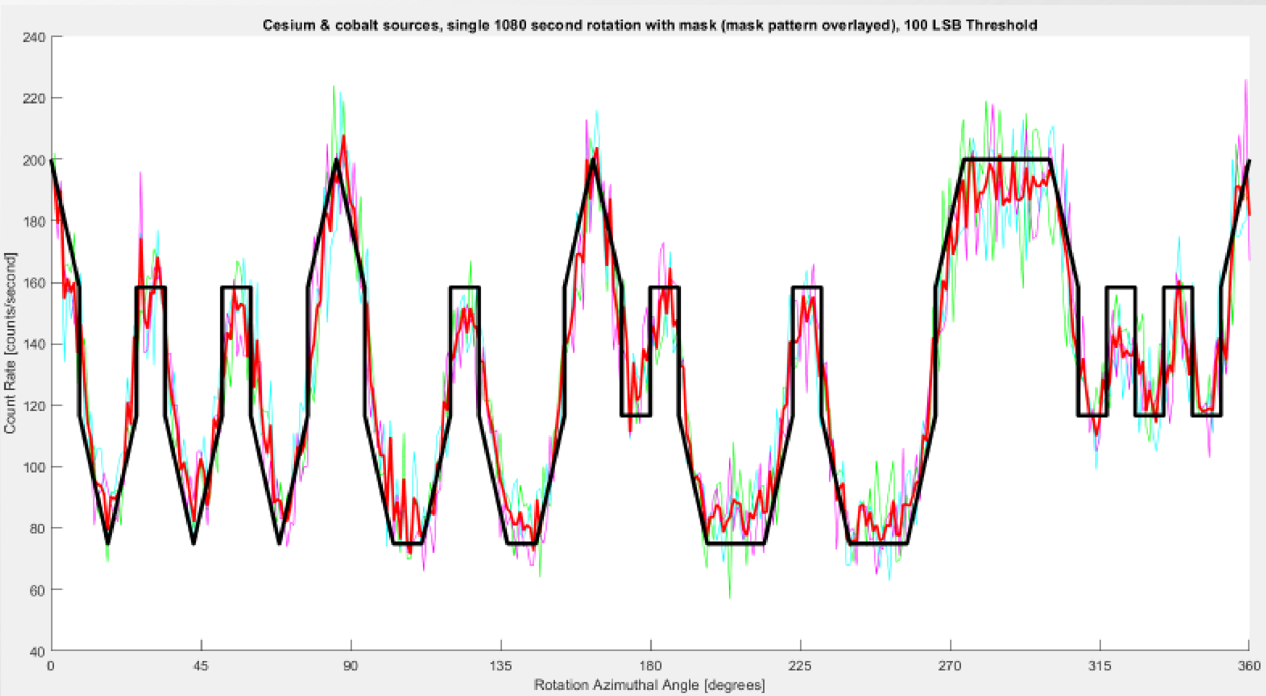
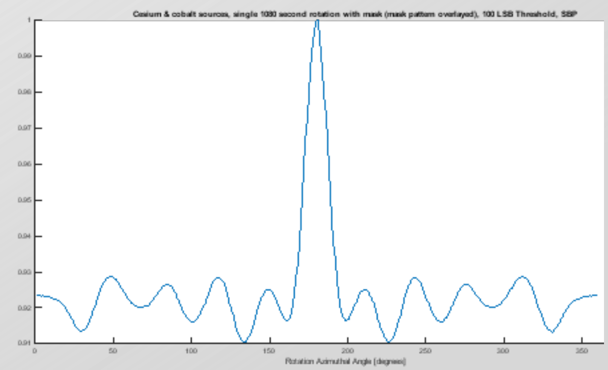
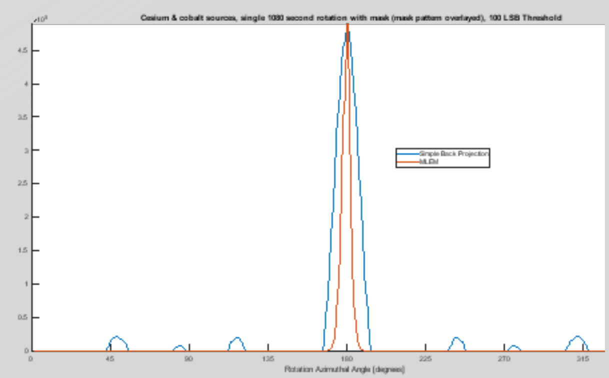
- Angular resolution ranges from 15º to 5º SBP and MLEM, respectively.
- Result: first experimental results match the ideal point response well.







MTV Impact

- **Personnel transitions**
  - John Kuchta is a virtual intern at Sandia National Laboratories where he will continue working on unconventional TEI mask designs and optimizations
- **Technology transitions**
  - This project is being conducted in collaboration with the Radiation and Nuclear Detector Systems group at Sandia National Laboratories and supports NA-22 funded projects there.

Coded Aperture Optimization - Sandia

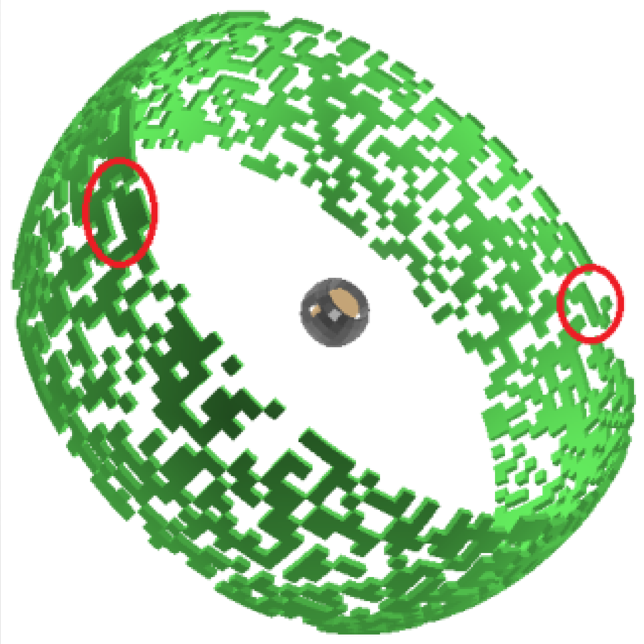
- Point spread function
  - "square" spread function
  - "circle" spread function

  Better representation for extended sources

- Great Deluge Algorithm
  - random patterns

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

  - N_x and N_y are the dimensions of the coded aperture pattern and a and A are the pattern and the Fast Fourier Transform of the pattern, respectively

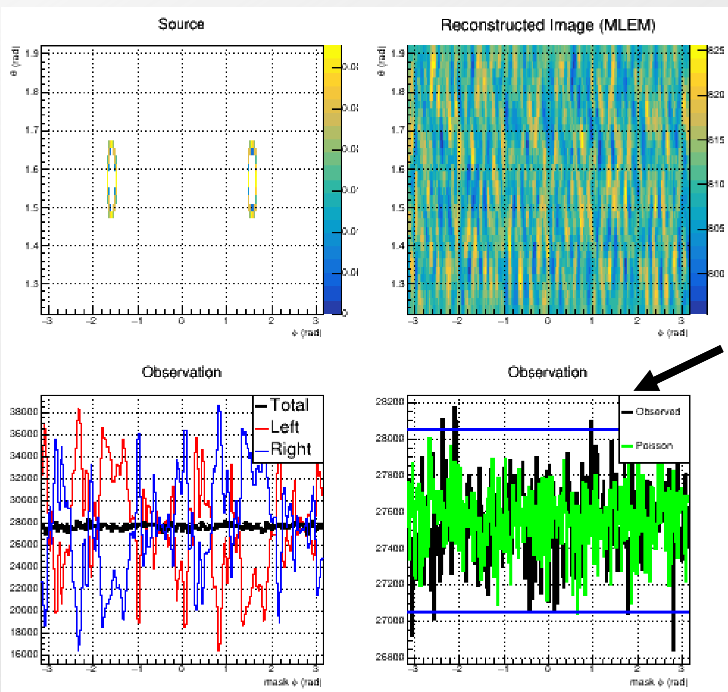


Sandia COGNIZANT mask-antimask cTEI configuration

Zero Knowledge Testing of Modified Extended Sources - Sandia

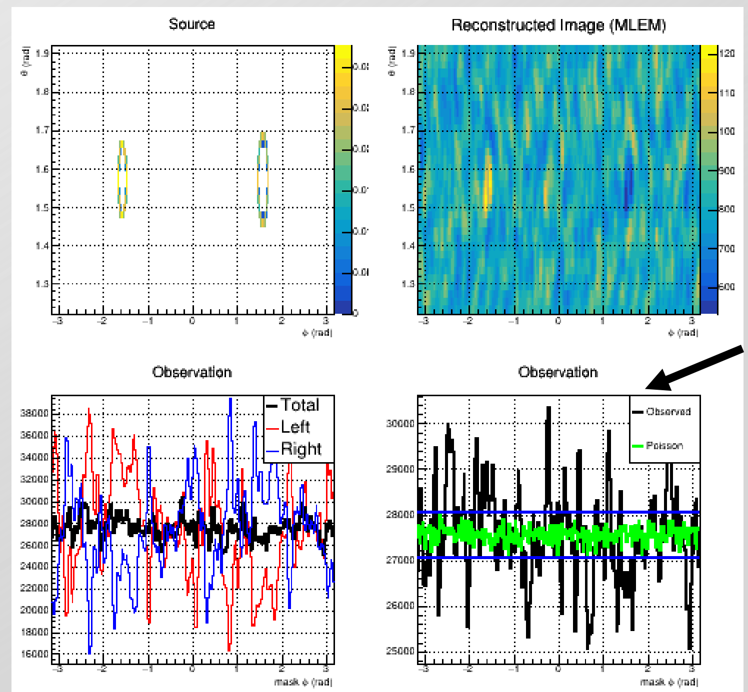
- An ideal mask anti-mask pattern should view two identical ring sources as Poisson noise
  - Maximum deviation from Poisson is desired when sources are not identical in ring diameter

Identical Eu Ring Sources of Diameter 5 cm



Very little deviation from Poisson noise

One Eu Source Diameter is Modified to 6 cm

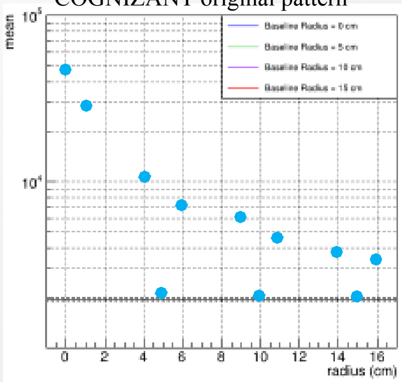


Deviation from Poisson noise

Zero Knowledge Metric Comparison - Sandia

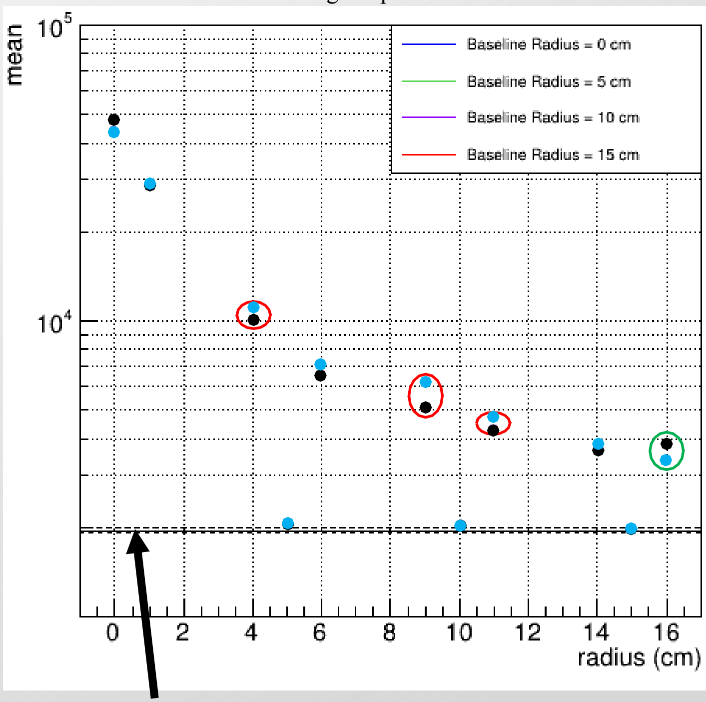
- Mean of negative log likelihood (NLL)
- GDA generated patterns perform worse than COGNIZANT original pattern for smaller sources but better for extended sources

COGNIZANT original pattern

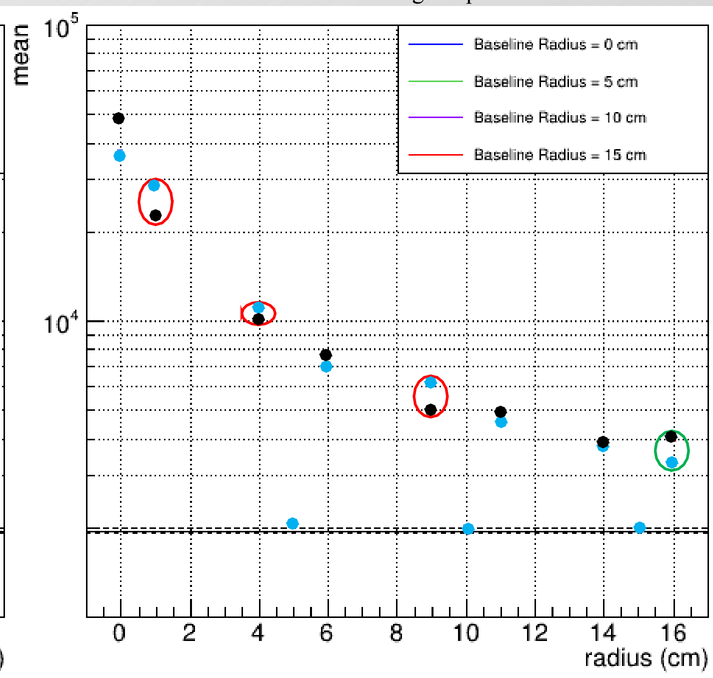


1st Source Radius	Modified Source Radius
0 cm	0 cm
0 cm	1 cm
5 cm	4 cm
5 cm	5 cm
5 cm	6 cm
10 cm	9 cm
10 cm	10 cm
10 cm	11 cm
15 cm	14 cm
15 cm	15 cm
15 cm	16 cm

GDA Optimized FOM Pattern overlapping COGNIZANT original pattern



GDA Pattern #3 overlapping COGNIZANT original pattern



Poisson noise (3 sigma)

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Simulation Designs

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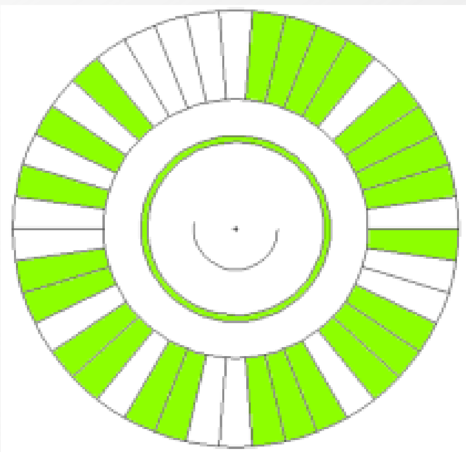
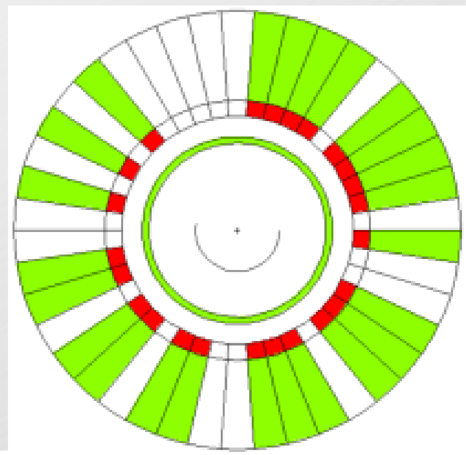
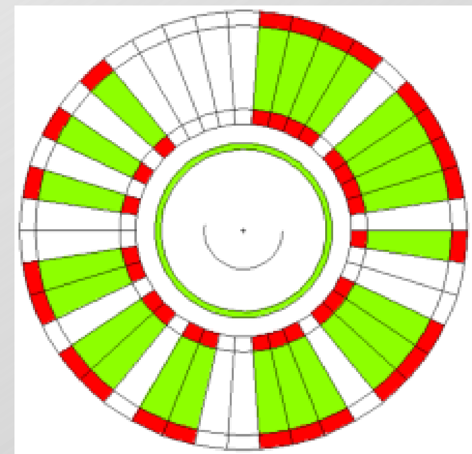
- First 5 LANTERN design variations with fixed inner/outer diameters
  - Polycarbonate (green)
  - Tungsten (red)



4.34075 kg

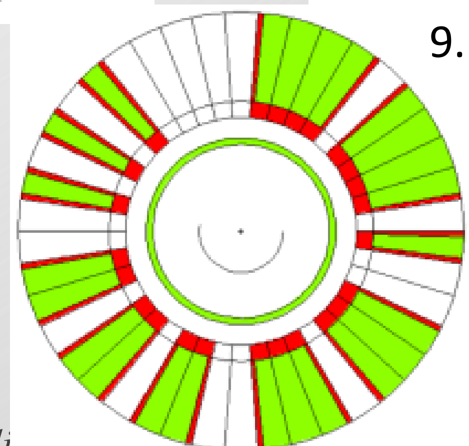


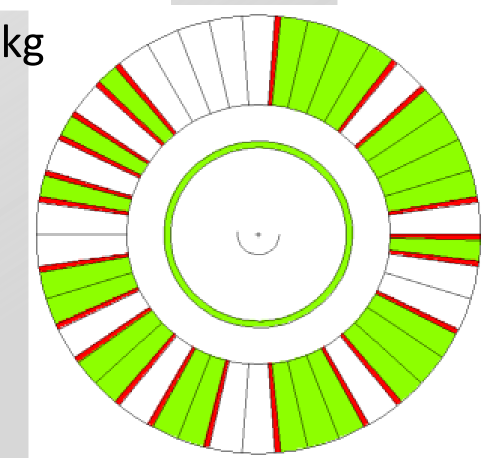
9.16375 kg



23.41575 kg

17.85265 kg





13.02965 kg

Simulation Results – Gamma Source Modulation

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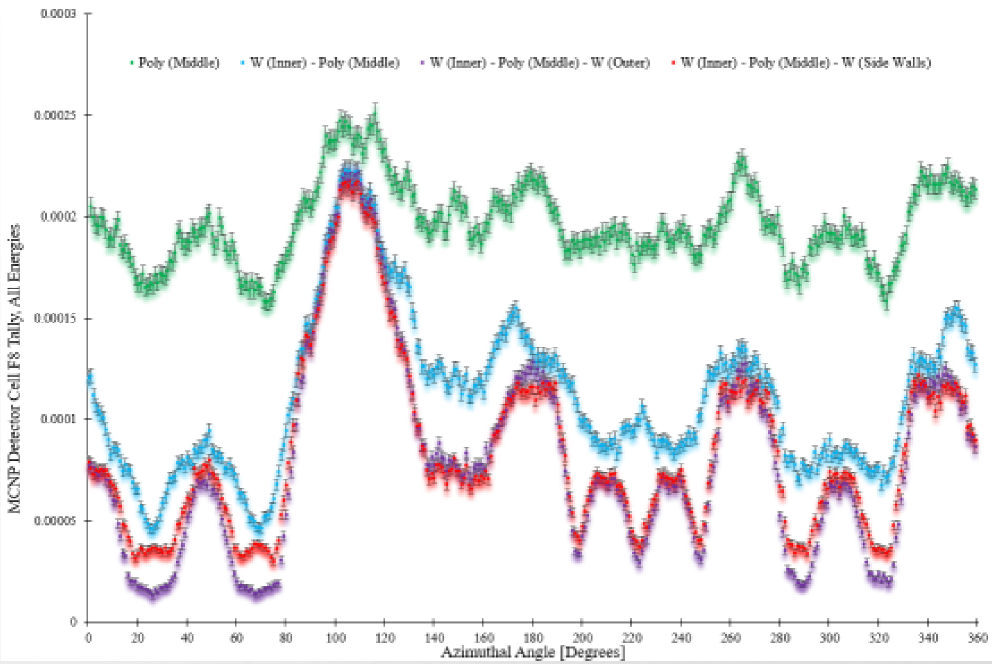
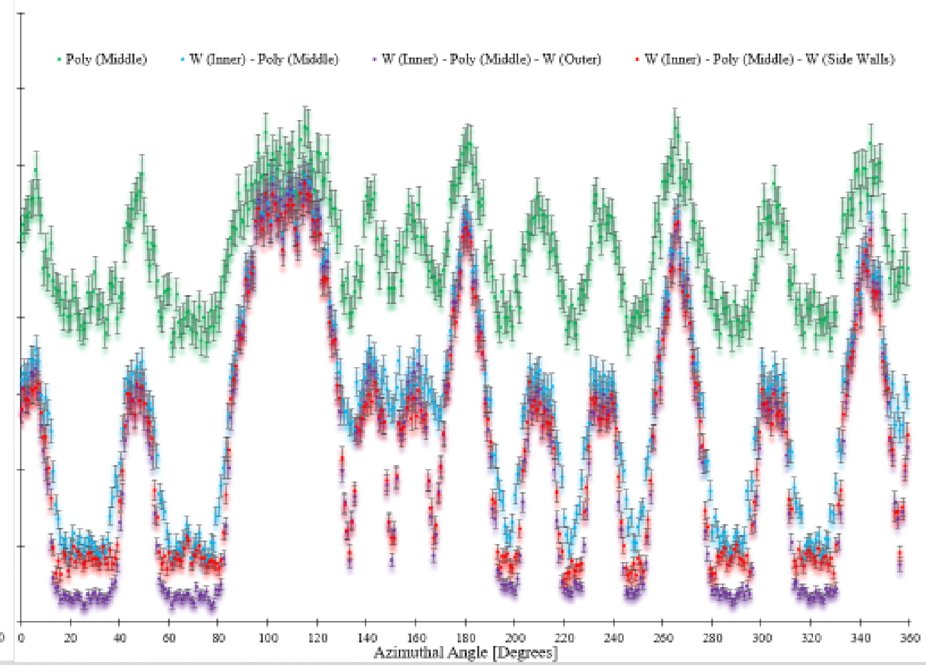
Stilbene (2 inch)



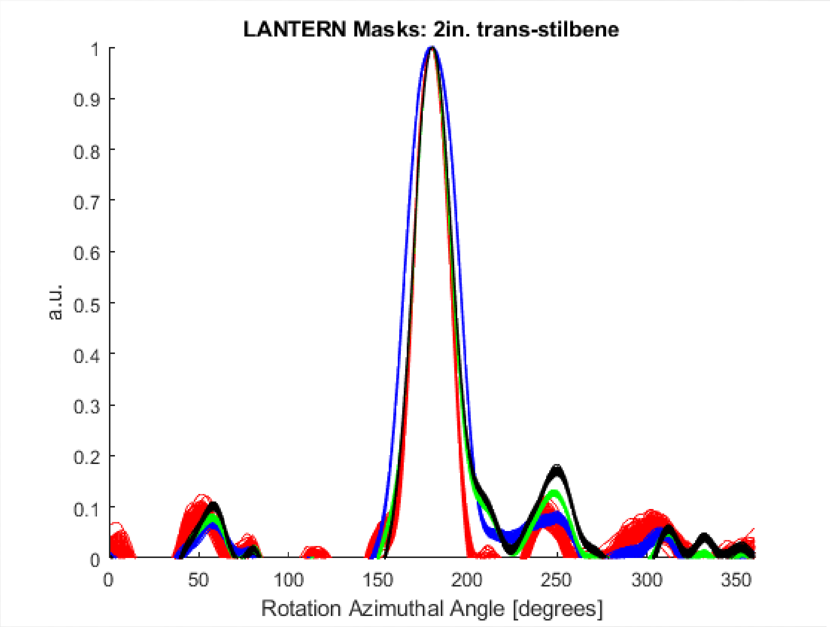
CLLBC (1 inch)

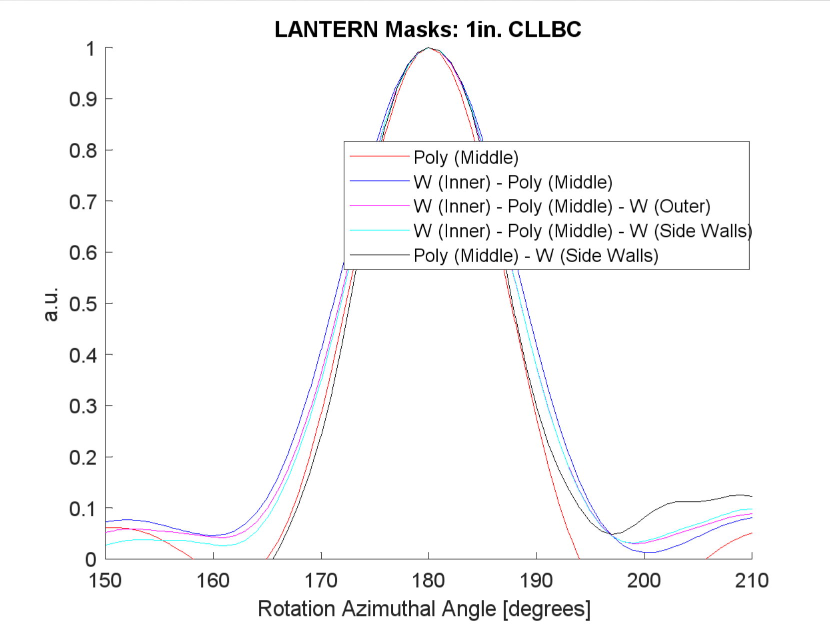


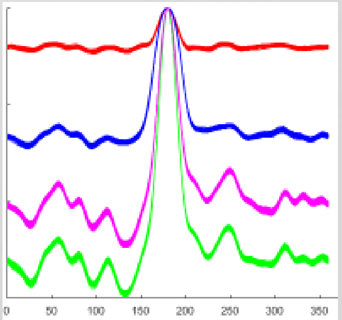
- Detectors larger than 1 inch in diameter have modulation plot artifacts because there is less space between it and the mask
- Result: tungsten wall addition to the side of open elements decreases escape through closed mask elements

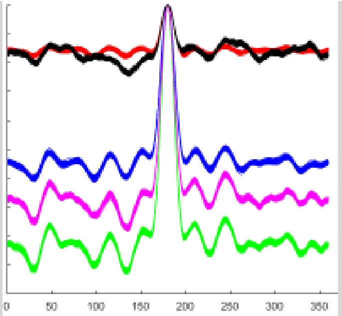
Simulation Results – Angular Resolution

- Simulated angular resolution ranges from 9º - 12º. Larger detectors result in greater side lobe noise.
- Result: Design with poly and tungsten side lobes (black) has low SNR.



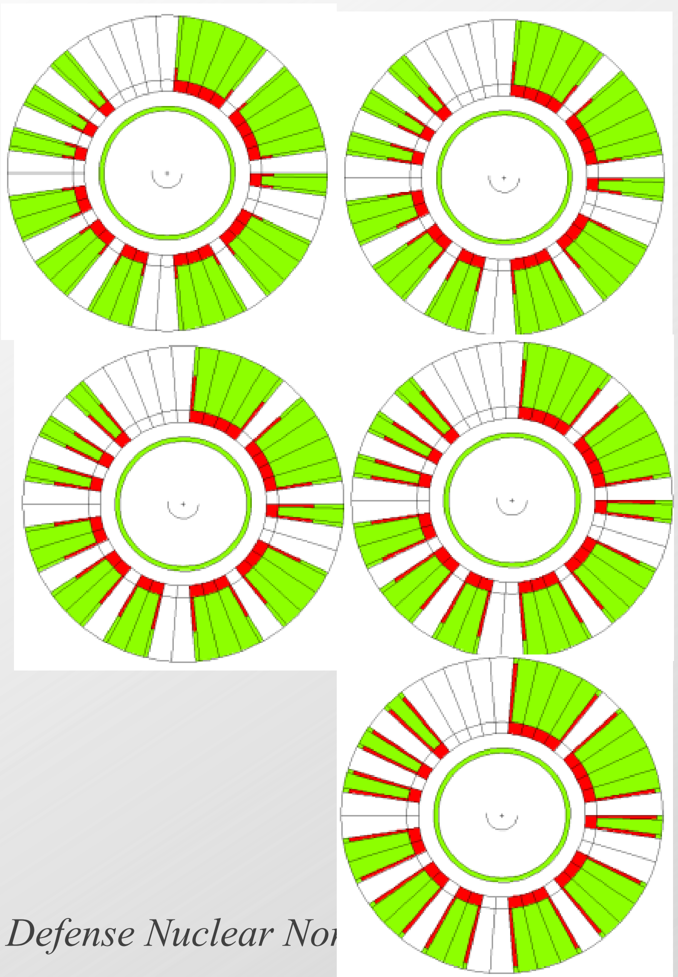


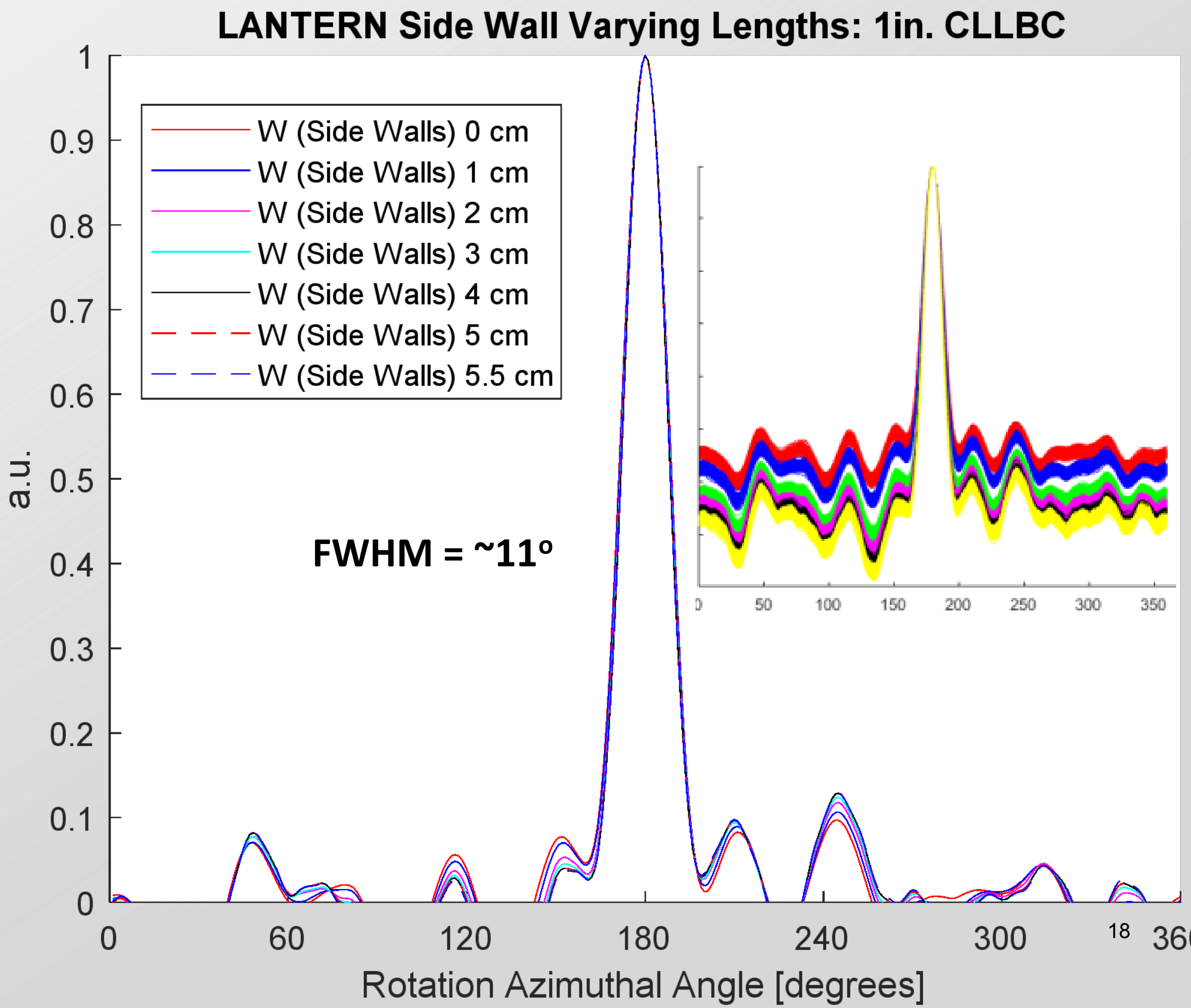




Simulation Results – Tungsten Side Walls

- Side wall extension improves source intensity but does not significantly improve angular resolution and increases side lobe noise.





Conclusion

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- PHASE 1: design and implement initial system
  - coded aperture optimization methods coded aperture for LANTERN and COGNIZANT need to be further developed
  - dual particle sources need to be measured for further LANTERN validation and more initial designs need to be implemented
- PHASE 2: simulate and implement complex designs
  - tungsten side walls are useful in decreasing escape through closed mask elements
  - weight, SNR, and image resolution still need to be optimized as mask thickness and other detectors still need to be tested

Acknowledgments

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Sandia National Laboratories

The authors would like to acknowledge Melinda Sweany and the rest of the Radiation and Nuclear Detector Systems group from Sandia National Laboratories for their valuable research and technology.

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525. The US DOE National Nuclear Security Administration, Office of Defense Nuclear Nonproliferation Research and Development for co-funding this work. This presentation has been reviewed and approved for unlimited release as document SAND2021-3546 PE.

Acknowledgements

The Consortium for Monitoring, Technology, and Verification would like to thank the NNSA and DOE for the continued support of these research activities.

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Extra Slides

Mask Test Bed

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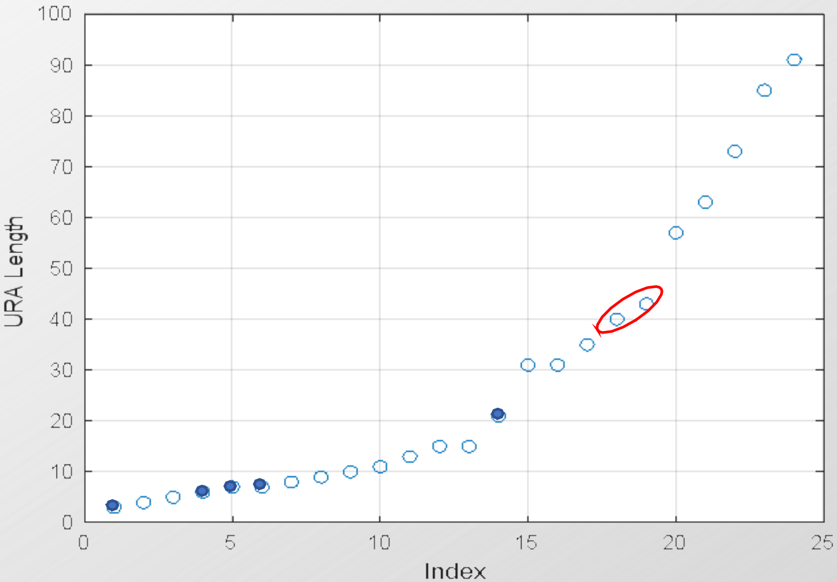
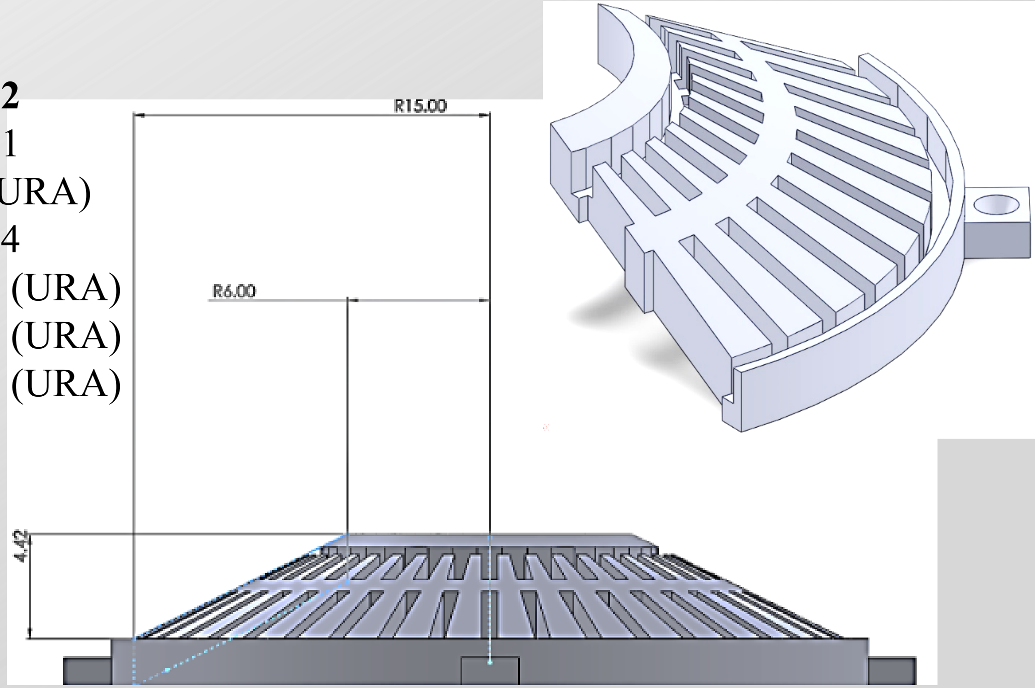
- Design of a mask bed for testing of several unconventional cTEI masks
- Goal: Allow for even and odd numbered mask patterns (can have URAs as well as mask-antimask patterns)



42
21
(URA)
14
7 (URA)
6 (URA)
3 (URA)



Detector Setup

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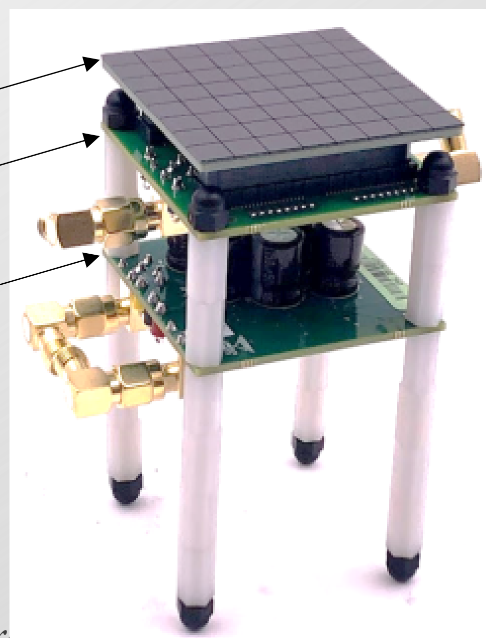
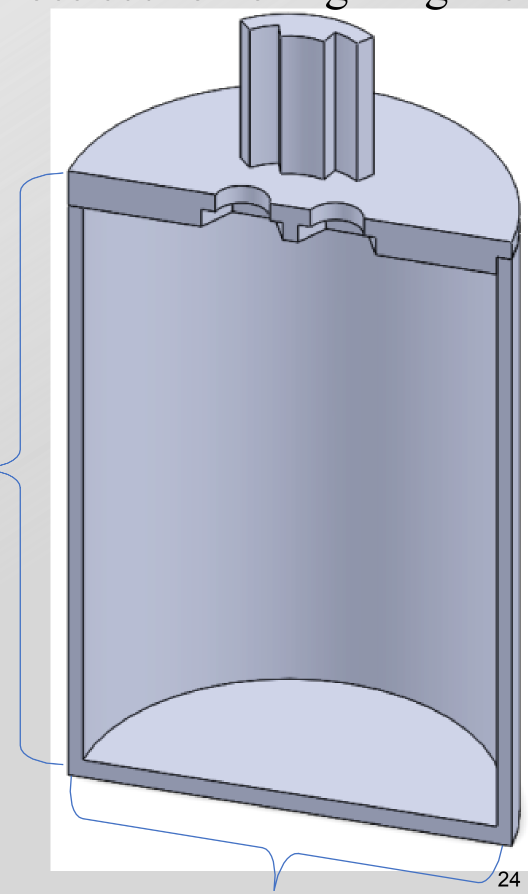
- 16x16 array of 4mm x 4mm SensL J-Series SiPMs
- Summing board and power board from Sandia National Laboratories
- Goal: Allow for ease of crystal swapping



Cross section of light tight box



First System Results

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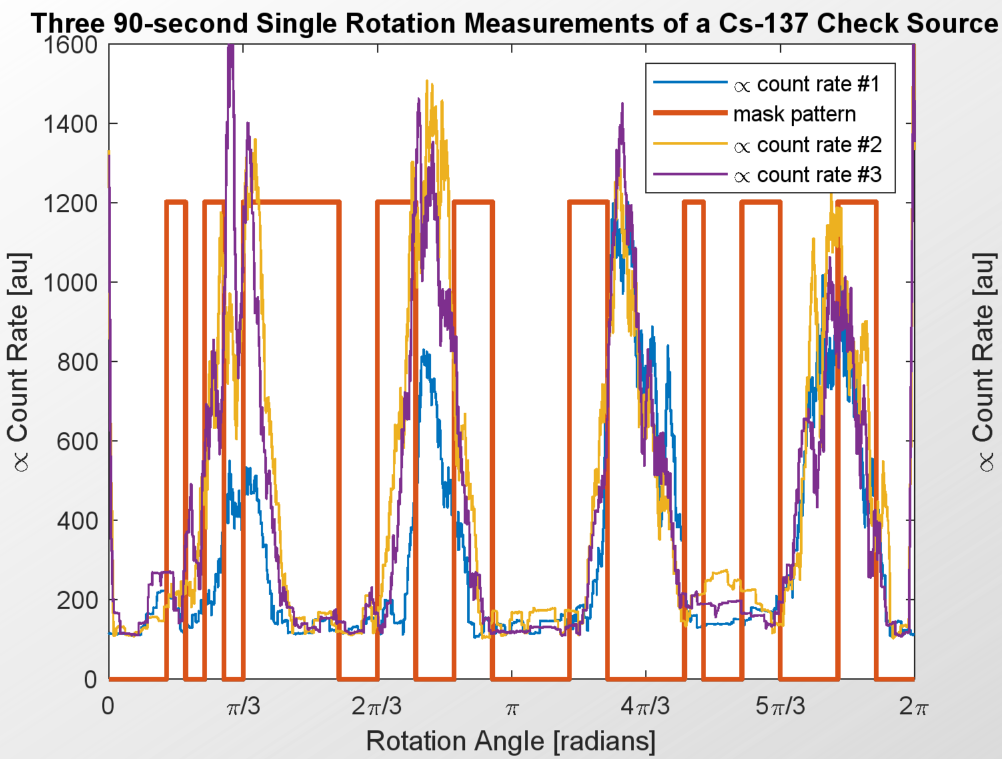

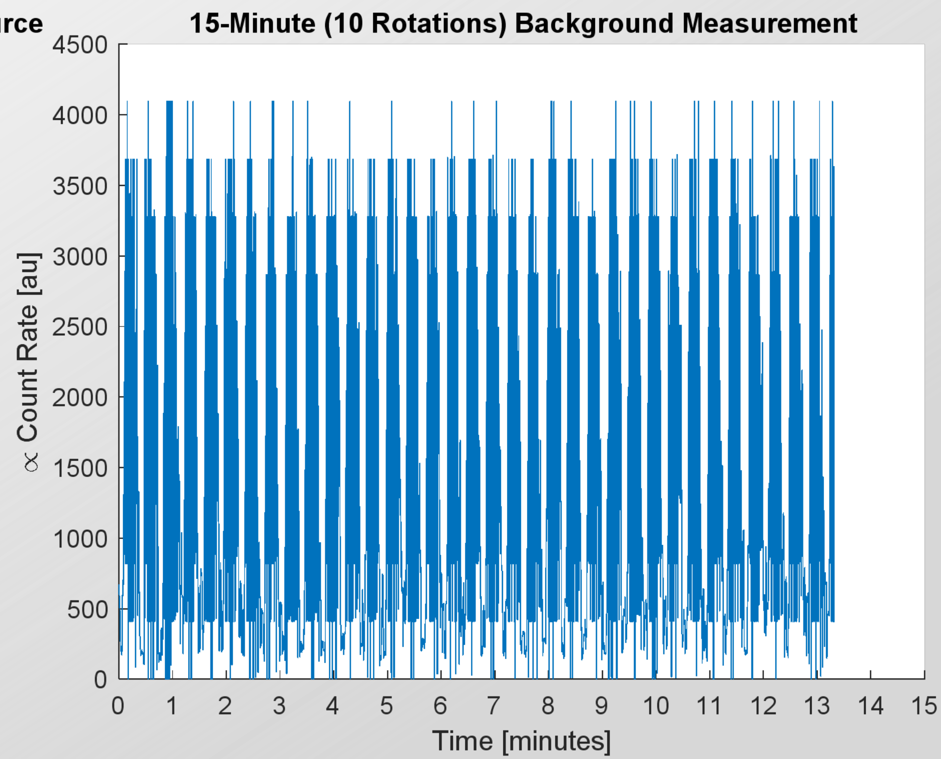

- **Single Rotation Measurements**
  - Consistent modulation over several measurements
- **Multiple Rotation Measurements**
  - Issues with CAEN Compass and real time data collection