2020 IEEE Nuclear Science Symposium (NSS) and Medical Imaging Conference (MIC)

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Time-Encoded Dual Particle Imager (lanTErn)

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NNSA Mission Relevance

Nonproliferation

NNSA works to prevent nuclear weapon proliferation and reduce the threat of nuclear and radiological terrorism around the world. The agency endeavors to prevent the development of nuclear weapons and the spread of materials or knowledge needed to create them.

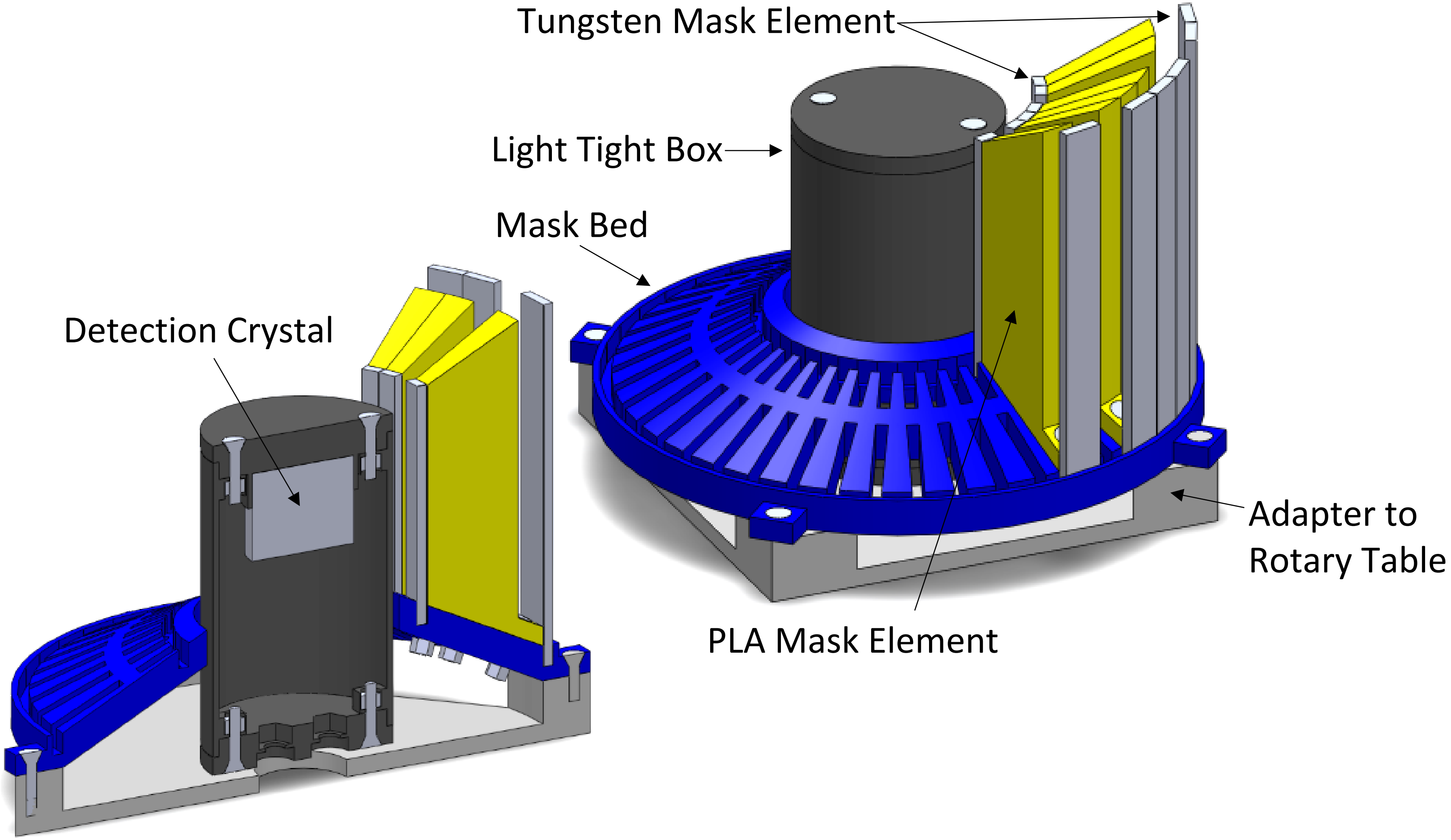
- Nonproliferation applications: source verification and search operations
- Need for a compact, cost-effective fast neutron imager

Monzano Alarm and Nuclear Material Consolidation Project

https://en.wikipedia.org/wiki/Multiple_independently_targetable_reentry_vehicle

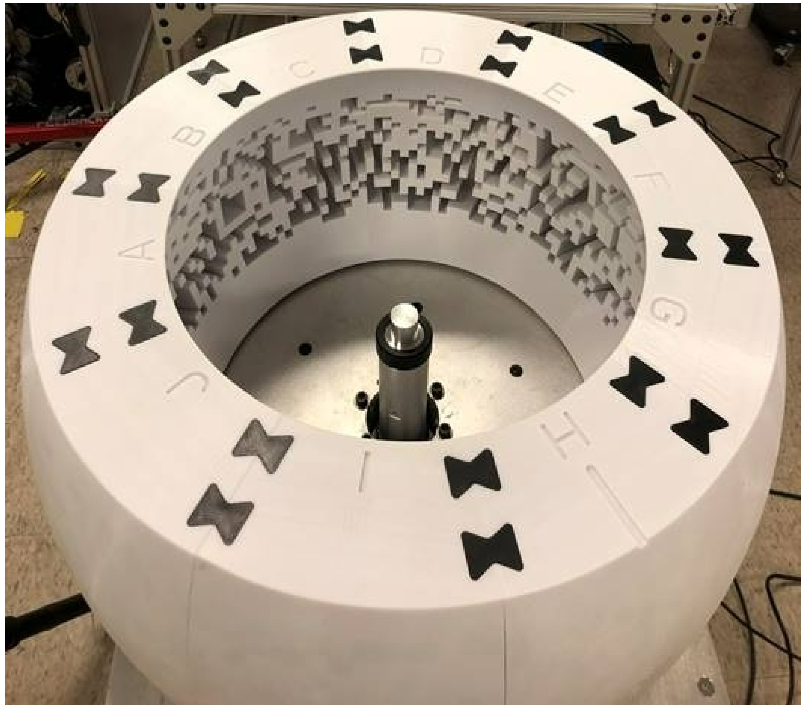
Presentation Overview

- System Comparisons
- cTEI Mask Designs
- Detector Setups
- Theoretical Models and Results
- System Status



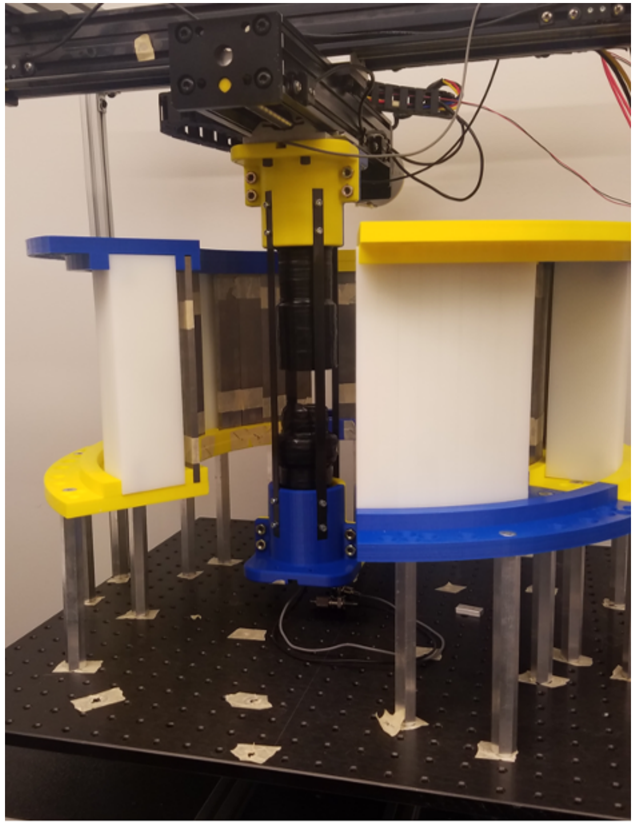
System Comparisons

CONFIDANTE (Sandia)



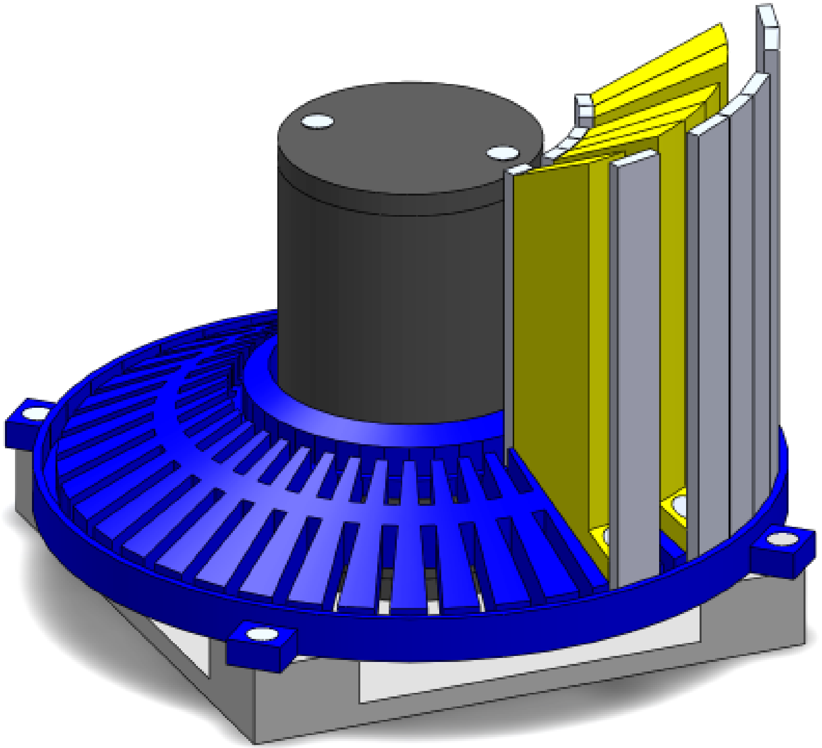
Outer Diameter: 66.6 cm
Inner Diameter: 56.6 cm

MATADOR (Michigan)



Outer Diameter: 51.4 cm
Inner Diameter: ~25 cm

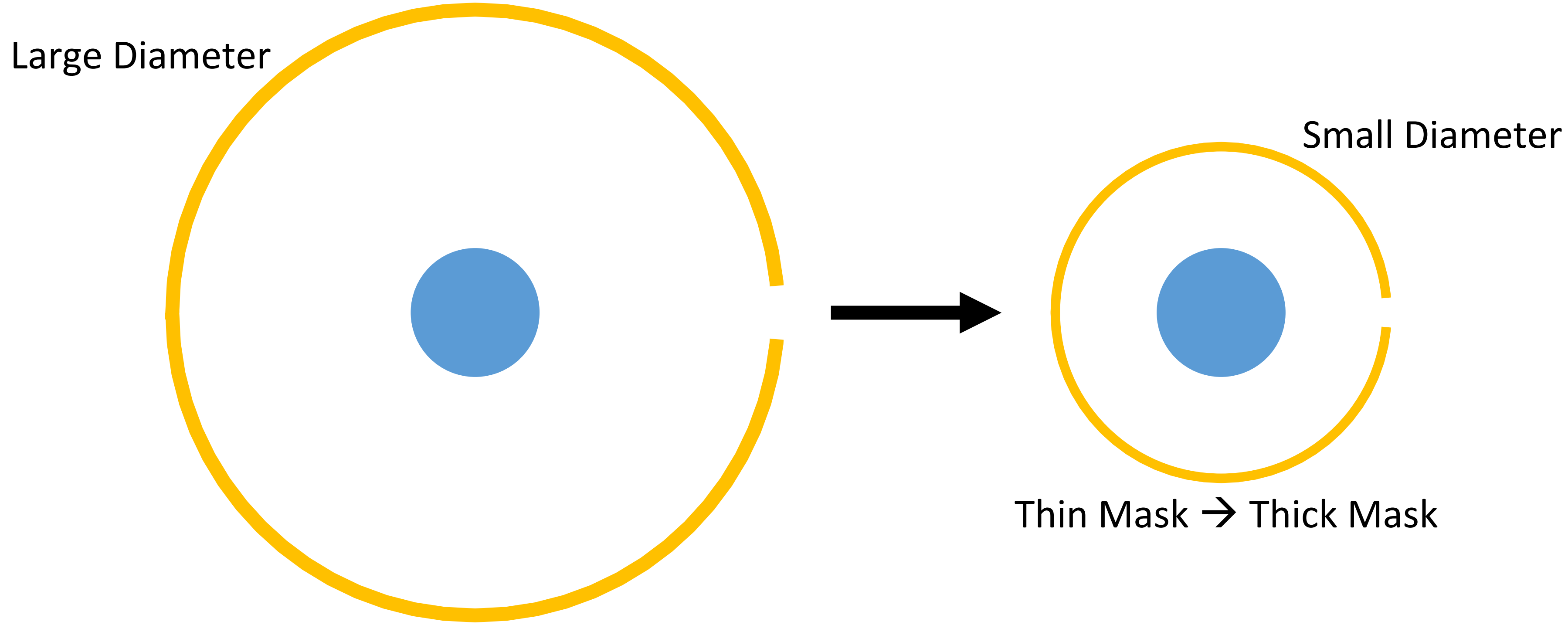
lanTErn (Michigan)



Outer Diameter: 30.635 cm
Inner Diameter: ~12 cm

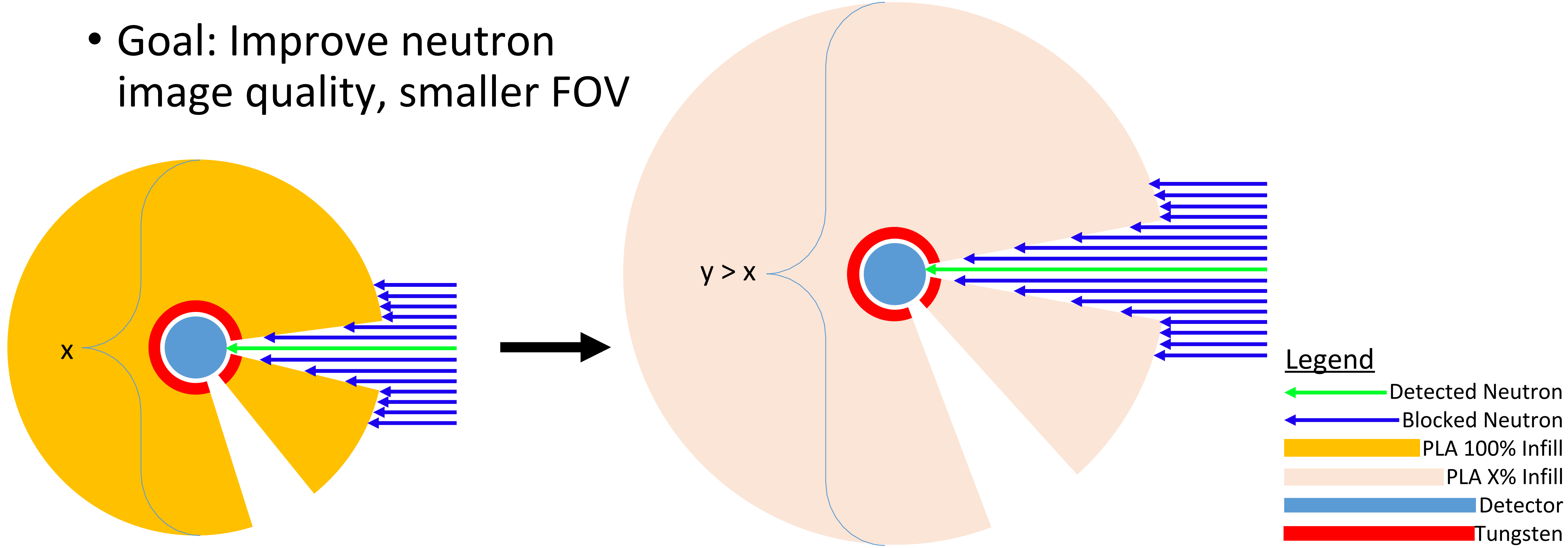
Motivation

- 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.



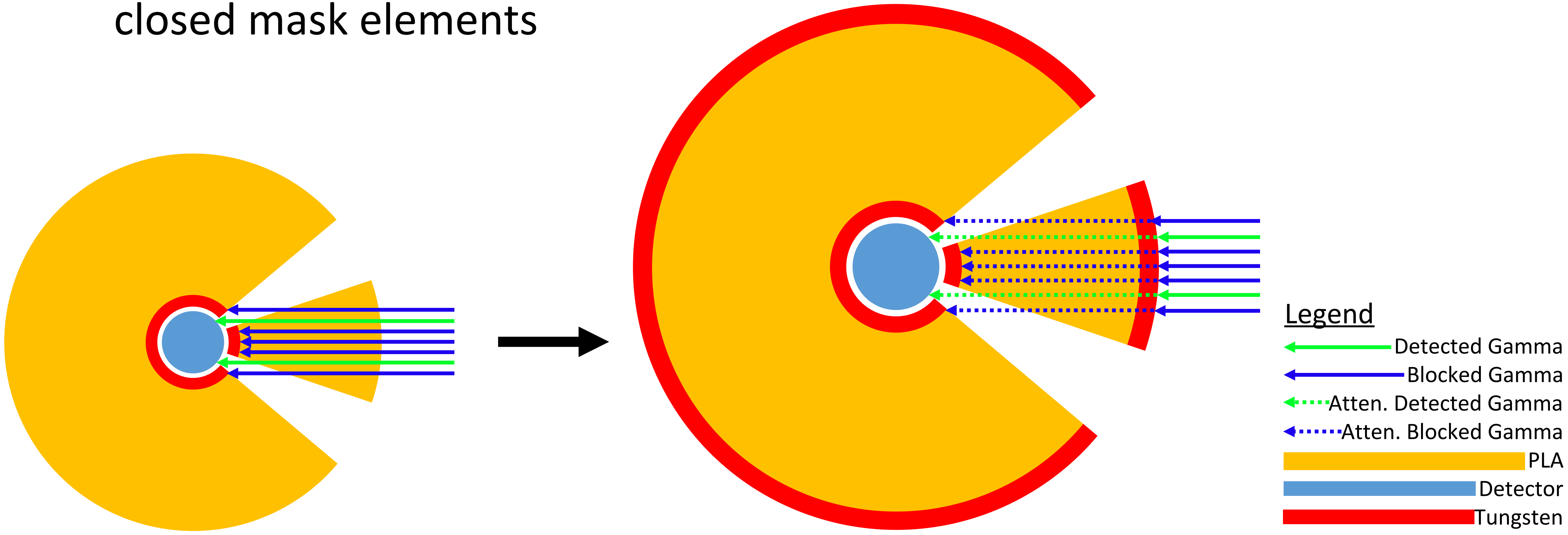
Variable Density Mask (Neutrons)

- Infill of PLA is user specified with the use of 3D printing
- For fixed mass, maintaining attenuation with increased collimation
- Goal: Improve neutron image quality, smaller FOV



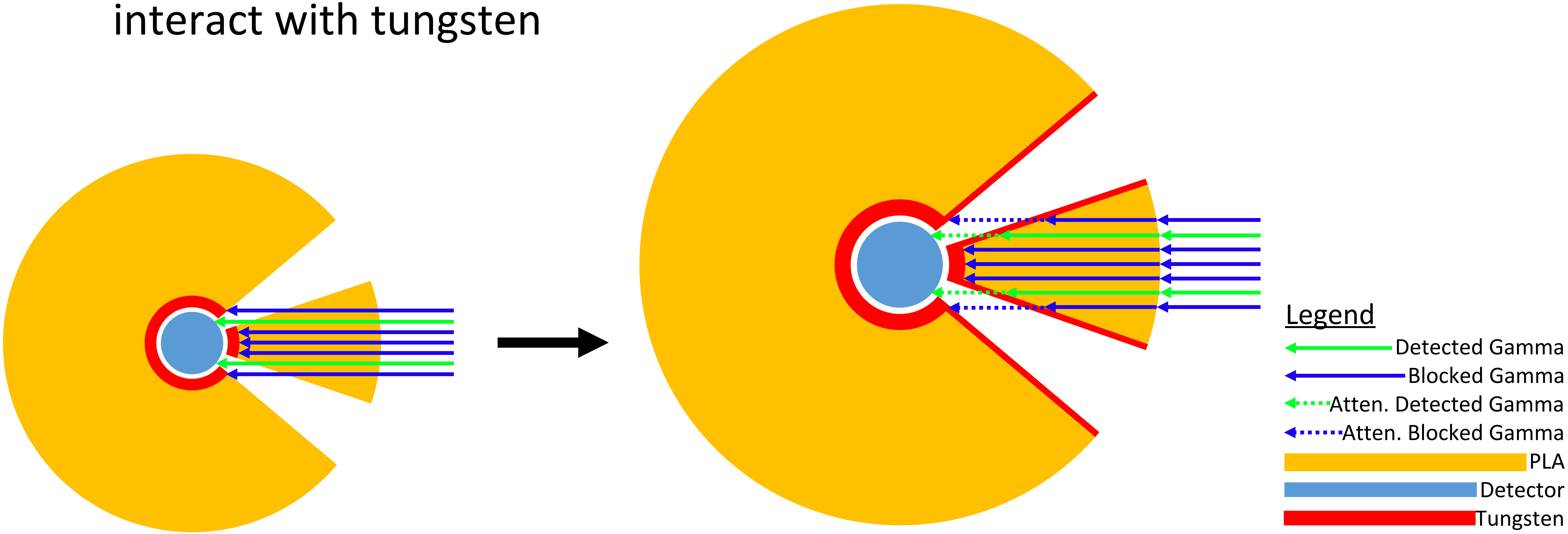
Three Layered Mask (Gamma Rays)

- Addition of an outer ring of tungsten
- Goal: Increase gamma ray collimation, decrease admittance through closed mask elements



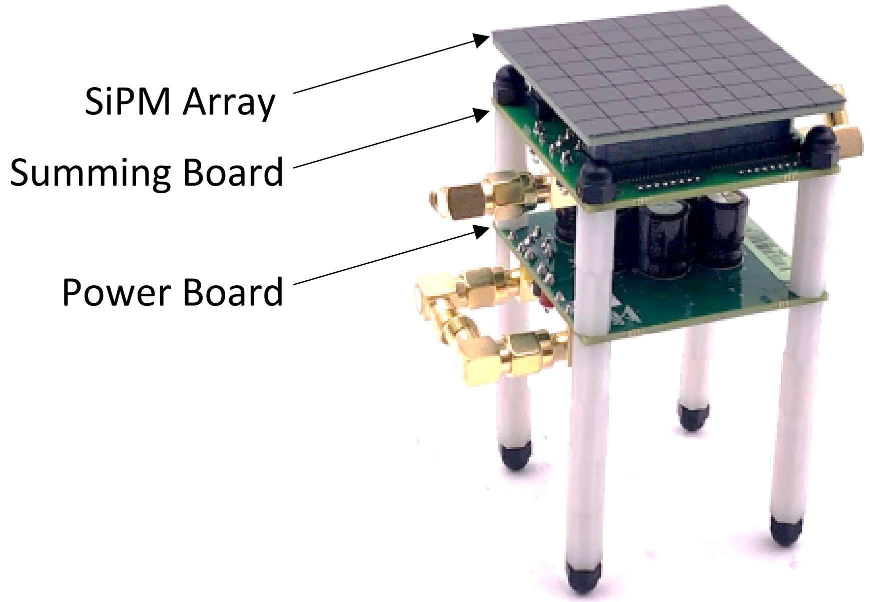
Hollow Mask (Gamma Rays)

- Addition of tungsten on side walls of each open element
- Goal: Ensure that all gamma rays in front of a closed element can interact with tungsten

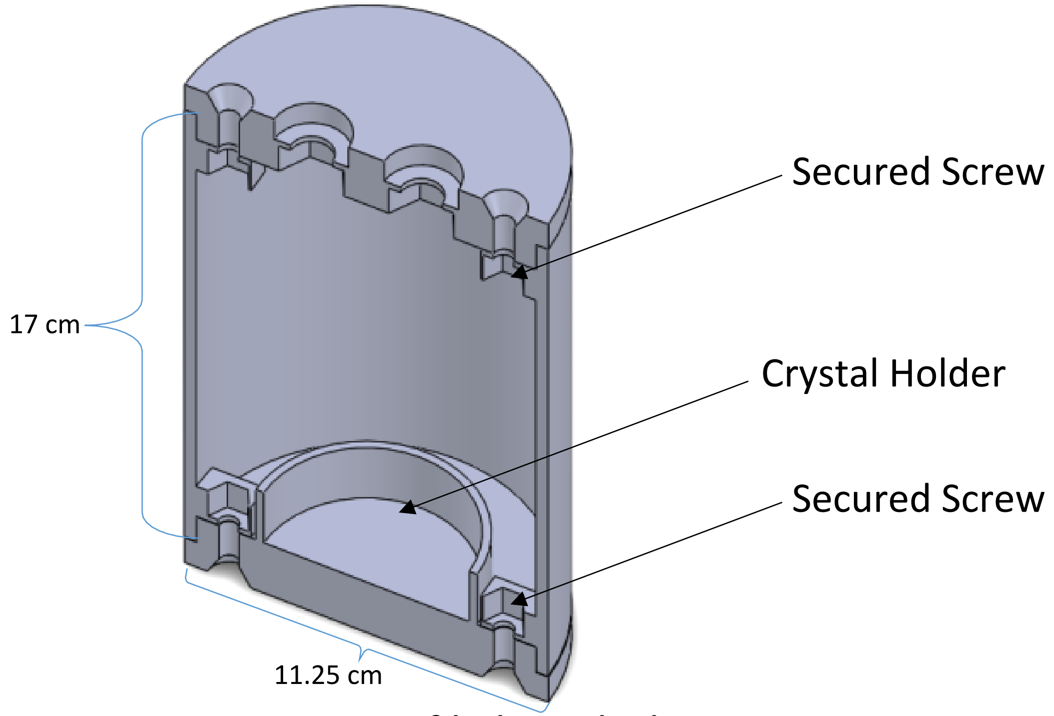


Michigan Detector Setup

- 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



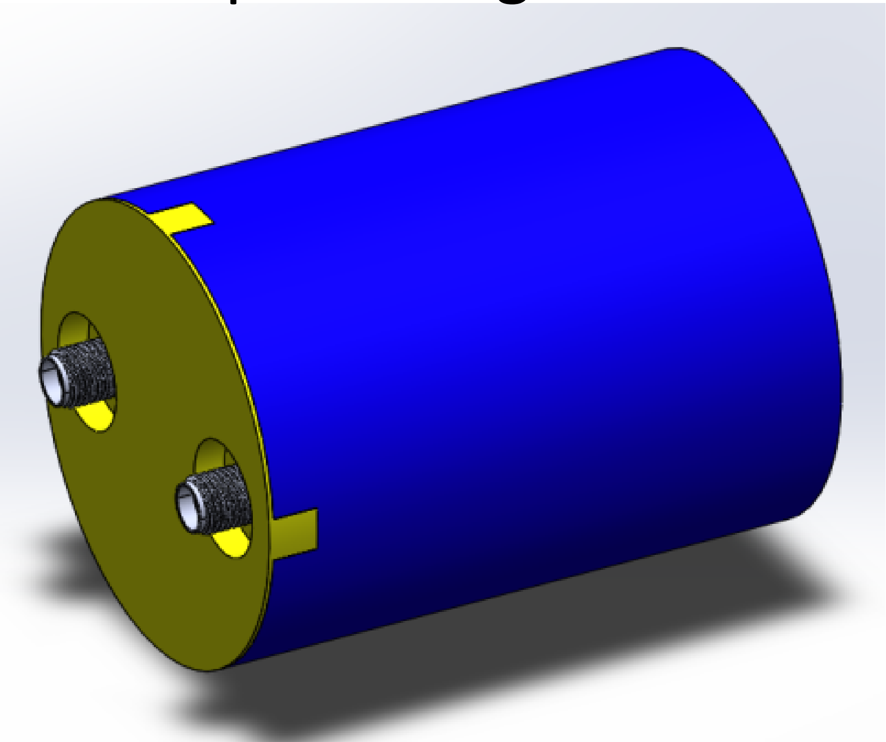
3D printed polycarbonate light tight box



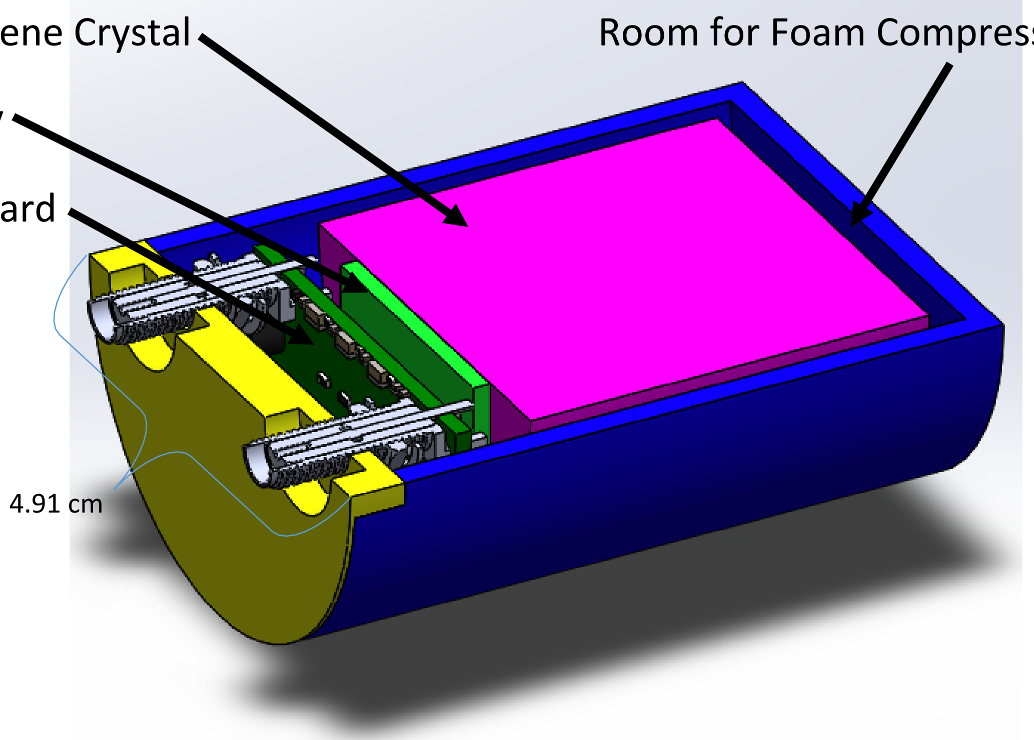
Cross section of light tight box

Sandia Detector Setup

- 4x4 array of 6mm x 6mm Hamamatsu SiPMs
- Goal: Summing board and crystal specific design for light tight box. Compact design for minimal radiation scatter



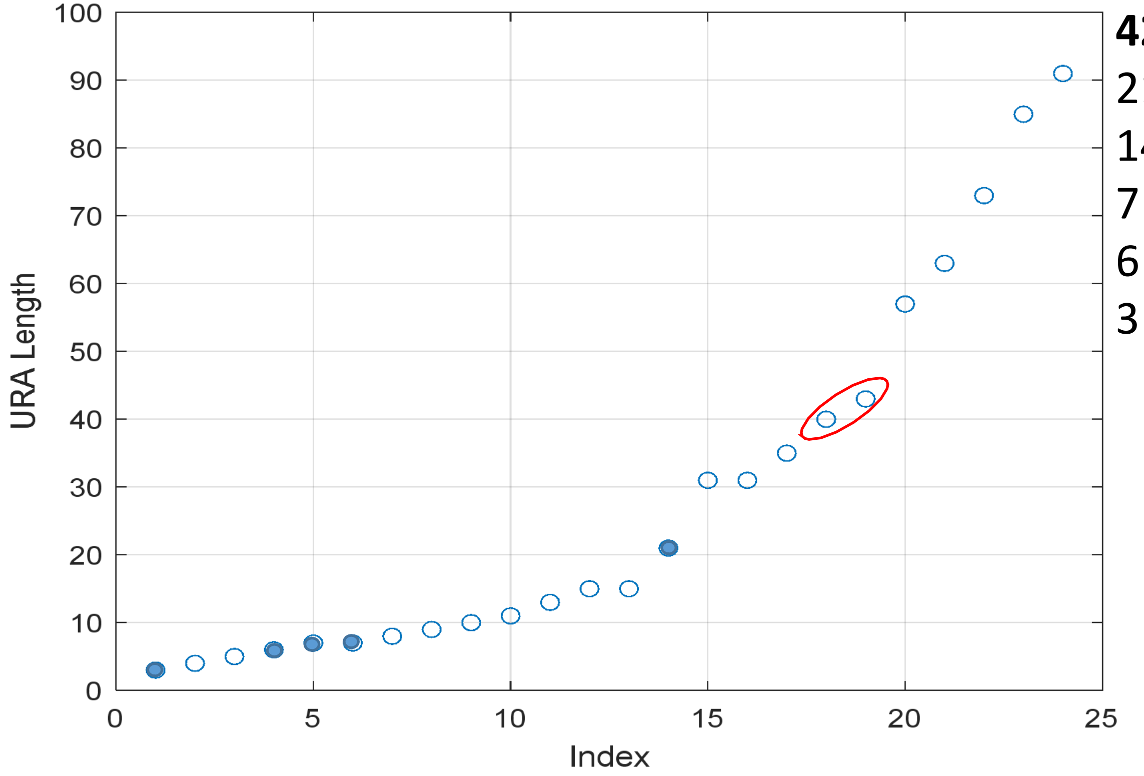
3D printed light tight box



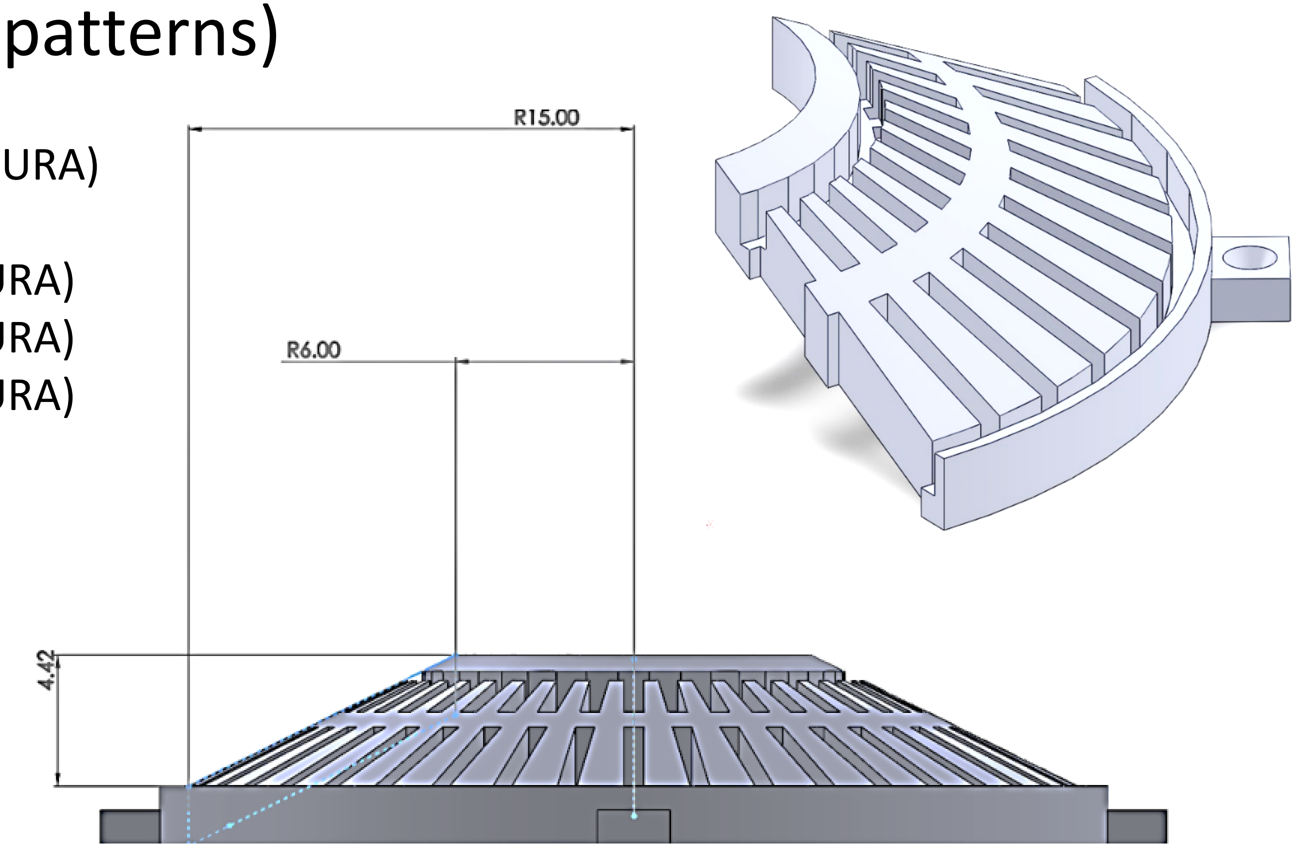
Cross section of light tight box

Mask Test Bed

- 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)



Mask Pattern Design

- Including the detector response instead of ideal coded aperture
- Goal: Create a pattern that produces a delta function for the point spread function

Using a URA (ideal coded aperture):

$(\ \otimes \ ) =$

<u>Point Spread Function</u>

$(\ \otimes \ )\otimes(\ \otimes \ )$

Detector Response

Mask Pattern

Point Spread Function Term Rearranging

$(\ \otimes \ )\otimes(\ \otimes \ ) = (\ \otimes \ )\otimes(\ \otimes \ ).$

There is not a URA for a 42 element mask, so a mask must be created and compared to the URA 40, URA 43 and MURA 41.

Generate mask patterns to find one where

$(\ \otimes \ ) \approx$

to make the PSF closer to a delta function.

Design Summary

- Unconventional Mask Designs
  - Variable Density Mask – neutron collimation and attenuation
  - Three Layered Mask – gamma ray collimation (closed element attenuation)
  - Hollow Mask – gamma ray collimation (decreased closed element escape)
- Light Tight Box
  - Minimal scatter should be achievable with compact, 3D printed designs
- Mask Test Bed
  - Ability to test several designs, patterns and pixel pitches
- Mask Pattern Design
  - Creation of a coded mask pattern with respect to the detector response to improve image quality

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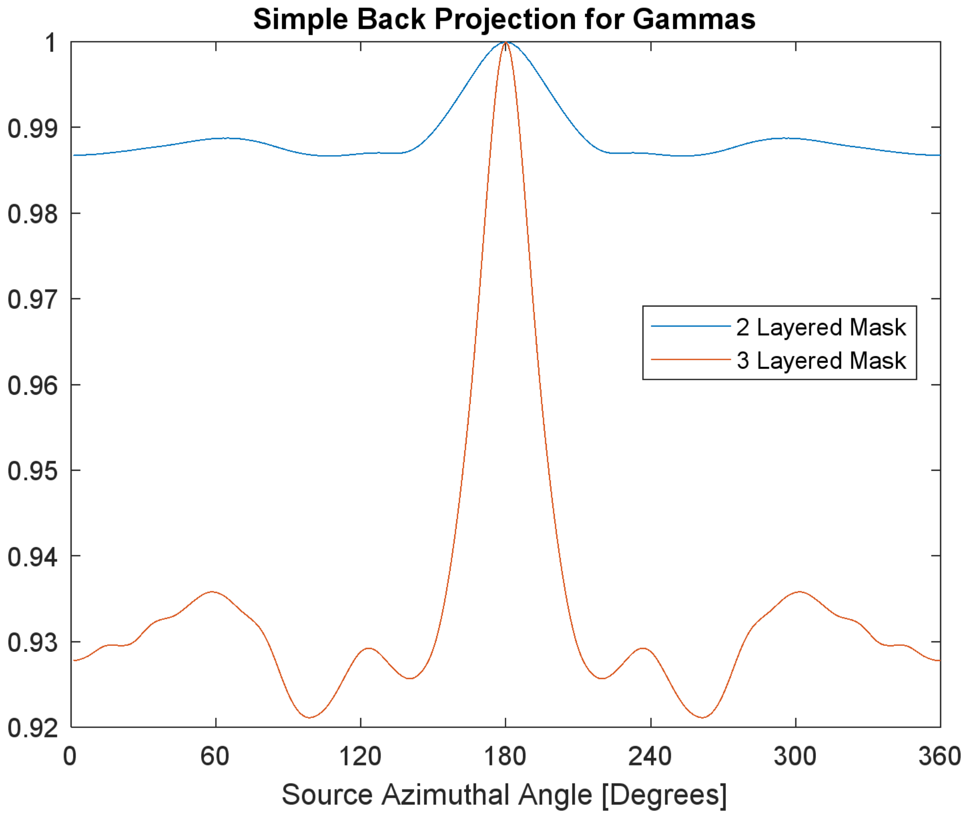
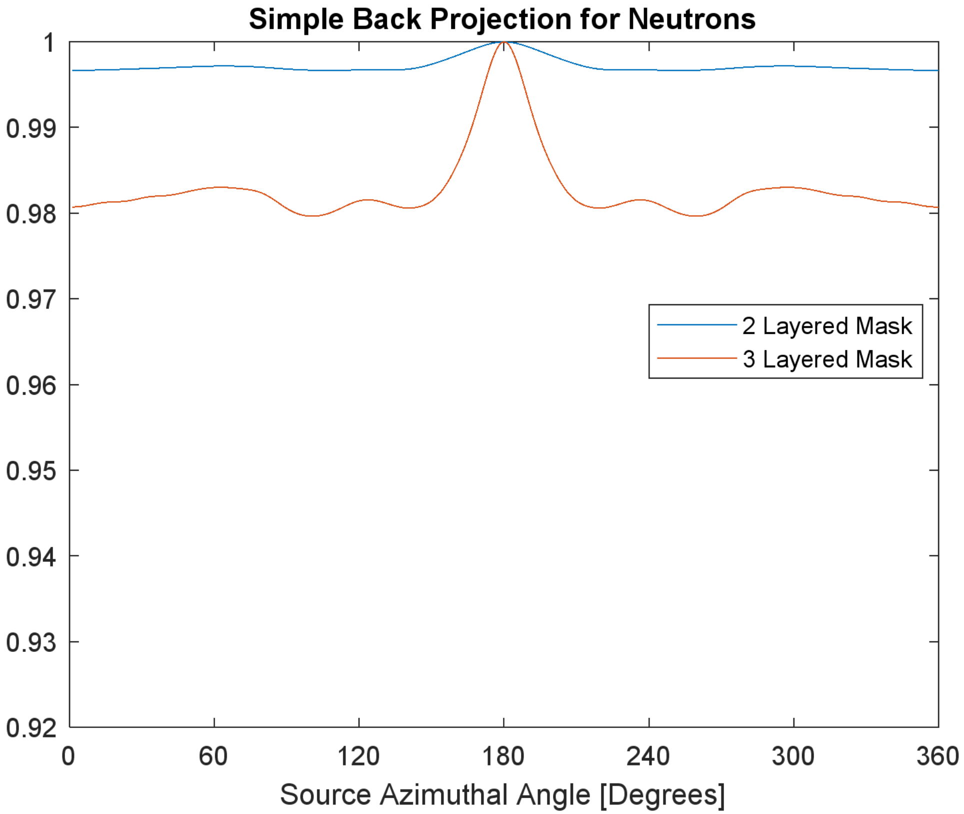
Theoretical Modeling Results

- Simple back projection (SBP) of the two layered mask compared to the three layered mask with a 41 MURA for 2 MeV neutrons and gamma rays



FWHM = 39.6° → 26.5°



FWHM = 39.7° → 26.2°

Theoretical Modeling Conclusion

- Simple back projection image reconstruction shows greater modulation for both neutrons and gamma rays with the addition of the outer tungsten layer, more prominent for gamma rays
- Neutrons see a thicker low-Z mask and should have more attenuation, which is reflected in the lower FWHM in the SBP
- Gamma rays see two high-Z layers separated by the thickness of the PLA and more non-central peaks are present as the number of mask elements is increased

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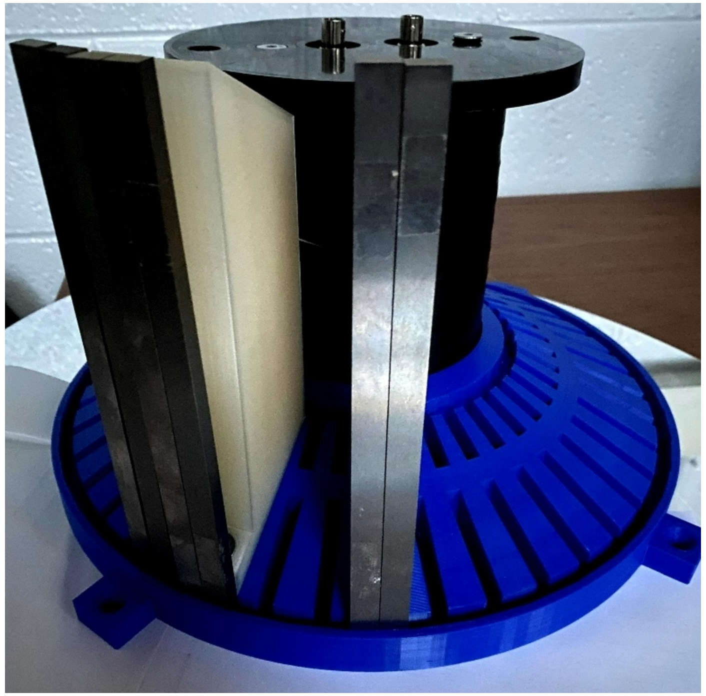
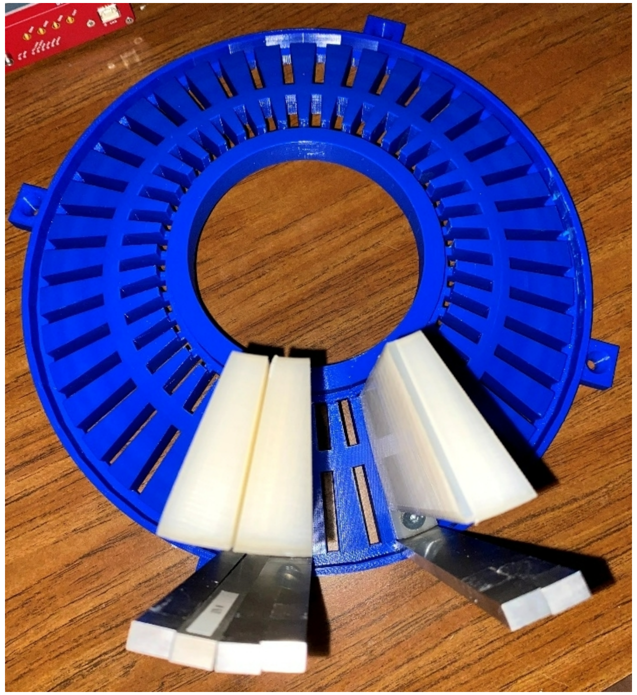
Current Status

- Assembling the three layered mask with a 21 element URA pattern
- Goal: Test the verified mask pattern (URA 21) then develop a mask-antimask pattern or an image reconstruction optimized pattern, each with 42 elements





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