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Office of Defense Nuclear Nonproliferation Research and Development

University Program Review (UPR) 2019 Meeting

Warhead Verification using Time-Encoded Imaging

NSSC – Nuclear Science & Security Consortium

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Introduction

Name: Rebecca Krentz-Wee

Department & Academic Institution: UC-Berkeley, Nuclear Engineering

Academic Advisor: Kai Vetter

Lab Mentor: Peter Marleau

Standing: Grad

Title of project: Warhead Verification using Time-Encoded Imaging

Brief Research Description: Development of a warhead confirmation system using two-dimensional time-encoded imaging (2D-TEI) to provide an authenticatable option for confirmation measurements.

Focus Area/Crosscutting Area: Nuclear Instrumentation and Nuclear Security Policy

Outline

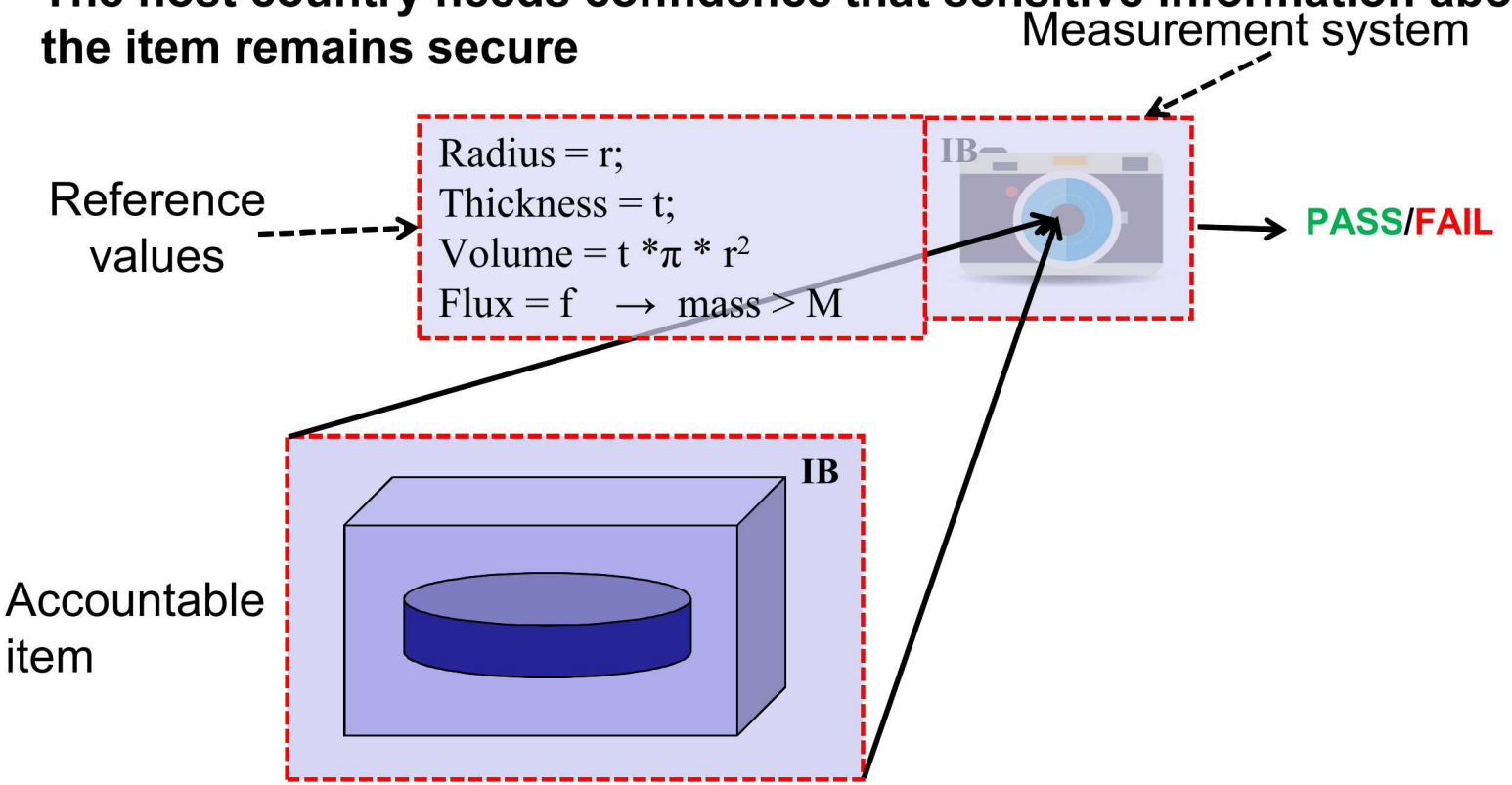
- **Arms control context: what is needed?**
- **What is the proposed technology?**
  - Time-encoded imaging background
  - Anti-symmetry verification concept
  - Fast neutron proof-of-concept measurements
- **How do we improve the imaging system given operational constraints?**
  - Size vs time vs performance
  - Simulation and modeling
- **Summary**

Arms control context

- Current & previous treaties counted delivery vehicles as a measure of the number of deployed nuclear weapons
- At a small number of weapons and for stockpile dismantlement, individual warheads may need to be verified
- In a future arms control treaty, how do we authenticate a warhead?
- The monitoring party needs confidence that an item truly is what it is declared to be
- The host country needs confidence that sensitive information about the item remains secure

Arms control context – attribute verification

- **In a future arms control treaty, how do we authenticate a warhead?**
- **The monitoring party needs confidence that an item truly is what it is declared to be**
- **The host country needs confidence that sensitive information about the item remains secure**



Arms control context – template verification

- **In a future arms control treaty, how do we authenticate a warhead?**
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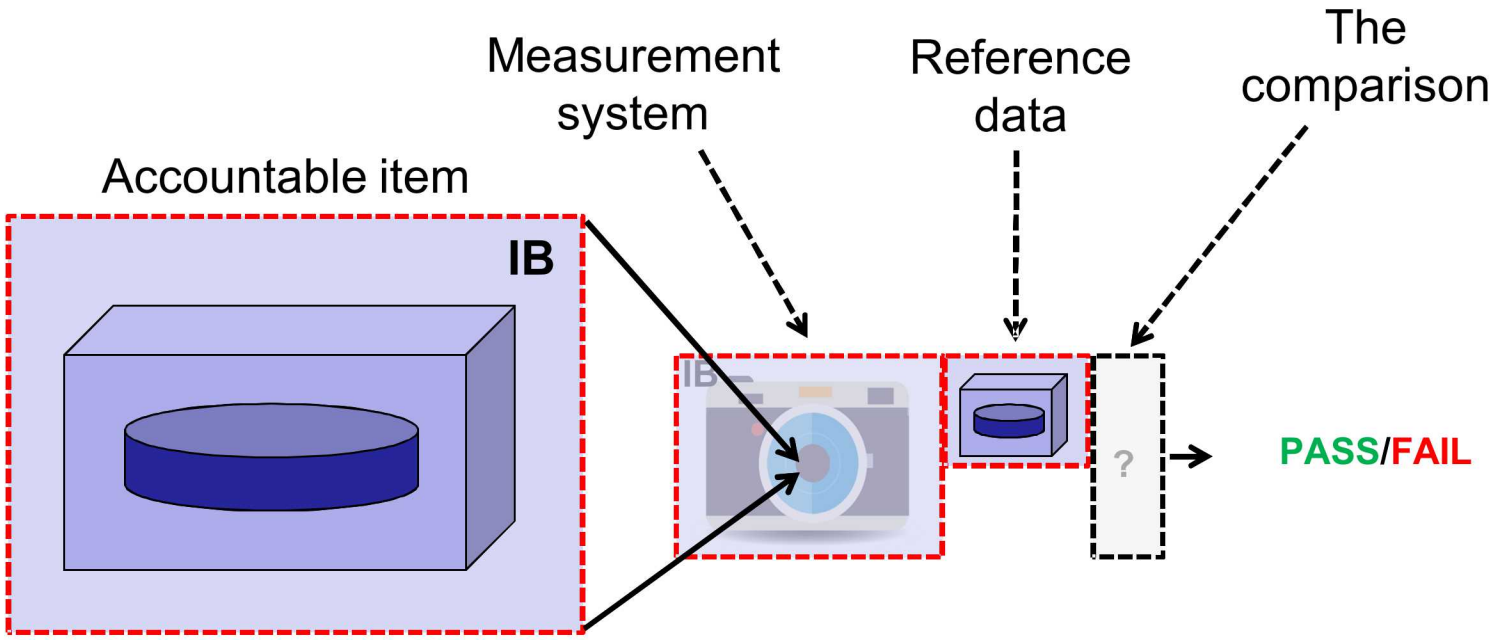
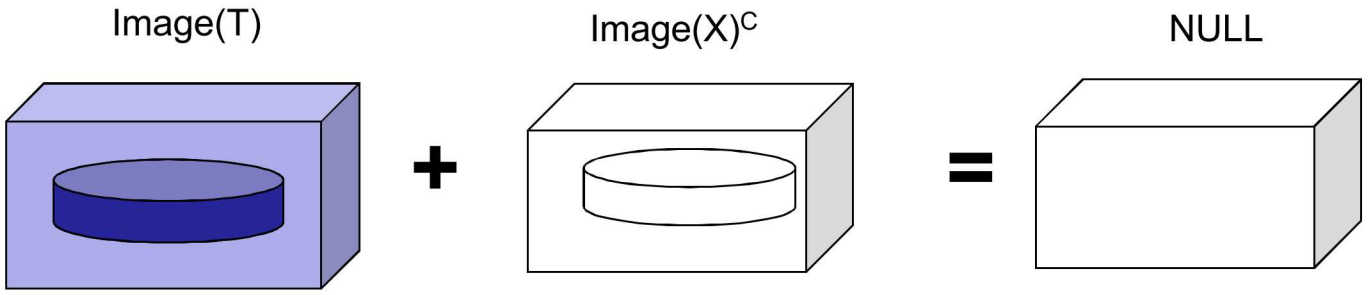


Arms control context

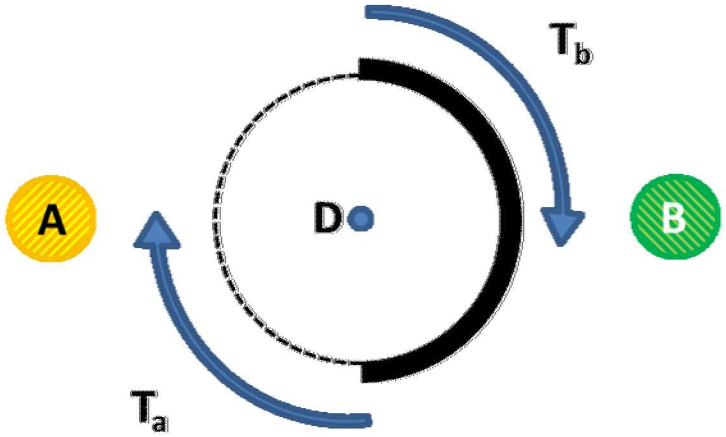
- In a future arms control treaty, how do we authenticate a warhead?
- The monitoring party needs confidence that an item truly is what it is declared to be
- The host country needs confidence that sensitive information about the item remains secure
- Can we decrease the amount of information behind information barriers while still maintaining confidence?

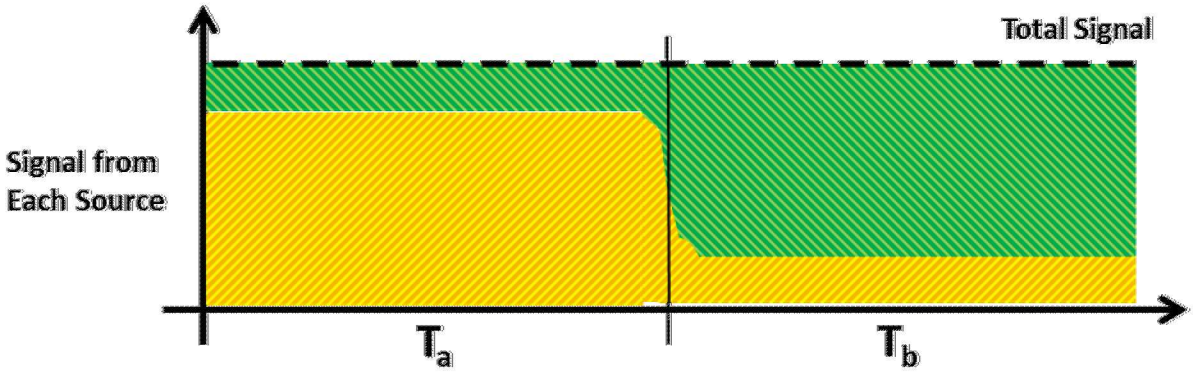
Arms control context

- In a future arms control treaty, how do we authenticate a warhead?
- The monitoring party needs confidence that an item truly is what it is declared to be
- The host country needs confidence that sensitive information about the item remains secure
- Proposed solution: complementary comparison (turn one image into its complement) at all times



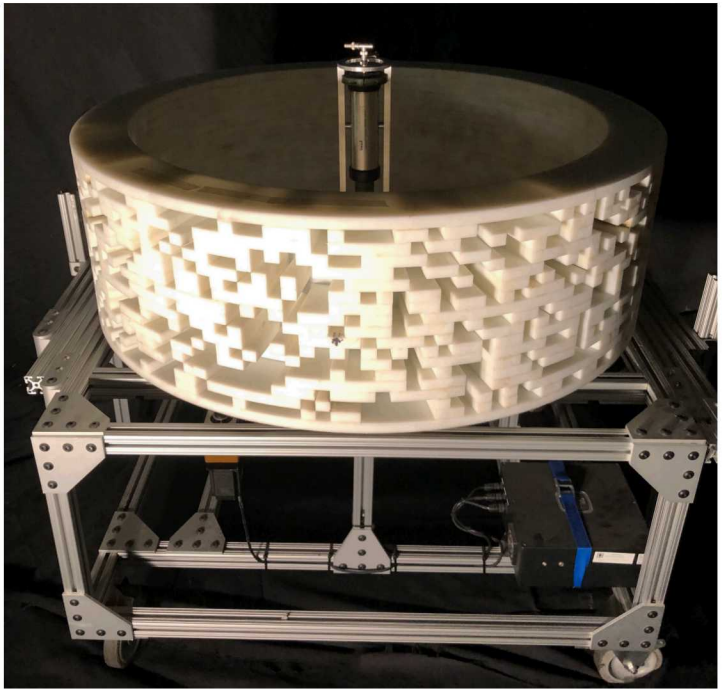
A simple example



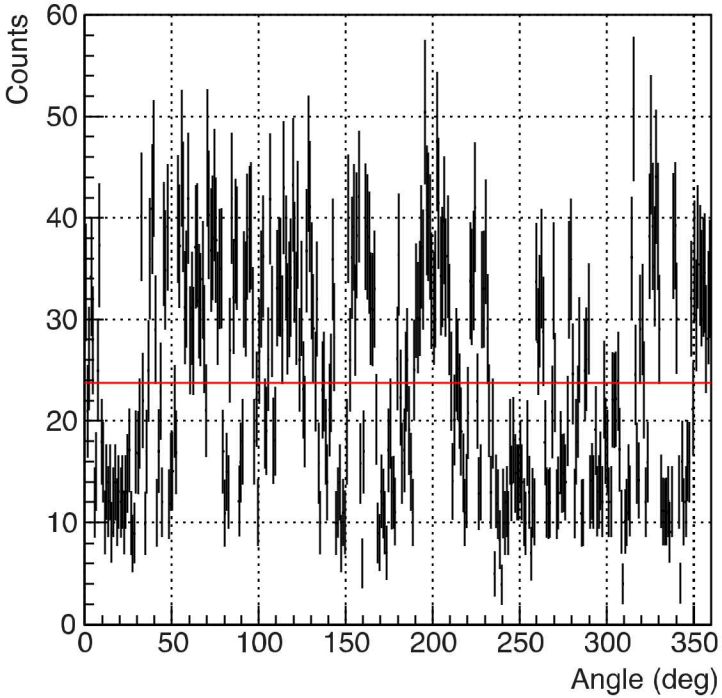


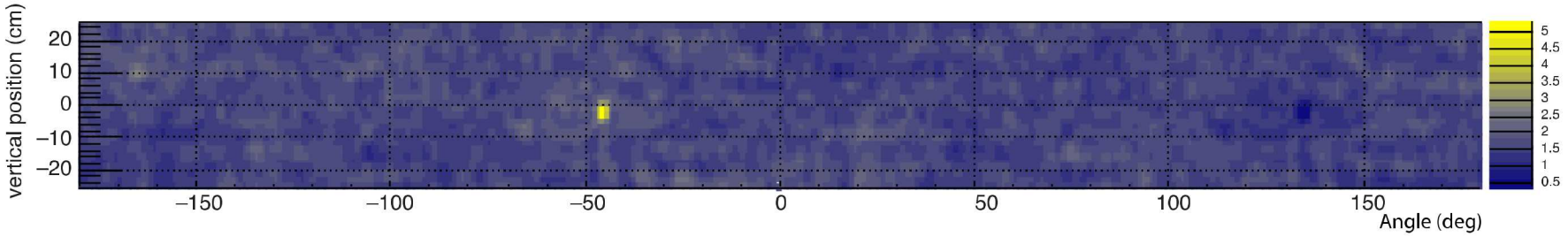
- The simplest possible imaging system with this property: half mask, half aperture.
- The fraction of total count rate coming from A and B is unknown at any given angle.
- In this example, the location (and shape) of the boundary between regions is not revealed.

Time-Encoded Imaging

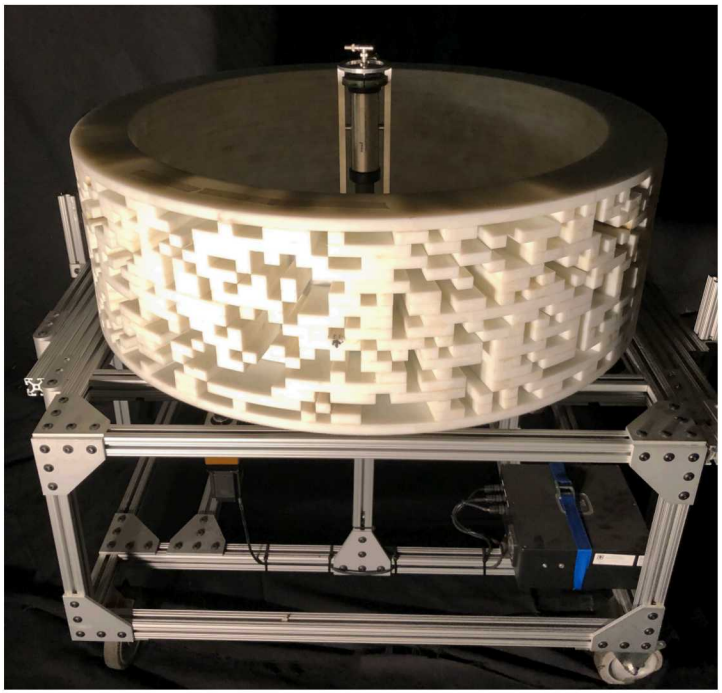


2-D coded mask modulates the source as it rotates; the modulation pattern can be unfolded to a 2-D image





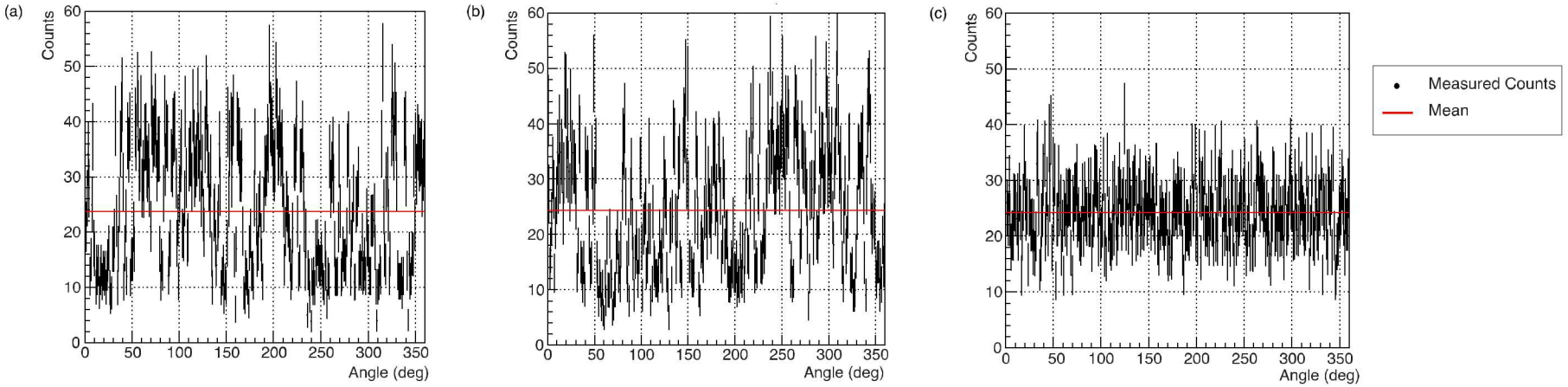
Fast neutron system



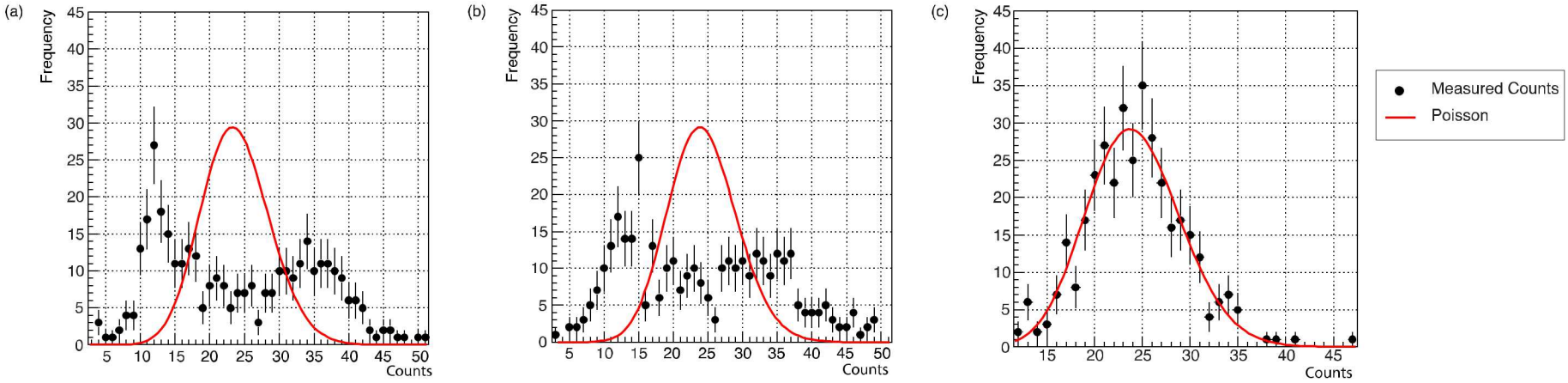
- HDPE mask
  - 1.9 cm x 1.9 cm x 10.16 cm elements
  - 150 elements/layer
  - 17 layers
  - 1 m diameter
- 2.54 cm x 2.54 cm stilbene detector
- Hamamatsu PMT
- 2 sets of measurements
  - Small Cf-252 source
  - PuO_2 hemispherical shells

Neutron system with a small Cf-252 source

Counts in the detector as a function of mask rotation angle



Distribution of counts per unit angle

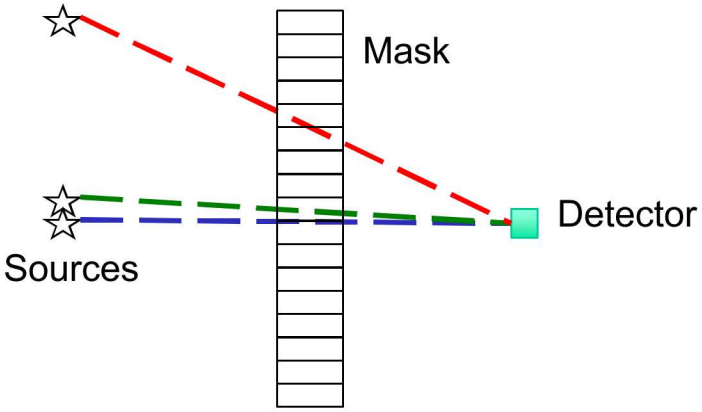


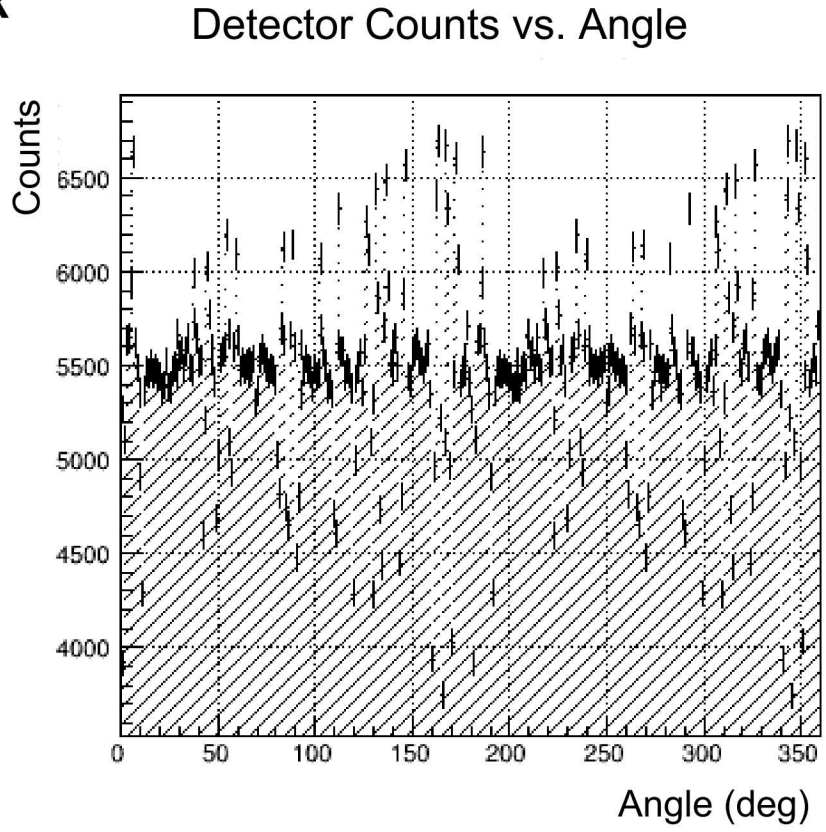
Constraints and Limitations

- **How can we improve the system?**
- **Need to balance tradeoffs in**
  - Size
    - Smaller system is easier to work with
    - Smaller size worsens efficiency and time to detection, or the system angular resolution
  - Measurement time
    - Shorter measurement time is preferred
    - Shorter measurement times require a larger detector; this either worsens the system angular resolution and performance or drives the entire system to a larger size
  - Performance
    - Need sufficient angular resolution for imaging
    - Better angular resolution either drives the system size up or the detector size down, decreasing efficiency and increasing measurement times

Constraints and Limitations

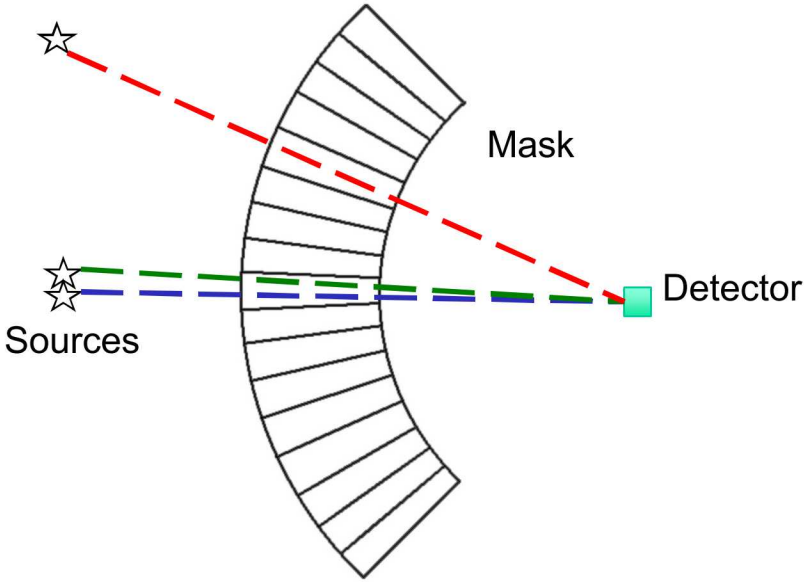
- **Improve imaging performance by changing the shape of the mask and detector**
- **Concern: edge effects in a cylindrical mask cause partial attenuation instead of the desired open/closed effect**

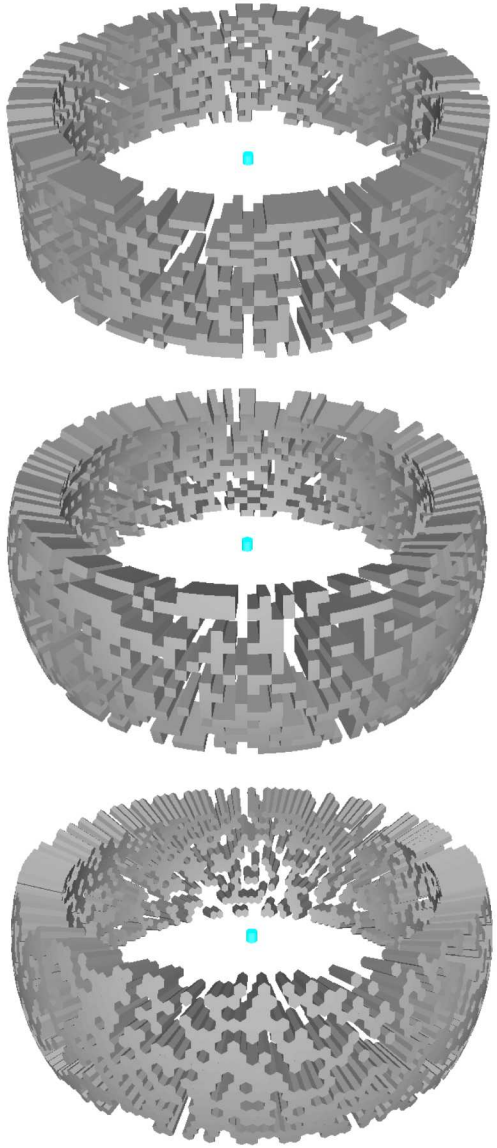




Constraints and Limitations

- **Improve imaging performance by changing the shape of the mask and detector**
- **Concern: edge effects**
- **Potential solutions: spherical mask, spherical detector, hexagonal mask elements**

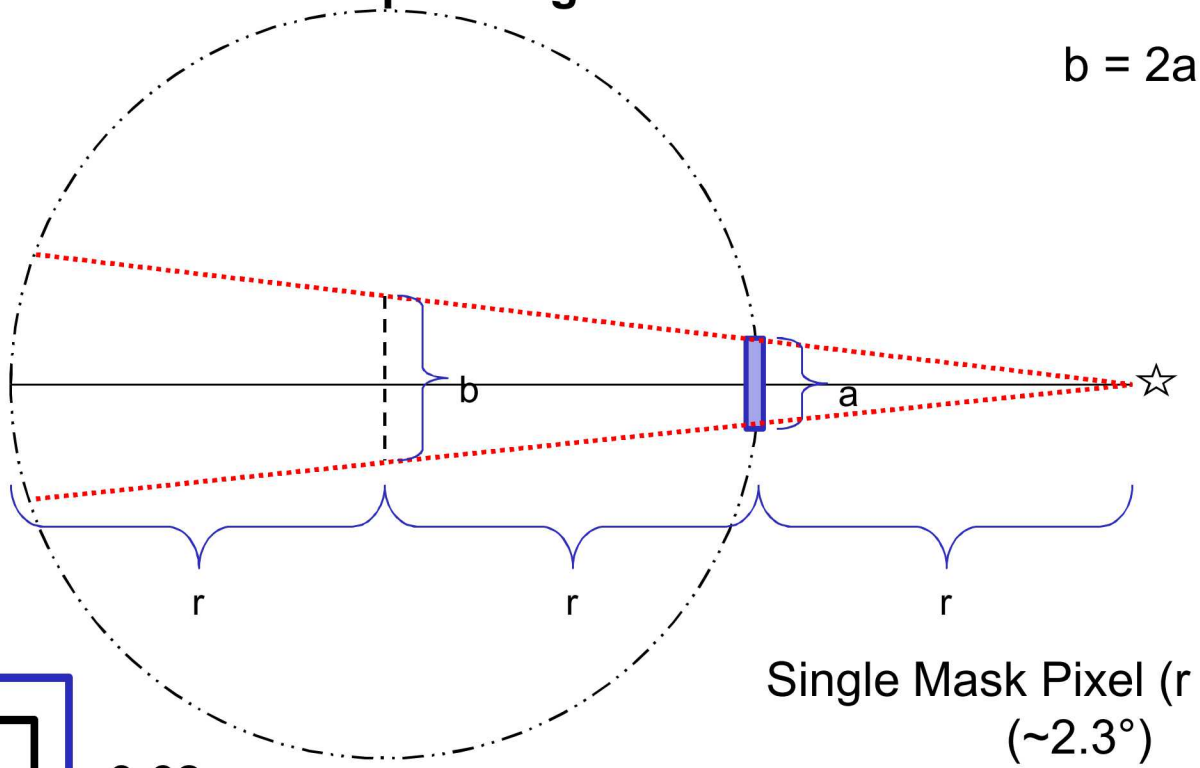


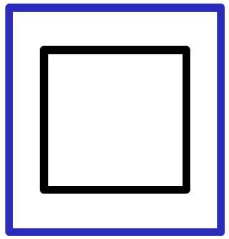


Constraints and Limitations

- **Can the system be smaller?**
- **How does that impact angular resolution and efficiency?**

b = 2a = ~4 cm

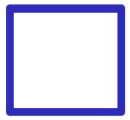




4.18 cm

3.62 cm

Single Mask Pixel (r = 50 cm)
(~2.3°)



1.9 cm

2.09 cm

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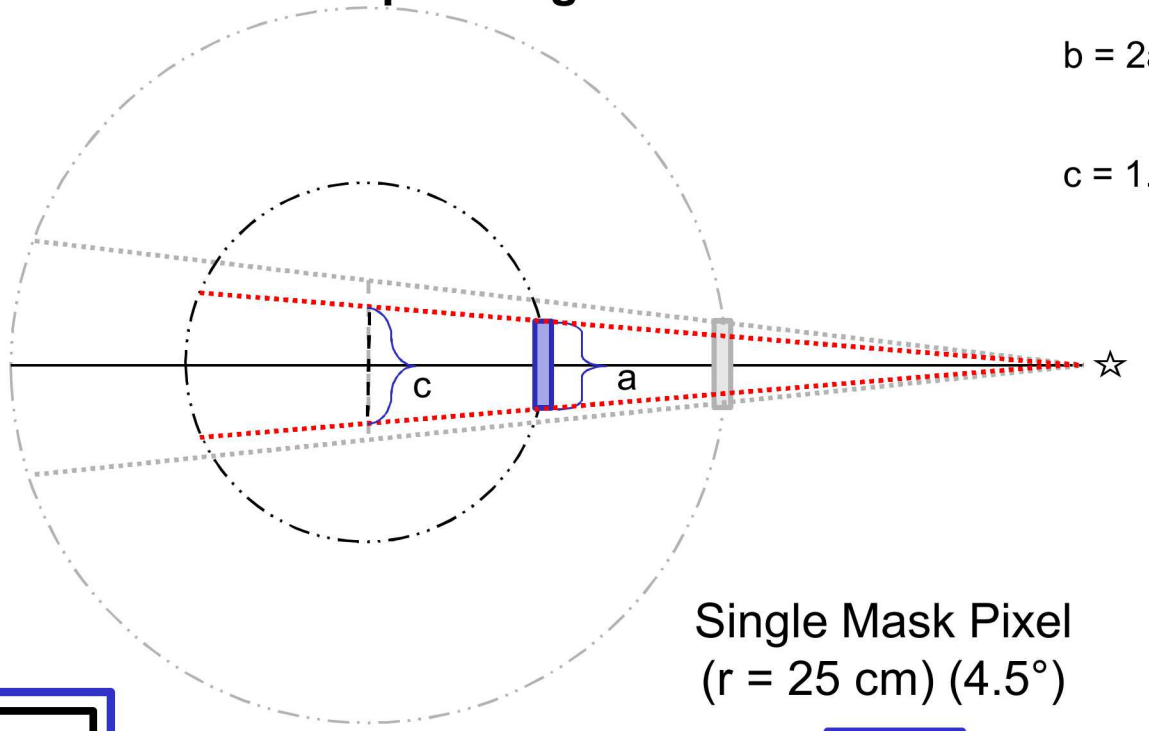
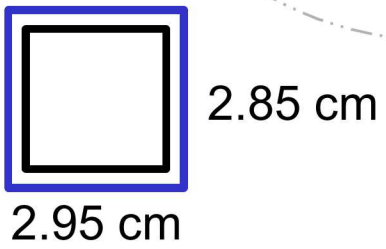
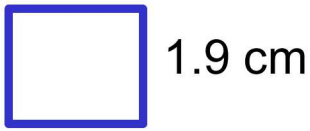




Single Mask Pixel
(r = 25 cm) (4.5°)



Constraints and Limitations

- **Can the system be smaller?**
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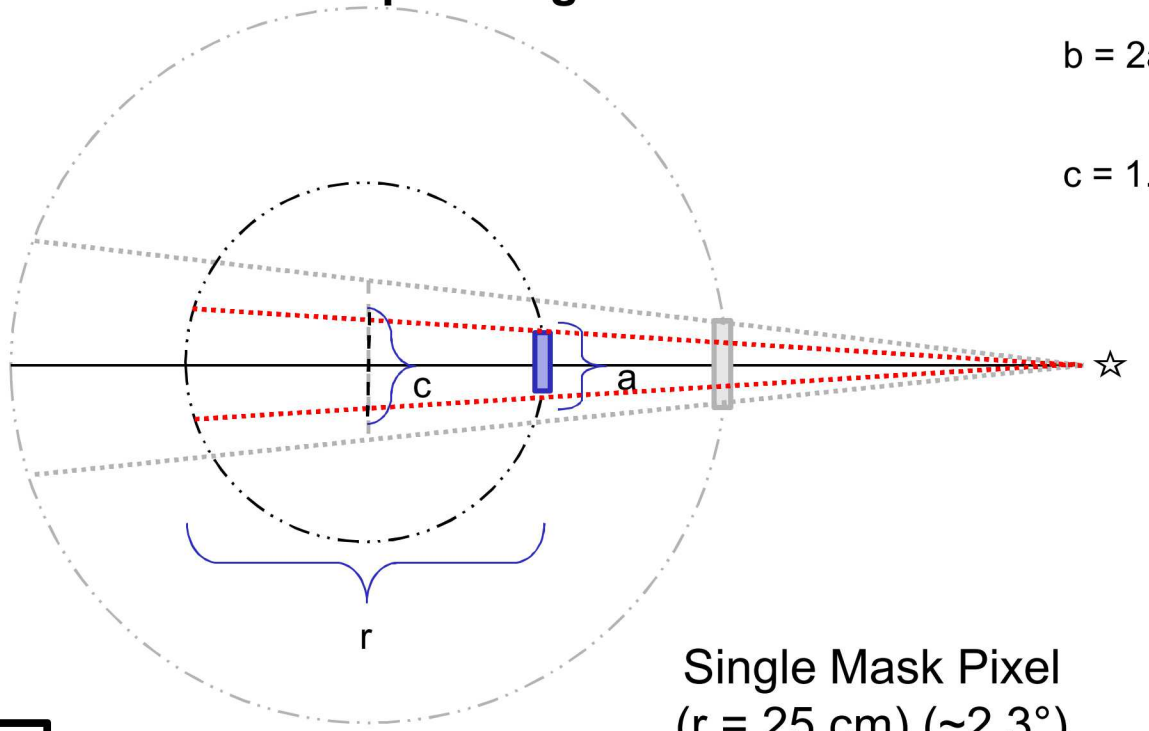
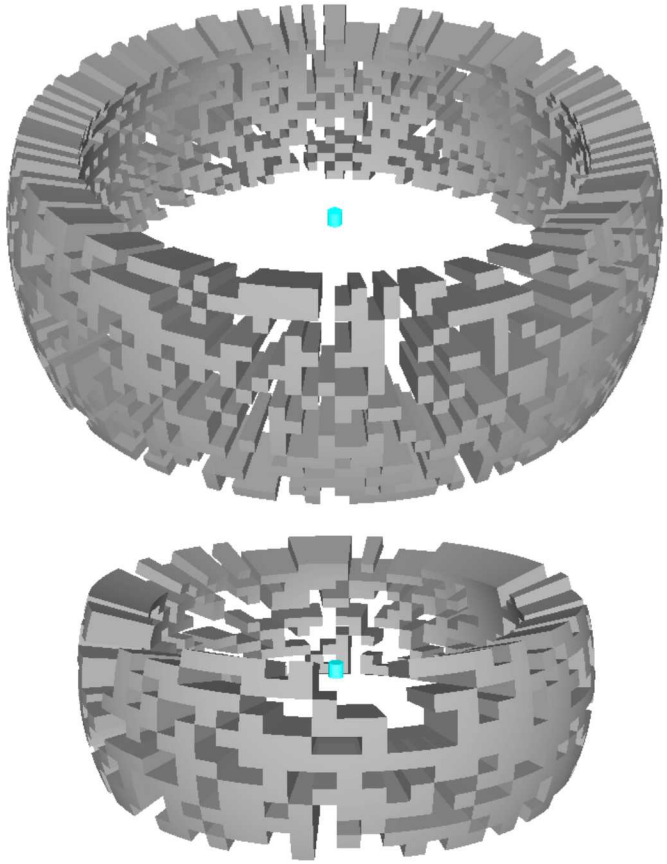


Constraints and Limitations

- Simulations and modeling in process to study the tradeoffs between size and angular resolution/performance given a time constraint and a discrimination task
- Mask diameters of 100 cm, 76 cm, 50 cm
- Different number of mask elements (angular resolution): 150, 80, 60
- Different size detectors (efficiency): 2.5 cm, 3.8 cm, 5 cm



Summary and Future Work

- **Built and tested a fast neutron time-encoded system for verification**
- **Simulations to understand constraint space**
  - Size vs time vs performance
- **Building a gamma-ray system**
  - Tungsten alloy, smaller system
  - Designed with Patricia Schuster at UM
  - Will be completed this summer for measurements at Sandia

Acknowledgements

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UNIVERSITY OF MICHIGAN — Patricia Schuster, Ricardo Lopez Lemus, Quinn Killian

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