SAND2018-10963PE

Nuclear Science and Security Consortium

Fall Workshop and Advisory Board Meeting 2018

Warhead Verification Using Time-Encoded Imaging

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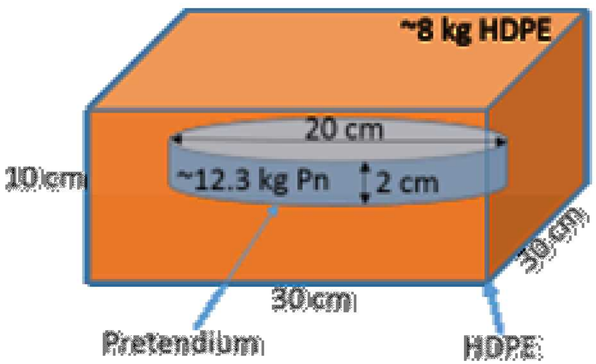
Outline

- **Motivation**
  - Authentication question
- **Time Encoded Imaging**
- **CONFIDANTE**
  - Concept
  - Prototype
  - Multiplicity

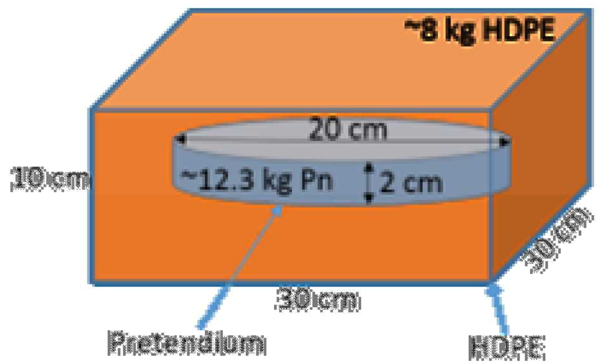
Challenge: Item Authentication & Certification

Authentication - the process by which a monitoring party gains confidence that reported characteristics of an entity reflect the true state of that entity

Certification – the process by which a host party gains confidence that sensitive information regarding an entity or facility remains secure.



= (?)

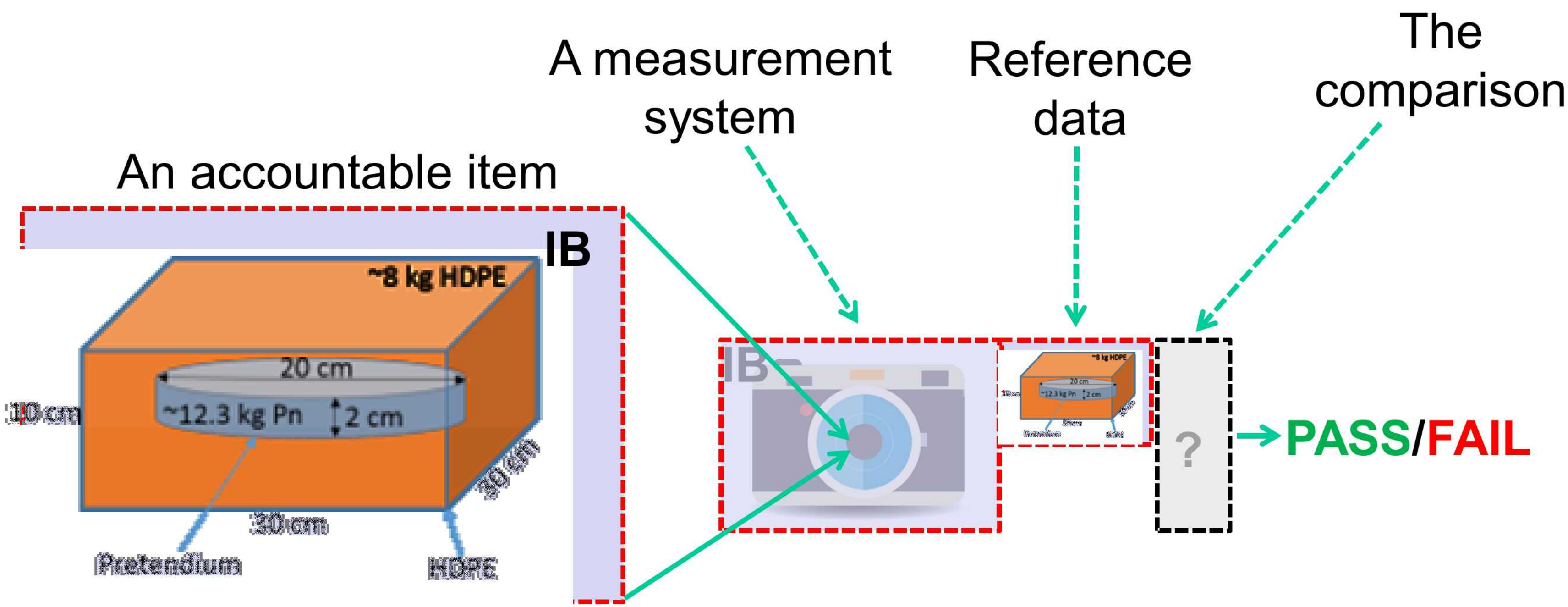


Object T = valid type
1 TAI

Object X = ?

E. Brubaker, "Workshop on Techniques for Protection of Imaging Information: Challenge Problem", SAND2016-4047 O

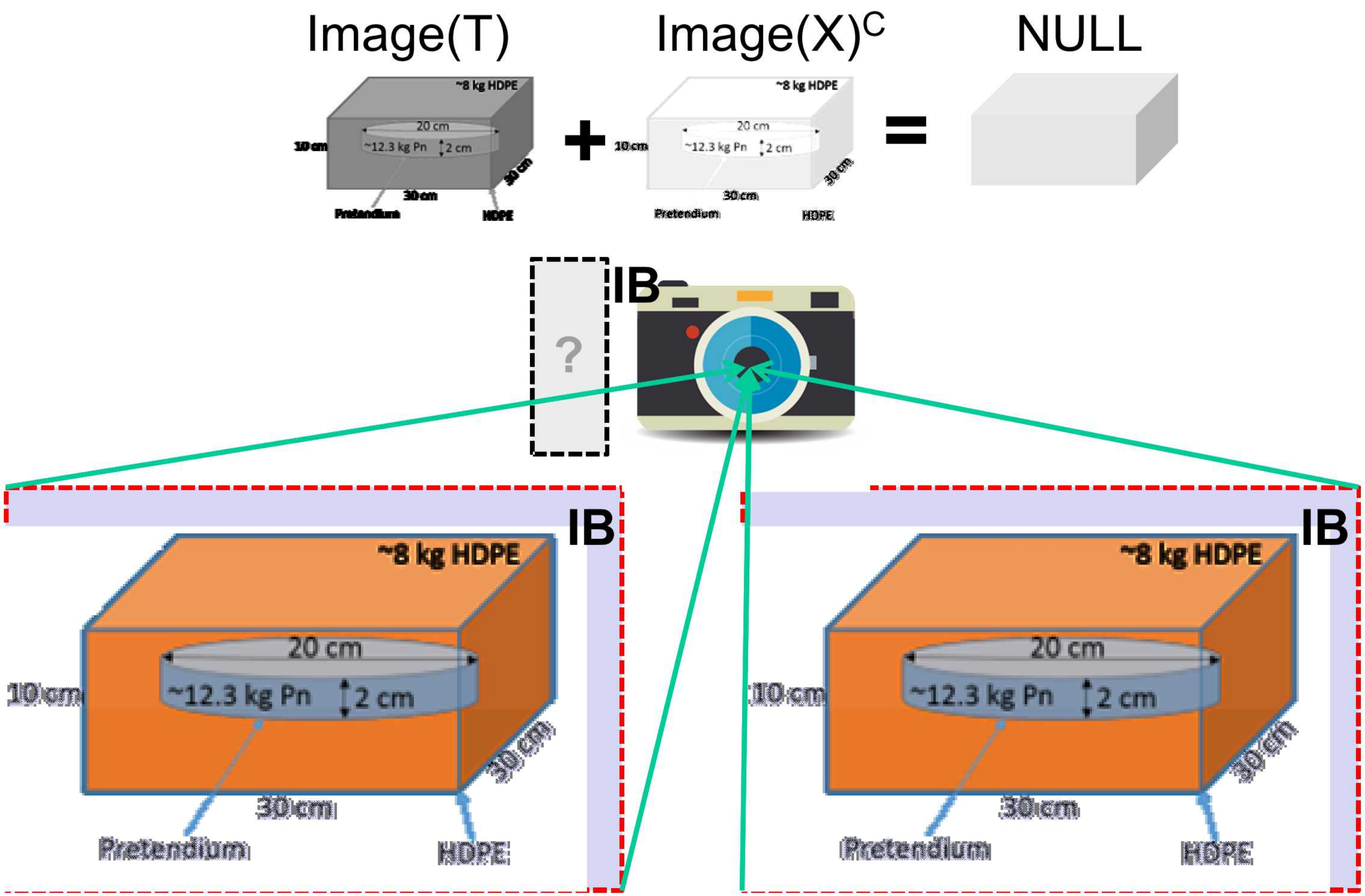
Generic confirmation by comparison to a reference



Can we decrease the amount of information behind a barrier while still maintaining confidence?
Can we get rid of a barrier all together?

Proposal – complementary comparison

- **What we need is to turn one image into its complement *at all times*.**



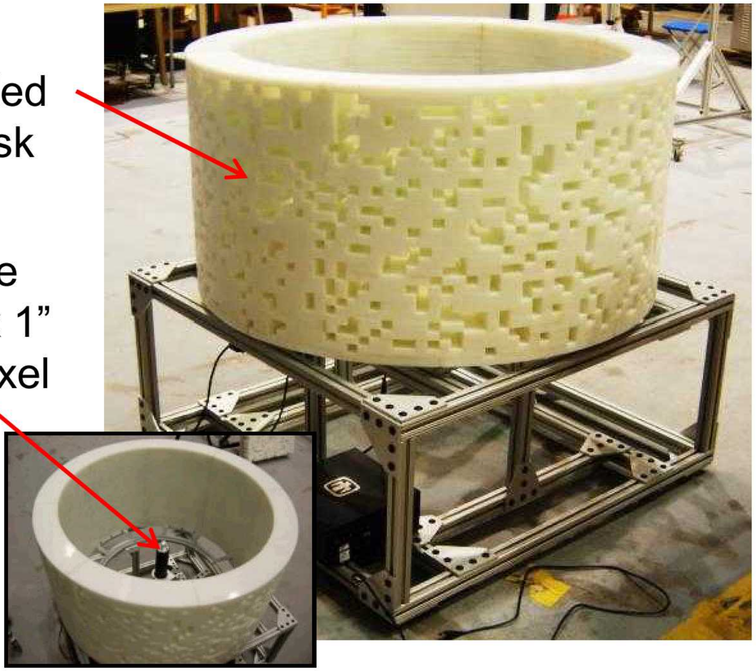
Item T = valid TAI

Item X = ?

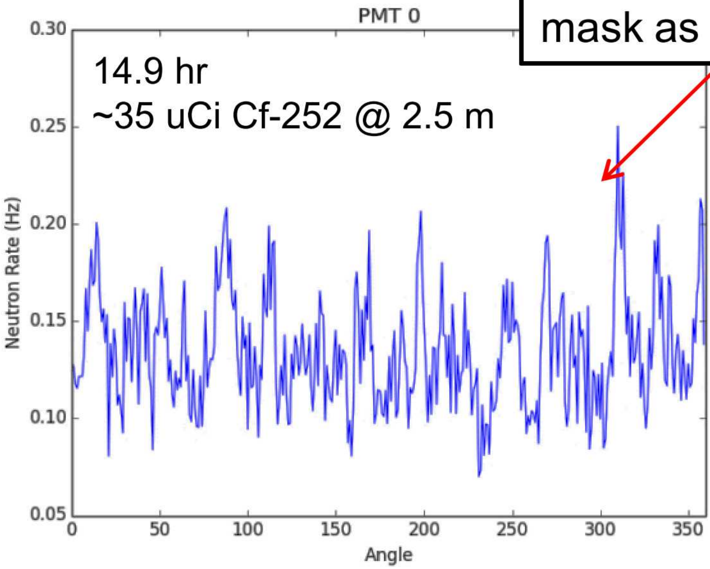
2D Time-Encoded Imaging (TEI)

2-d coded mask

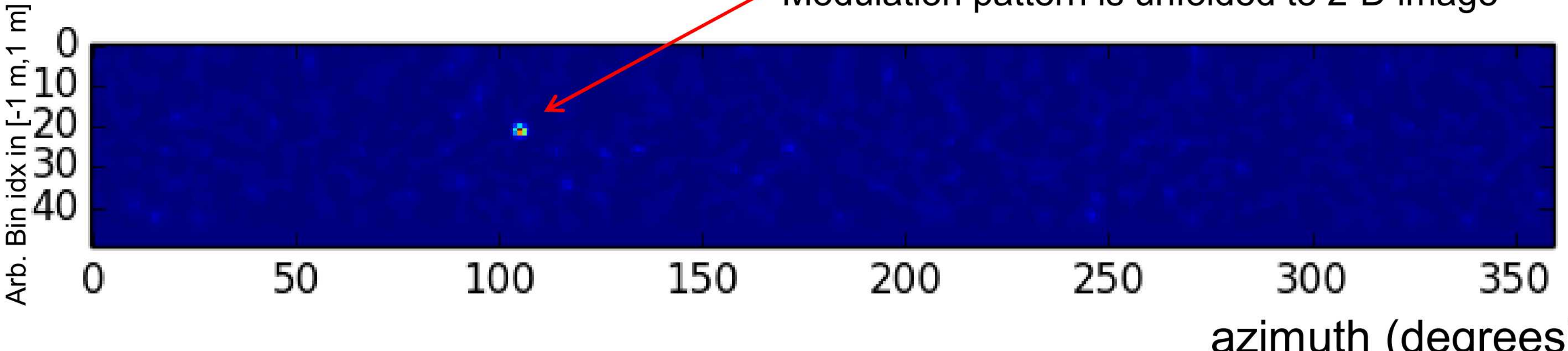
Single 1"D x 1" LS pixel



Single pixel rate is modulated by the mask as it rotates.



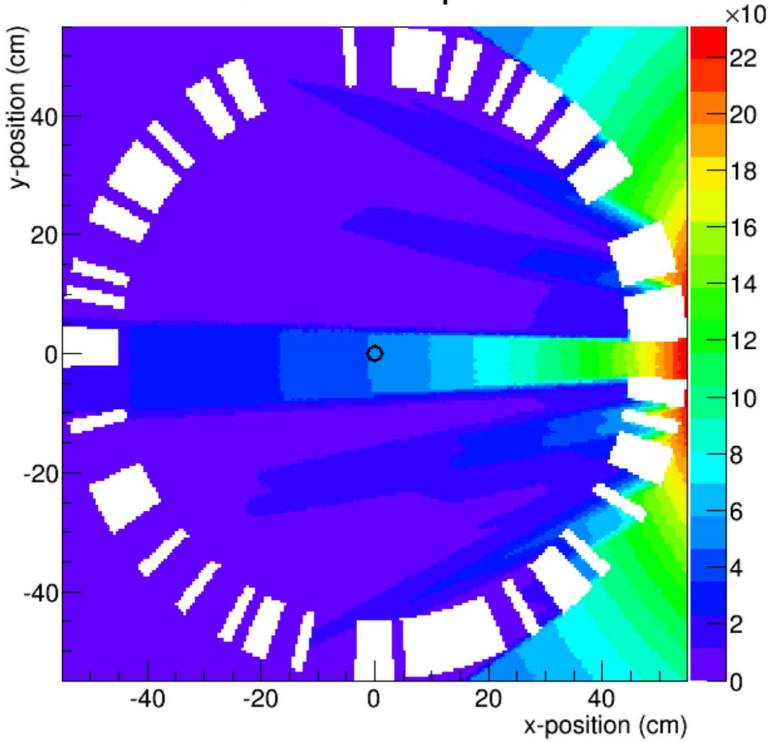
Modulation pattern is unfolded to 2-D image



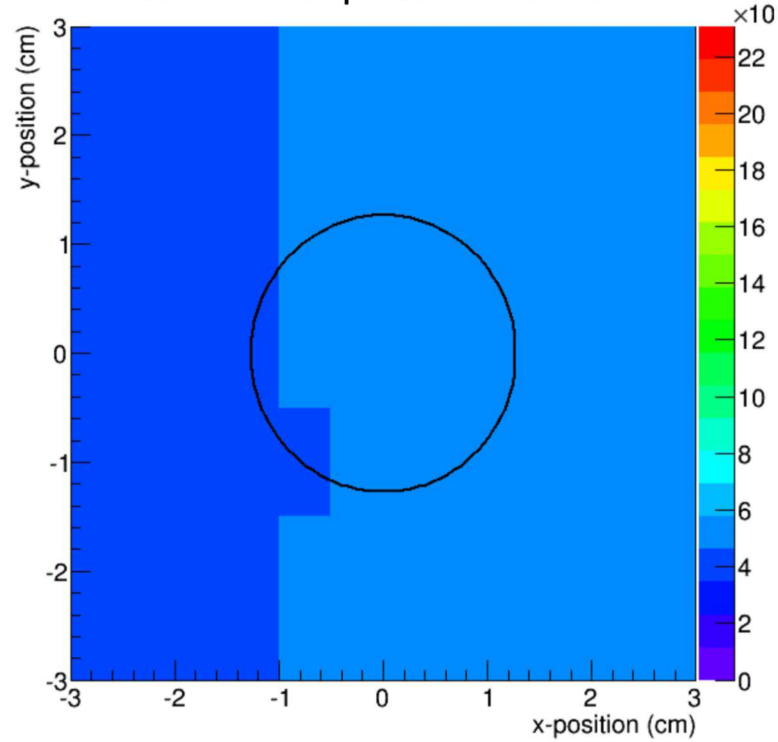
J. Brennan, E. Brubaker, M. Gerling, P. Marleau, K. McMillan, A. Nowack, N. LeGalloudec, M. Sweany, "Demonstration of Two-dimensional Time-encoded Imaging of Fast Neutrons", Nuclear Instruments and Methods A, 2015

Time Encoded Imaging

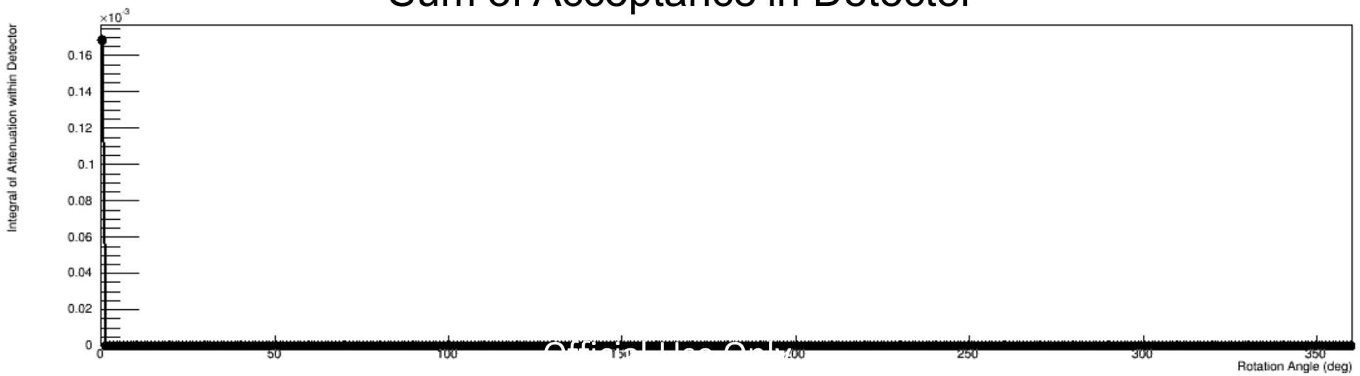
Relative Acceptance



Relative Acceptance at Detector

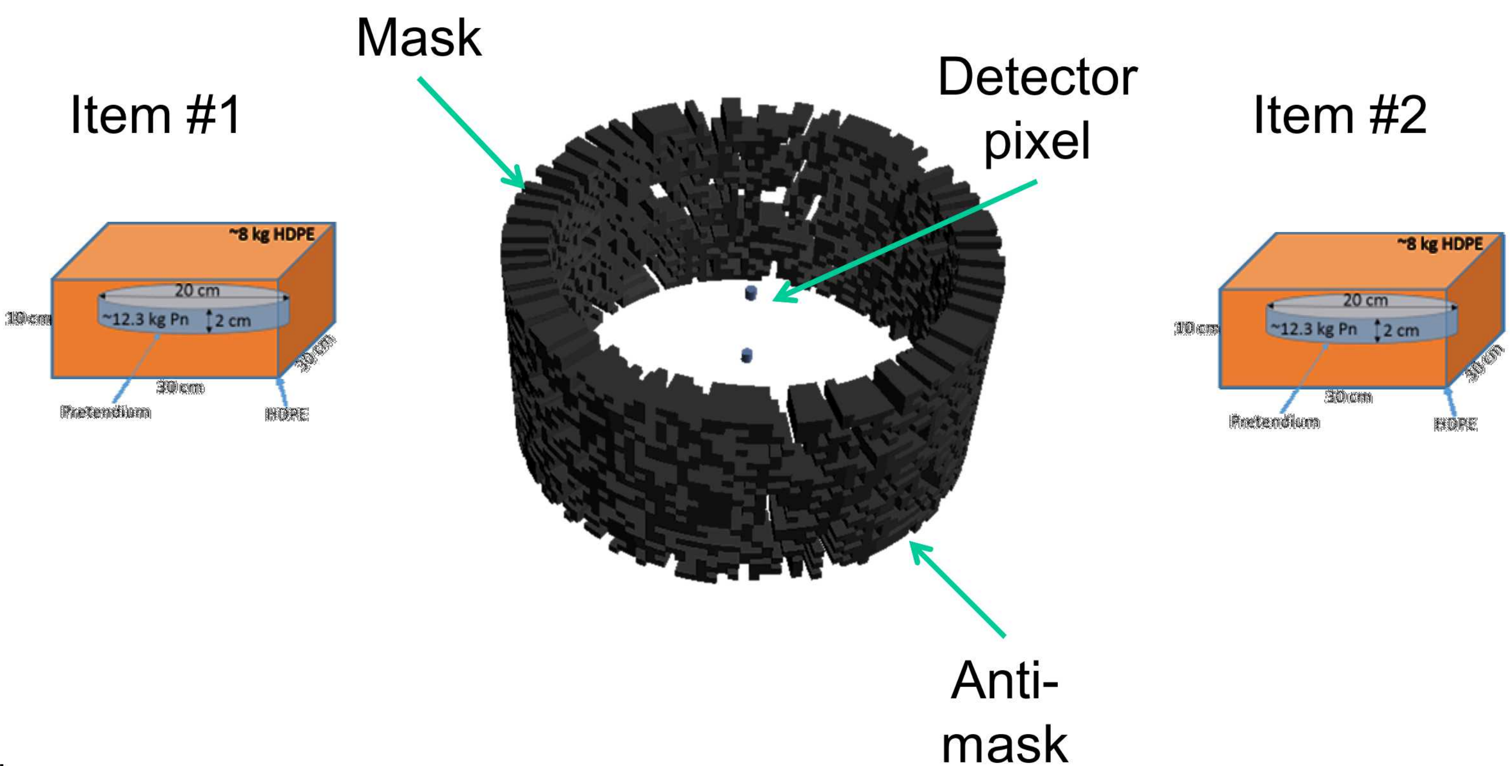


Sum of Acceptance in Detector

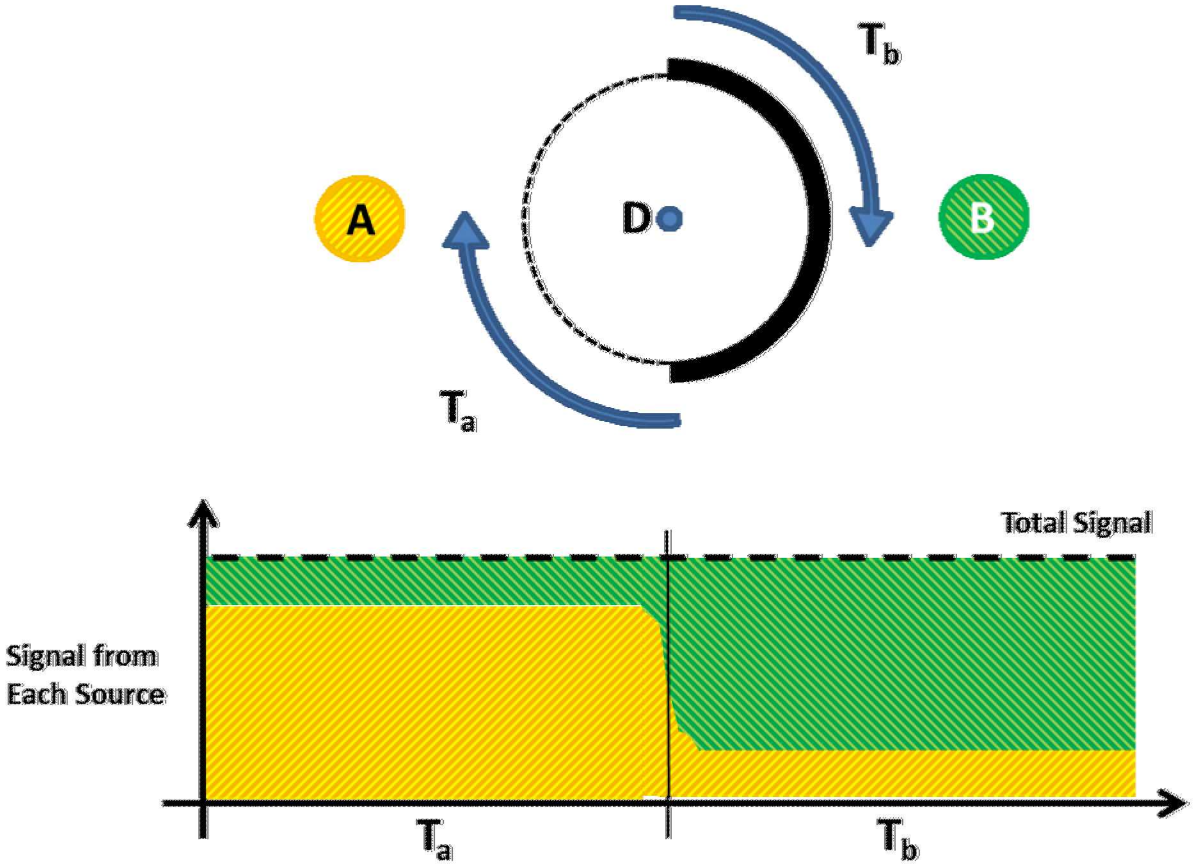


Solution: 2D-TEI mask/anti-mask

If the mask is designed such that one side is the anti-mask of the other, then **Item #2 projects the anti-image of Item #1 at all times** **if and only if they are identical!**

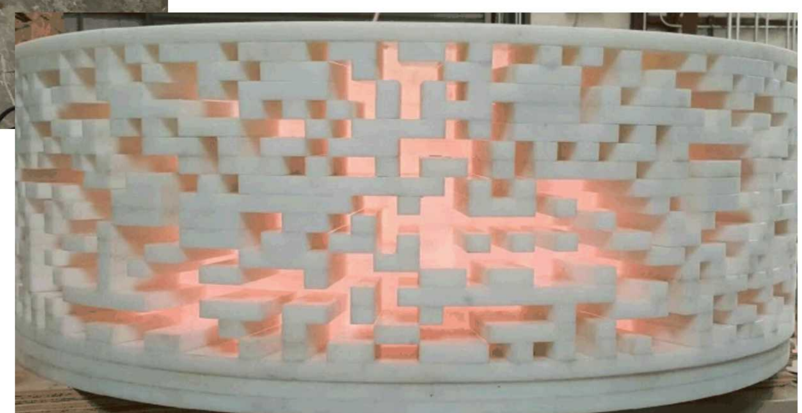


A very simple example

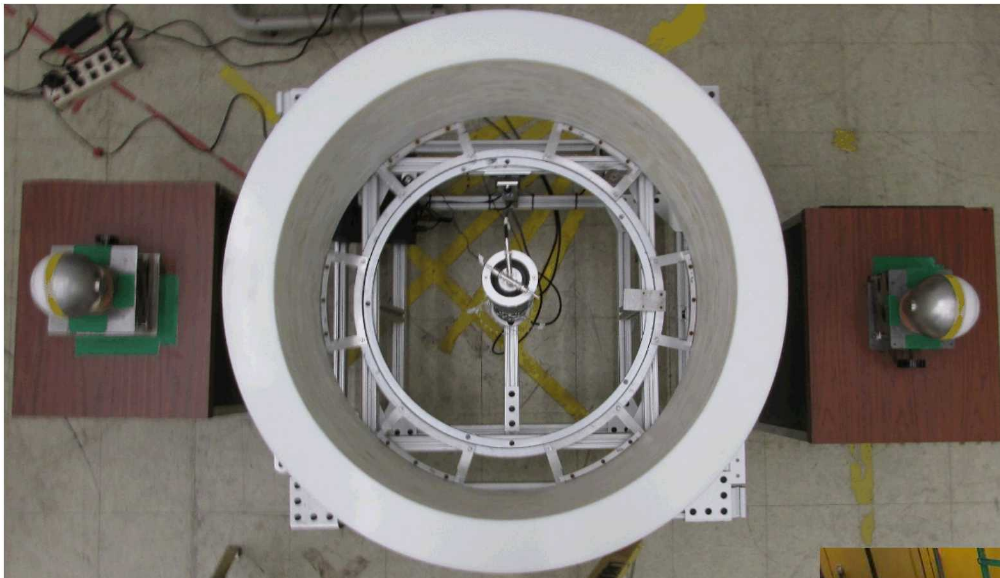


- The simplest possible mask with this property: half mask, half aperture.
- The fraction of total count rate coming from A and B is unknown at any given angle.
- In this example, the location (and shape) of the boundary between regions is not revealed.

CONFIDANTE



LLNL's PuO_2 Hemisphere comparison



- One hemisphere was placed on either side of CONFIDANTE (180 deg. apart).
- ~68 hours of data was taken.

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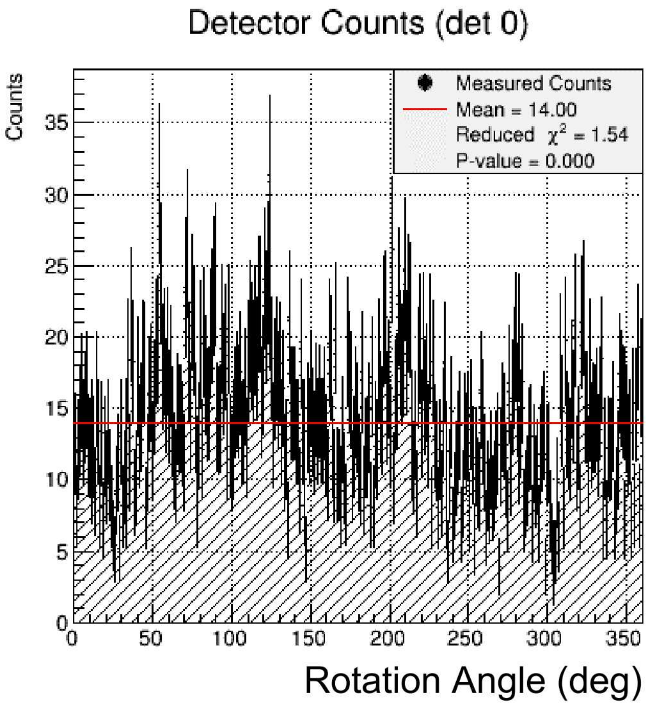
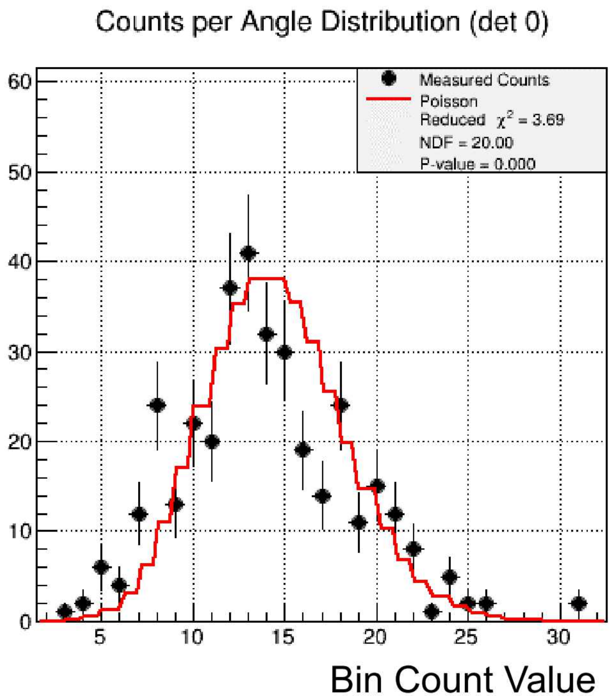
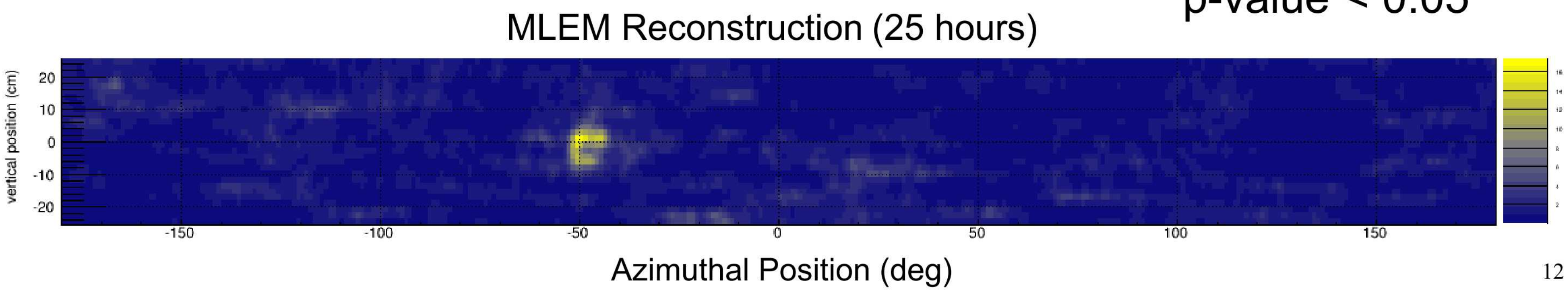
One PuO_2 sphere – 25 hours

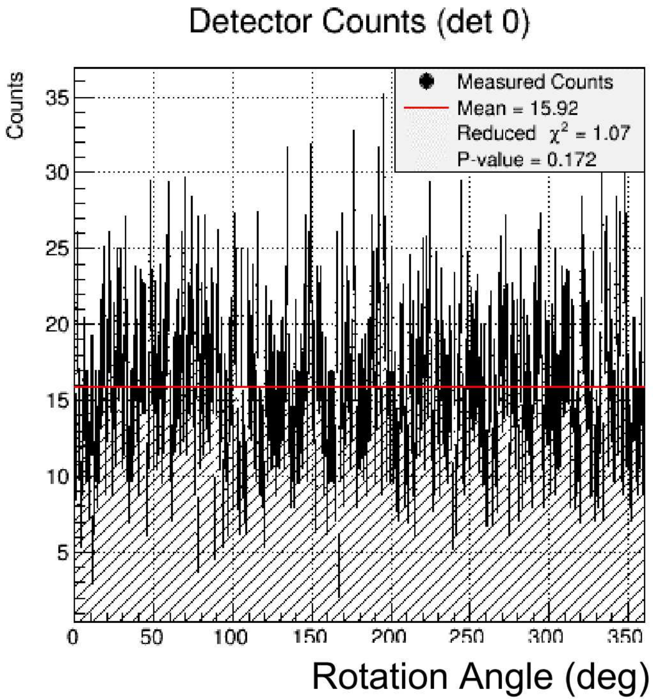


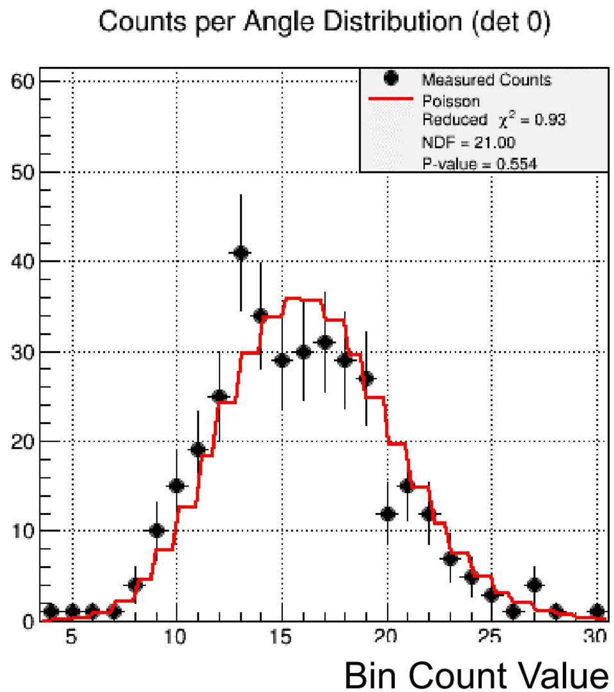


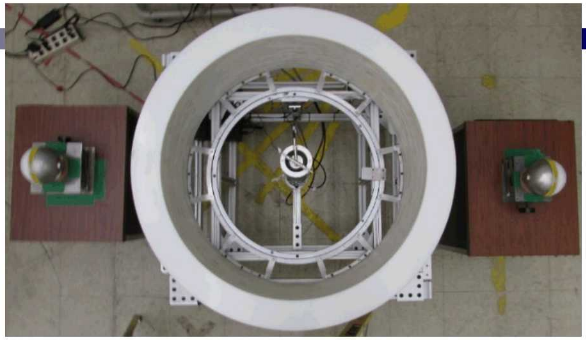
- 2 hours was sufficient for χ^2 convergence.
- Can reject the null-hypothesis (constant rate) with p-value < 0.05



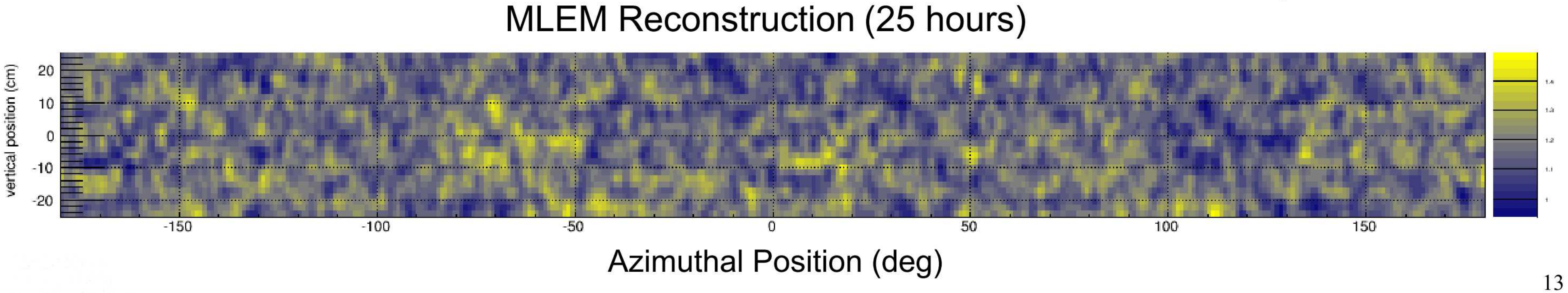
Two aligned PuO_2 hemispheres (positive)



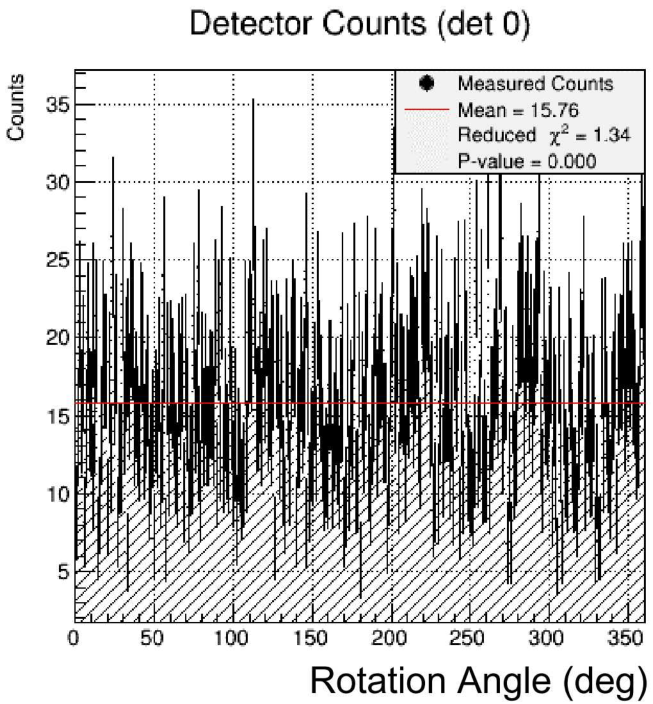


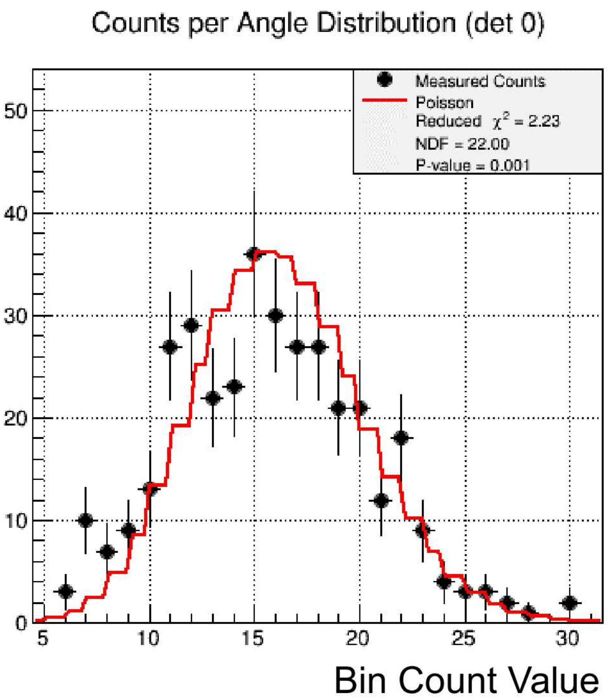


- 25 hours was sufficient for χ^2 convergence.
- We ***cannot*** reject the null-hypothesis (constant rate) with p-value = ~0.5

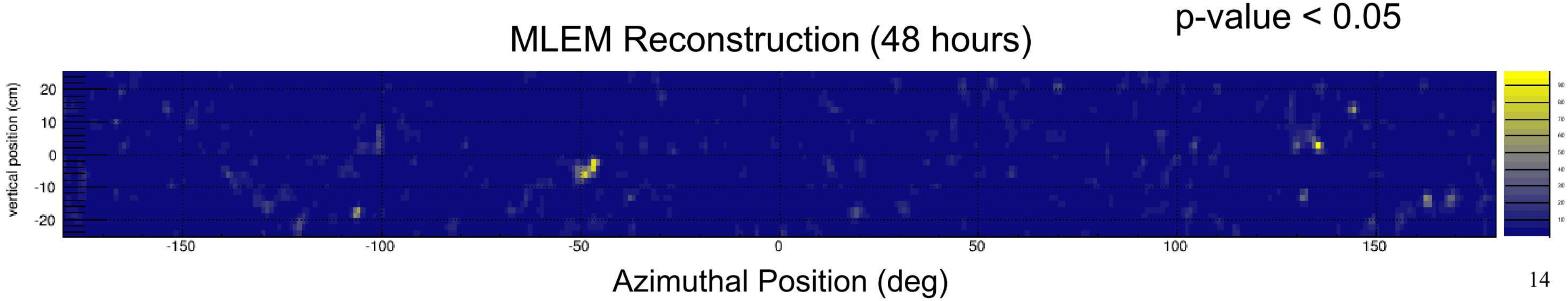


Two misaligned PuO_2 hemispheres (negative)



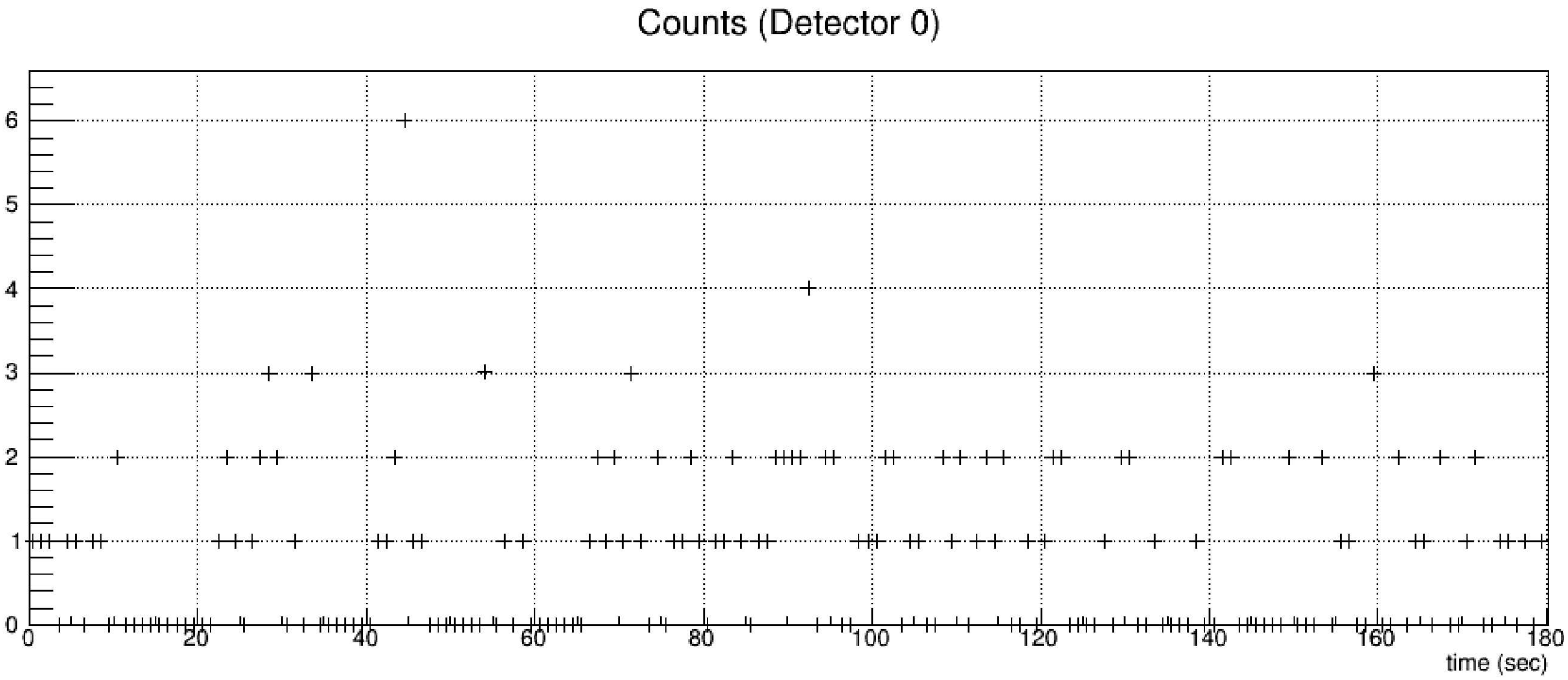


- One hemi was rotated by 90° .
- 15 hours was sufficient for χ^2 convergence.
- We reject the null-hypothesis (constant rate) with p-value < 0.05



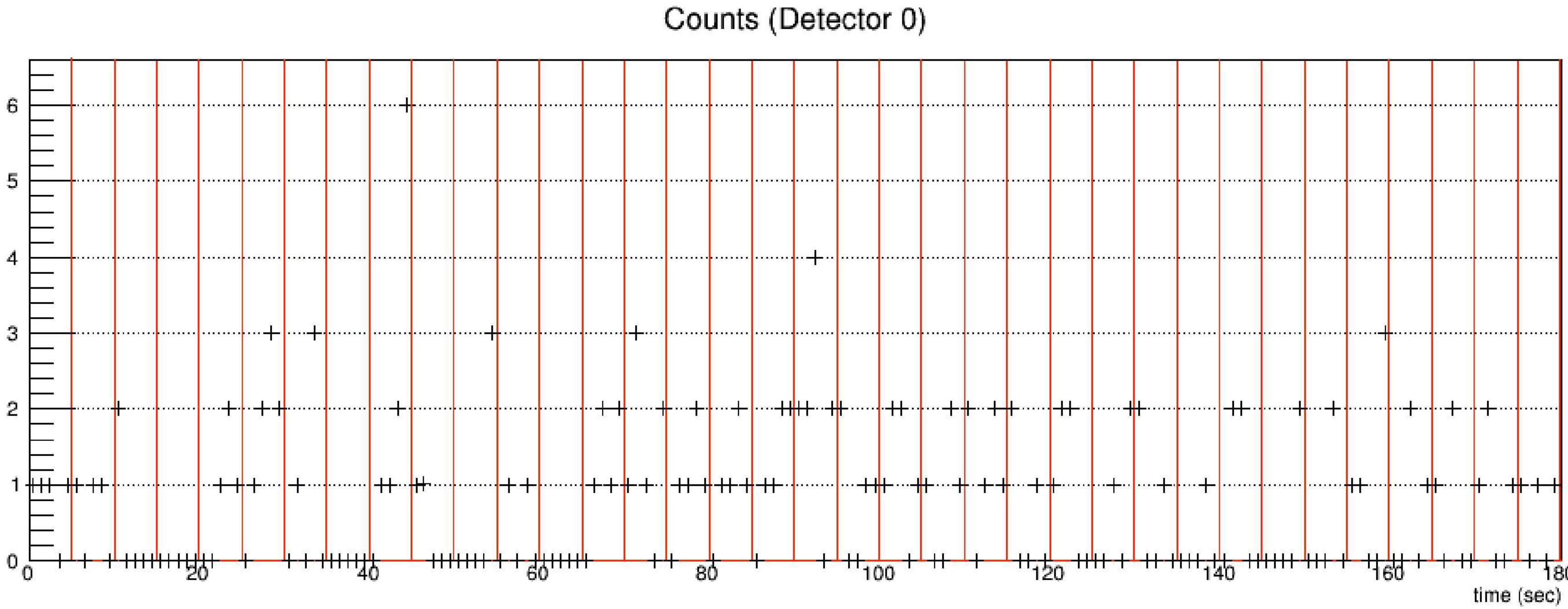
Multiplicity

- Saving events time/location could reveal sensitive information



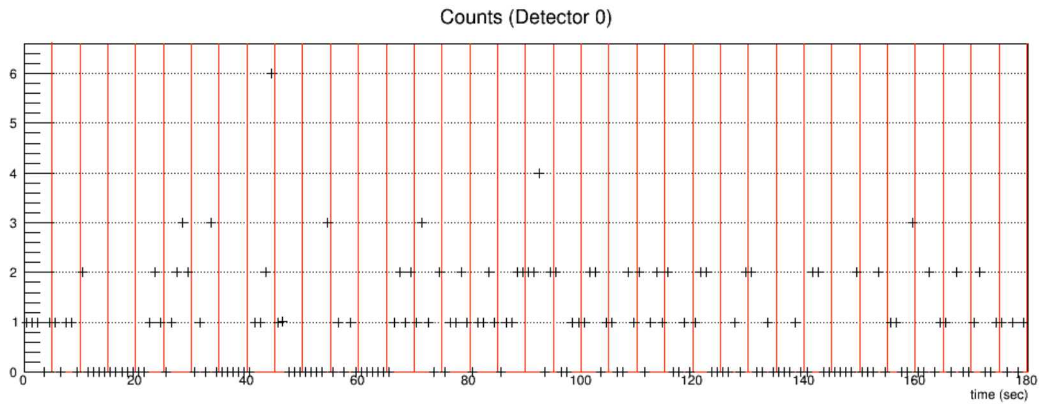
Multiplicity

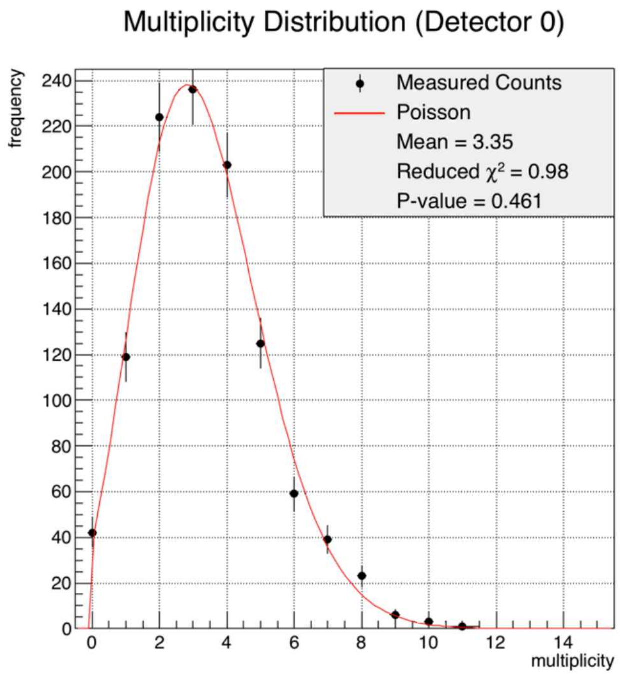
- Saving events time/location could reveal sensitive information
- Count the number of events in angle bin, removing exact location



Multiplicity

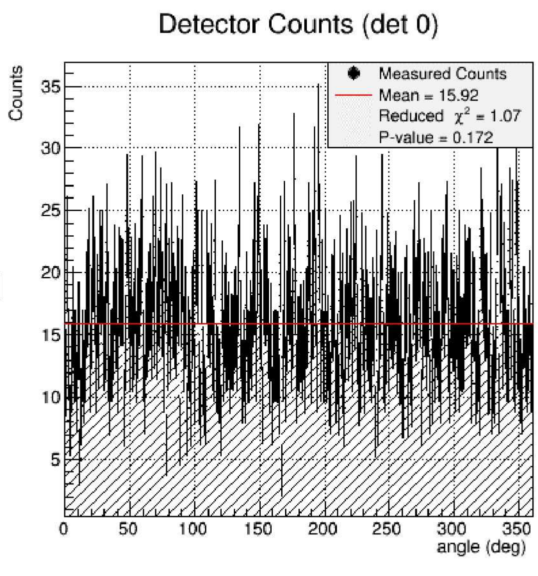
- Saving events time/location could reveal sensitive information
- Count the number of events in angle bin, removing exact location
- Looks like a multiplicity using time windows

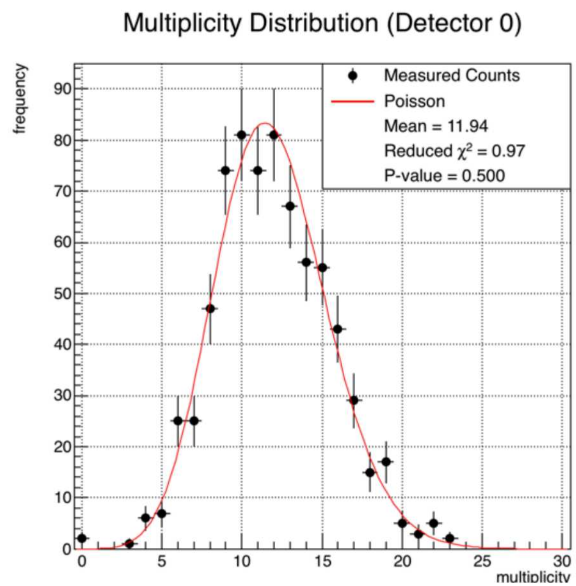


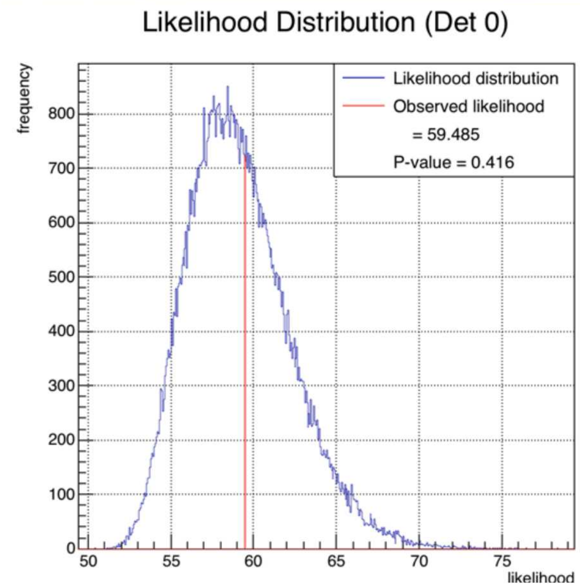


Multiplicity comparison

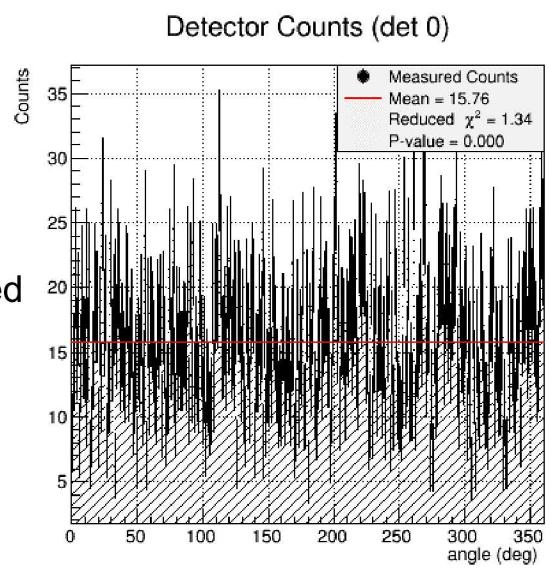
Matched

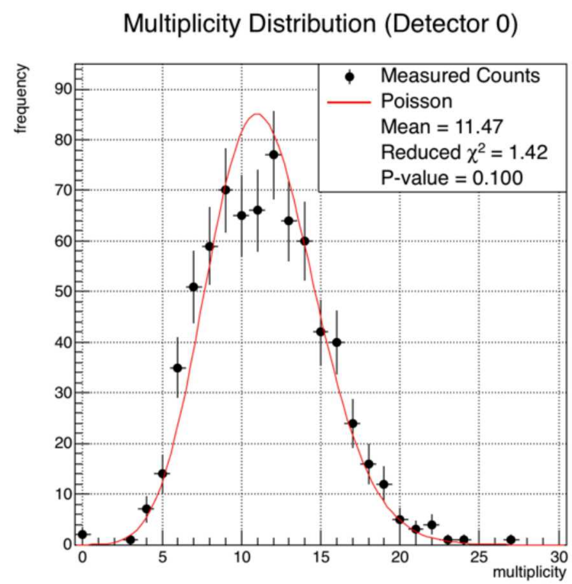


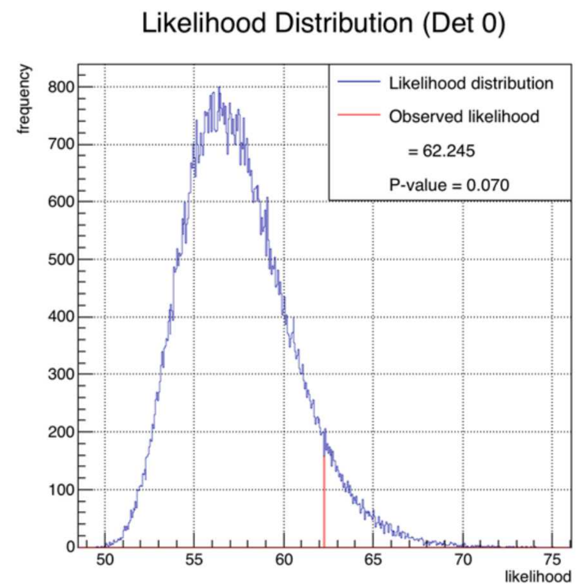




Misaligned

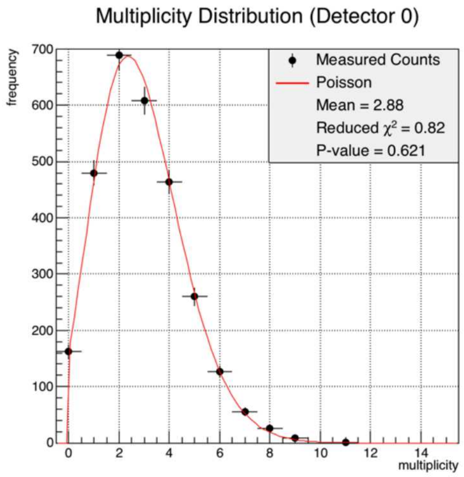


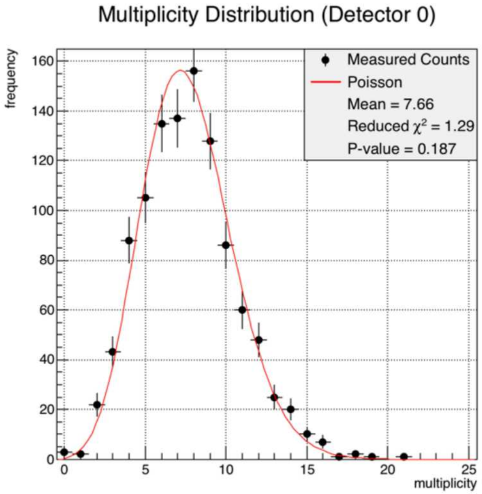


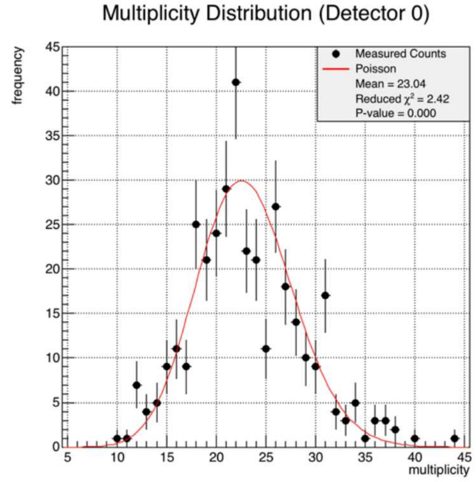


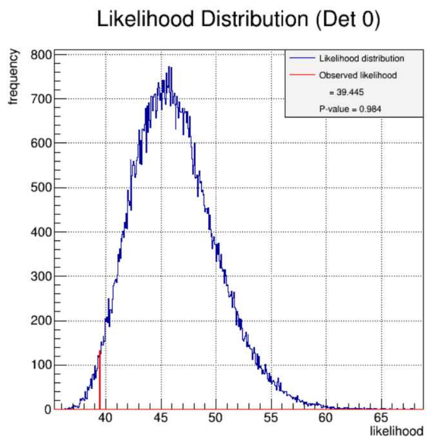
Limitations using multiplicity

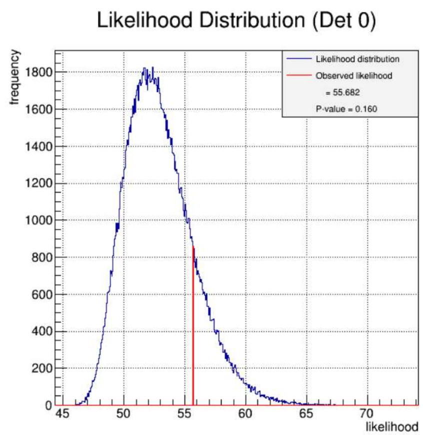
Misaligned Pu hemisphere data at different “speeds”

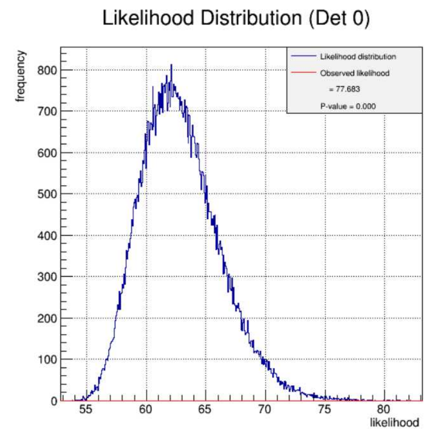












Works best with a mean higher than ~10 counts/angle, which may require a very slow rotation speed and a long total measurement time

Future work

- Optimal multiplicity system design
  - Constraints
    - Spatial resolution (angle)
    - Mean rate (rotation speed)
    - Total time
- Gamma system
  - Improves confidence to measure both gamma rays and neutrons

Disclaimer

Sandia National Laboratories

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Dan Throckmorton

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UNIVERSITY OF CALIFORNIA

Kai Vetter

UNIVERSITY OF MICHIGAN

Patricia Schuster

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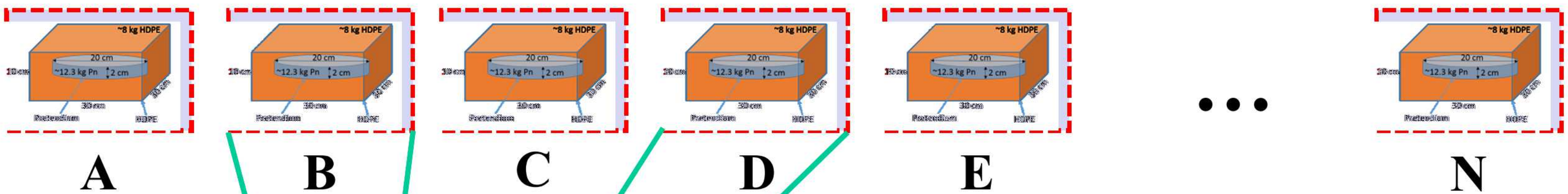
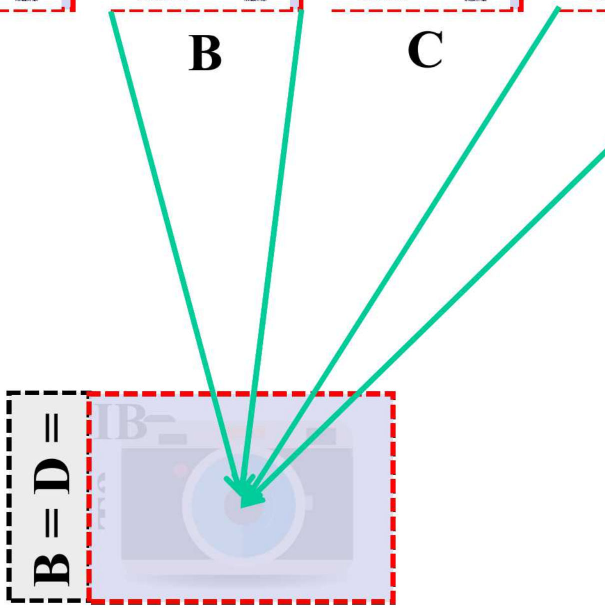
Extra Slides

CONOPS and Inspector Choice

- The ZKP CONOPS offers an interesting way to gain authentication confidence.
- Presented with N objects and k comparison measurements will be made.





Probability of being selected (if random) =

$$1 - \left(1 - \frac{1}{N}\right)^{2k}$$

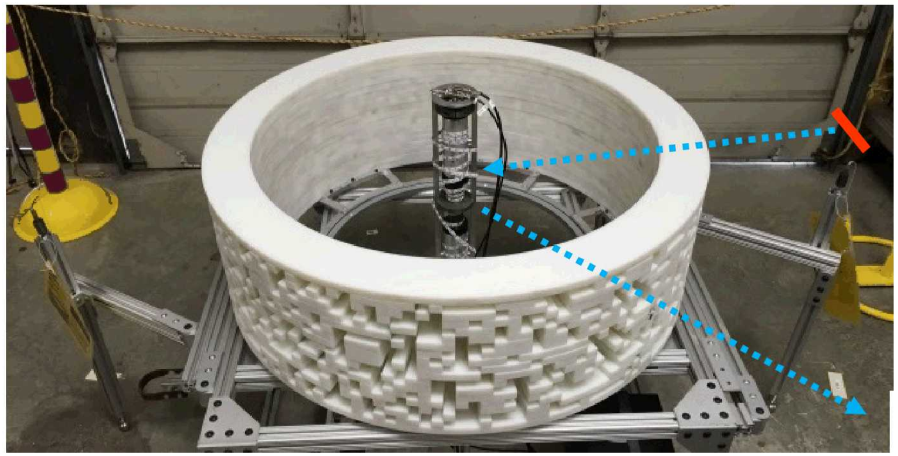
If T is one of the objects, then even if neither X nor T are selected, there was a chance for both to have been selected with probability =

$$\left(1 - \left(1 - \frac{1}{N}\right)^{2k}\right)^{2}$$

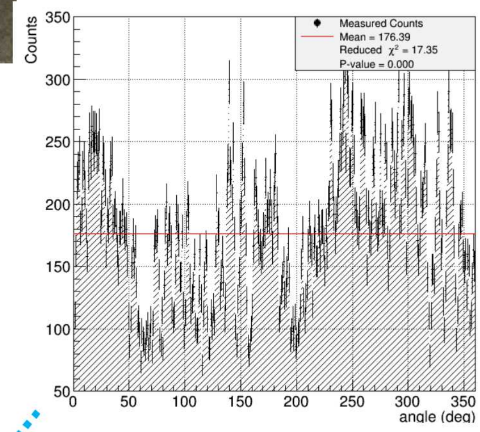
providing some degree of confidence

Results: Double Point Source Measurements

Measurement of a double “line” source (~20 hours)

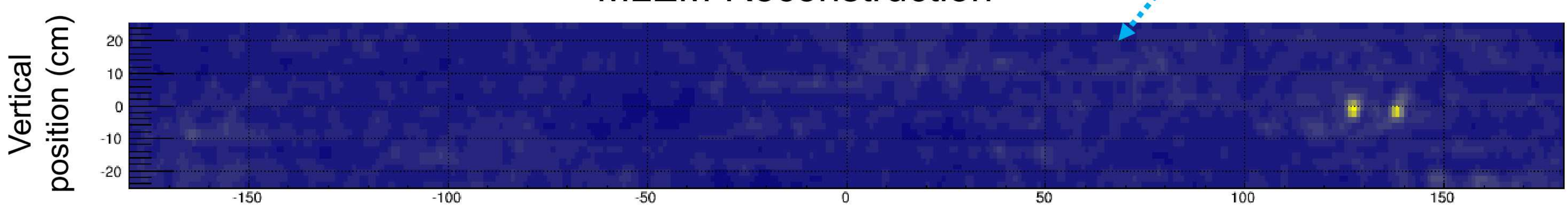


Neutron Counts



Rotation Angle (deg)

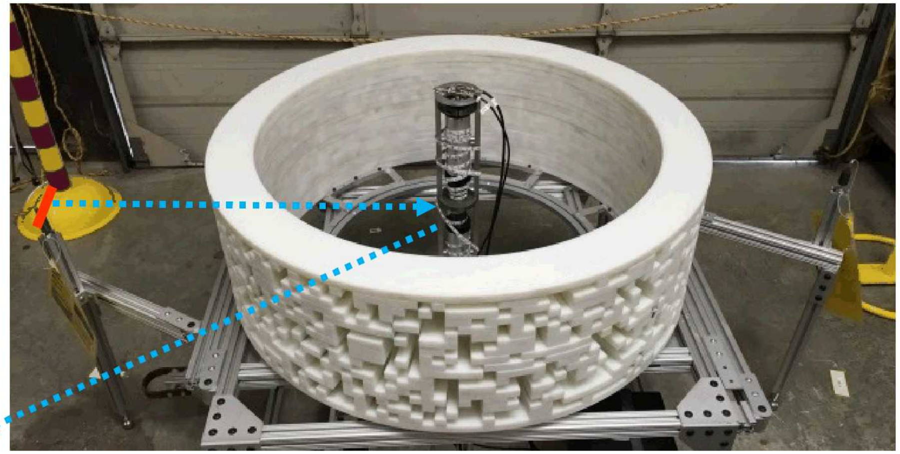
MLEM Reconstruction



Azimuthal Position (deg)

Results: Double Point Source Measurements

Measurement of a double “line” source (~20 hours)



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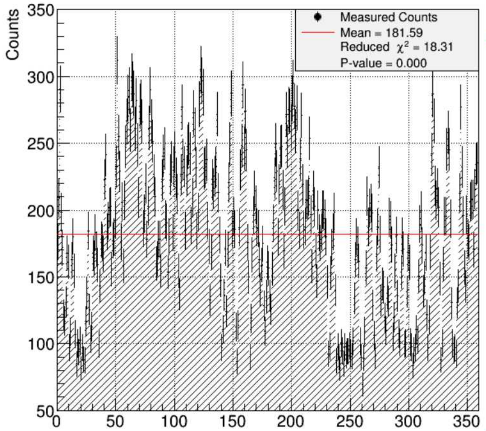
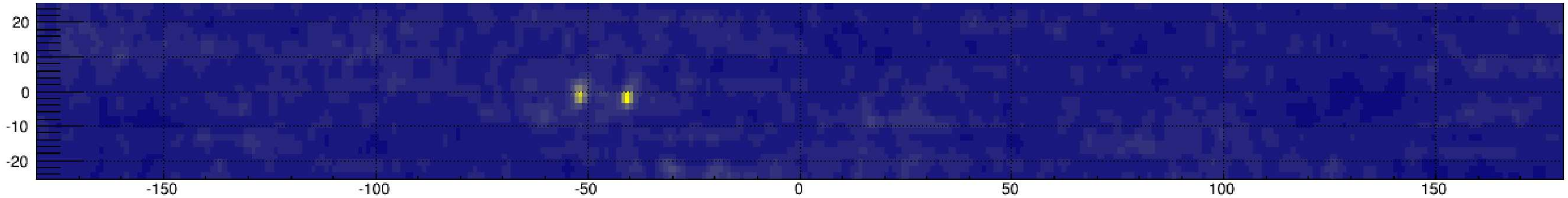


Rotation Angle (deg)

MLEM Reconstruction

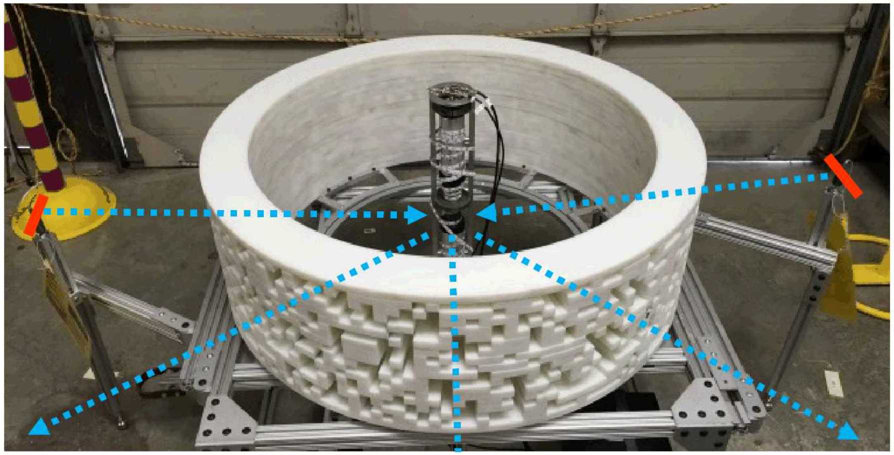


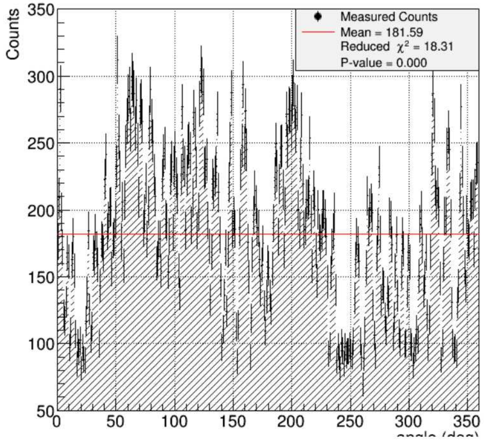
Vertical position (cm)

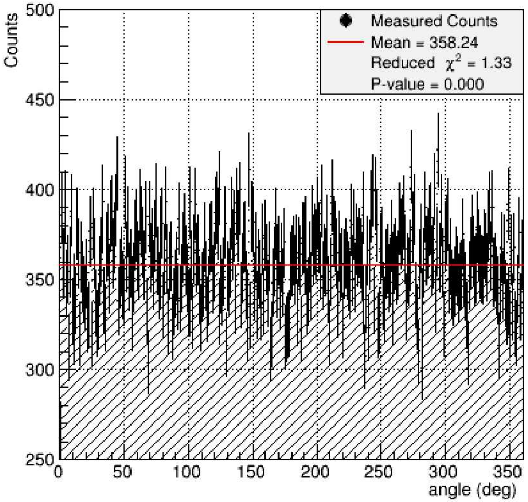
Azimuthal Position (deg)

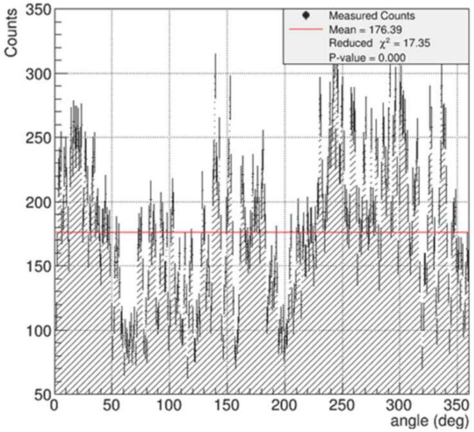
Results: Double Point Source Measurements

Measurement of two double "line" sources on opposite sides ***simultaneously*** (~20 hours)



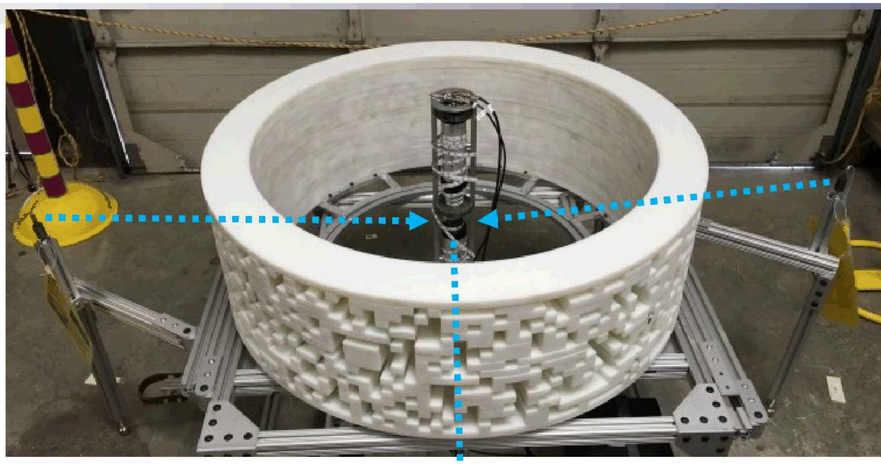


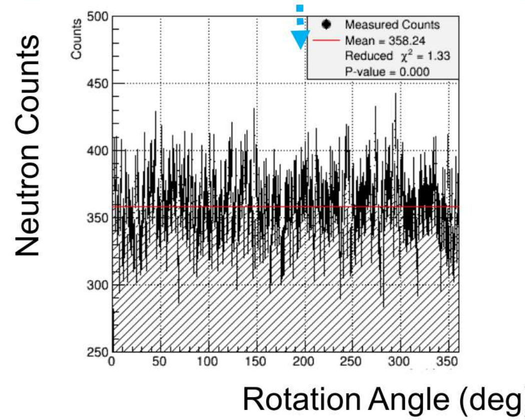




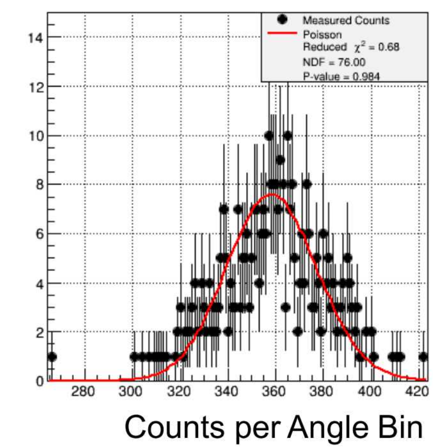
Results: Double Point Source Measurements

Measurement of two double “line” sources on opposite sides ***simultaneously*** (~20 hours)





Count Distribution (Poisson – red curve)



MLEM Reconstruction