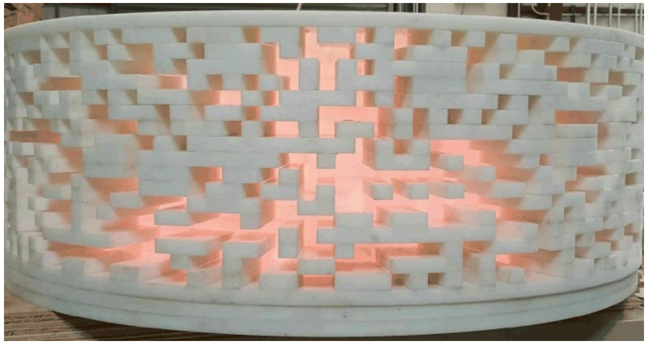
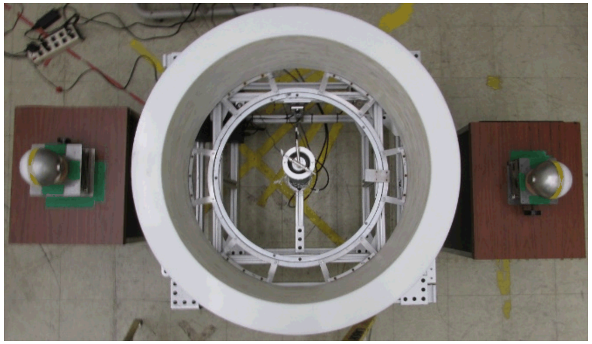
SAND2017-13309PE



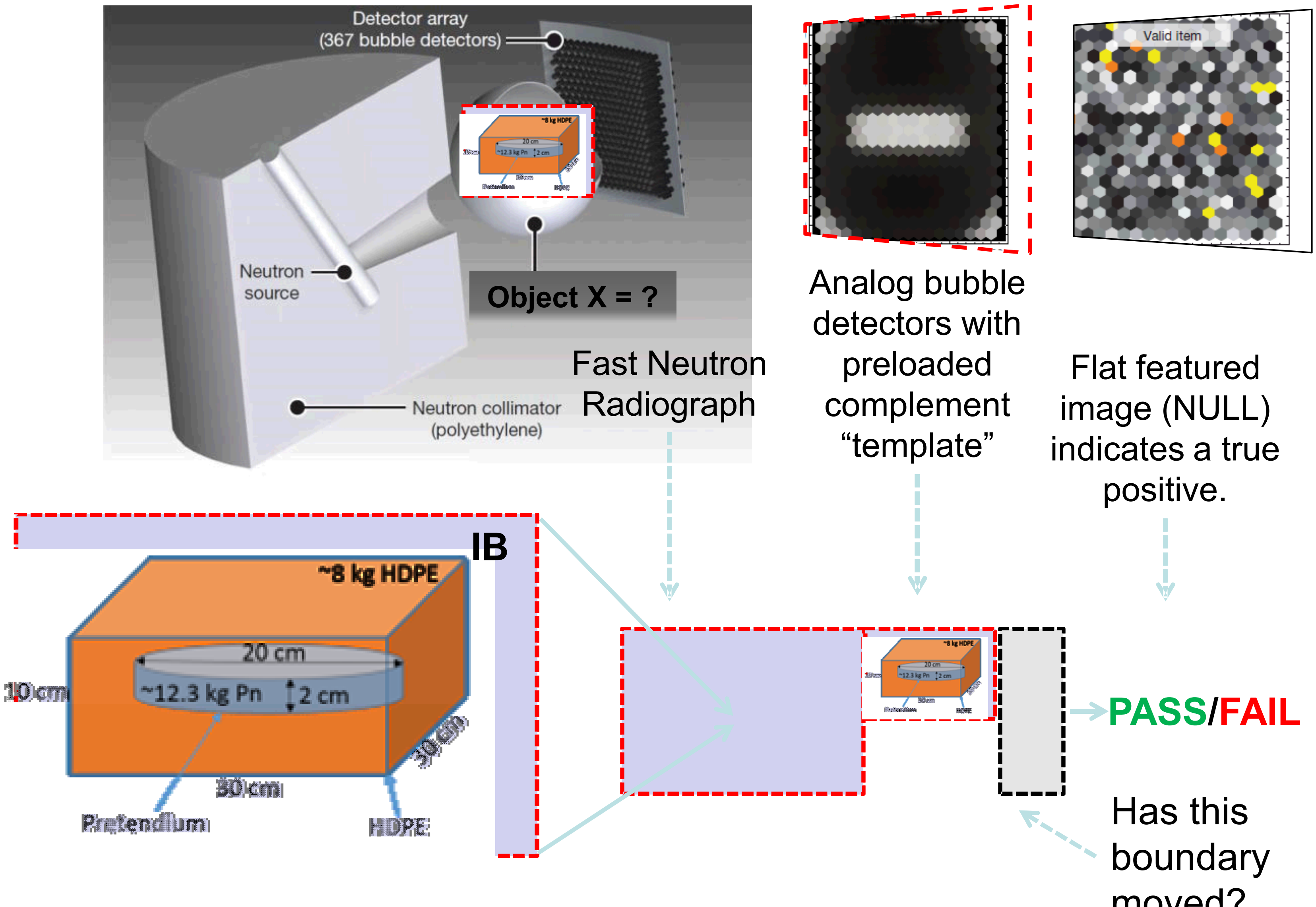


# CONFIDANTE Research Questions

Peter Marleau

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and 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.

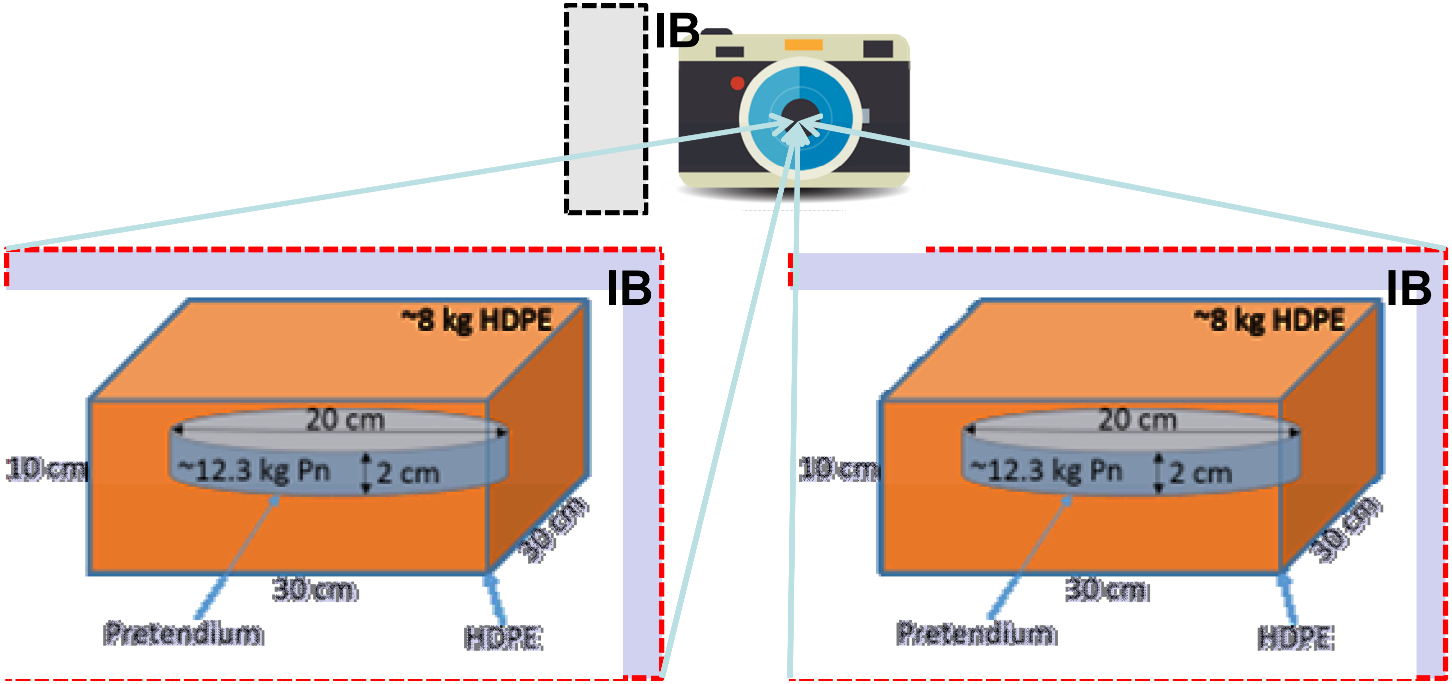
# Zero Knowledge Protocols – Glaser, Barak, and Goldston




Images borrowed from: Glaser, Barak, and Goldston, "A zero-knowledge protocol for nuclear warhead verification", doi:10.1038/nature 134557

# Zero Knowledge comparison measurement?

- Is there a physical implementation of the confirmation measurement that an inspecting party can watch and authenticate?
- **It would be great if we could get a physical NULL as an indication of positive confirmation at all times, *not just at the end*.**

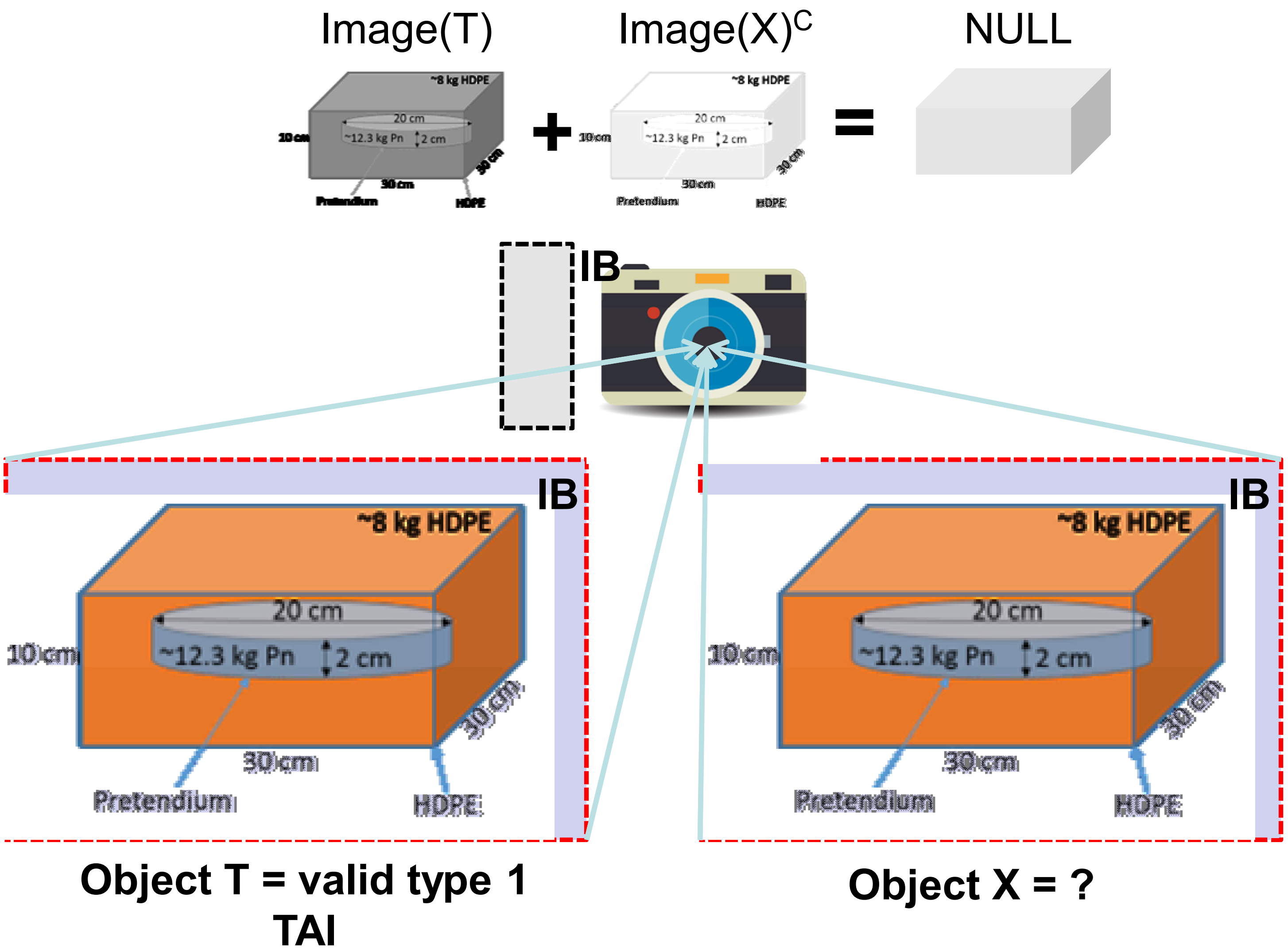



**Object T = valid type 1 TAI**

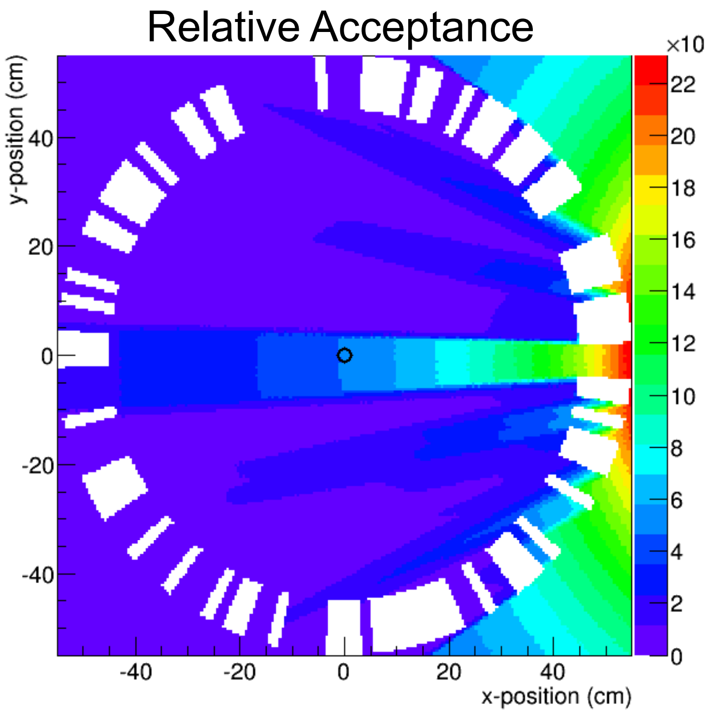
**Object X = ?**

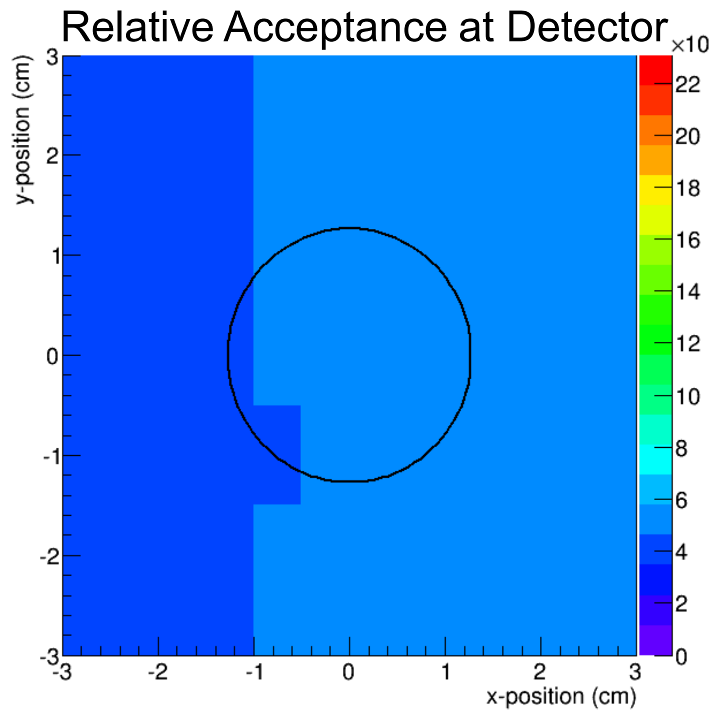
# Proposal – complementary comparison

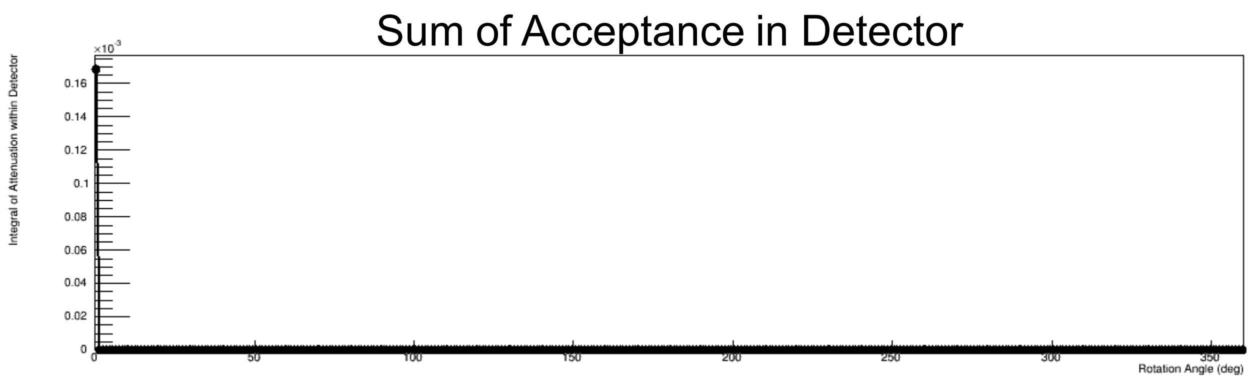
- What we need is to turn one image into its complement ***at all times***.



# Time Encoded Imaging



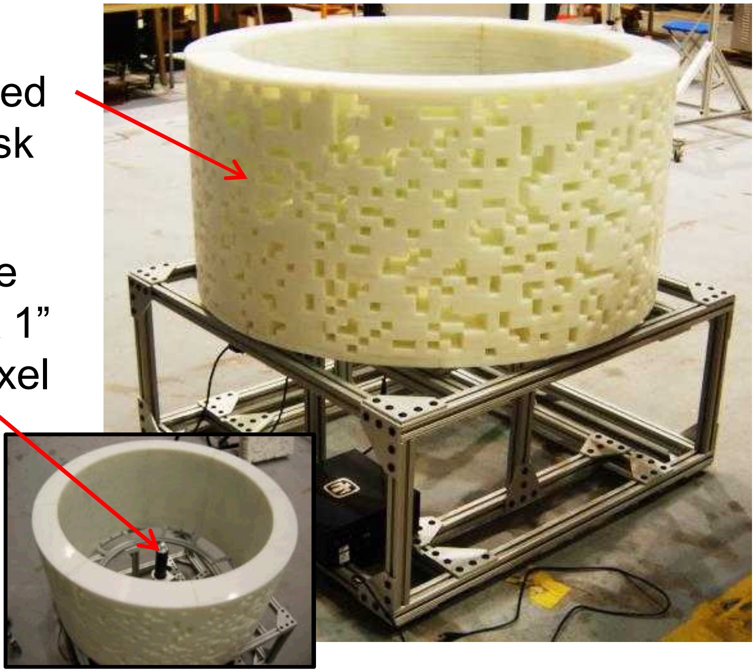



# 2D Time-encoded Imaging (TEI)

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

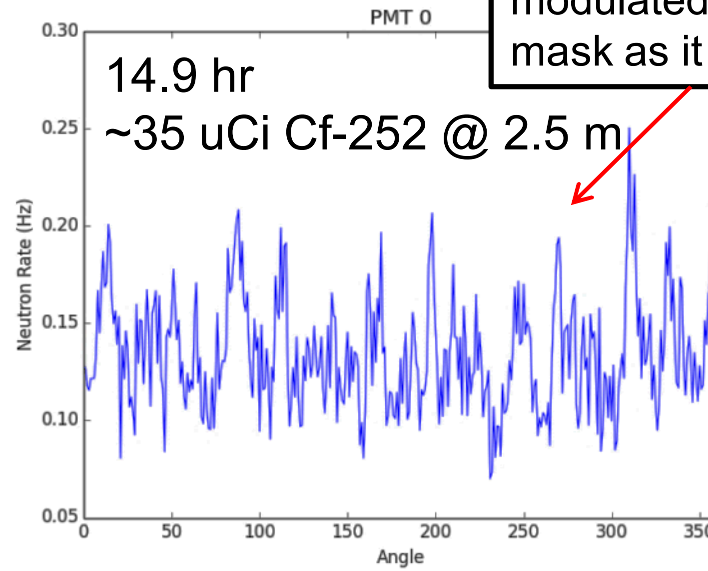
2-d coded mask

Single 1"D x 1" LS pixel

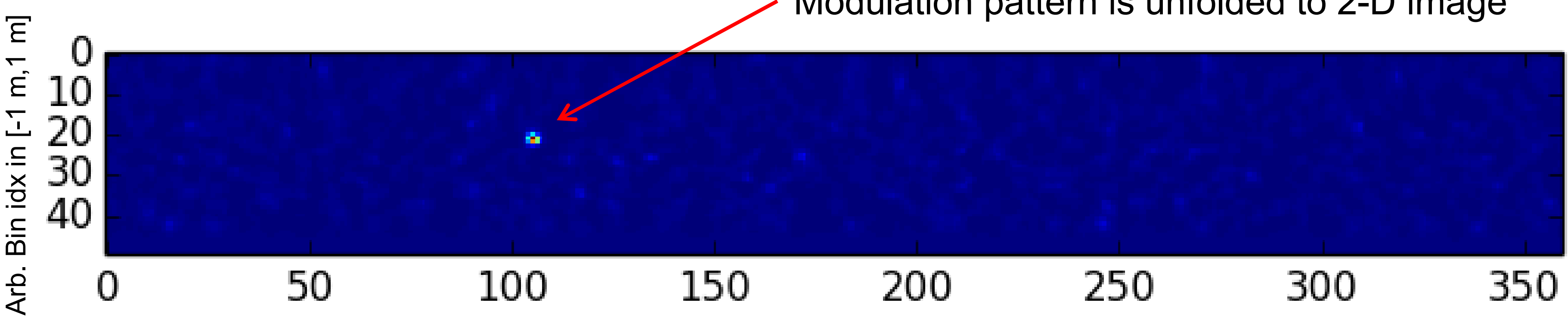


Single pixel rate is modulated by the mask as it rotates.

14.9 hr
~35 uCi Cf-252 @ 2.5 m



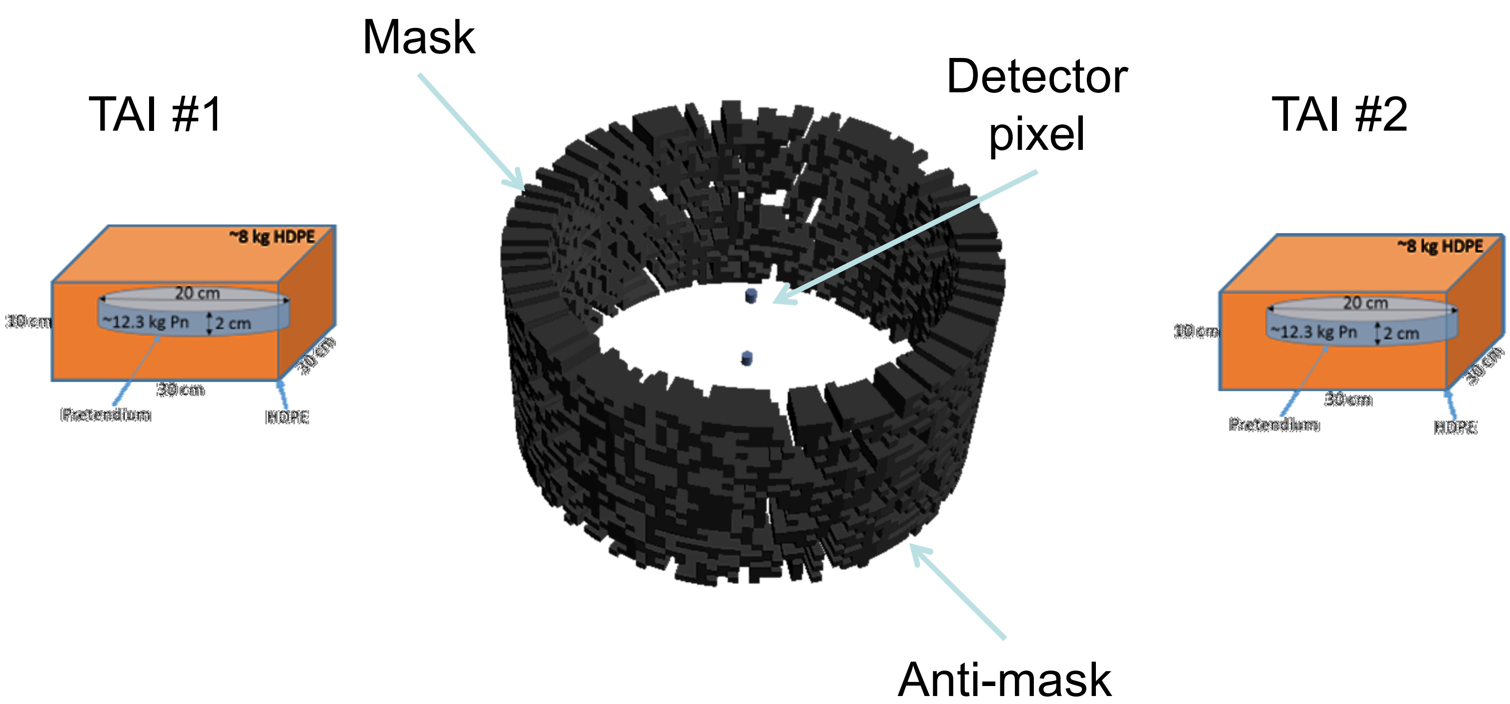

Modulation pattern is unfolded to 2-D image



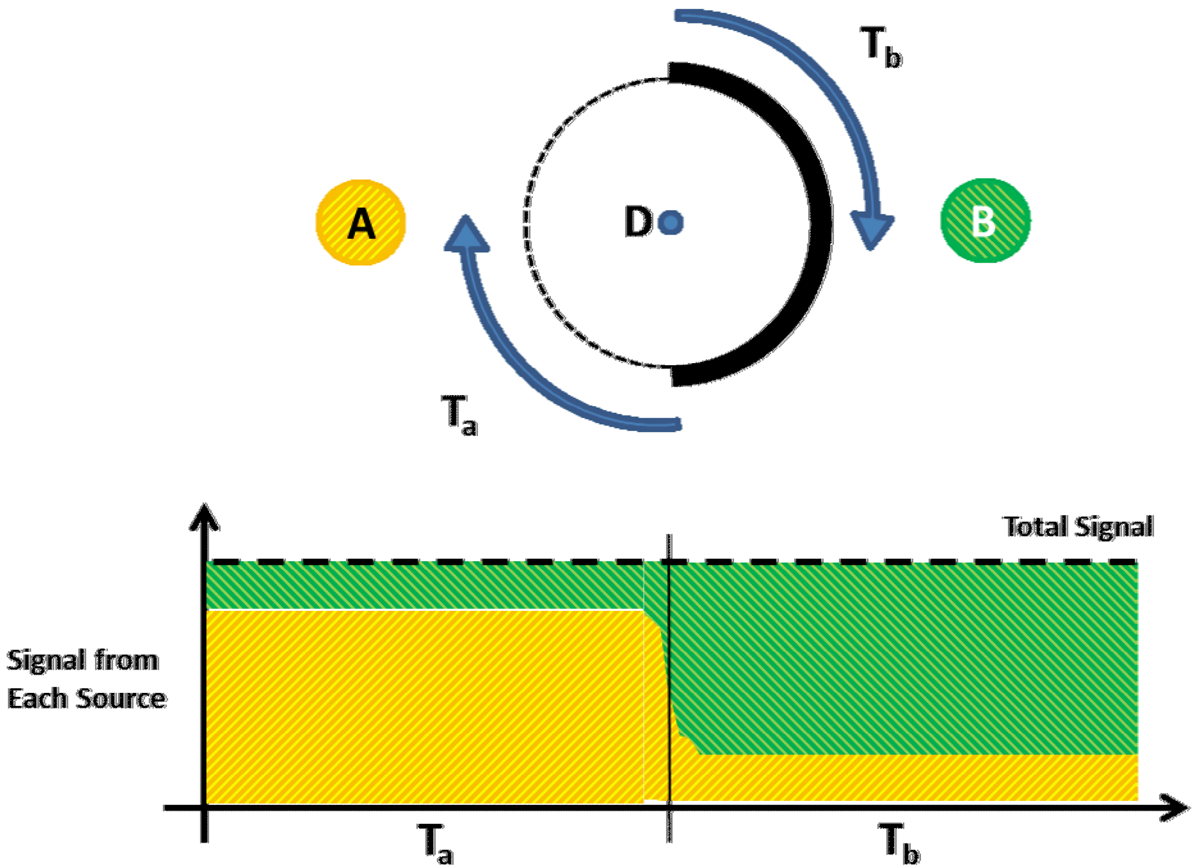
# Here's where the magic happens …

If the mask is designed such that one side is the anti-mask of the other, then **TAI #2 projects the anti-image of TAI #1 at all times**

**if and only if they are identical!**

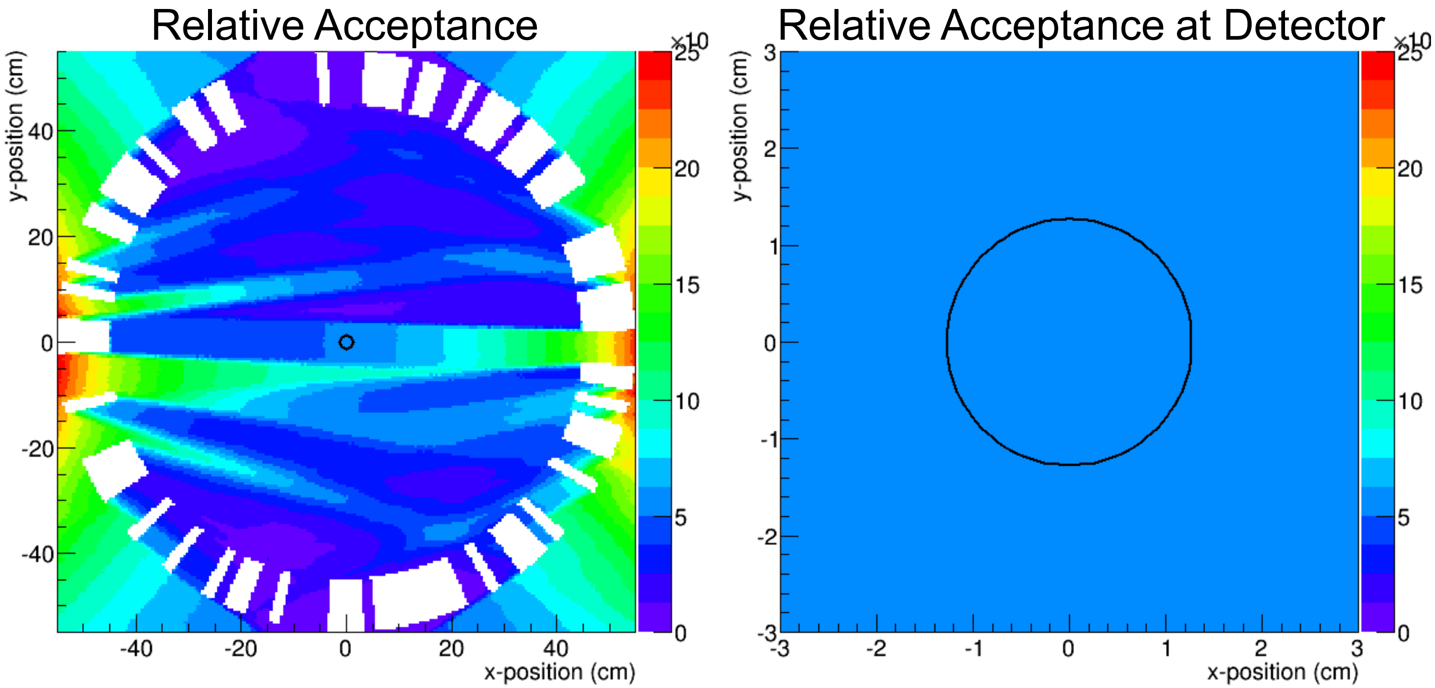


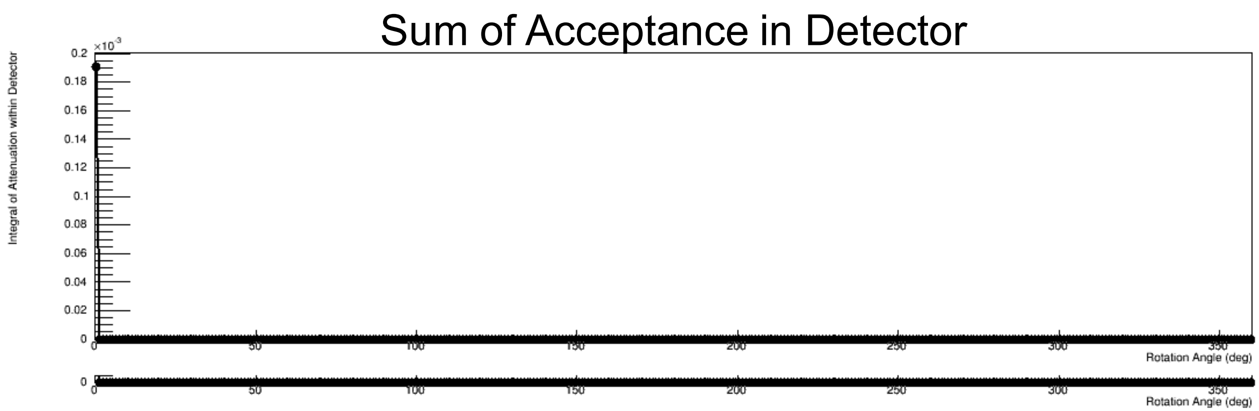
# A very simple example



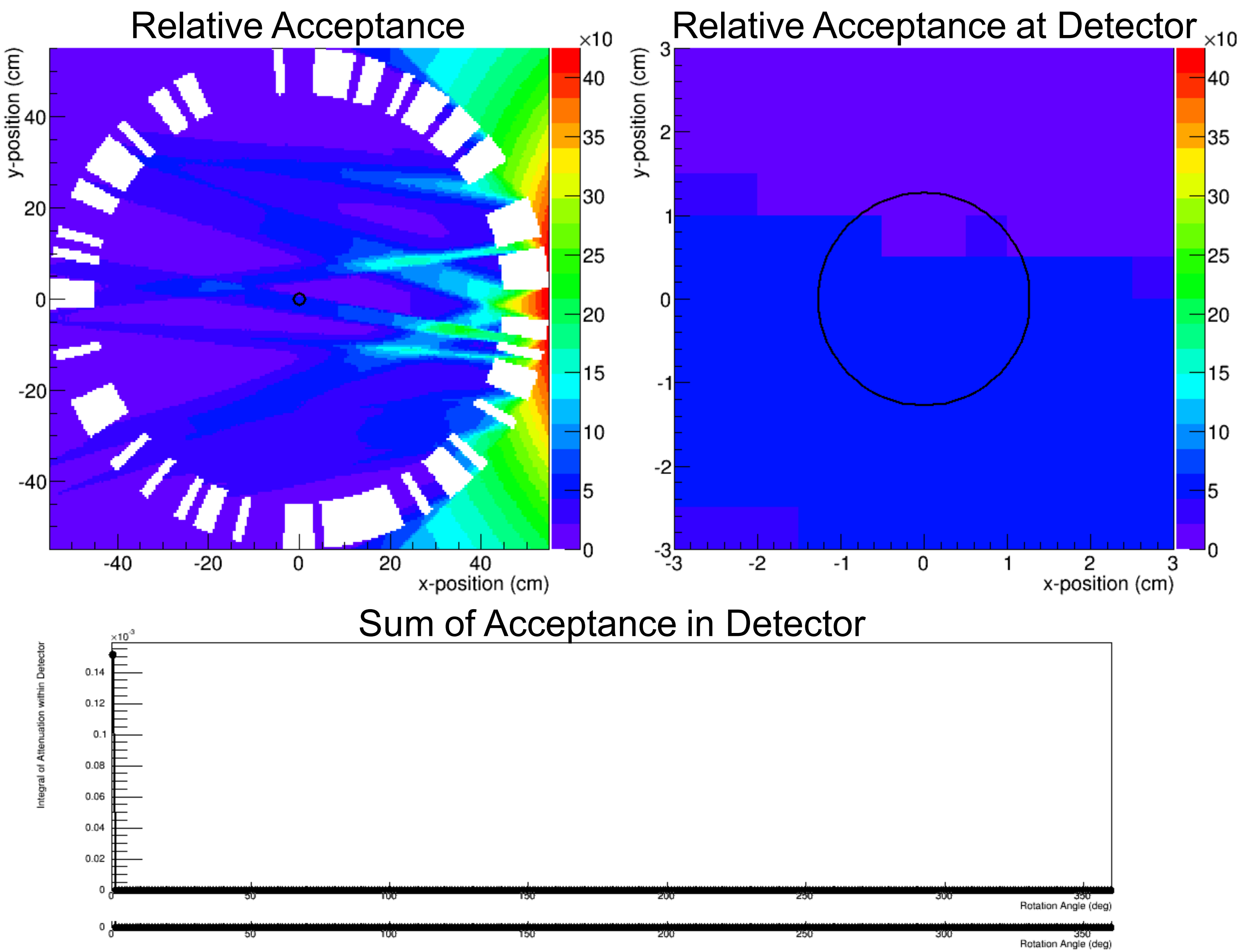

- The simplest possible mask with this property: half mask, half aperture.
- The fraction of total count rate coming from A and B is unknown at any given angle.
- In this example, the location (and shape) of the boundary between regions is not revealed.

# Single Point Source on opposite sides

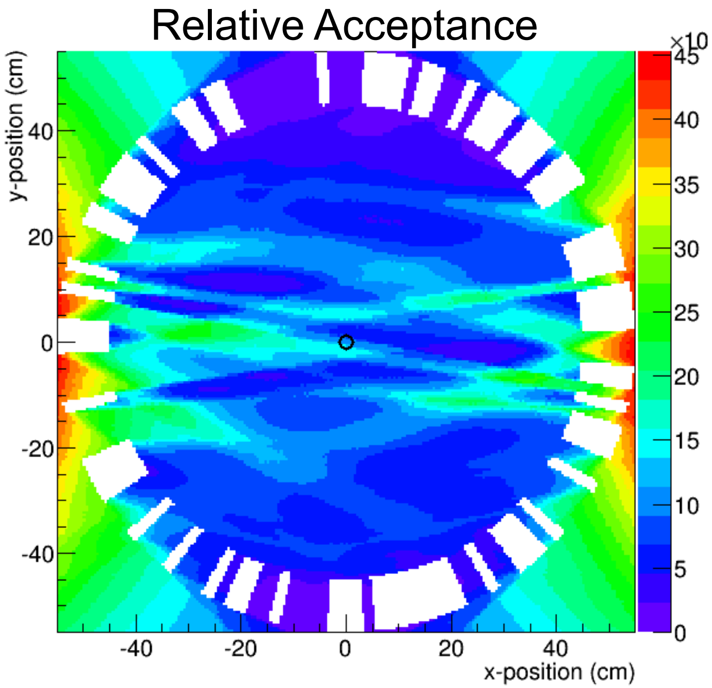


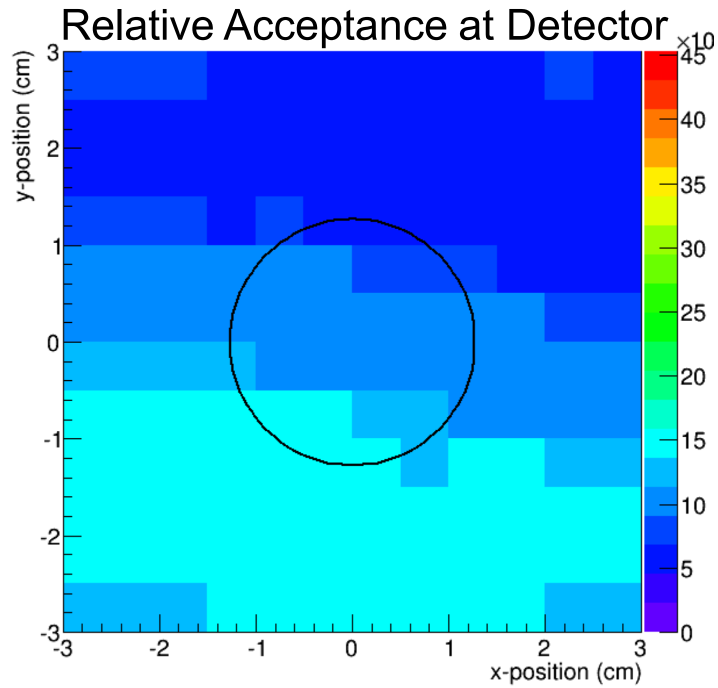



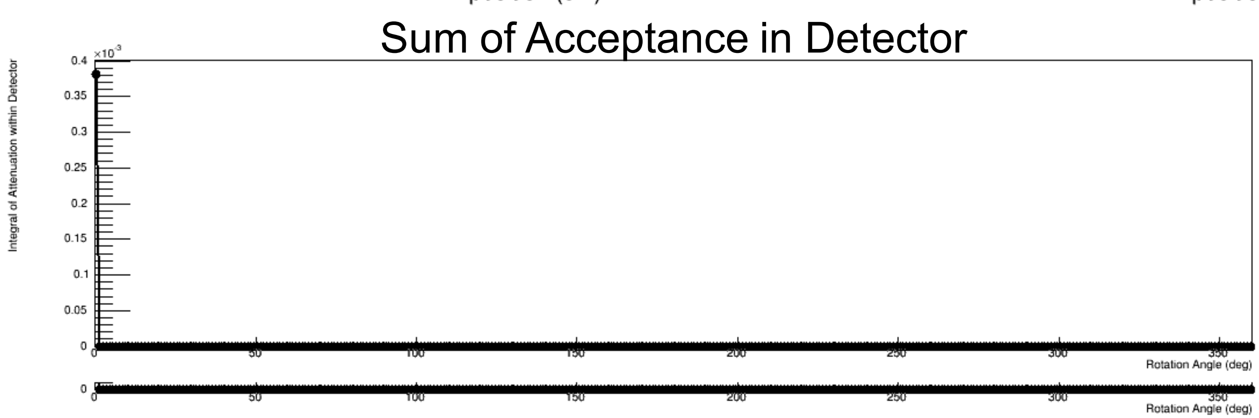
# Two Point Sources on one side



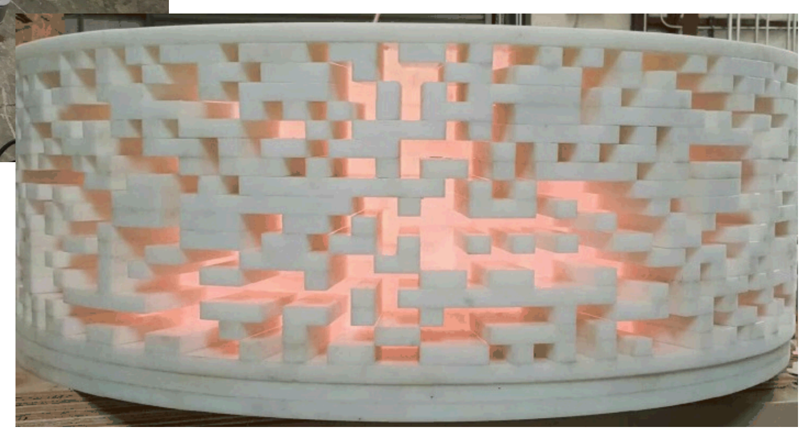
# Two Point Sources on opposite sides



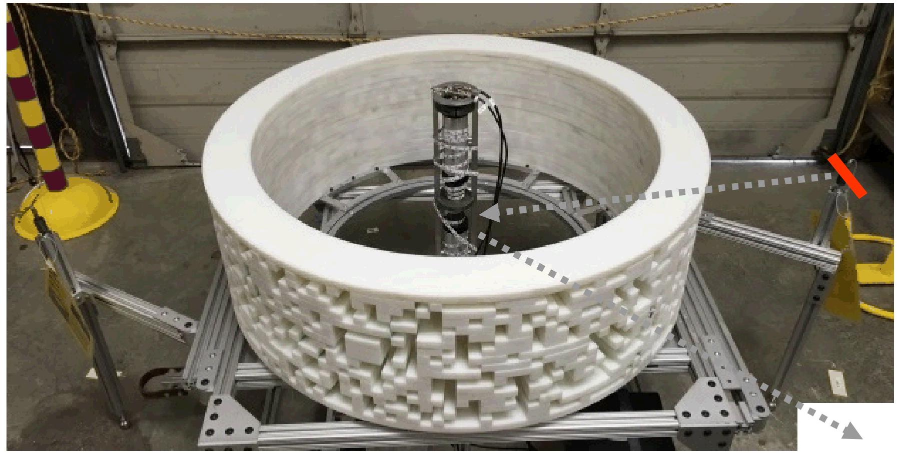



# CONFIDANTE

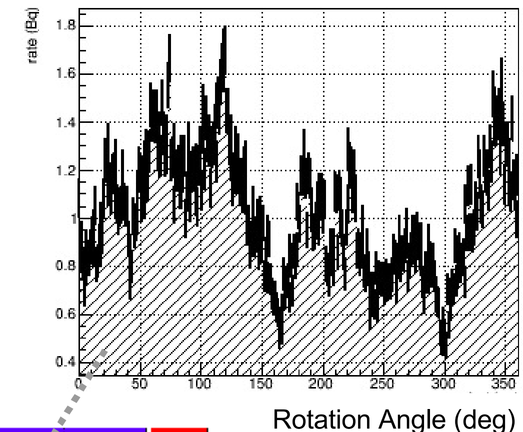



# Results – Double point source measurements

Measurement of a double "line" source on one side (~20 hours)



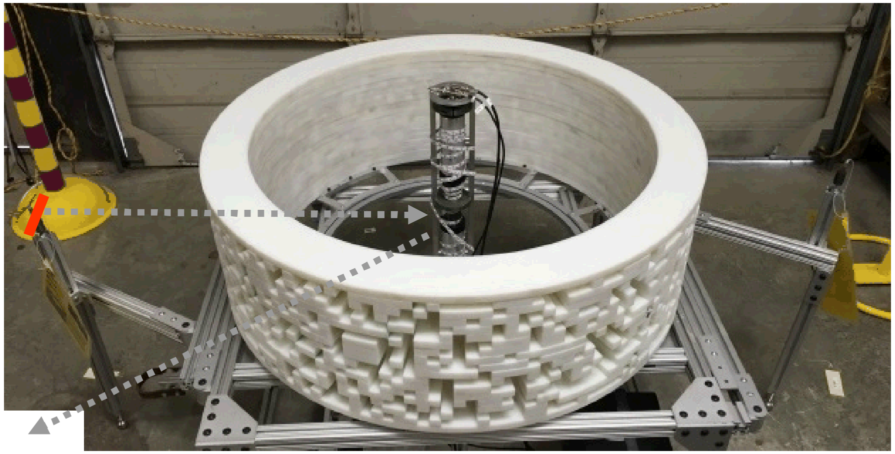
Neutron Rate



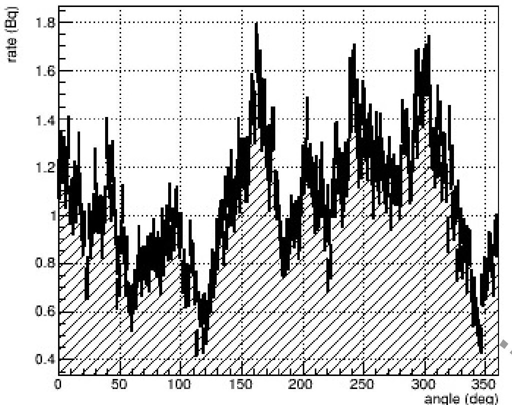

MLEM Reconstruction

# Results – Double point source measurements

Measurement of a double “line” source on the opposite side (~20 hours)

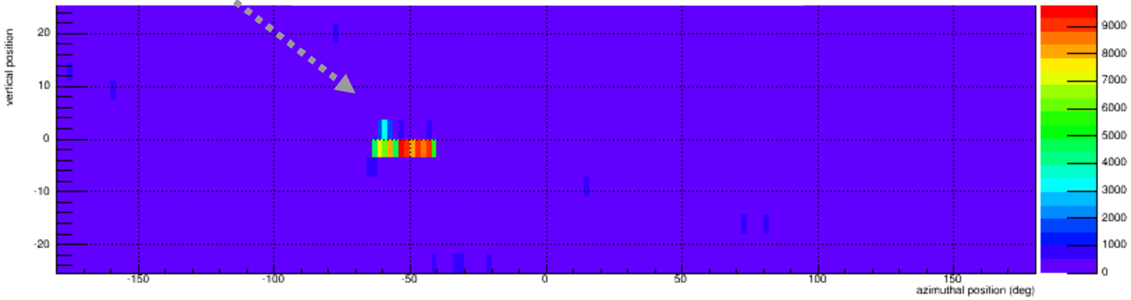


Neutron Rate




Rotation Angle (deg)

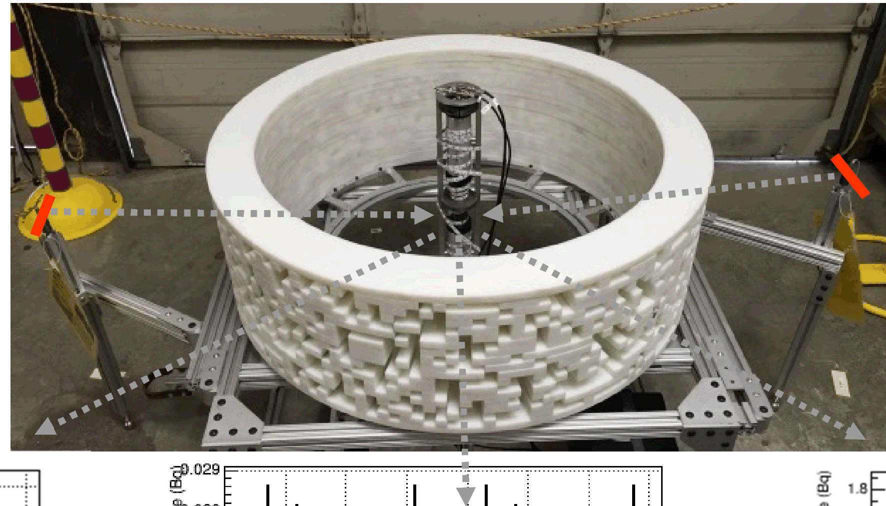
MLEM Reconstruction

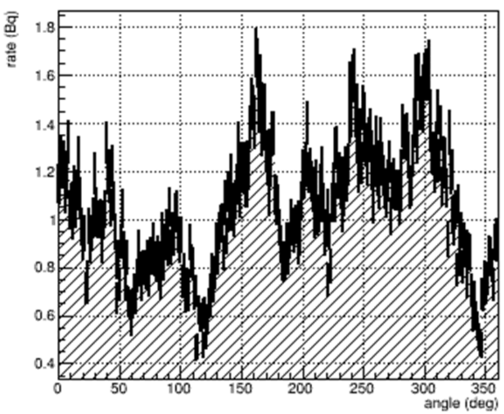


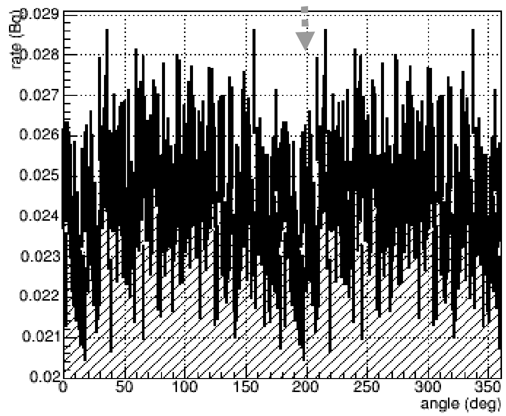

Azimuthal Position (deg)

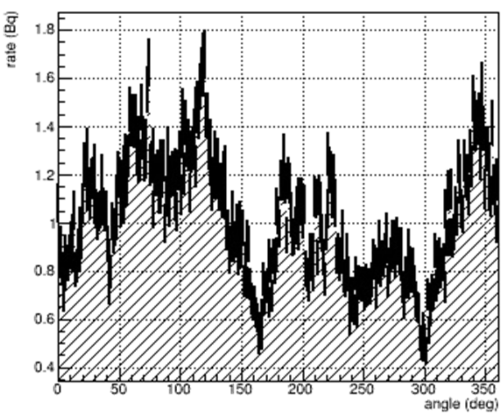
# Results – Double point source measurements

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



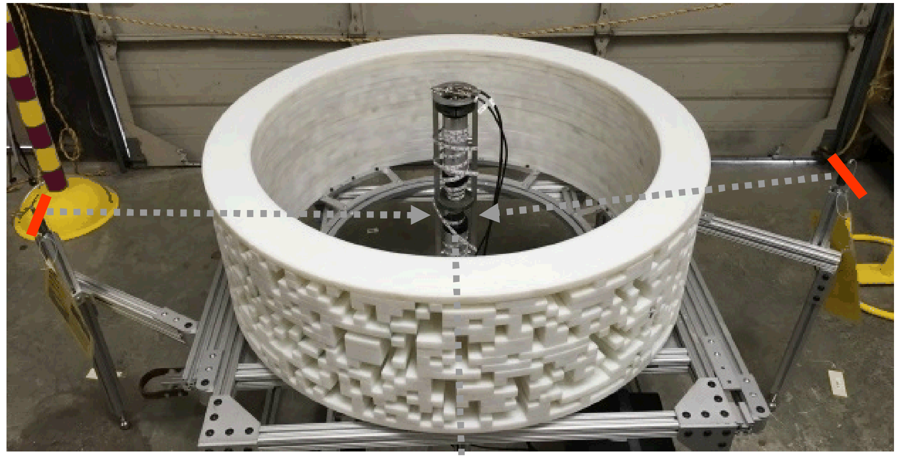


# Results – Double point source measurements

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

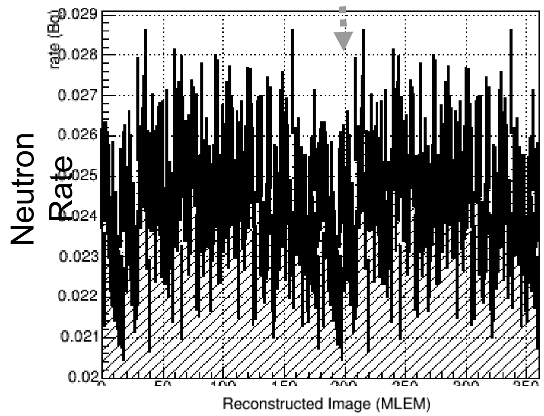


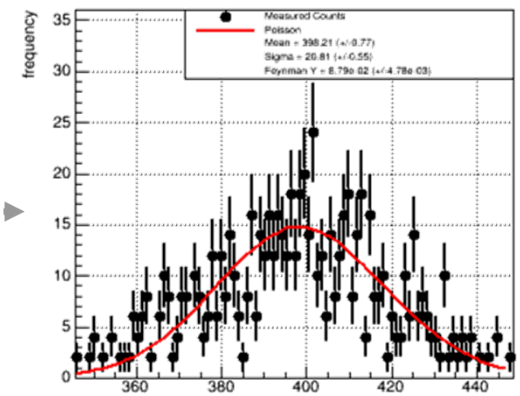
Feynman Y

$$= \left(\frac{variance}{mean} - 1\right)$$

$$= 0.0354$$

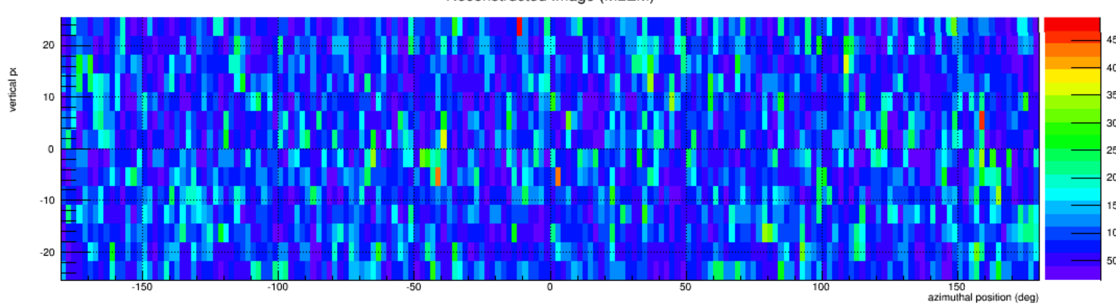
Count Distribution
(Poisson – red curve)



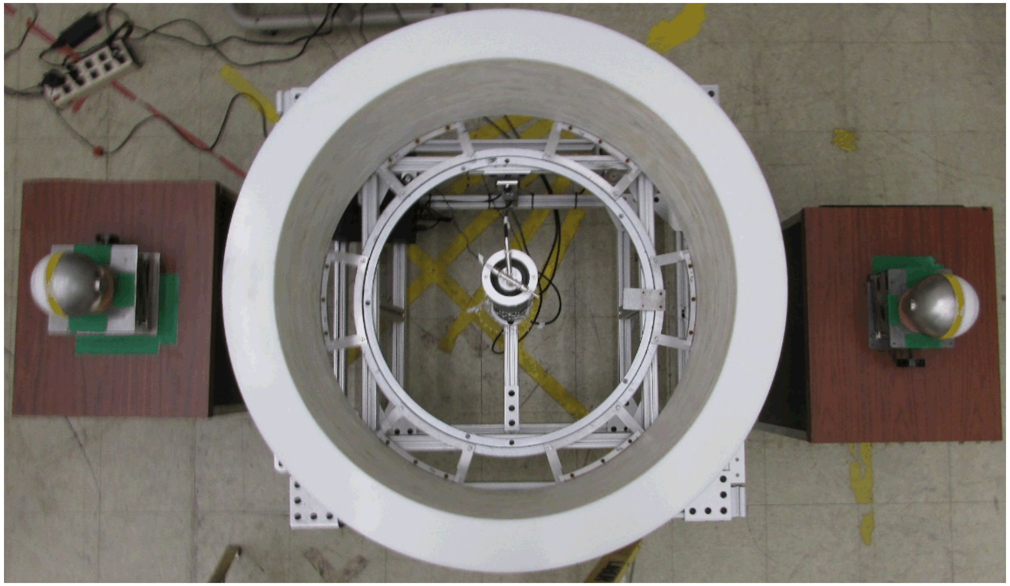

Bin Count Value

MLEM
Reconstruction




Azimuthal Position (deg)

# LLNL's $PuO_2$ Hemisphere comparison

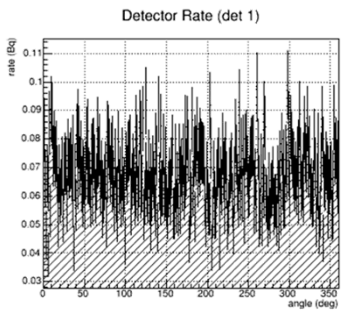


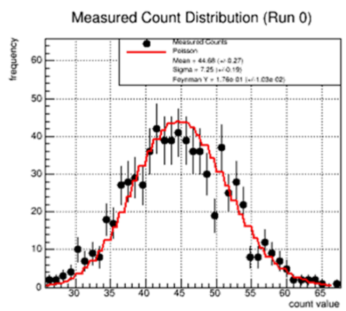
- One hemisphere was placed on either side of CONFIDANTE (180 deg. apart).
- ~68 hours of data was taken.

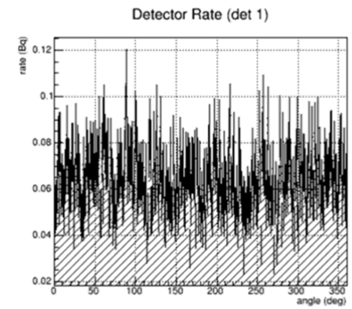
# Feynman Y Test Statistic – 10,000 bootstrapped trials

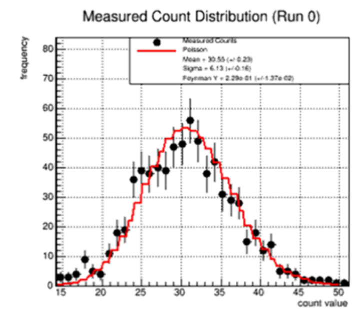
**Identical Hemis**

**Misaligned Hemis**

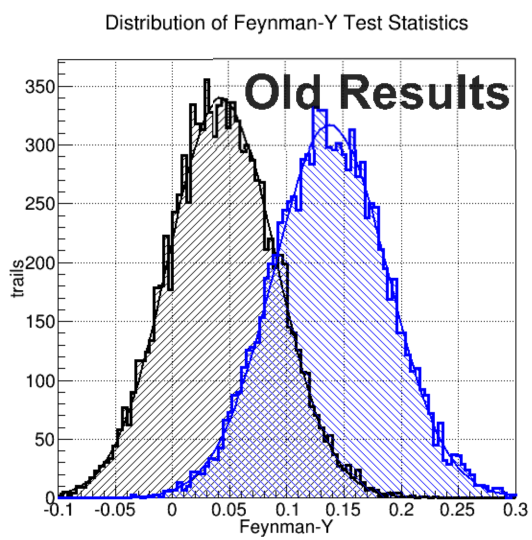



Feynman Y $= \left(\frac{variance}{mean} - 1\right) = 0.0209$




Feynman Y $= \left(\frac{variance}{mean} - 1\right) = 0.324$

Black – 10,000 bootstrapped trials of two “identical” $PuO_2$ hemispheres (~48 hours)

Blue – 10,000 bootstrapped trials of two “non-identical $PuO_2$ hemispheres (~48 hours)

# Statistical null hypothesis test results

| Object 1 | Object 2 | mean counts /deg | $\sigma^2$/deg | χ2/NDF | $P(\chi^2,NDF)$ |
|---|---|---|---|---|---|
| | Two $^{252}Cf$ at 130° | 202.61 | 872.25 | 4.39 | 9E-152 |
| Two $^{252}Cf$ at -50° | | 228.17 | 1219.55 | 5.43 | 2E-216 |
| Two $^{252}Cf$ at -50° | Two $^{252}Cf$ at 130° | 377.92 | 391.31 | 1.05 | 0.25 |
| | $PuO_2$ hemi at 130° | 9.97 | 12.45 | 1.28 | 3E-4 |
| $PuO_2$ hemi at -50° | | 24.73 | 47.77 | 1.98 | 2E-25 |
| $PuO_2$ hemi at -50° | $PuO_2$ hemi at 130° | 19.16 | 19.56 | 1.04 | 0.27 |
| $PuO_2$ hemi at -50° | $PuO_2$ hemi rotated by 90° at 130° | 30.00 | 39.73 | 1.36 | 7E-6 |

# Research Questions

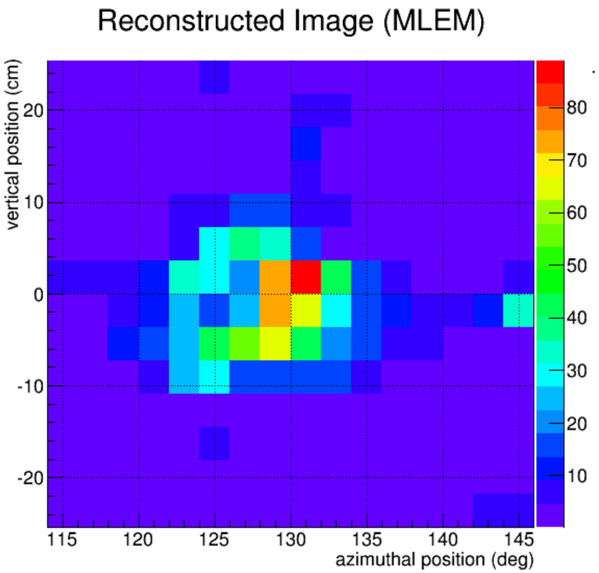
- Considering the concept and associated CONOPS, what sensitive information might be at risk?
  - Is there any remaining information in the measurement results that should be protected?
  - Are there particular design features to worry about?
  - Is there expected variability to worry about?
    - Between treaty accountable items.
    - Between containers or environments.
    - Are there other factors that can cause variability between items or measurements?
- Are there further steps that can be taken to mitigate information risk?
  - Changes to hardware, firmware, software.
  - Procedural changes.

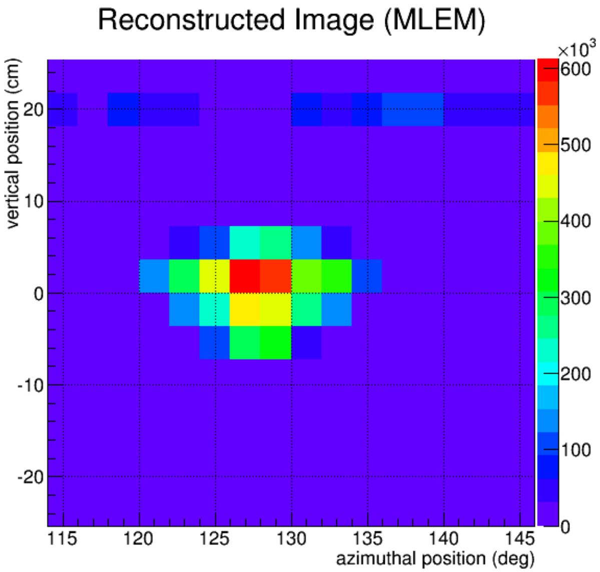
# Additional Slides

# LLNL's $PuO_2$ Hemispheres

Measurement of plutonium dioxide hemispherical shells at LLNL.

Neutron Image

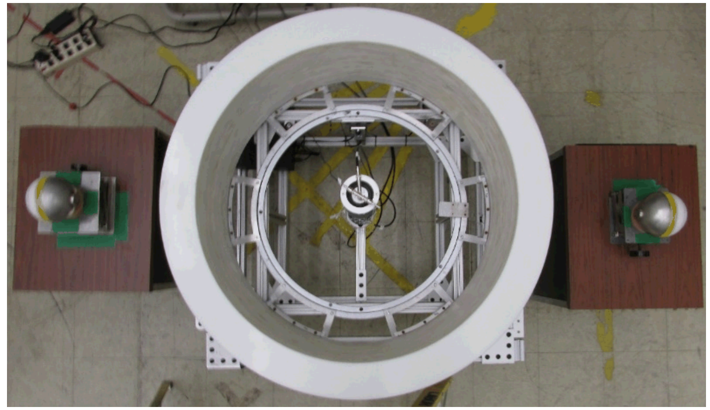



Gamma-ray Image

# LLNL's $PuO_2$ Hemi positive measurement

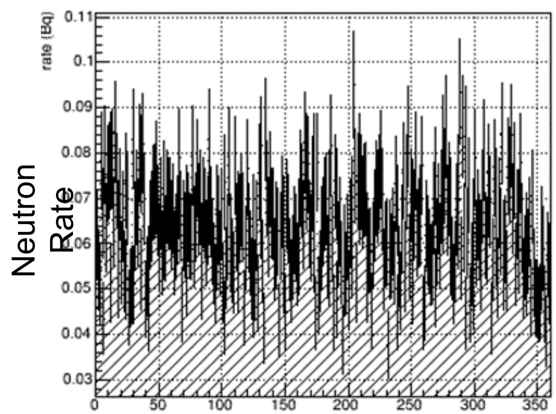
- One hemisphere was placed on each side (180 deg) of CONFIDANTE.
- ~68 hours of data was taken.



Feynman Y

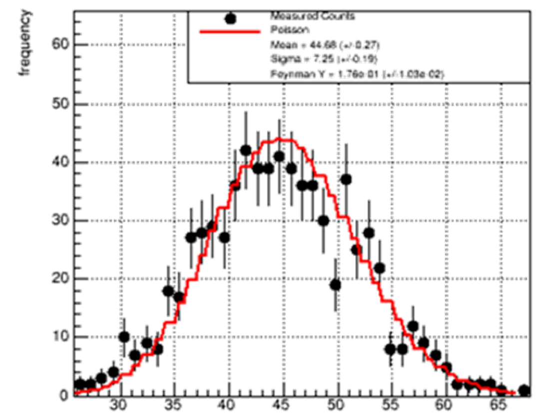
$$= \left(\frac{variance}{mean} - 1\right)$$

$= 0.0176 \pm 0.00103$



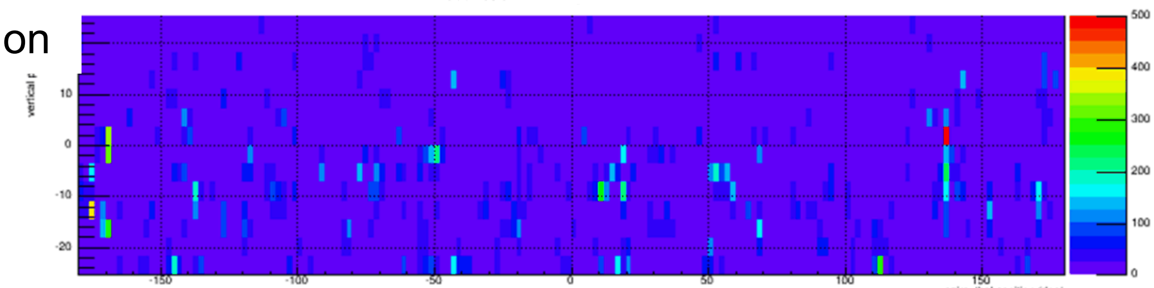

Rotation Angle (deg)

Count Distribution
(Poisson – red curve)




Bin Count Value

MLEM Reconstruction

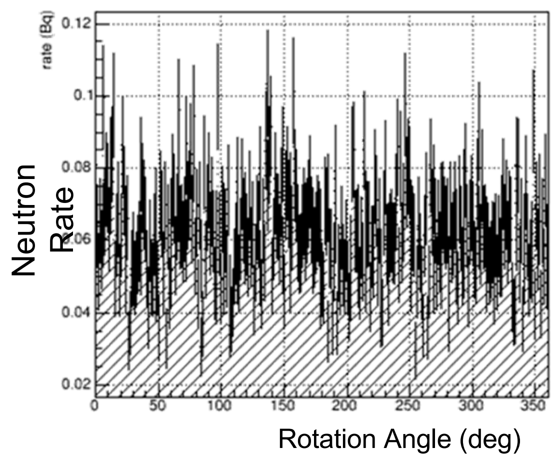



Azimuthal Position (deg)

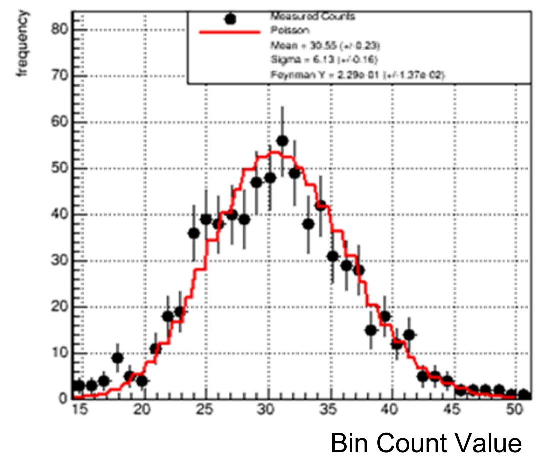
# LLNL's $PuO_2$ Hemi negative measurement

- One hemisphere was placed on each side (180 deg) of CONFIDANTE.
- One was rotated by 90 degrees.
- ~48 hours of data was taken.


Feynman Y
$= \left(\frac{variance}{mean} - 1\right)$
$= 0.229 \pm 0.0137$




Count Distribution (Poisson – red curve)




MLEM Reconstruction