SAND2016-5169PE

Exceptional service in the national interest

Sandia National Laboratories

CONfirmation using a Fast-neutron Imaging Detector with Anti-image NULL-positive Time Encoding (CONFIDANTE)

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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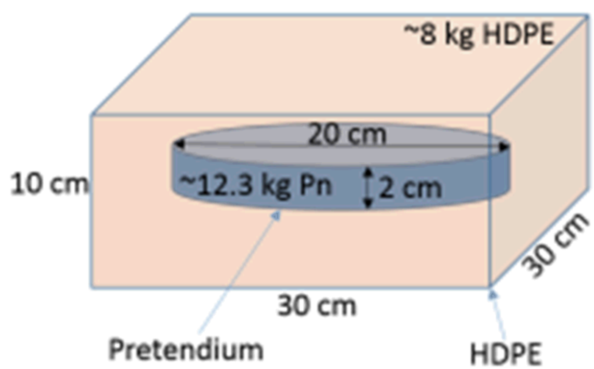
Challenge problem

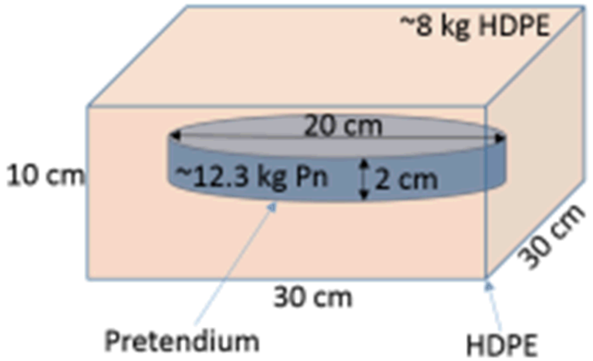
- The inspecting party has or had access to measure item T, which is known to be a valid type 1 treaty accountable item (TAI) through some other mechanism.



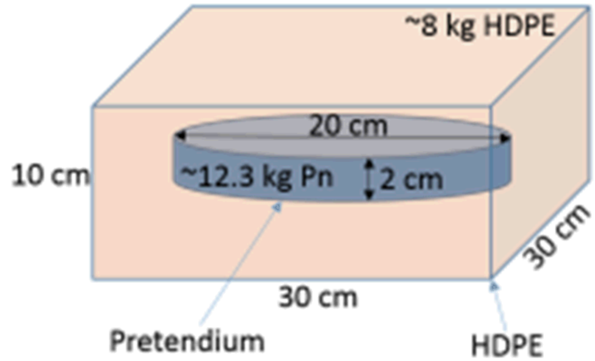
Object T = valid type 1 TAI

Challenge problem

- The inspecting party has or had access to measure item T, which is known to be a valid type 1 TAI through some other mechanism.
- In the course of an inspection, the host presents item X and declares it as a type 1 TAI
- Item X should pass the verification measurement if it is a type 1 TAI, and fail if it is significantly different.



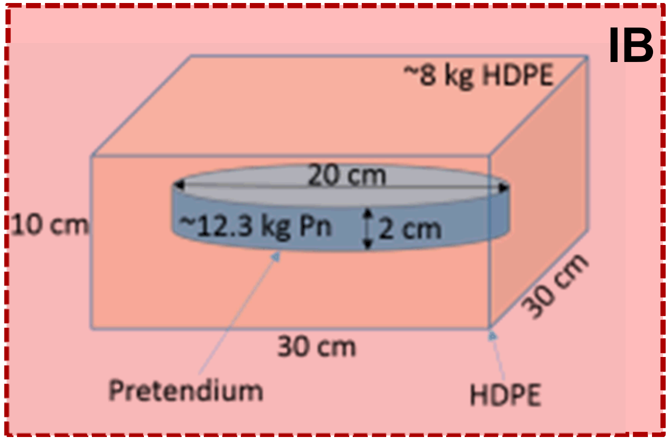
Object T = valid type 1 TAI



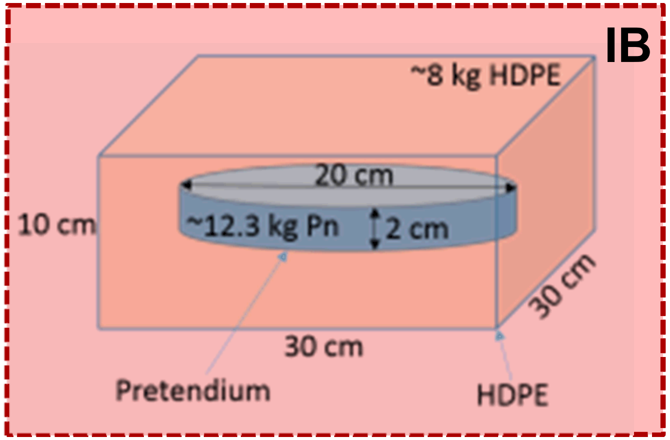
Object X = ?

Challenge problem

- The inspecting party has or had access to measure item T, which is known to be a valid type 1 TAI through some other mechanism.
- In the course of an inspection, the host presents item X and declares it as a type 1 TAI
- Item X should pass the verification measurement if it is a type 1 TAI, and fail if it is significantly different.
- The host must be confident that the inspector has not learned the diameter *d* of the pretendium in item X, or any type 1 TAI



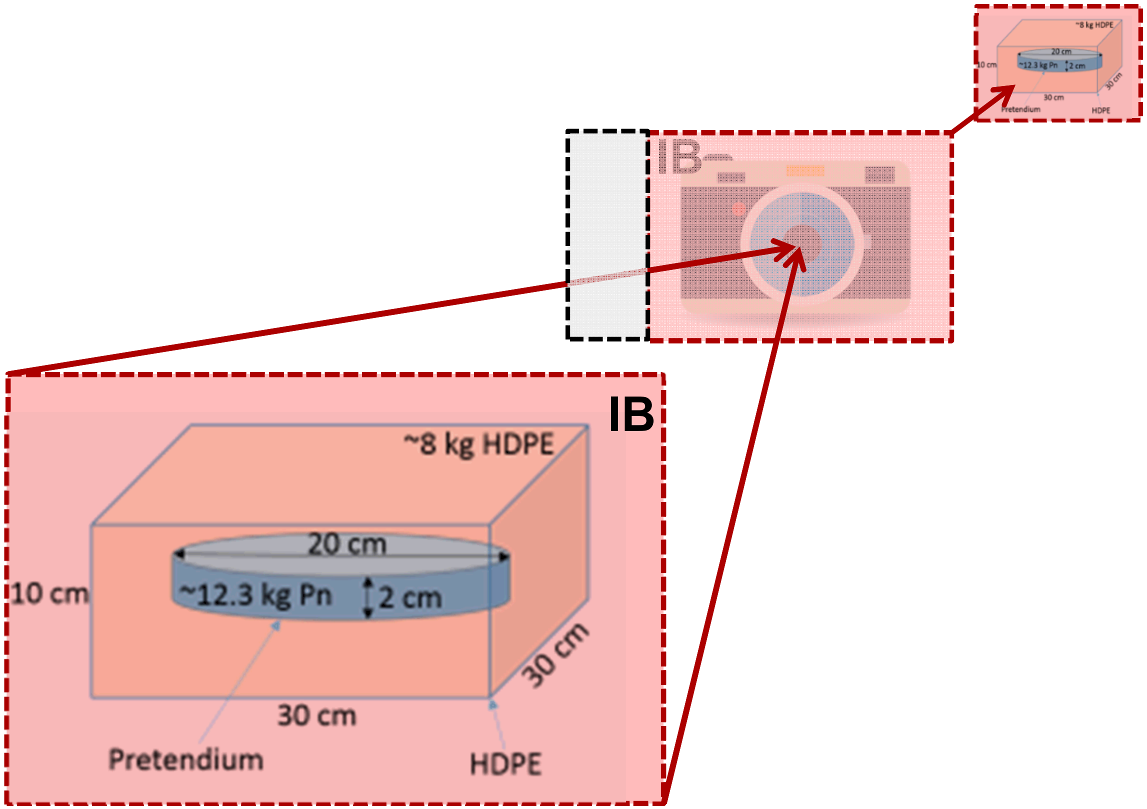
Object T = valid type 1 TAI



Object X = ?

Templates - generation

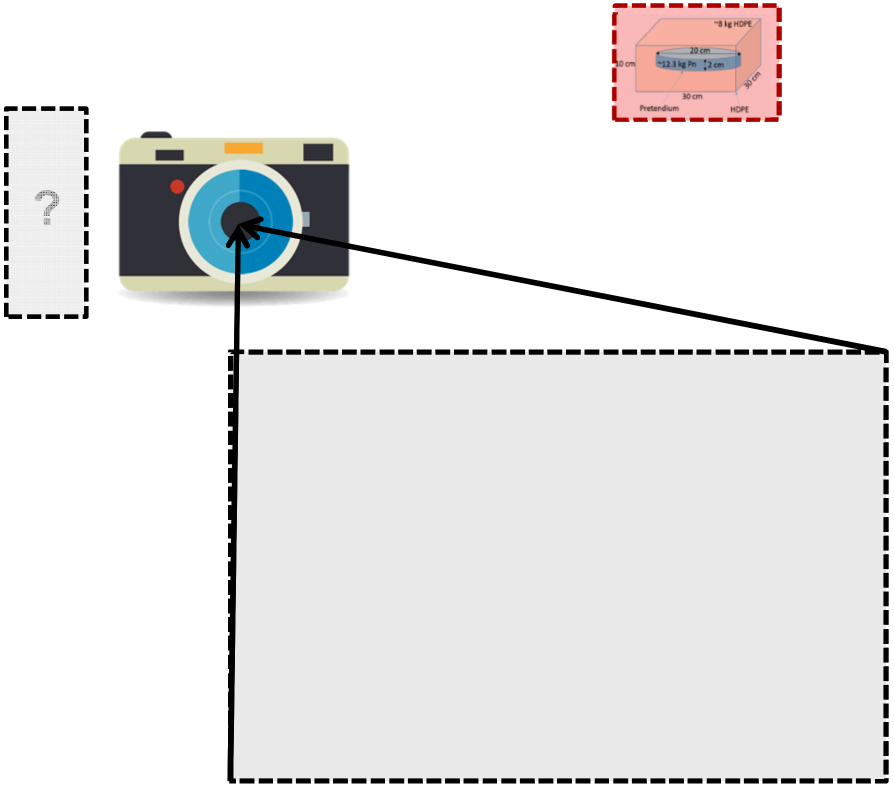
- We could generate a template behind an information barrier (IB) …



Object T = valid type 1 TAI

Templates - authentication

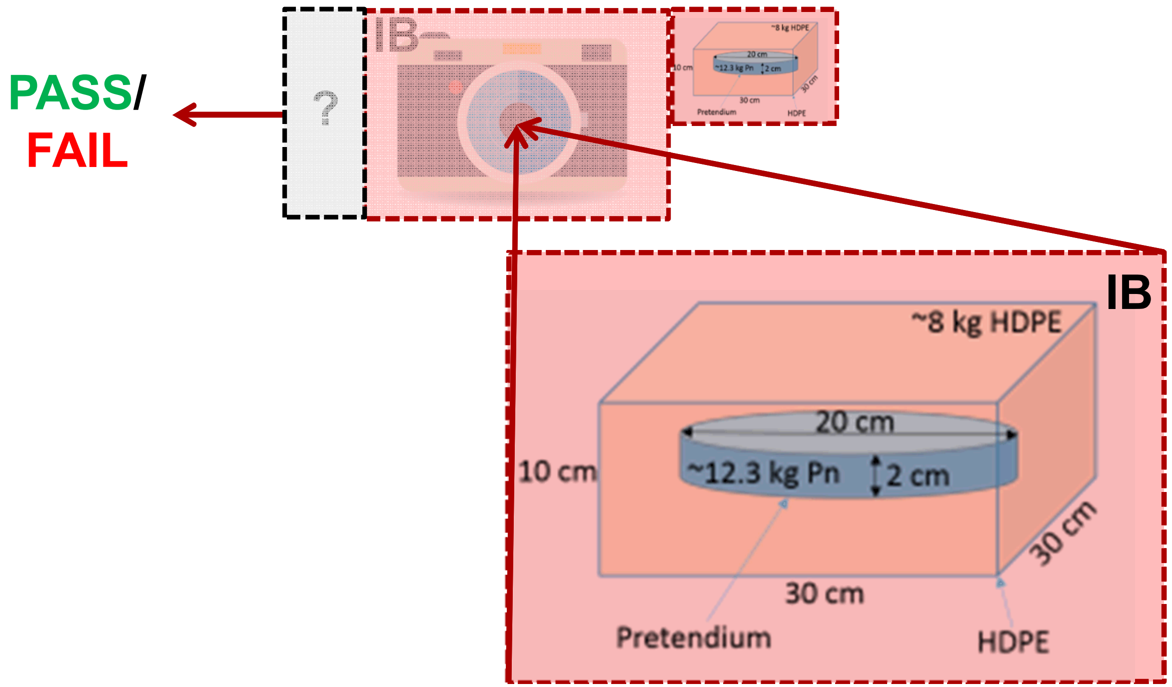
- Authenticate equipment …



Object Z = ?

Templates - comparison

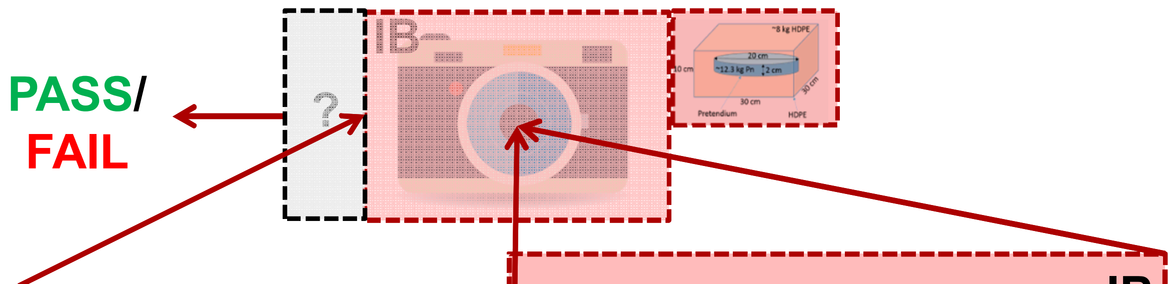
- Make comparison measurement…



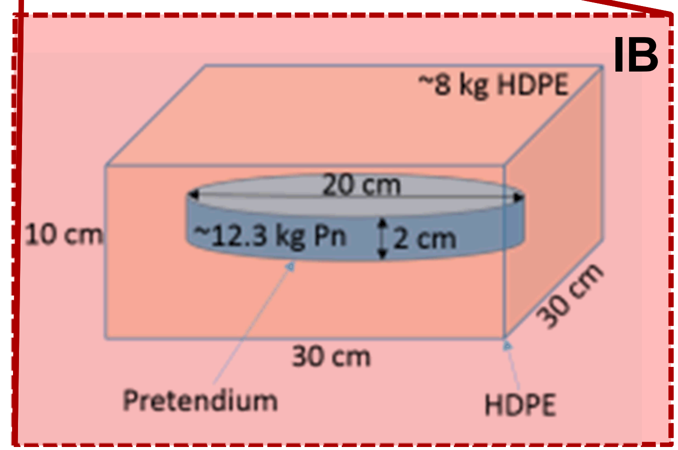
Object X = ?

Templates – who measures?

- Who makes the measurement? Is the measurement itself authenticatable?



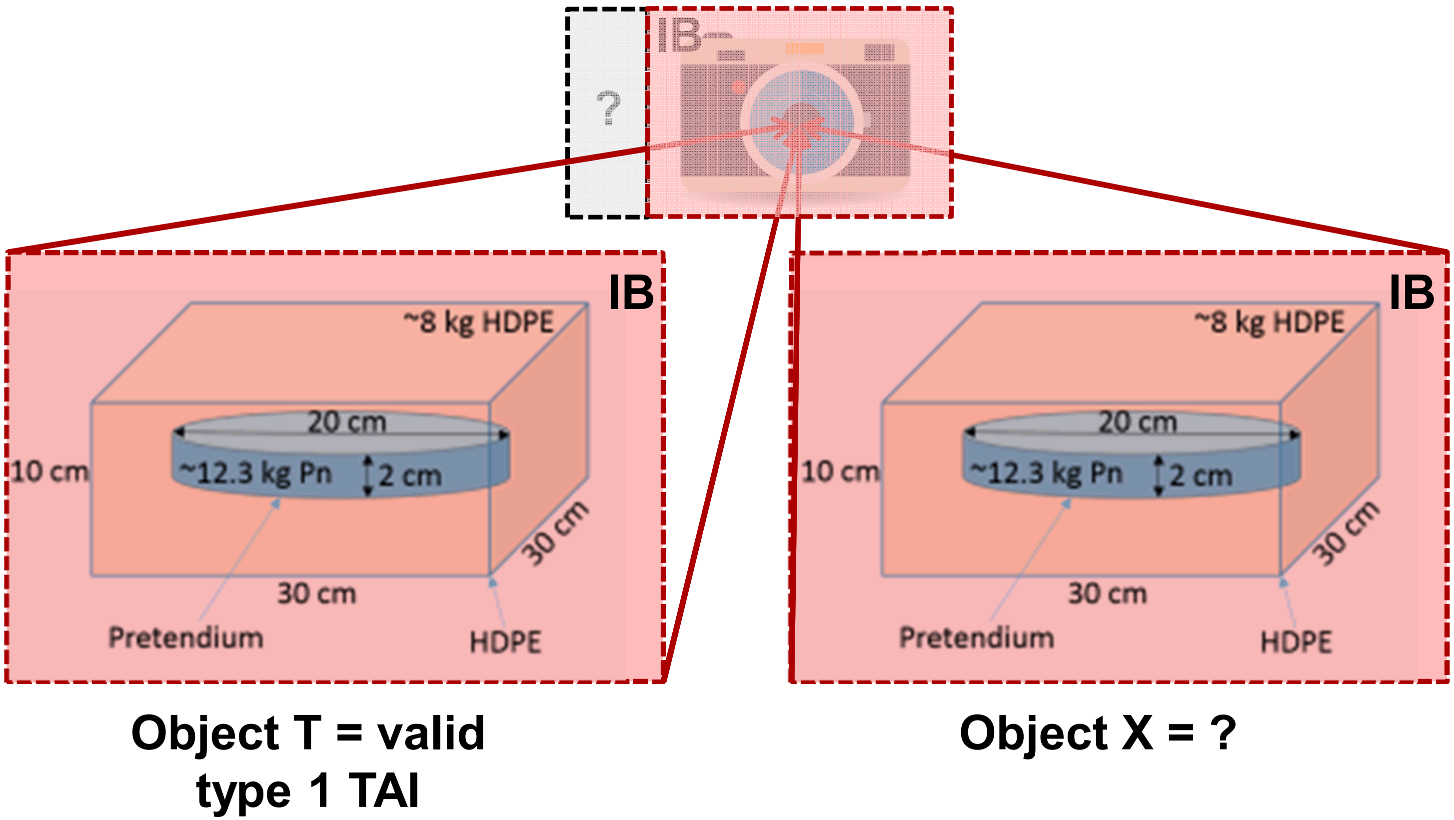
- The nature of this black/red boundary determines whether the host or inspector makes the measurement.
- This is where most of the effort has gone.
- At worst, the template forces the entire device and measurement to be behind an IB.



Object X = ?

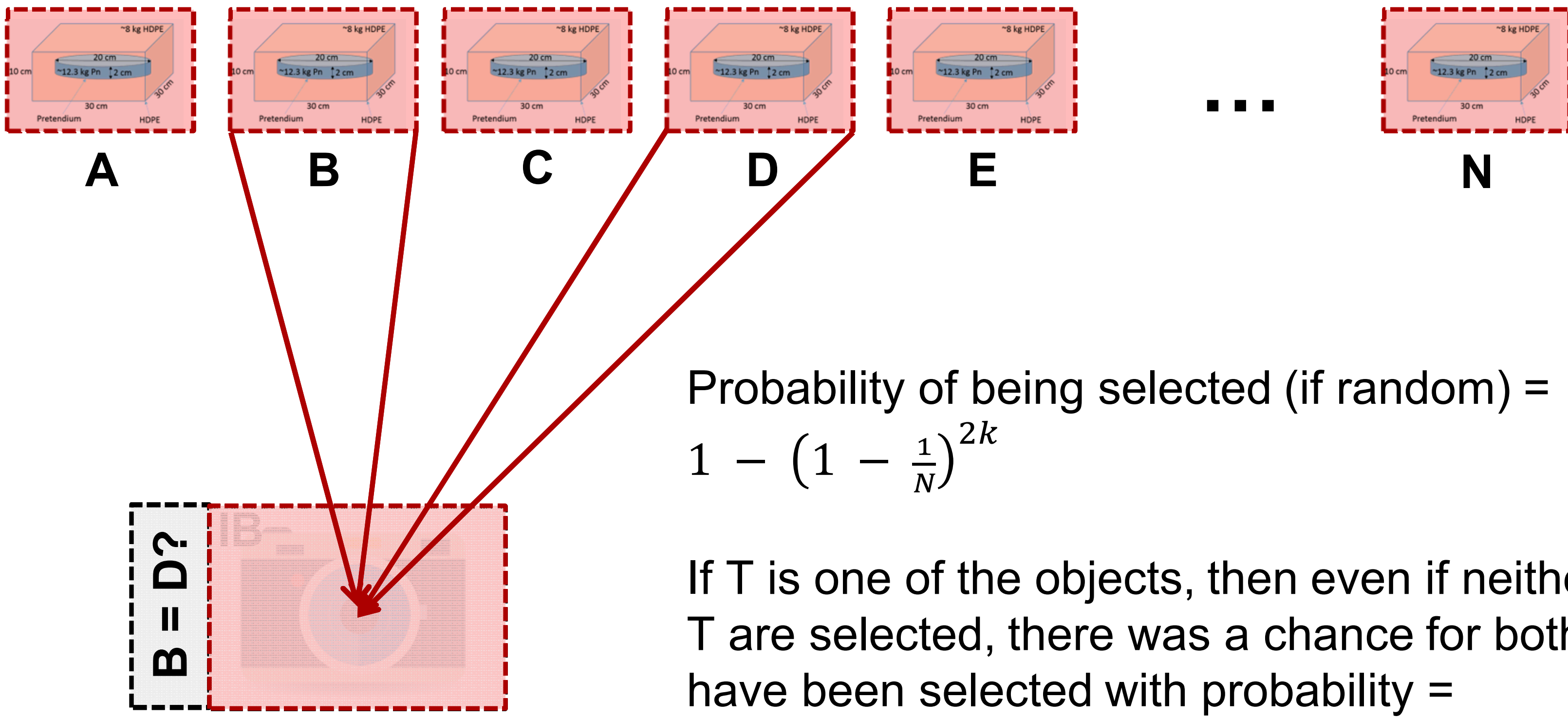
Proposal – comparison measurements

- Can we compare two objects directly without generating a template?
- If one object is T, then X is confirmed as a type 1 TAI.
- If neither object is T, then they are confirmed to be identical, but not T.
- If multiple object comparisons are confirmed and even one is T, then all objects are confirmed as type 1 TAIs.



Proposal – CONOPS and Inspector choice

- Presented with N objects and k comparison measurements will be made.



Probability of being selected (if random) =

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

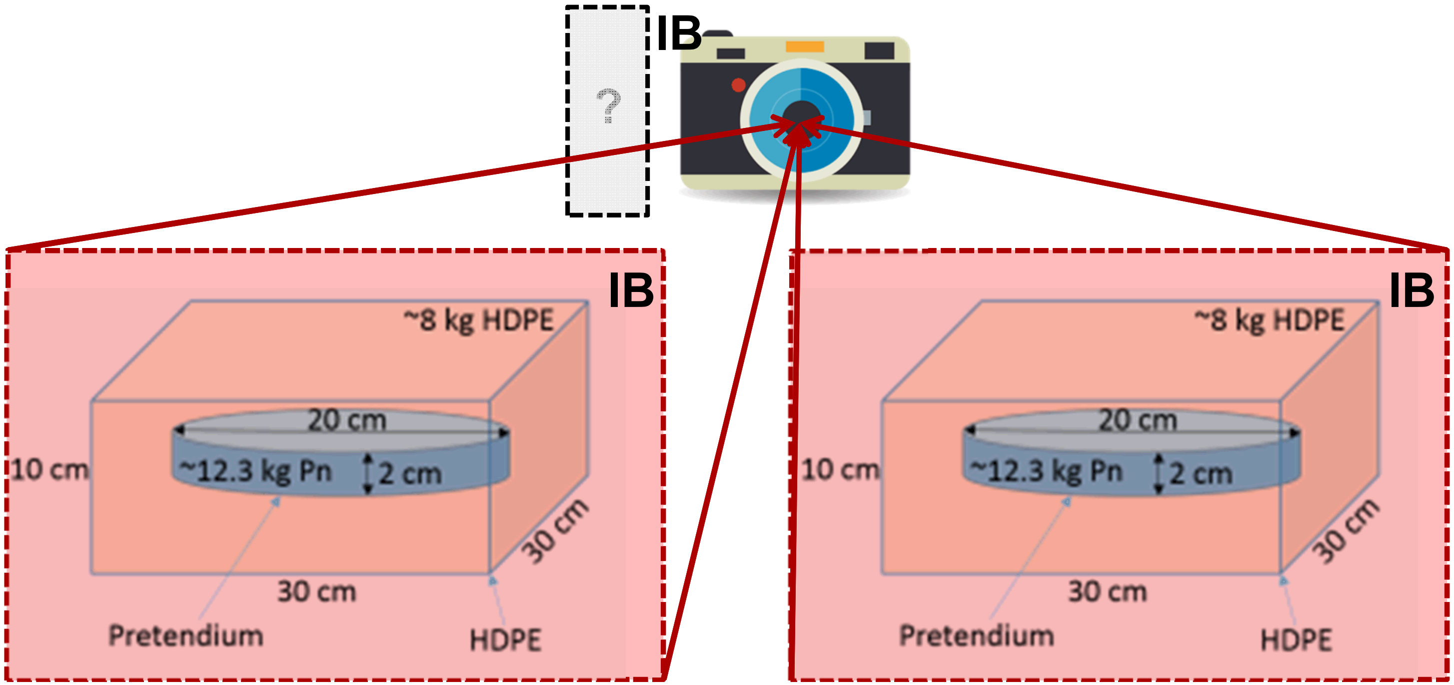
If T is one of the objects, then even if neither X nor T are selected, there was a chance for both to have been selected with probability =

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

providing some degree of confidence

Proposal – comparison measurements

- Is there a physical implementation of the confirmation measurement that the inspector can watch and authenticate?
- **It would be great if we could get a physical NULL as an indication of positive confirmation at all times, even during the measurement.**

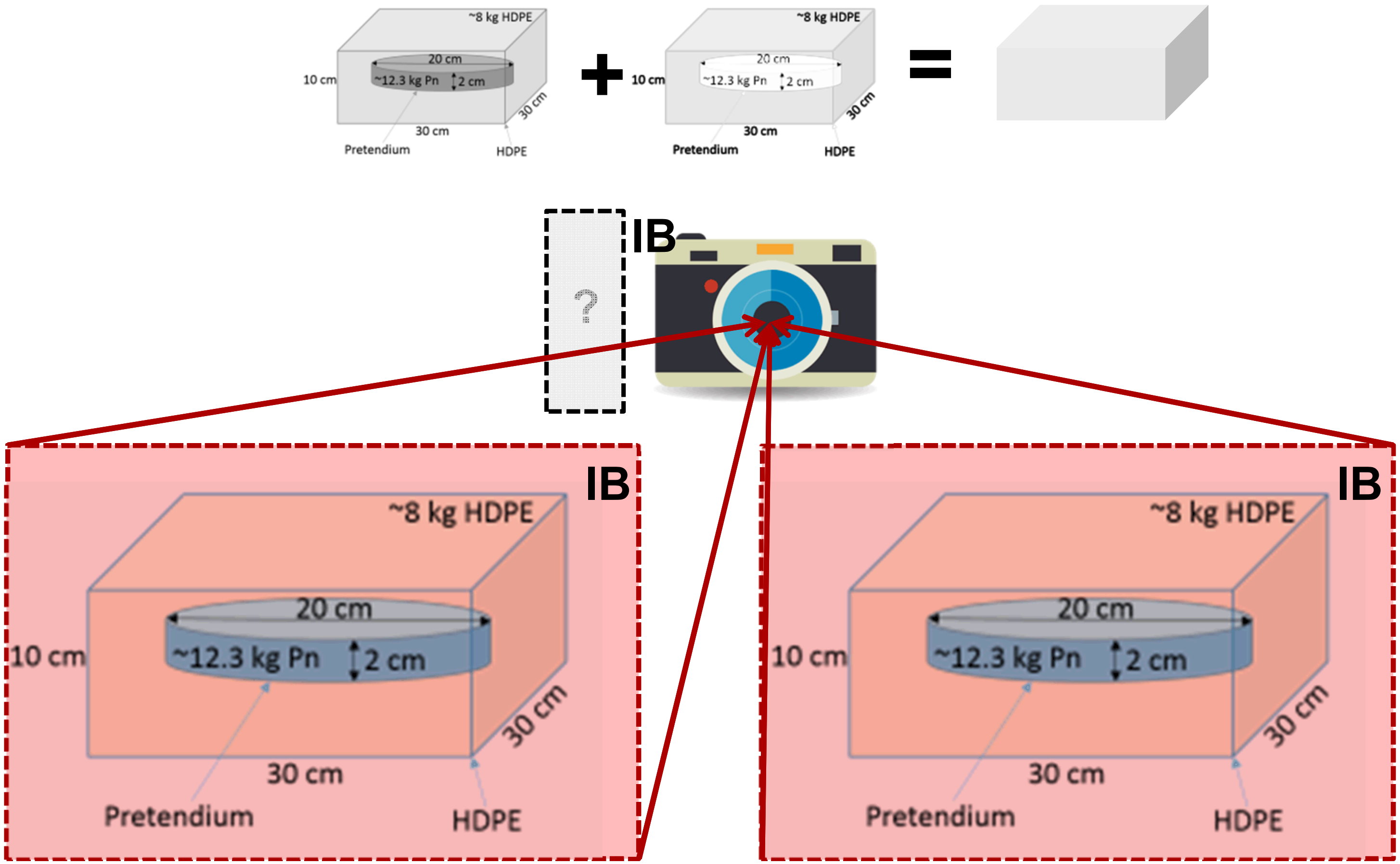


Object T = valid type 1 TAI

Object X = ?

Proposal – complementary comparison

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

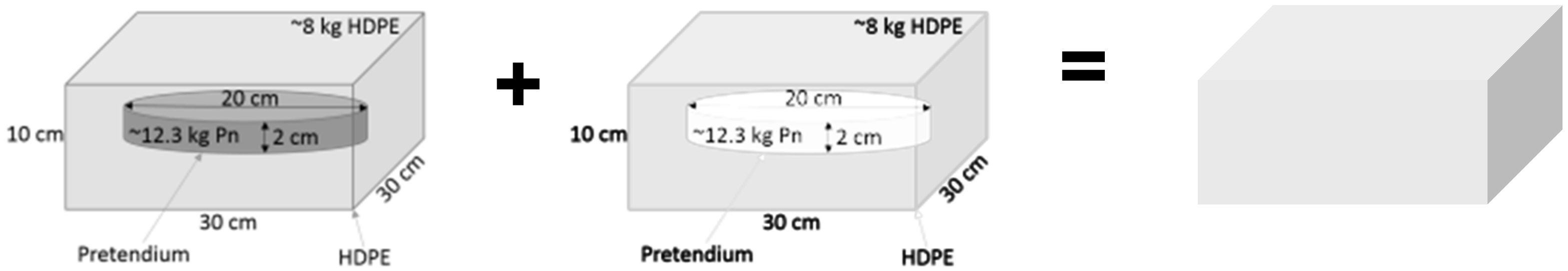


Object T = valid type 1 TAI

Object X = ?

Ok, but how? …

- One image is the complement of the other ***at all times***.



2D Time-encoded Imaging (TEI)

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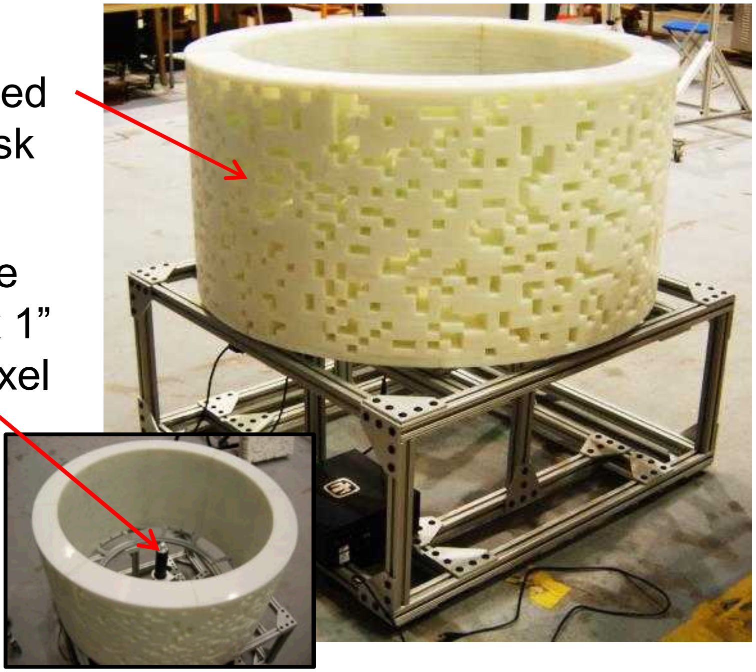
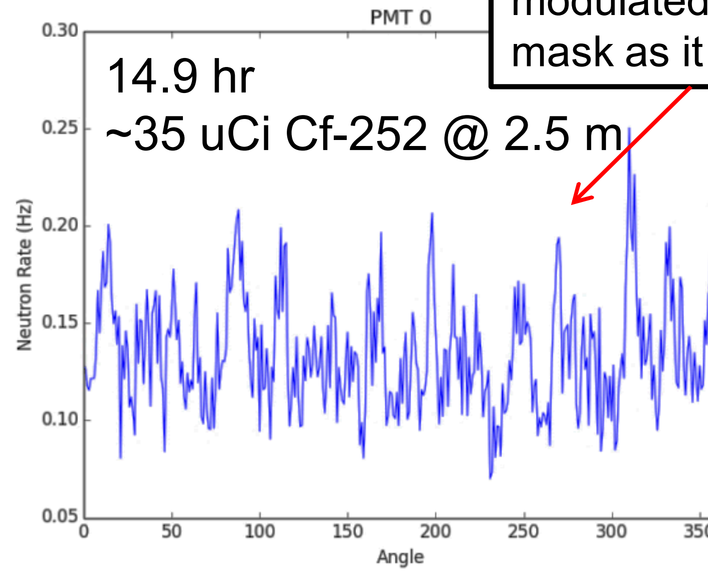
2-d coded mask

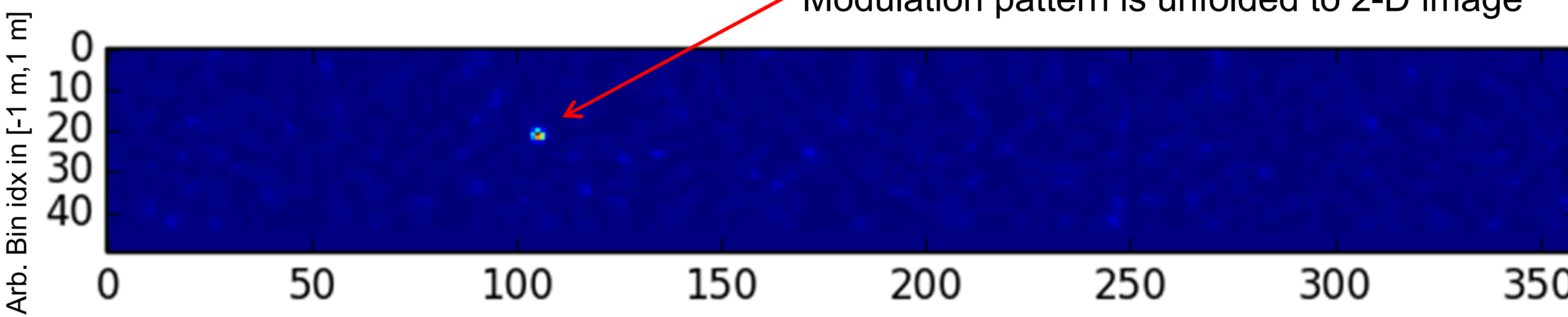
Single 1"D x 1" LS pixel



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



Modulation pattern is unfolded to 2-D image

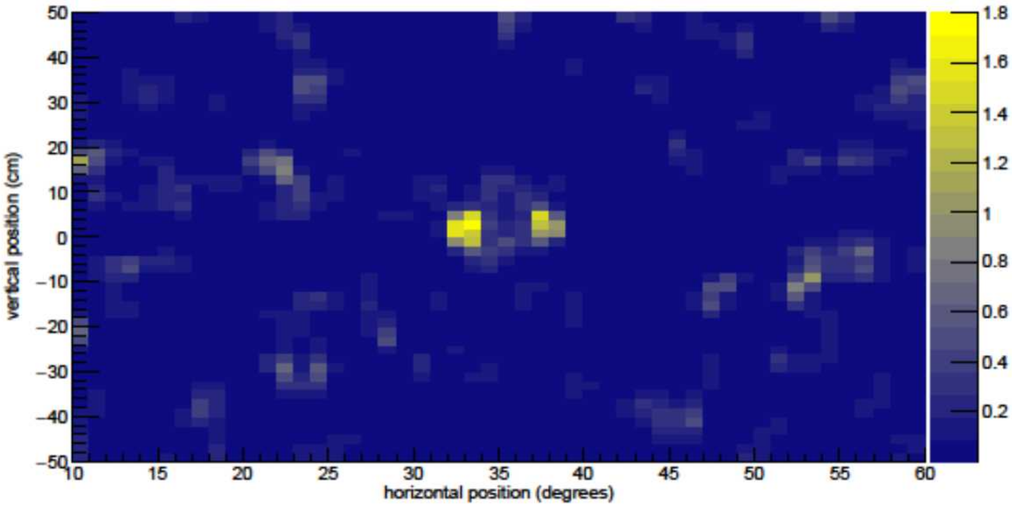


J. Brennan, E. Brubaker, M. Gerling, P. Marleau, K. McMillan, A. Nowack, N. LeGalloudec, M. Sweany, "Demonstration of Two-dimensional Time-encoded Imaging of Fast Neutrons", Nuclear Instruments and Methods A, 2015

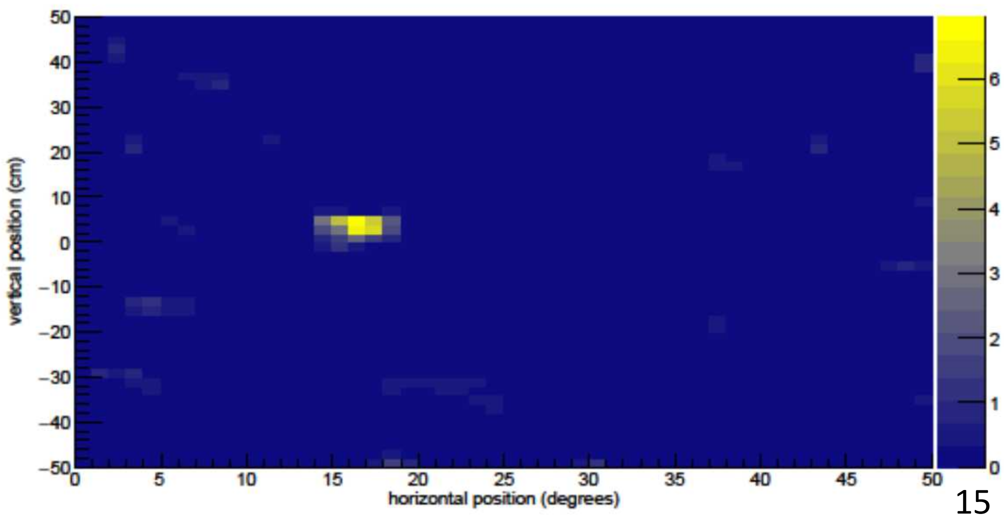
TEI-2D imaging – two point sources

Two 1.4e5 n/s ^{252}Cf point sources at 2.0 meters stand-off.

5 degree separation in 1 hour (50 mlem iterations)



2 degree separation in 24 hours (250 mlem iterations)

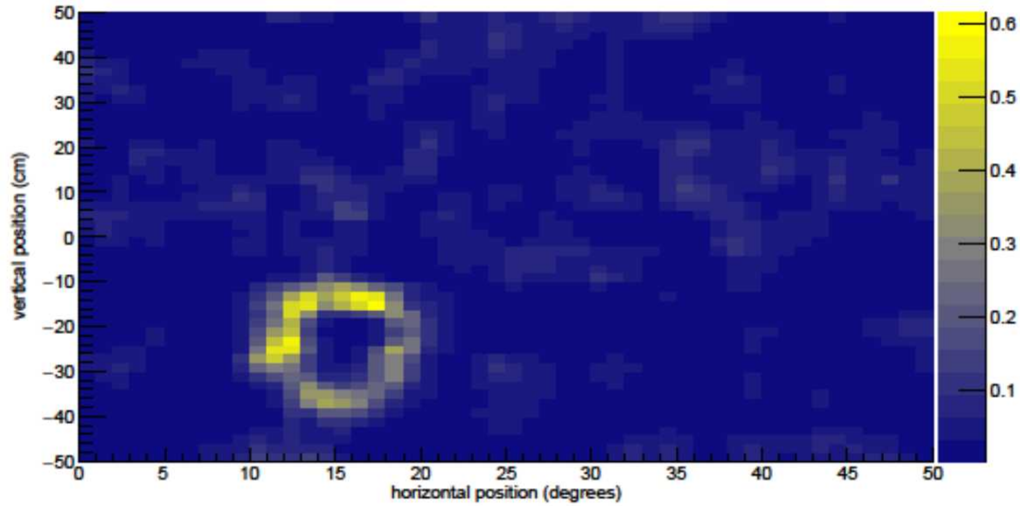


J. Brennan, E. Brubaker, M. Gerling, P. Marleau, K. McMillan, A. Nowack, N. LeGalloudec, M. Sweany, “Demonstration of Two-dimensional Time-encoded Imaging of Fast Neutrons”, Nuclear Instruments and Methods A, 2015

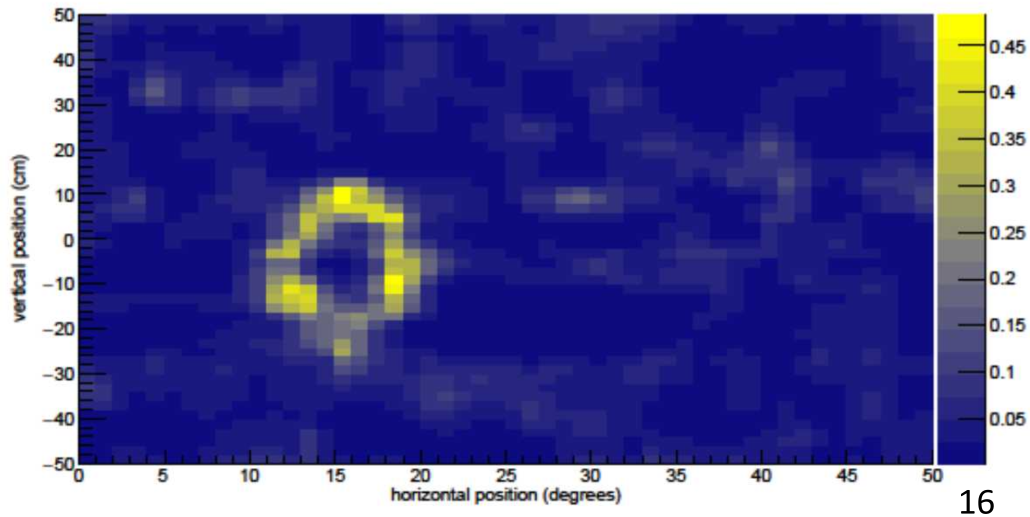
TEI-2D imaging – extended sources

A single 1.4e5 n/s ^{252}Cf source move through an extended pattern at 2 m.

72 hours
(100 mlem iterations)

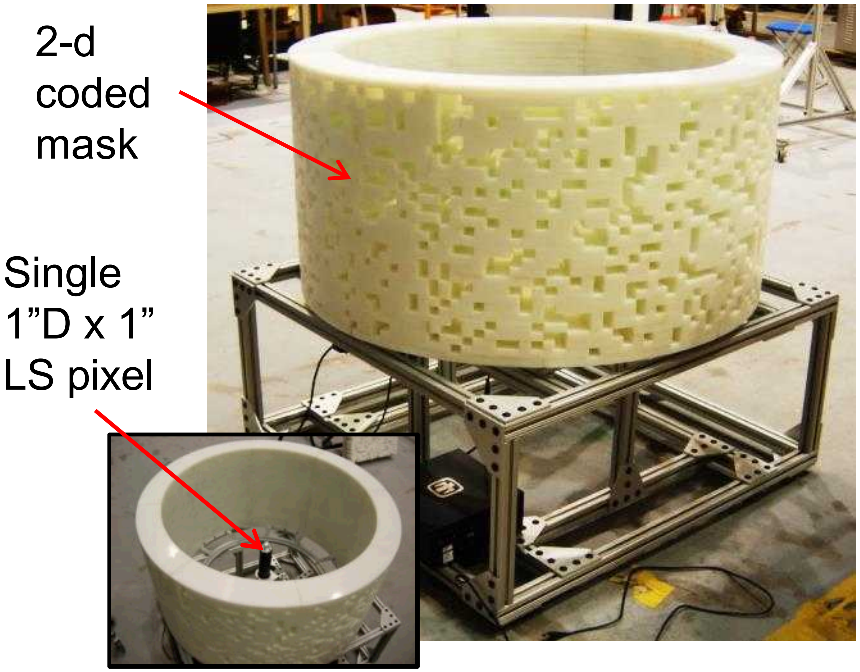


94 hours
(100 mlem iterations)



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

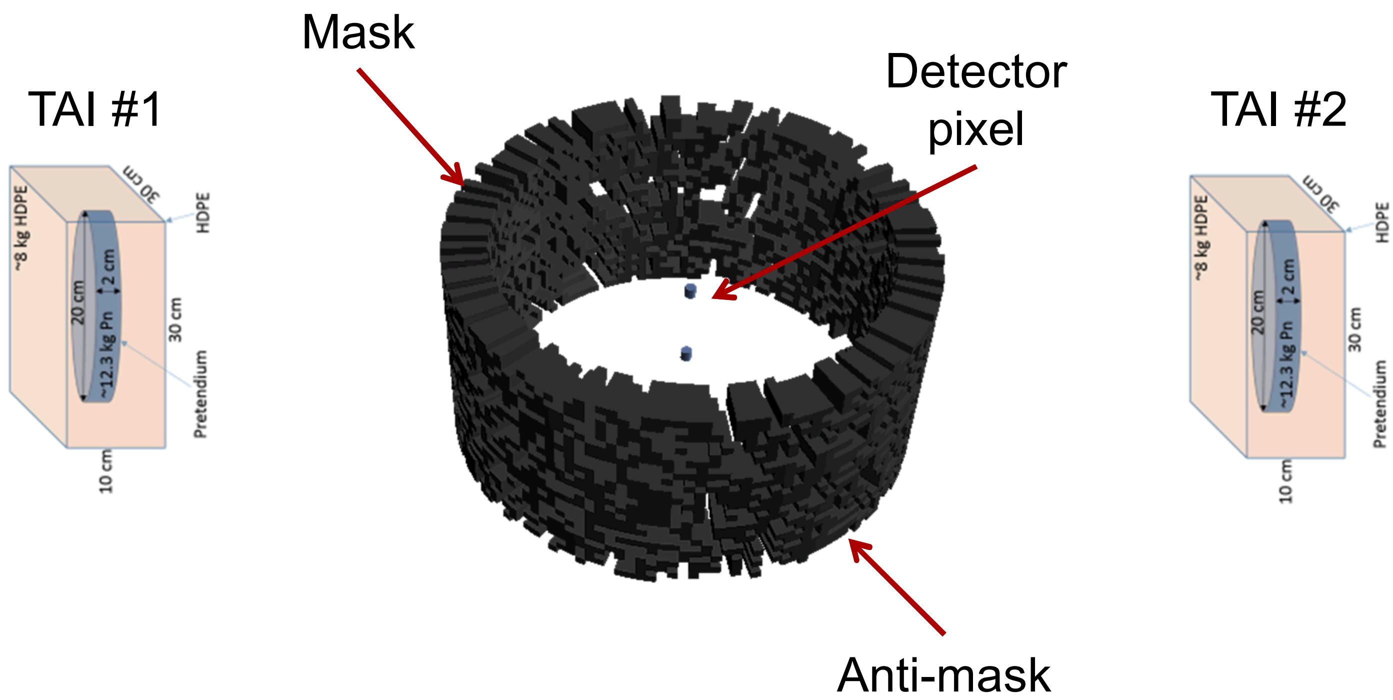
2D TEI – confirmation measurements?



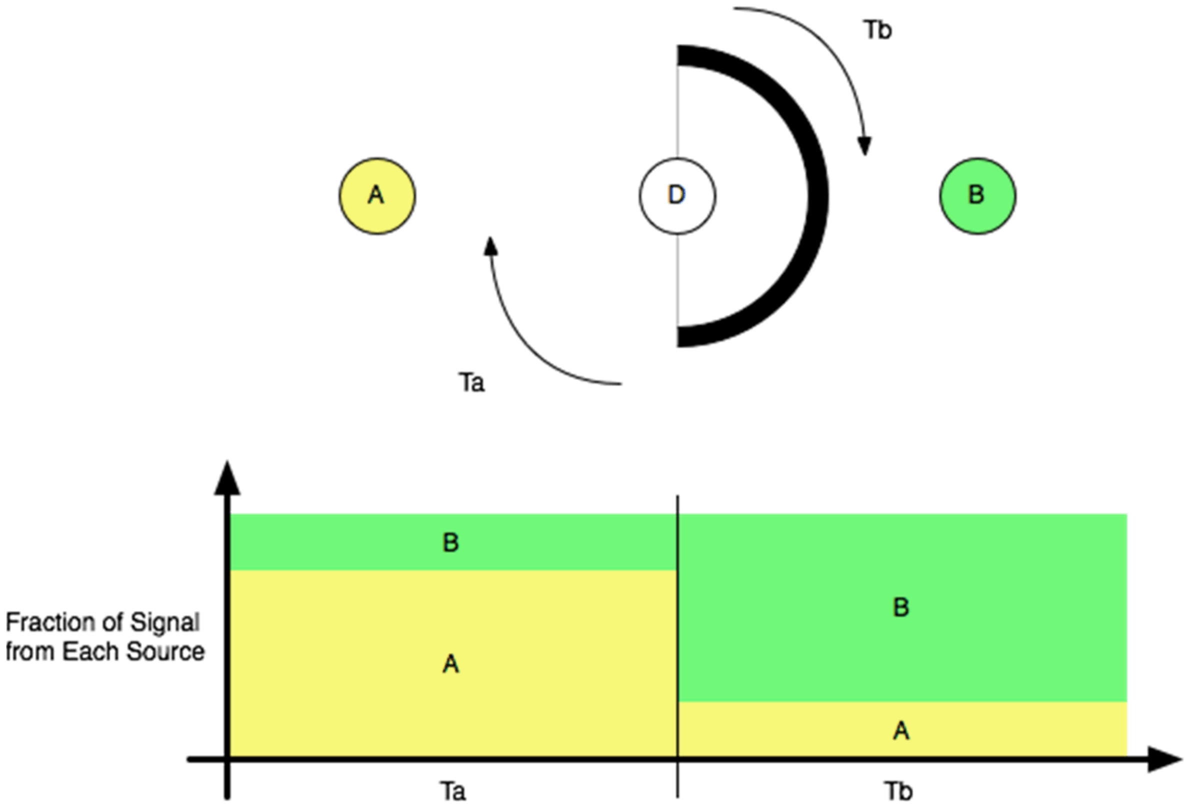
- **TEI is simple**
  1. Only one instrumented channel.
  2. Minimal calibration issues
     a) Information encoded in the relative rate of a single detector.
     b) Absolute gain doesn't matter.
     c) Gain can drift over time.
  3. Potential real-time analysis
     a) Single data stream.
     b) Events can be processed one at a time and update a test statistic.
- **Can we design a TEI confirmation system such that the detection rates can be monitored by an inspector without putting sensitive information at risk?**

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!

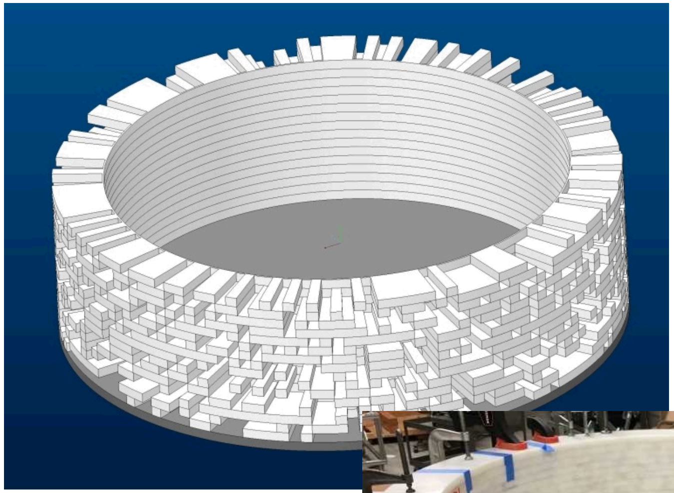


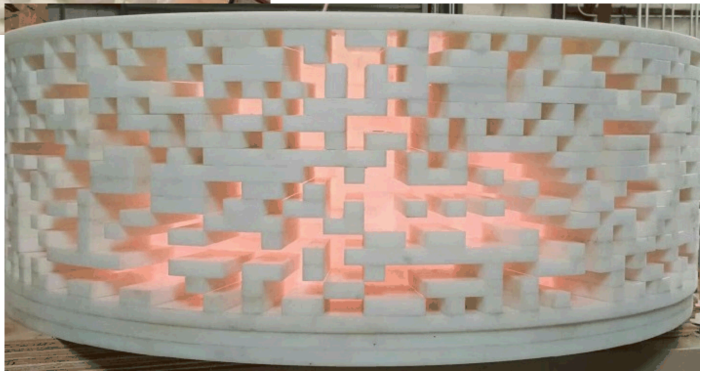
A very simple example



- For example, take a very simple mask: 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.

We're working on it

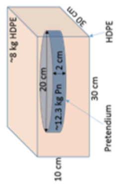


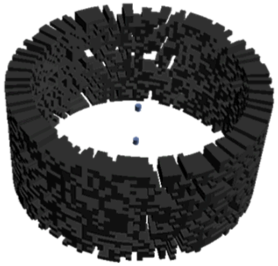


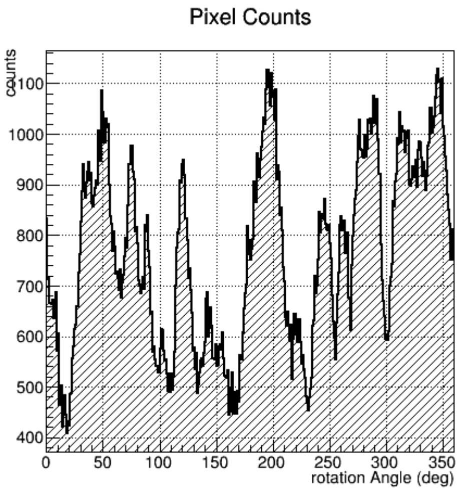
Modeling results - Single type 1 TAI (5e5 counts)

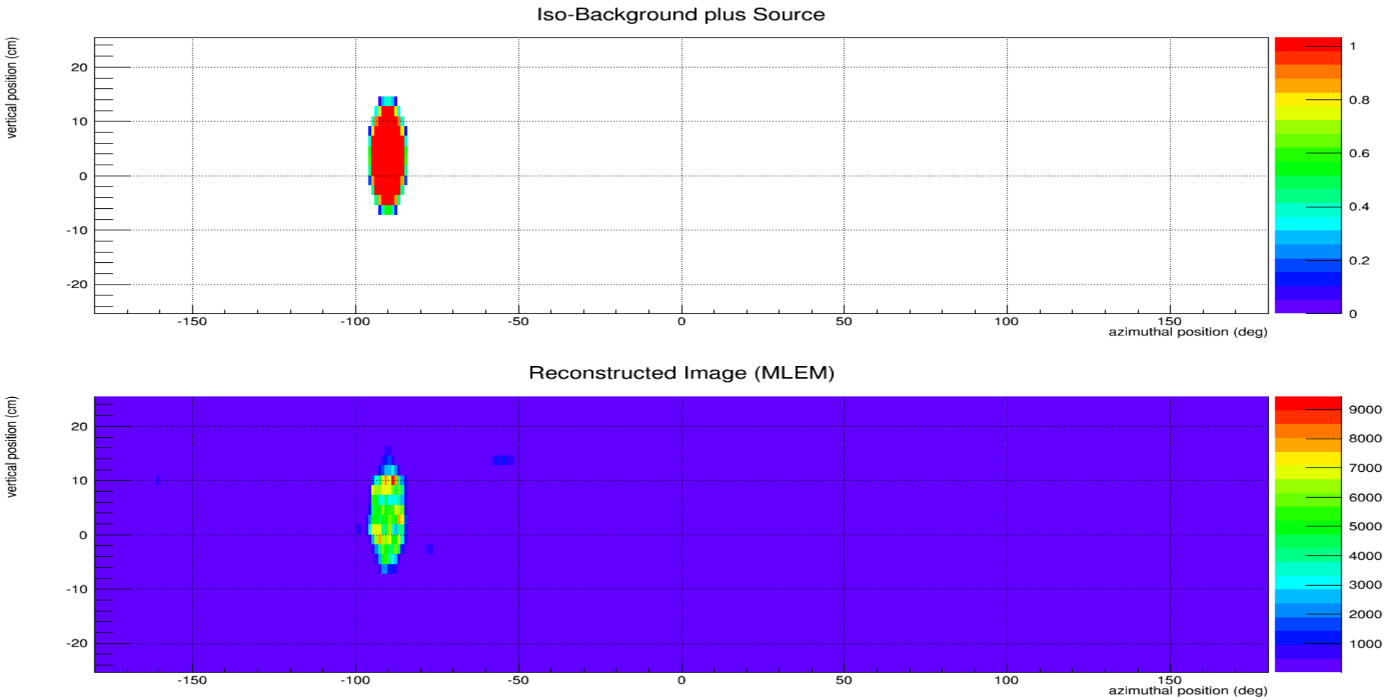
The system still functions as a standard TEI imager for any single object.

TAI T





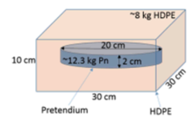


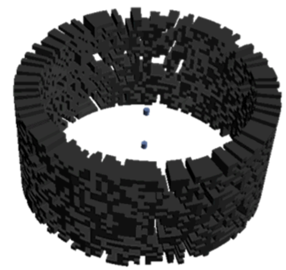


Modeling results - Single type 1 TAI (2.5e5 counts)

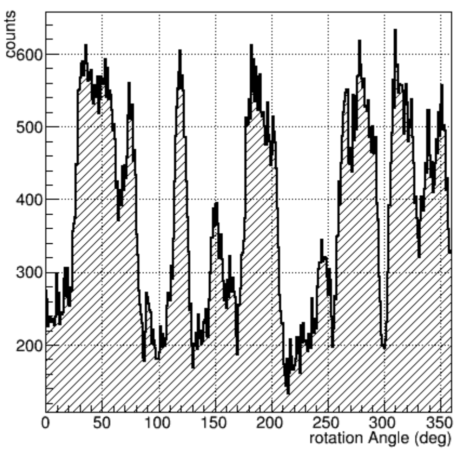
This orientation provides better discrimination between objects T and F.

TAI T

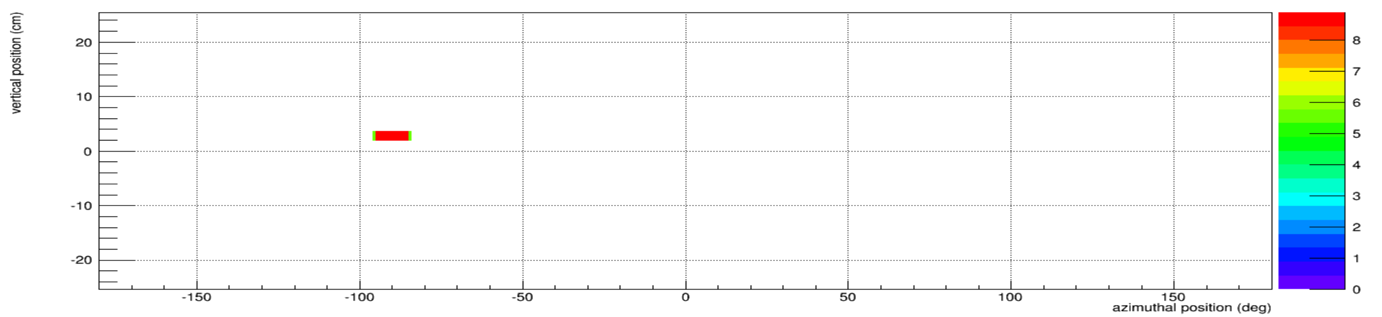




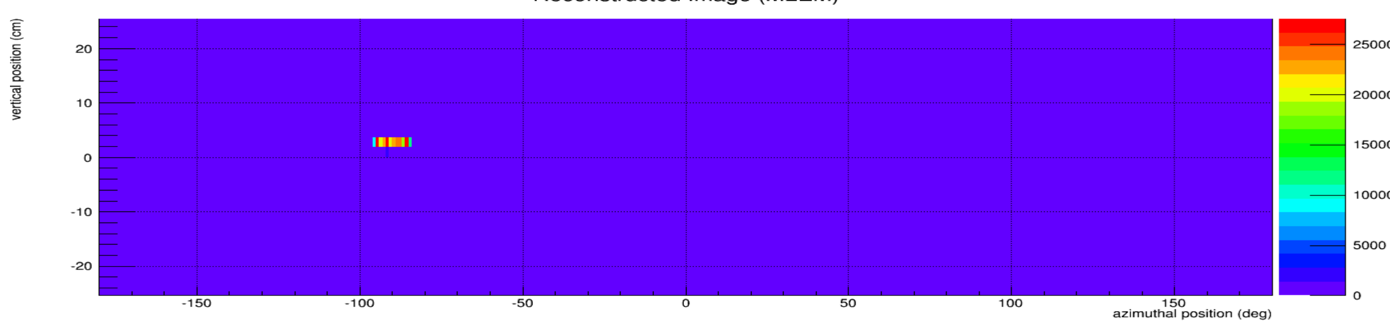
Pixel Counts



Iso-Background plus Source



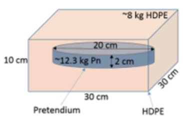
Reconstructed Image (MLEM)

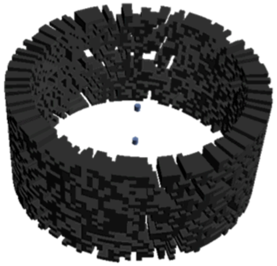


Modeling results – T vs. X (5e5 counts)

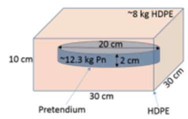
True “null”-positive confirmation comparison measurement between two type 1 TAIs.

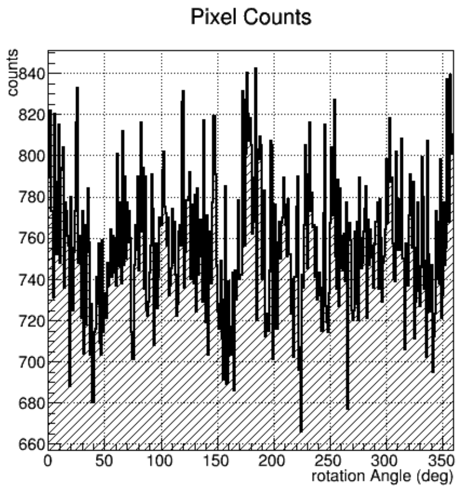
TAI T

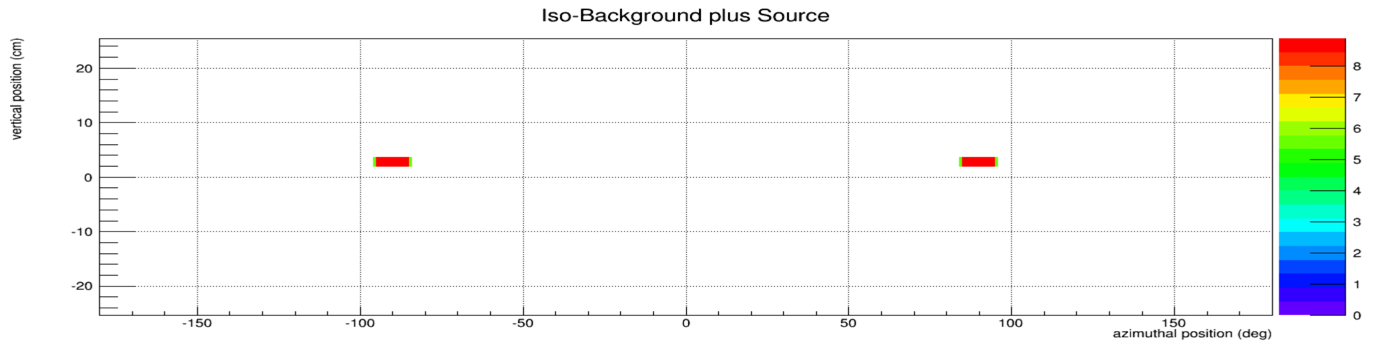


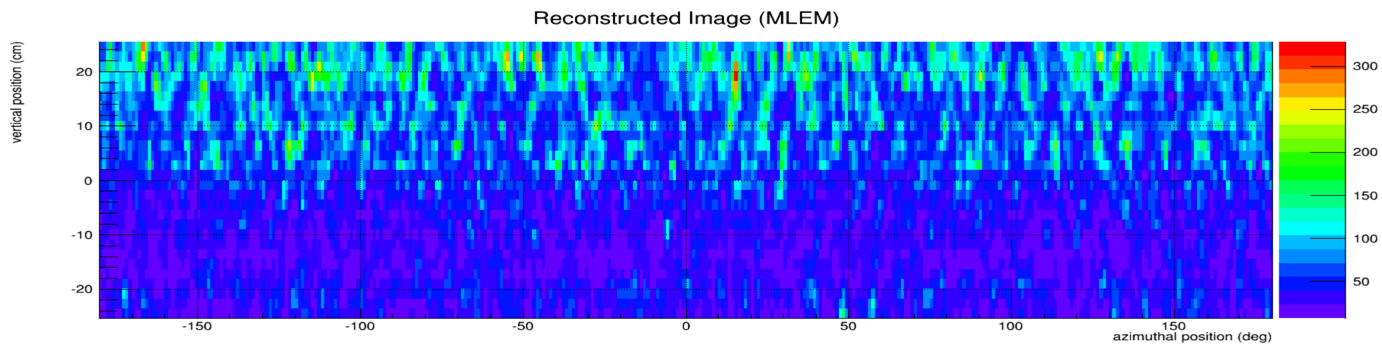


TAI X





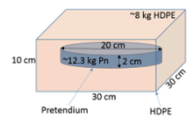


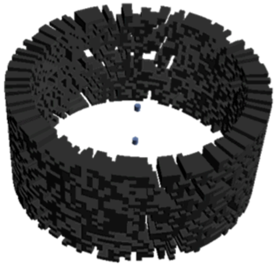


Modeling results – T vs. F (5e5 counts)

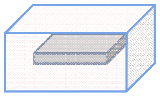
True non-null-negative confirmation comparison measurement between objects T and F.

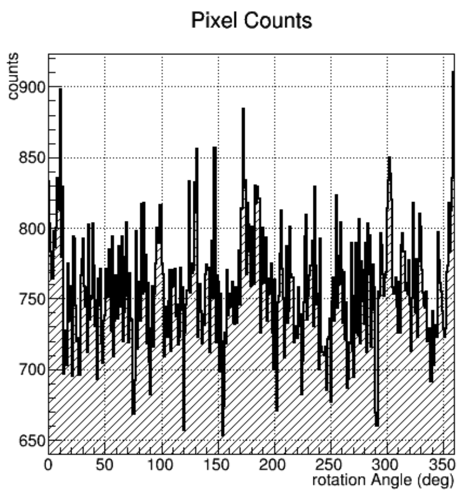
TAI T

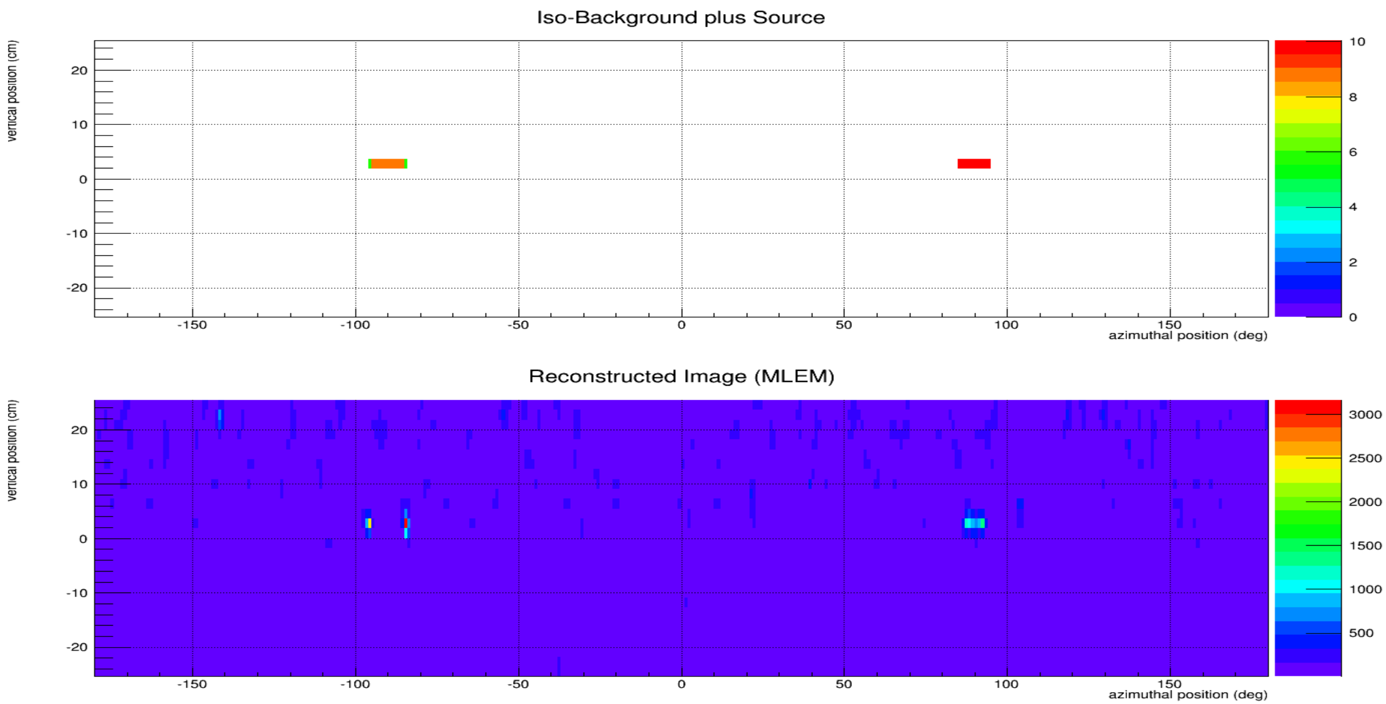




TAI F

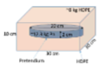


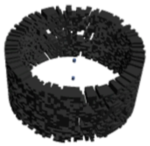


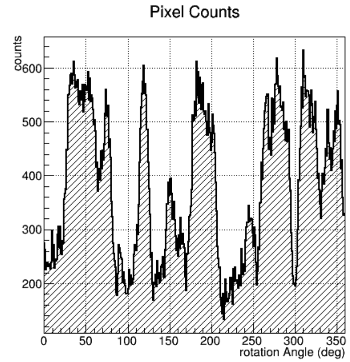


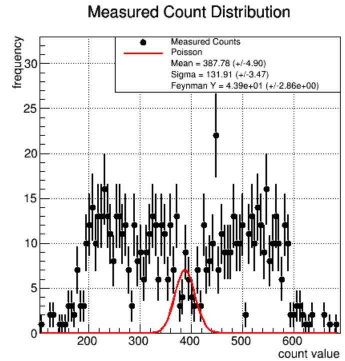
Single Test Statistic – Feynman Y

T







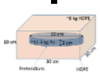


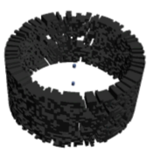
Feynman Y

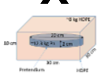
$= \left(\frac{variance}{mean} - 1\right)$

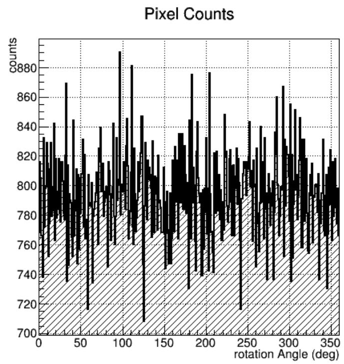
= 86.8 (+/-5.7)→
Far from Poisson

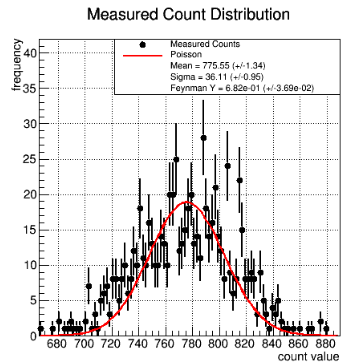
T X









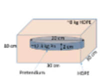


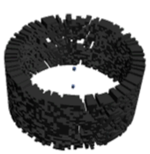
Feynman Y

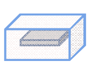
$= \left(\frac{variance}{mean} - 1\right)$

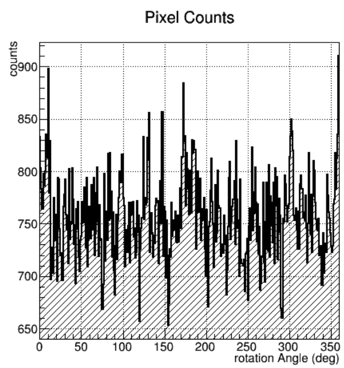
= 0.68 (+/-0.04)→
Fairly Poisson

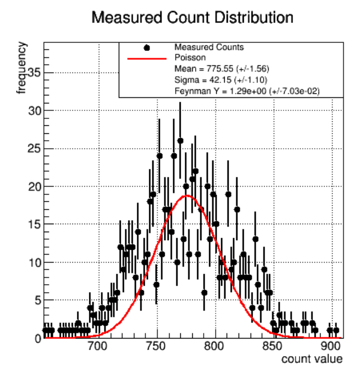
T F









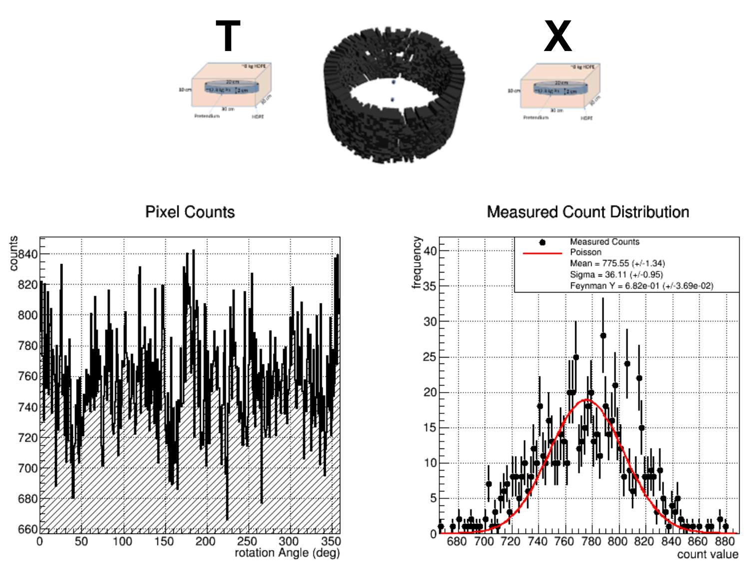


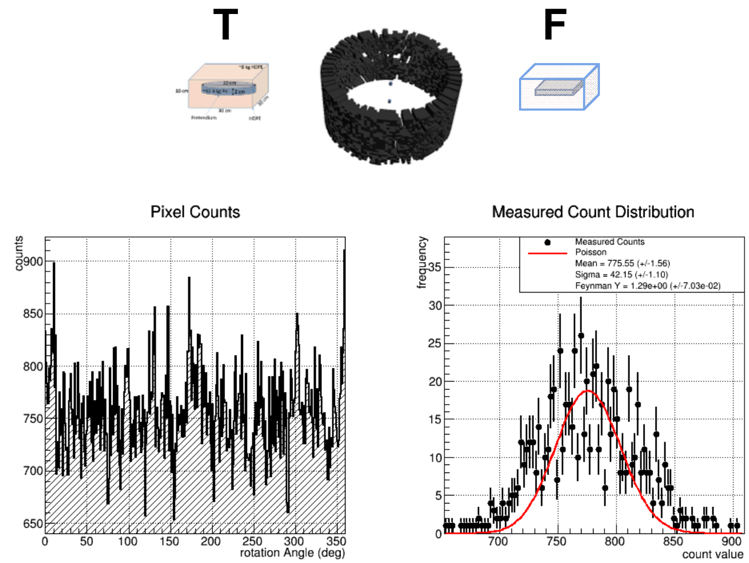
Feynman Y

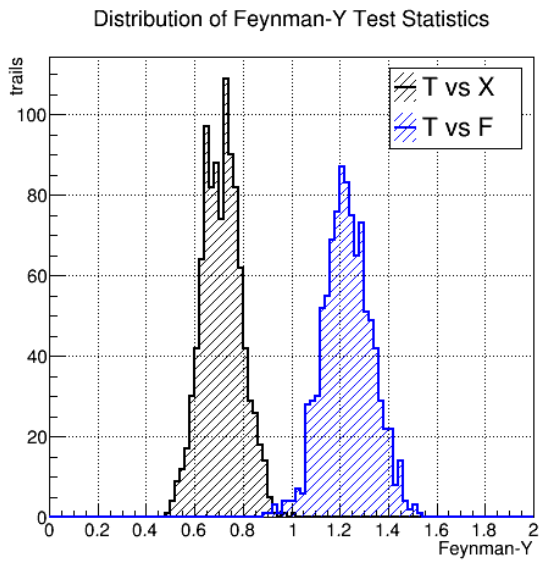
$= \left(\frac{variance}{mean} - 1\right)$

= 1.3 (+/-0.07)
→ Less Poisson

Feynman Y Test Statistic – 1000 trials of 5e5 counts







Modeling results – T vs. X (1000 trials of 5e5 counts)

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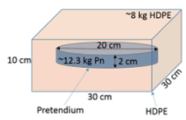
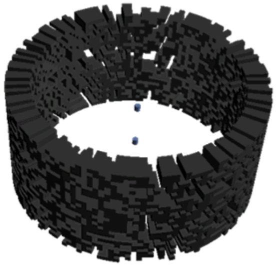
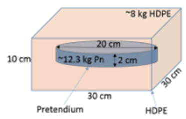
Even after summing 1000 trials worth of data, there isn't much evidence that sensitive information is present. This must be made more rigorous.

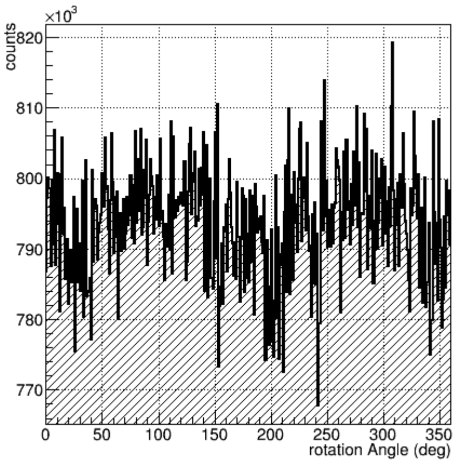
TAI T

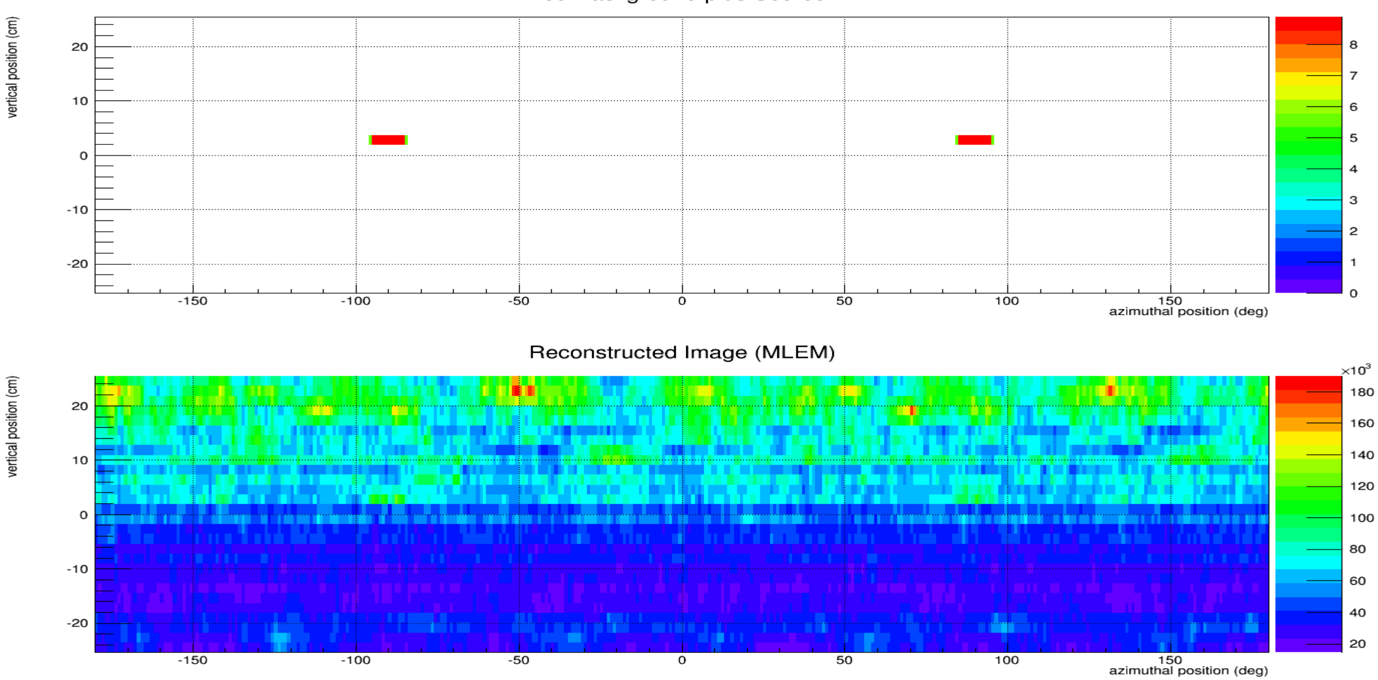




TAI X



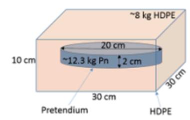


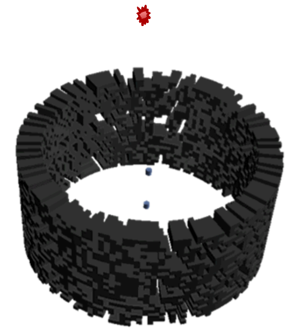


Modeling results – T vs. X plus point source (8e5 counts)

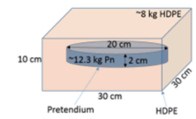
If (and only if) the TAIs are identical, only the third source is visible!

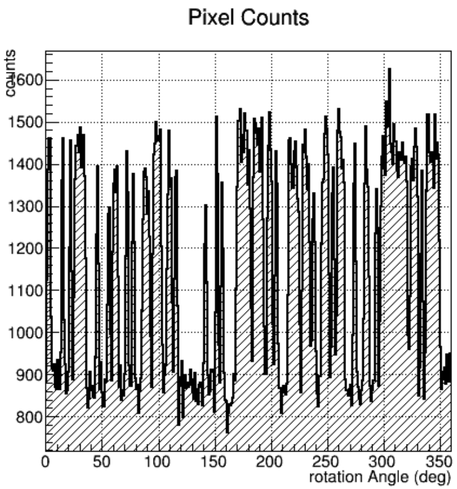
TAI T

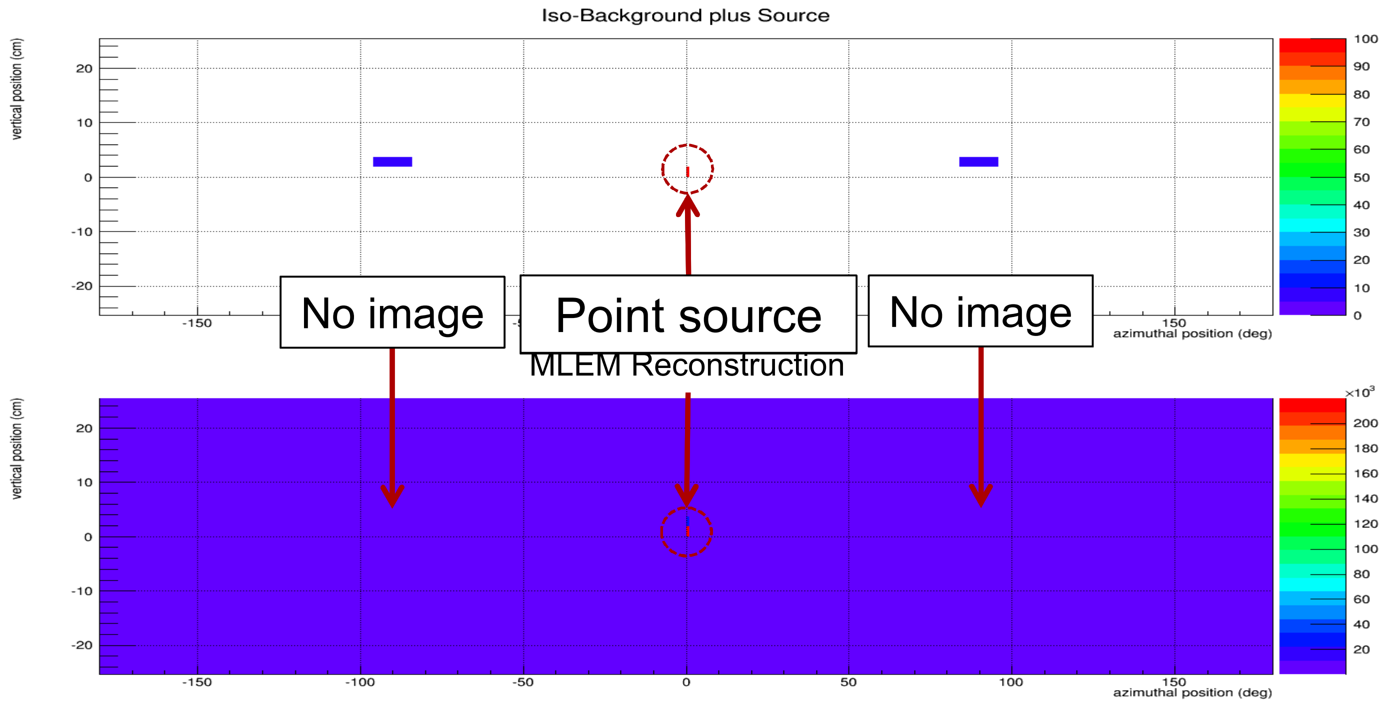




TAI X







Conclusions

A properly designed two-dimensional time-encoded imager can:

1. Confirm that two objects are identical in a single measurement with NULL (constant rate) indicating a positive result.
2. Because a NULL (constant rate) is present at all times, the inspecting party might be allowed full access to the measurement and data.
3. The Feynman-Y test statistic can be updated to further protect against sensitive information loss.
4. Can image any third inspector provided object during the confirmation measurement without revealing the first two objects as an authentication measure.

Extra Slides

Certification vs. Authentication: It's not just for hardware

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

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