

# Development of a Nonsensitive Template for a 2D Ring vs. Square Discrimination Task

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# Outline

- Background on arms-control-treaty verification & project summary
- Discrimination task description and data
- Discussion of linear models that don't discriminate on sensitive information
  - Observer: human or mathematical model that makes decisions

# Arms-Control-Treaty Verification

- Current treaties hold number of delivery systems accountable
  - New START treaty limits US to 1550 warheads on 700 delivery systems
- Future treaties may want to count warheads.
- Monitor wants to verify presence of warhead, host wants to preserve sensitive information on construction.
- Many current proposed methods utilize an information barrier (IB)
  - IB: hardware or software

# Verification task

Is it really a warhead?

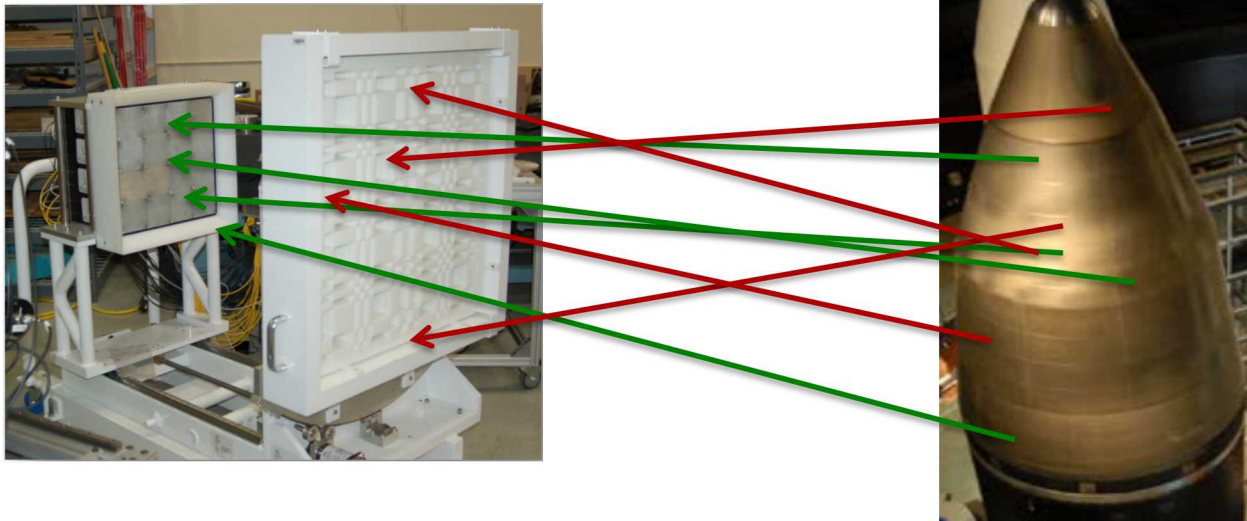
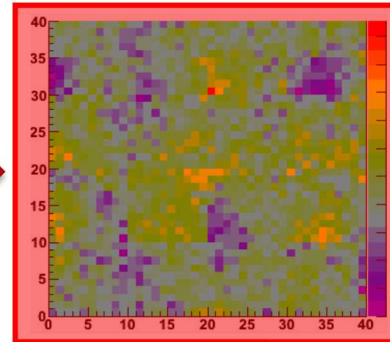
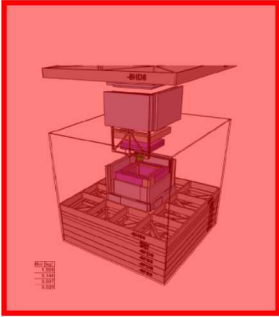


Photo from National Museum  
of the USAF

# “Traditional” Template Matching

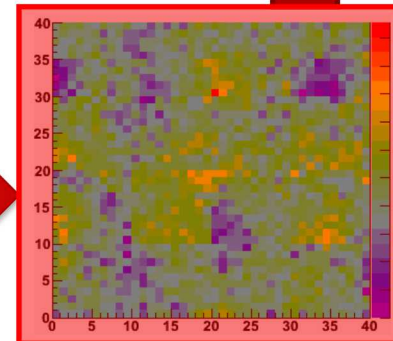
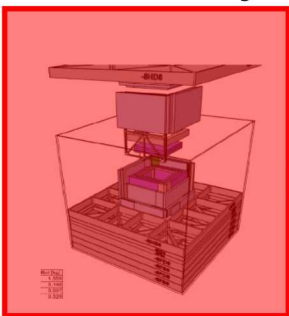
Trusted object



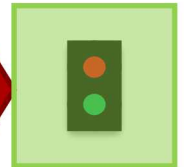
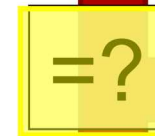
Calibration data is sensitive  
IB required

LEGEND	
Red	No Access
Yellow	Access Before & After
Green	Full Access

Tested object

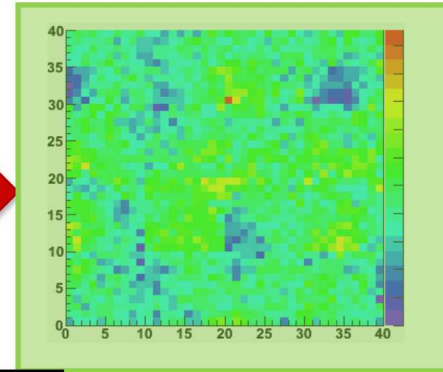
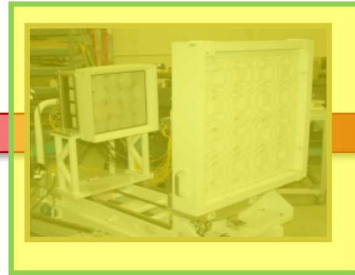
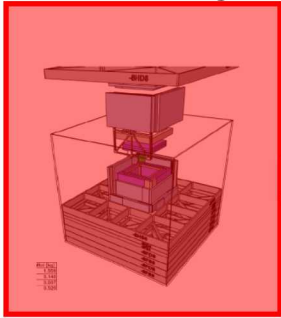


Tested detector data is sensitive  
IB required



# Our proposal

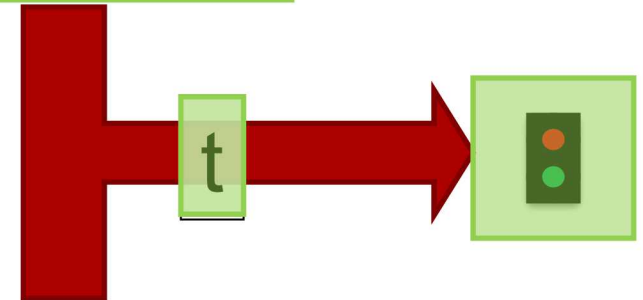
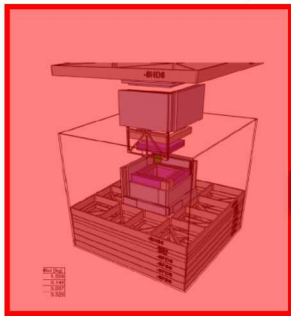
Trusted object



Hypothetical observer stores info sufficient for confirmation but not sensitive

LEGEND	
Red	No Access
Yellow	Access Before & After
Green	Full Access

Tested object



Testing data is processed event by event, only updating test statistic.

Data not aggregated

Think snapchat!



# Verification Task

Is it really a warhead?

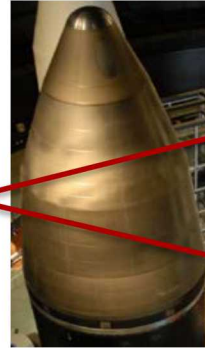


Photo from National Museum  
of the USAF

Is it the warhead or a spoof?



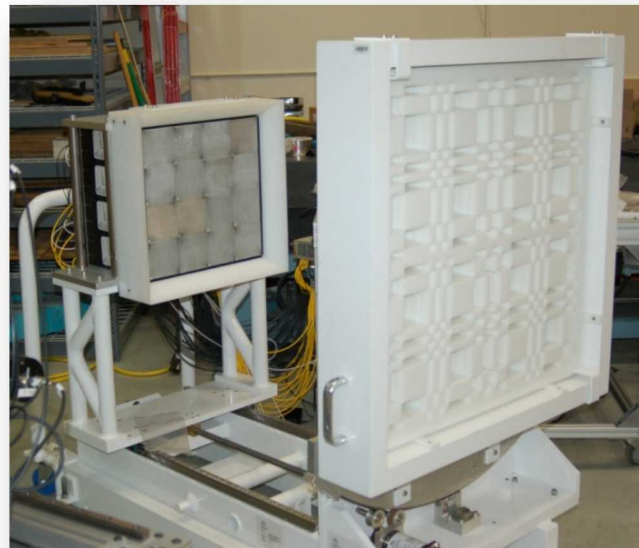
# Task – Discriminate ring and square source

- Binary discrimination using neutron spatial information.
- Distinguish a 20 cm diameter ring source from 20 cm length hollow square source
  - Modeled as 1mm thick.
- Desire model that can discriminate between geometries but unable to back out size of items.

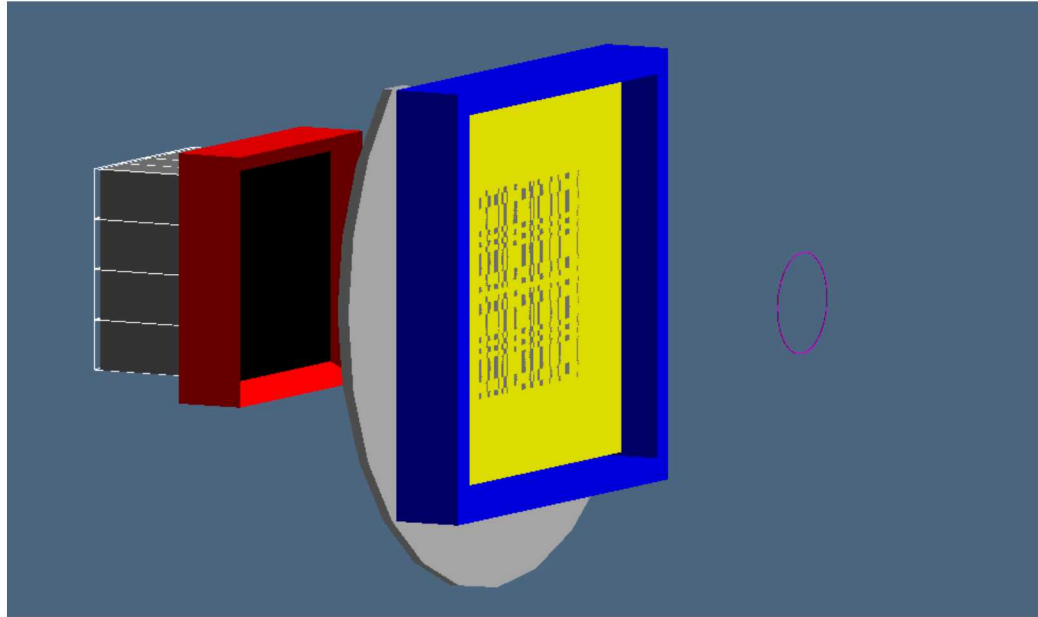


# Imaging System

- ORNL/SNL fast neutron coded-aperture imager developed for arms control treaty verification.
- Image plane consists of 16 organic-scintillator pixelated block detectors
  - Each block consists of a 10x10 array of 1 cm. pixels.
  - PSD and pixel id accomplished by 4 photomultiplier tubes.



# GEANT4 simulations

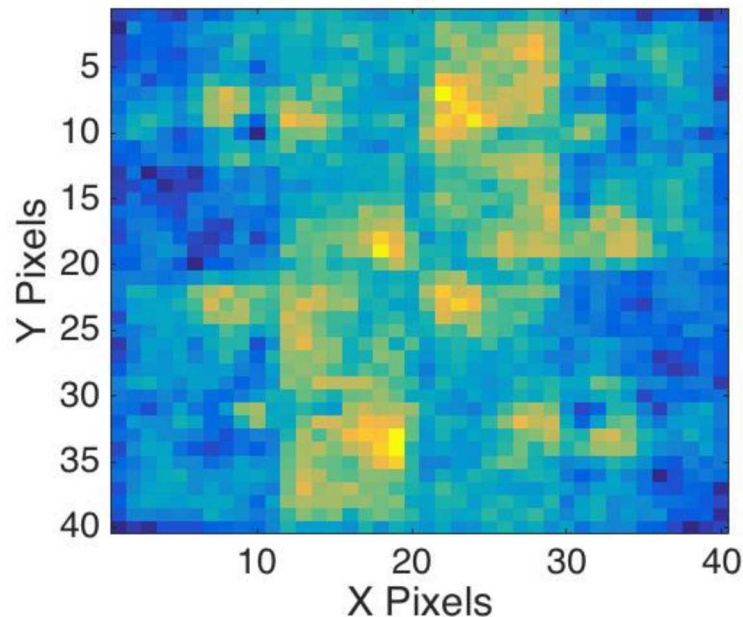


- Spontaneous fission done with G4FissLib (LLNL)
- Fission, elastic scattering, capture, EM processes modeled

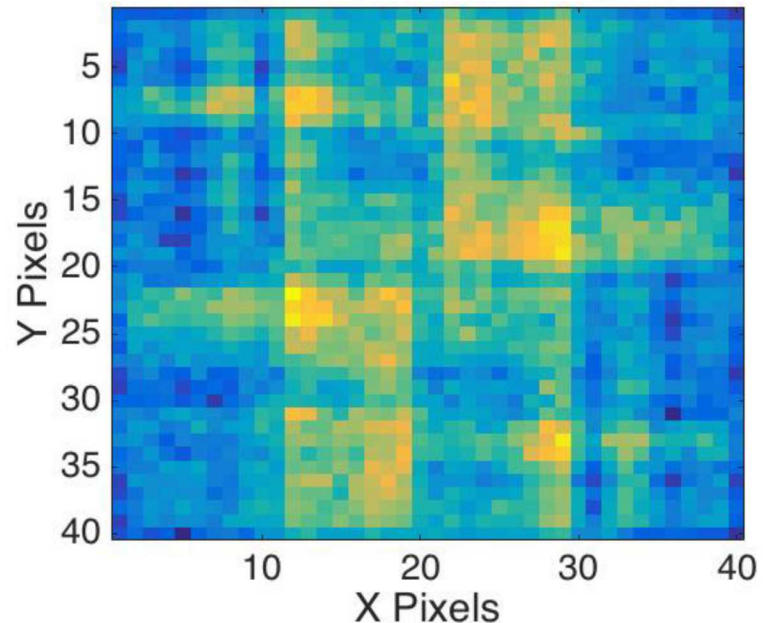
# GEANT4 Simulations

- Models built into transport application using GEANT4 toolkit to acquire testing and training data.
  - Only source and detector geometries incorporated

**20 cm diameter ring source projection**

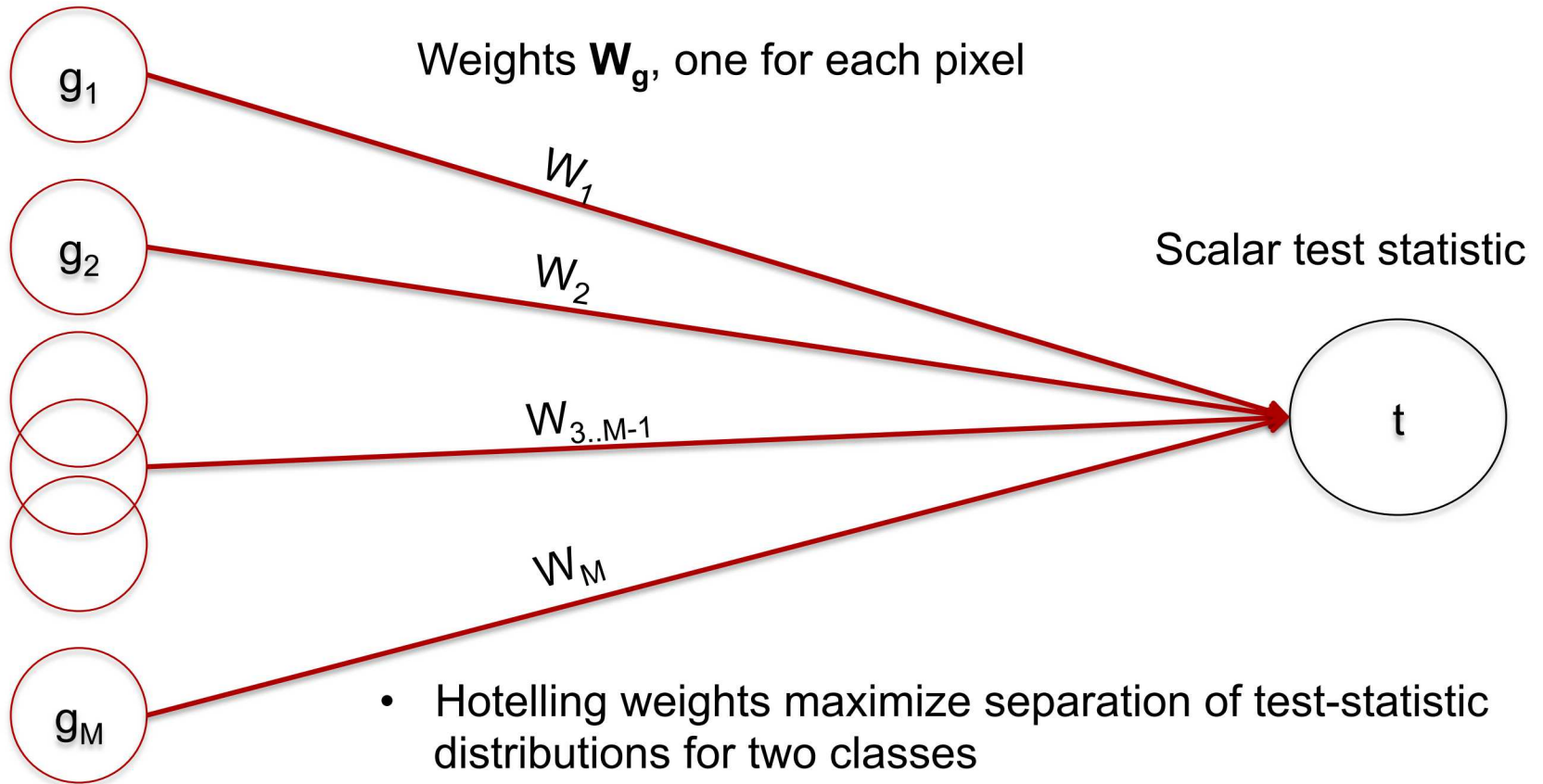


**20 cm length square source projection**



# Linear Template Observers

Projection data **g**  
(sensitive count map)



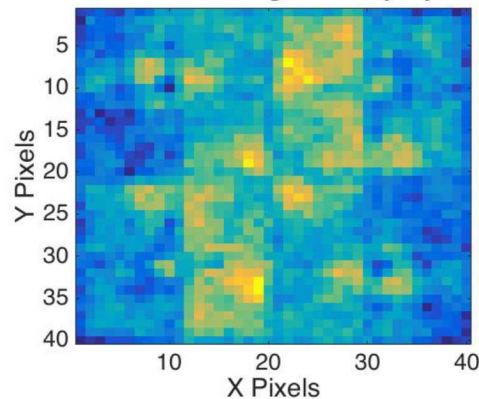
- Hotelling weights maximize separation of test-statistic distributions for two classes
- Take into account randomness in objects.
- Generally sensitive



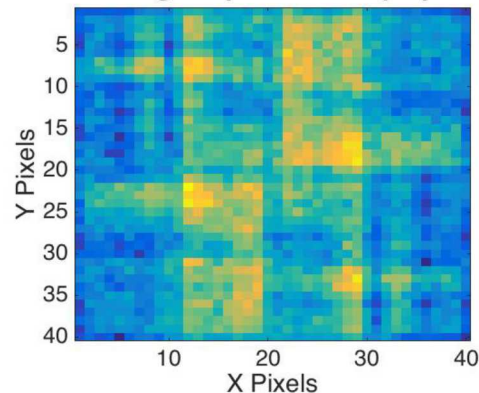
# Hotelling Weights – Ring vs. Square

$$\mathbf{W} = \mathbf{K}_g^{-1} \Delta \bar{\mathbf{g}}$$

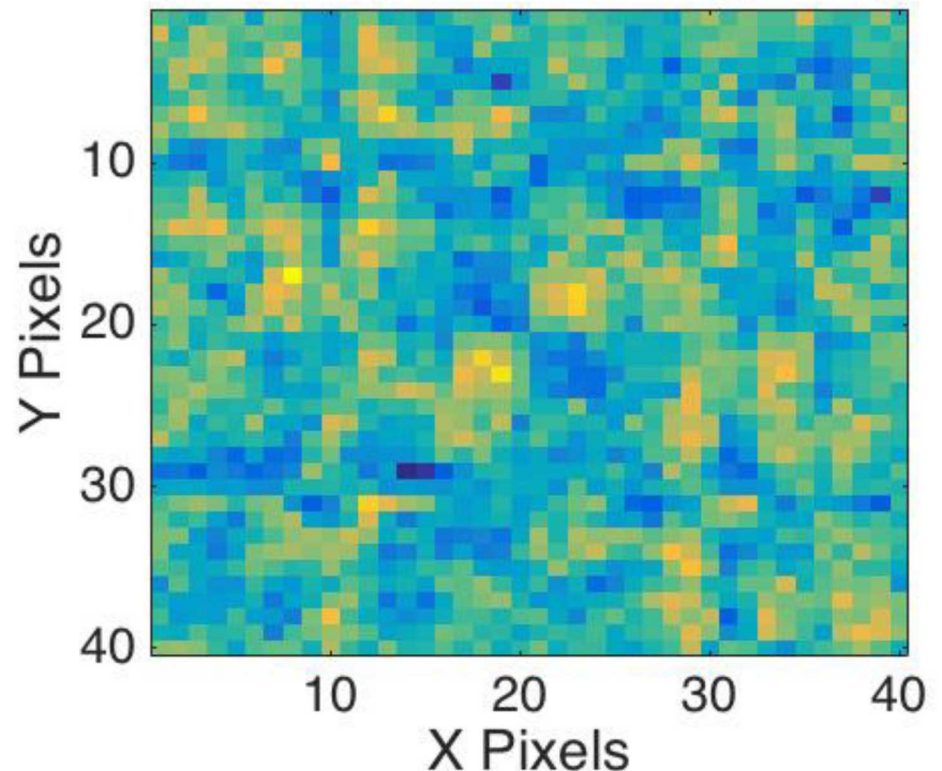
20 cm diameter ring source projection



20 cm length square source projection



Ring vs. Square Hotelling Weights

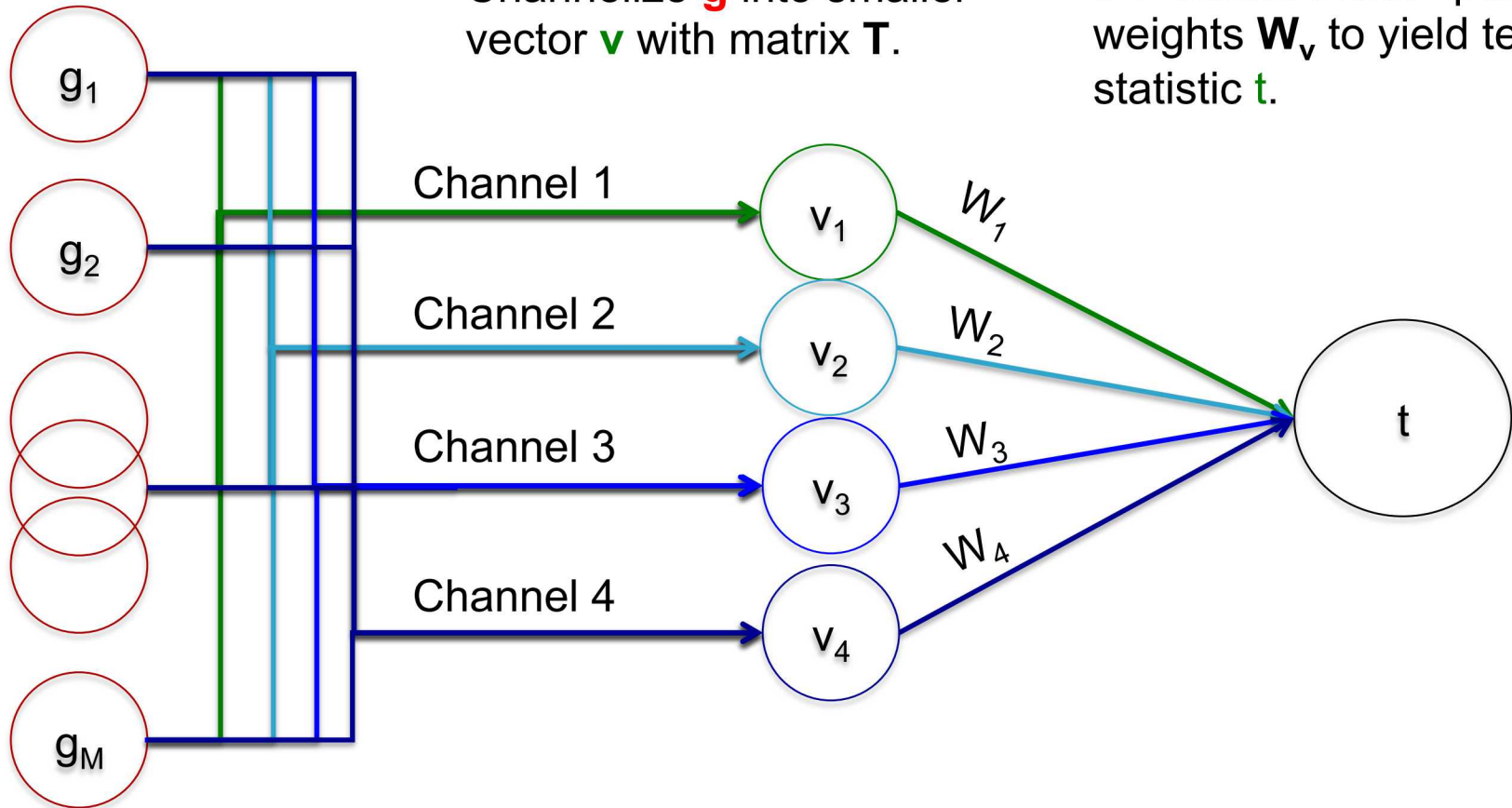


# Channelized Hotelling Observer

Projection data  $\mathbf{g}$   
(sensitive count map)

Channelize  $\mathbf{g}$  into smaller  
vector  $\mathbf{v}$  with matrix  $\mathbf{T}$ .

$\mathbf{v}$  combined with optimal  
weights  $\mathbf{W}_v$  to yield test  
statistic  $t$ .

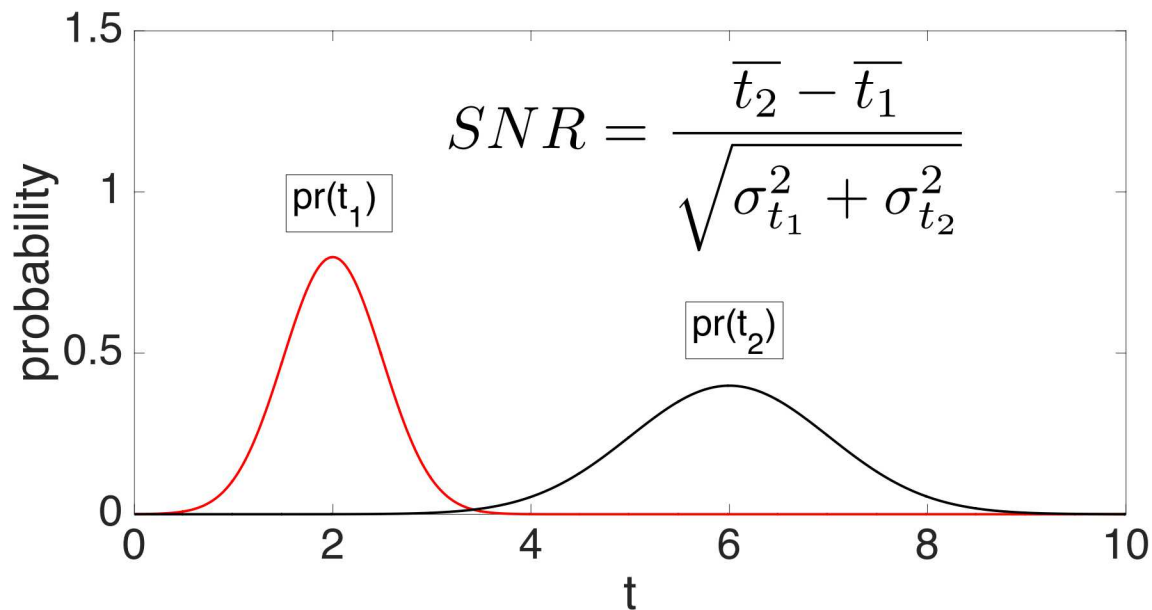




# Optimizing $\mathbf{T}$

- $\mathbf{T}$  can be optimized to maximize  $SNR^2$  of test statistic distributions for best performance.
  - Gradient descent with backtrack

$$f_{obj}(\mathbf{T}) = SNR^2(\mathbf{T})$$



# Non-sensitive model

- Ideally, the host could give the monitor the channelizing matrix, channelized values and test statistics for its measured TAIs.
- Since the monitor has the channelizing matrix, it could simulate its own items, trying to replicate the test-statistic distribution of the TAIs.
- The ideal model would return the same test-statistic distribution for any TAIs that have sensitive construction parameters (mass, size) within some tolerance.

# Toy problem

- Monitor needs to differentiate:
  - A: 20 cm diameter 2D ring source.
  - B: 20 cm length 2D hollow square source.
- Host wants to prevent release of size parameter of source A and B up to tolerance of 4 cm. Penalizes ability to distinguish
  - A: 20 cm diameter 2D ring source.
  - $A_{1,2}$ : 16 cm diameter, 24 cm diameter 2D ring source
  - B: 20 cm length 2D hollow square source
  - $B_{1,2}$ : 16 cm, 24 cm length 2D hollow square source.

# New objective function

$$f_{obj}(\mathbf{T}) = SNR_{[A,B]}^2(\mathbf{T}) - \eta \sum_{i=1}^2 (SNR_{[A,A_i]}^2(\mathbf{T}) + SNR_{[B,B_i]}^2(\mathbf{T}))$$

# New objective function

$$f_{obj}(\mathbf{T}) = SNR_{[A,B]}^2(\mathbf{T}) - \eta \sum_{i=1}^2 (SNR_{[A,A_i]}^2(\mathbf{T}) + SNR_{[B,B_i]}^2(\mathbf{T}))$$

Optimize performance  
discriminating circle and square

# New objective function

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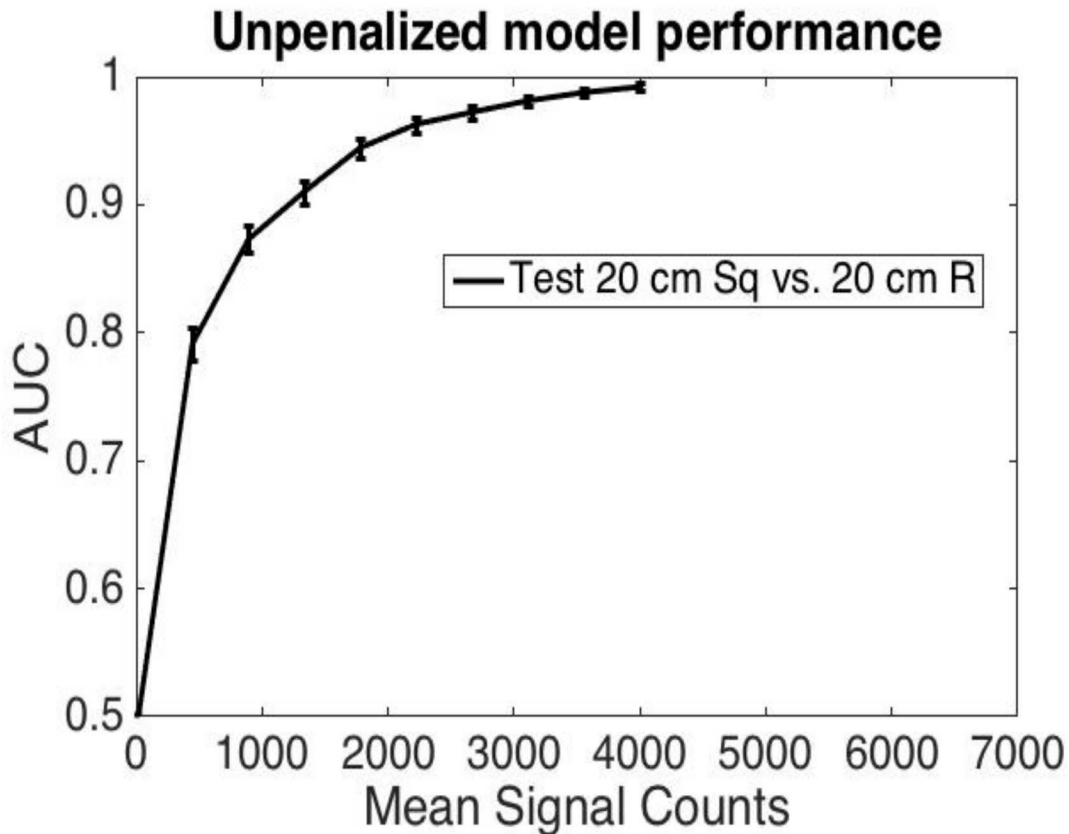
Optimize performance  
discriminating circle and square

Penalize discrimination between items of same geometry with different sizes



# Standard Optimization Performance

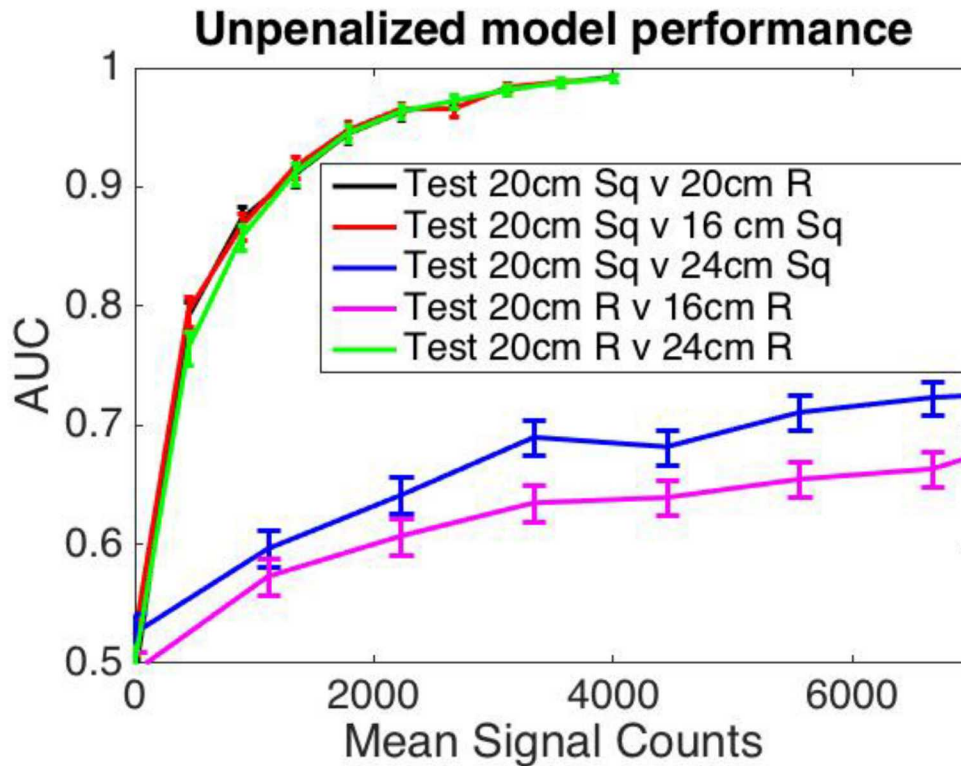
Area under ROC curve (AUC) is a measure of test-statistic distribution separation



Can differentiate two items in ~3000 detected counts.

# Standard Optimization Performance

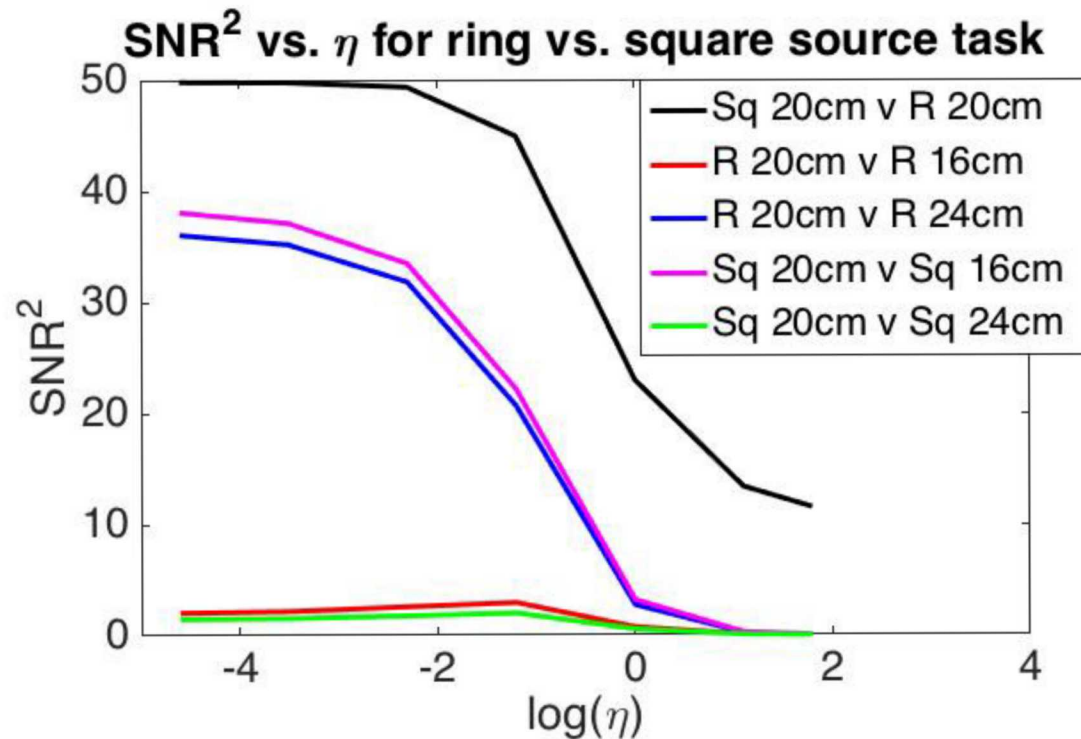
Area under ROC curve (AUC) is a measure of test-statistic distribution separation



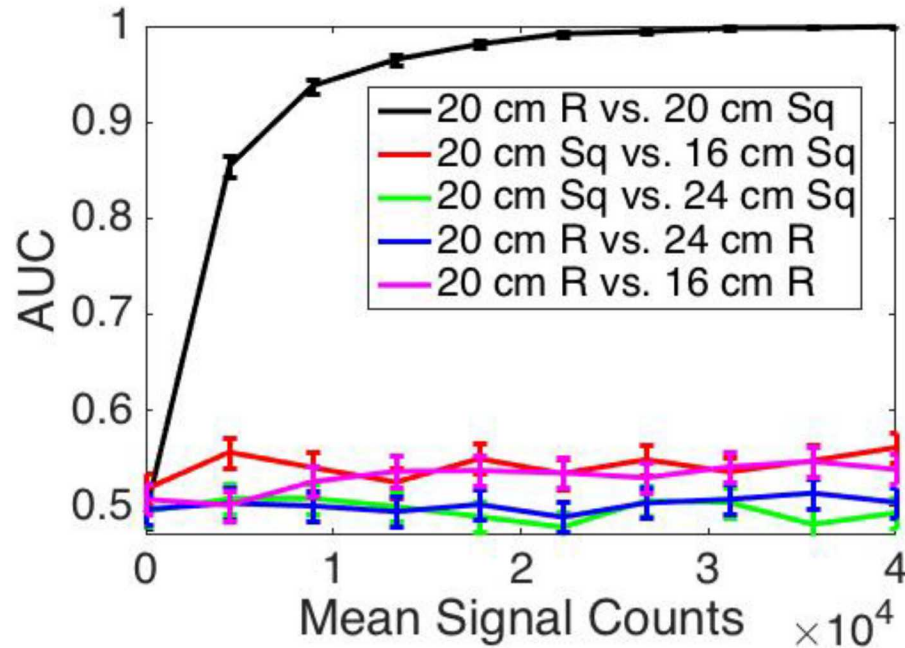
Model trained to differentiate 20cm square and ring sources can also differentiate sizes of those items.

# Effect of penalty term

$$f_{obj}(\mathbf{T}) = SNR_{[A,B]}^2(\mathbf{T}) - \eta \sum_{i=1}^2 (SNR_{[A,A_i]}^2(\mathbf{T}) + SNR_{[B,B_i]}^2(\mathbf{T}))$$

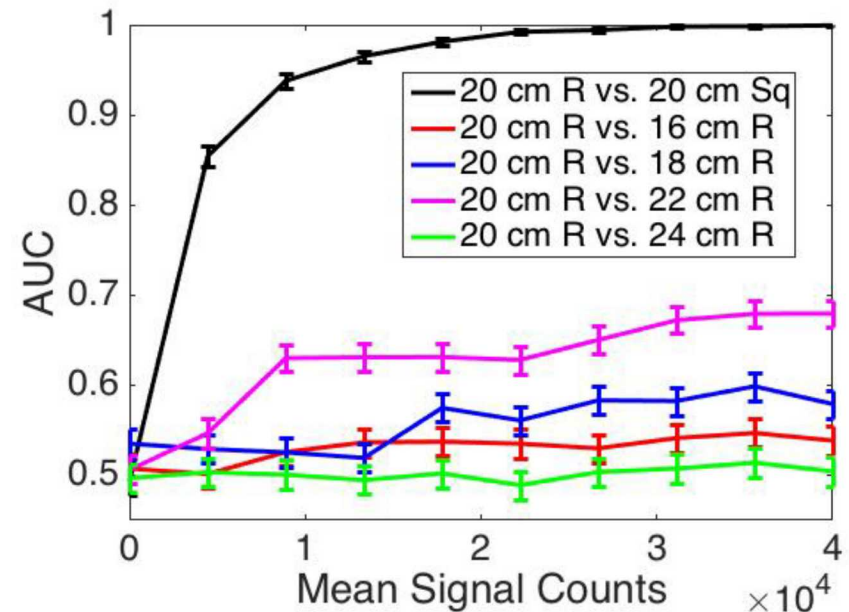
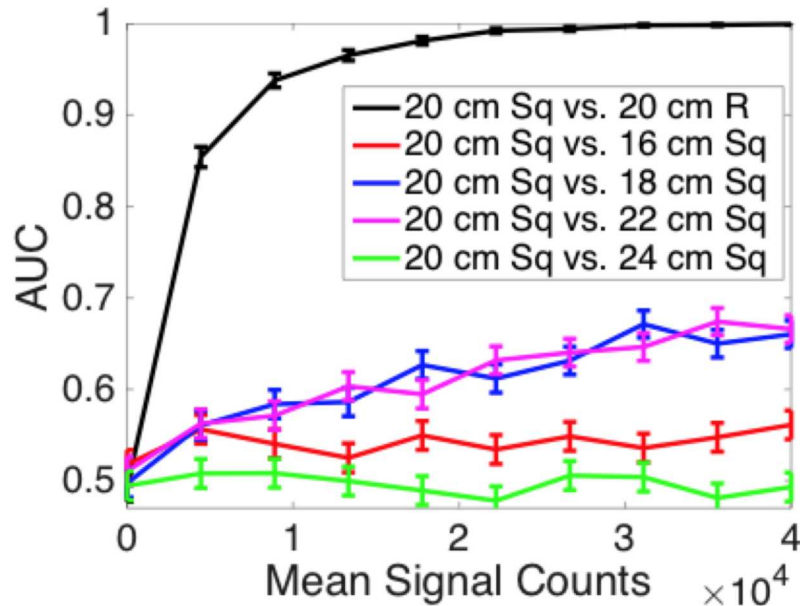


# Performance Change After Penalty



- Factor of 10 more signal counts required to differentiate geometries
- Significantly worse performance discriminating 20 cm items from 16, 24 cm items.

# Performance Change After Penalty



- Significantly worse performance discriminating 20 cm items from 16, 24 cm items.
- Performance discriminating 20 from 18, 22 cm items is higher

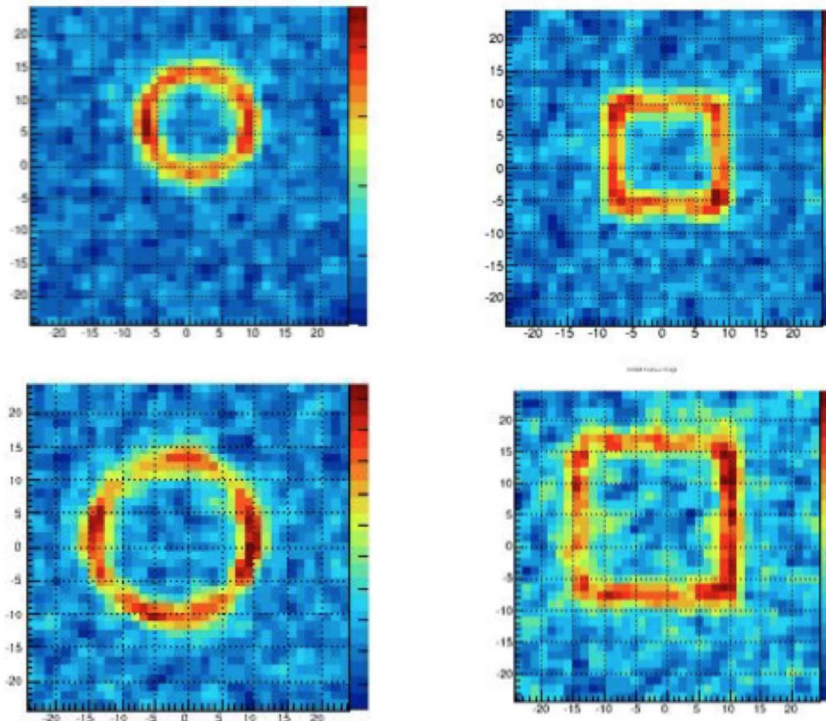
# Conclusion and future work

- Developed method to perform binary discrimination while having poor performance discriminating along predefined sensitive parameters.
- This is a case where multiple penalty terms would be required to prevent discrimination between the TAI and a range of items



# Future work – Ring vs. Square

- Experimental data has been taken on these square and ring sources at Sandia National Laboratories.
- Penalization effectiveness will be compared to simulations.
- We intend to publish results in TNS.
- Reconstructed images of data shown below.



# Thank you!



## Project Team

Dr. Matthew Kupinski

Dr. Nathan Hilton

Dr. Erik Brubaker

Dr. Peter Marleau



## Funding Sources

- NA-20

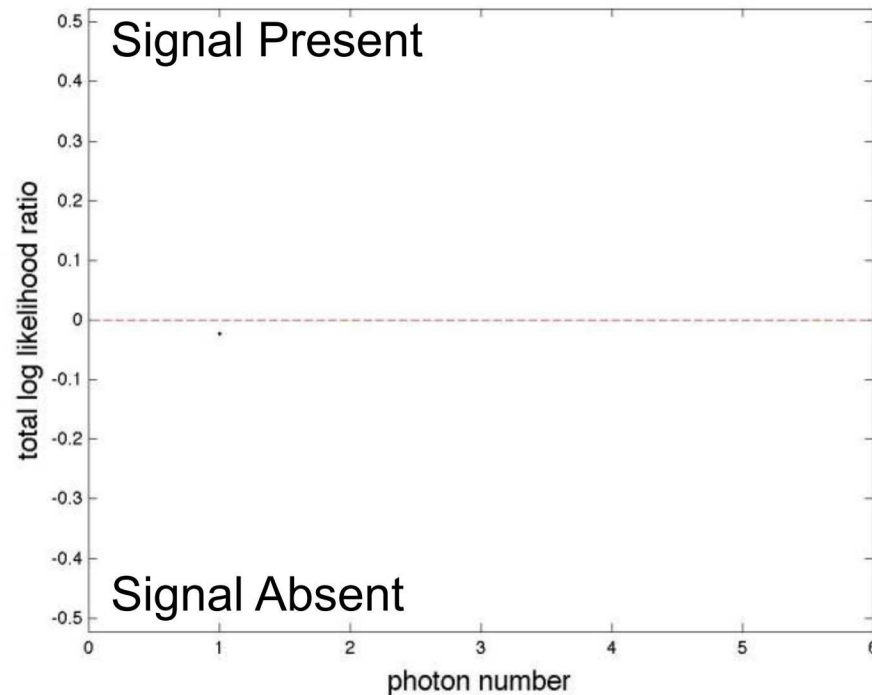
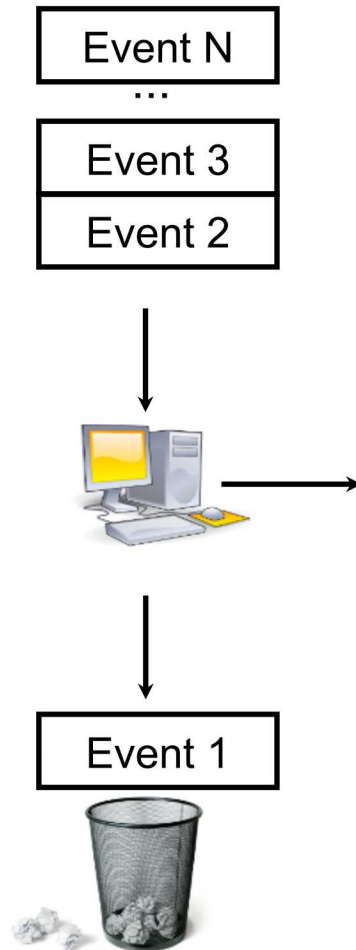
## Support

Sandia High Performance  
Computing Services



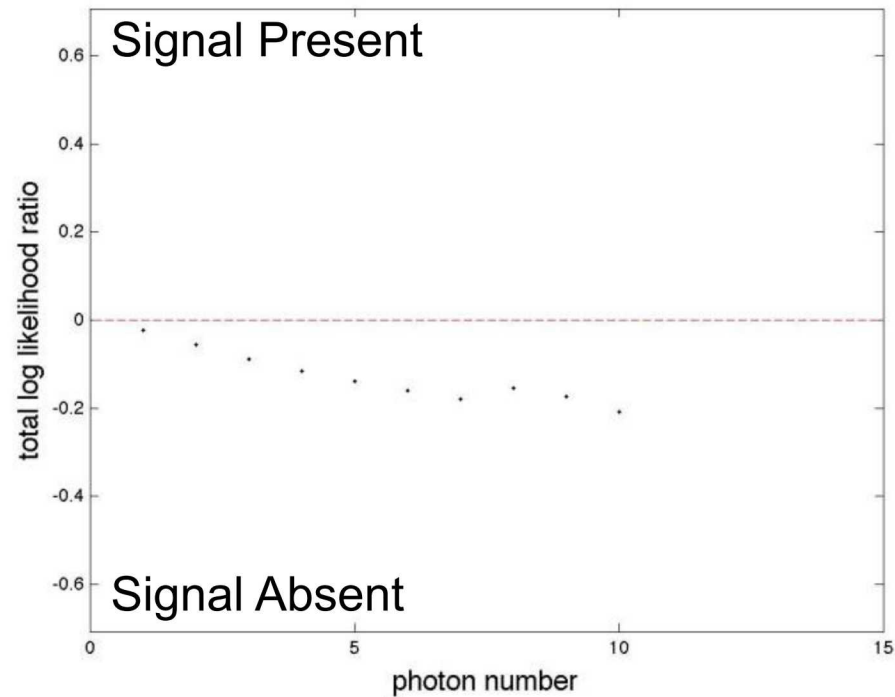
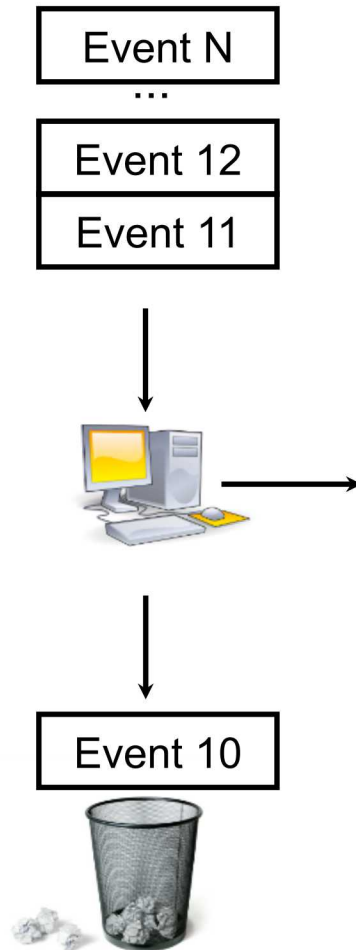
Questions?

# List-mode Processing



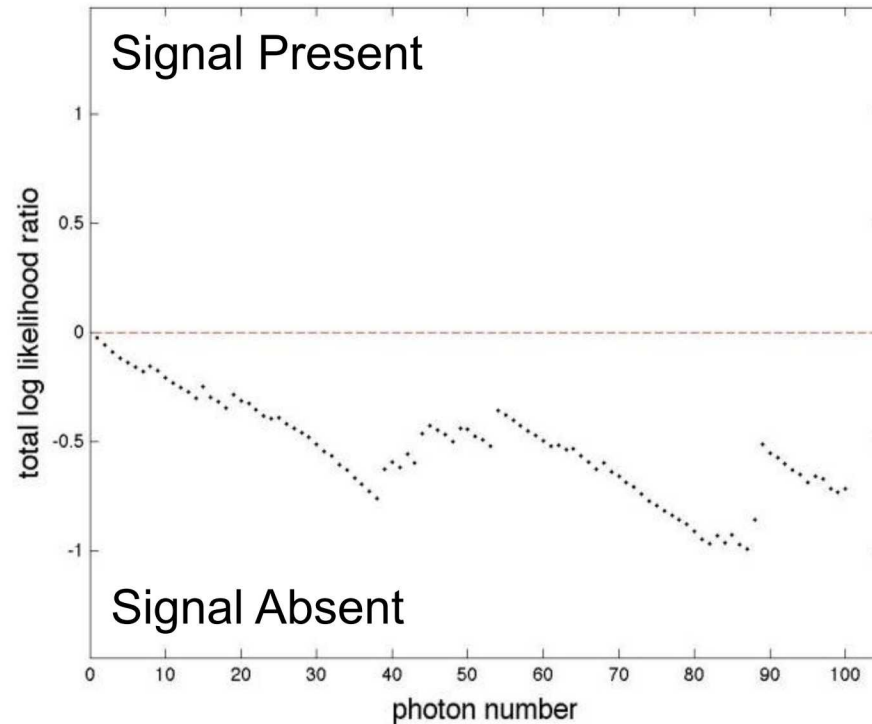
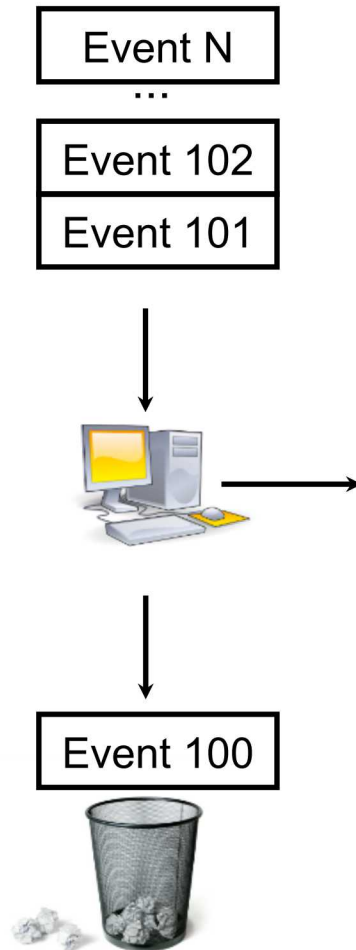
Output running sum is the likelihood of a signal being present, which is thresholded to make a decision.

# List-mode Processing



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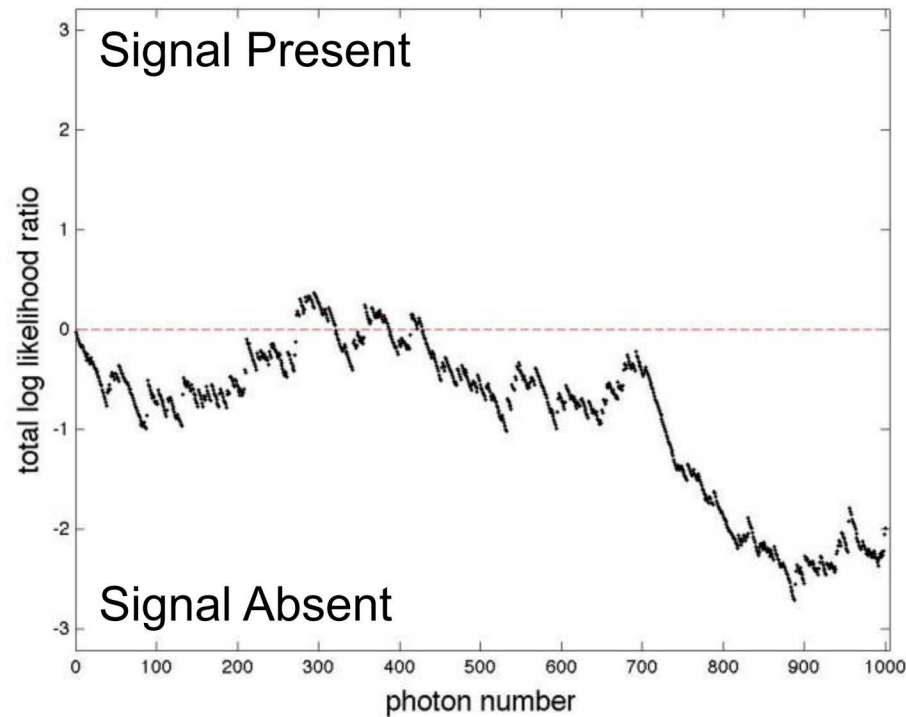
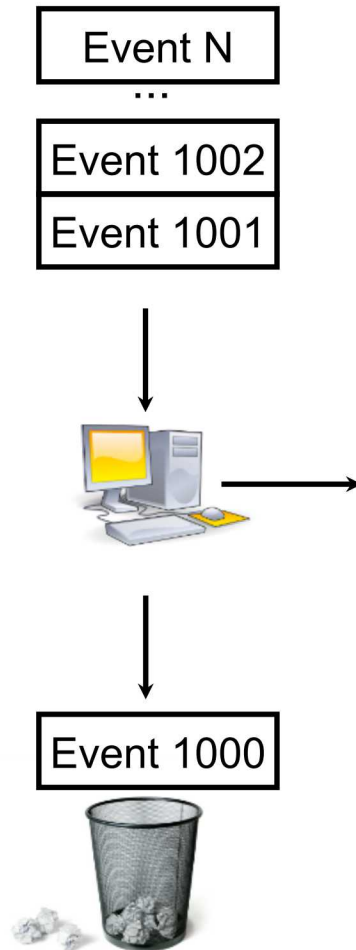
# List-mode Processing



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