THE UNIVERSITY OF ARIZONA

Sandia National Laboratories

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Nuclear Imaging for Treaty Verification with Enhanced Information Security

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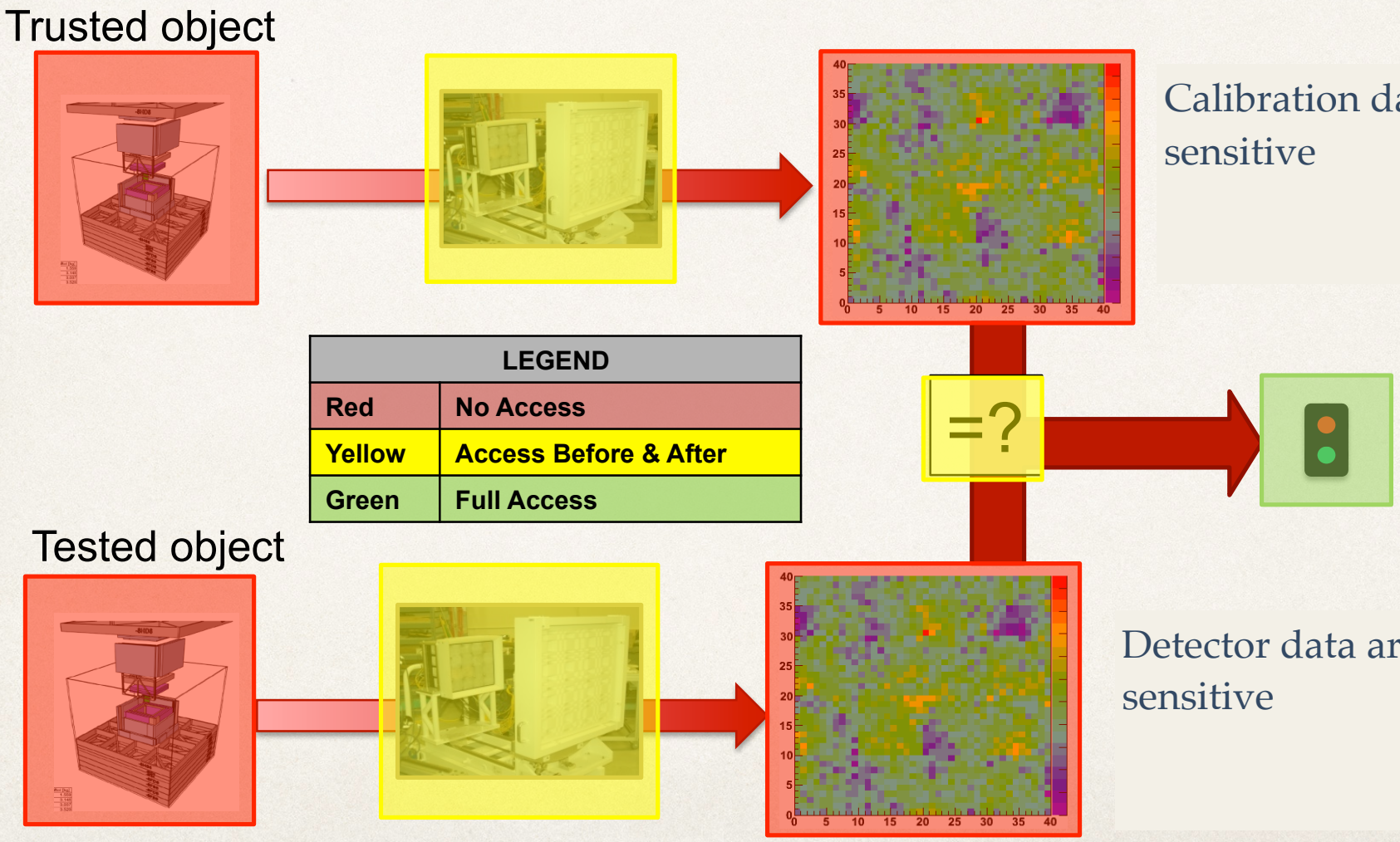
Outline

- Introduction
- Challenges
  - Using image data while preserving information security
  - Accounting for nuisance parameters
  - Generating template models that preserve information security
- Summary

Arms control/Treaty verification

- Cold War: the focus was on launchers as Treaty Limited Items
  - Launchers can be reliably counted.
  - Does the exact number of warheads matter in the limit of large numbers?
- Post Cold War: there is an emerging focus on warheads as well as launchers
  - New START Treaty (2011) limits US to 1550 warheads on 700 delivery systems.
- Future treaties: possible new focus on warhead monitoring and deep reductions
  - When warheads are treaty limited items, it is possible that "cradle to grave" accounting will be needed to reduce threat of breakout scenarios.
  - Reliable confirmation of dismantlement may require that the incoming item be determined to be a warhead with all the associated security challenges.
  - Imaging can examine the spatial and spectral distribution of SNM, an essential characteristic of a warhead.

Imaging and information



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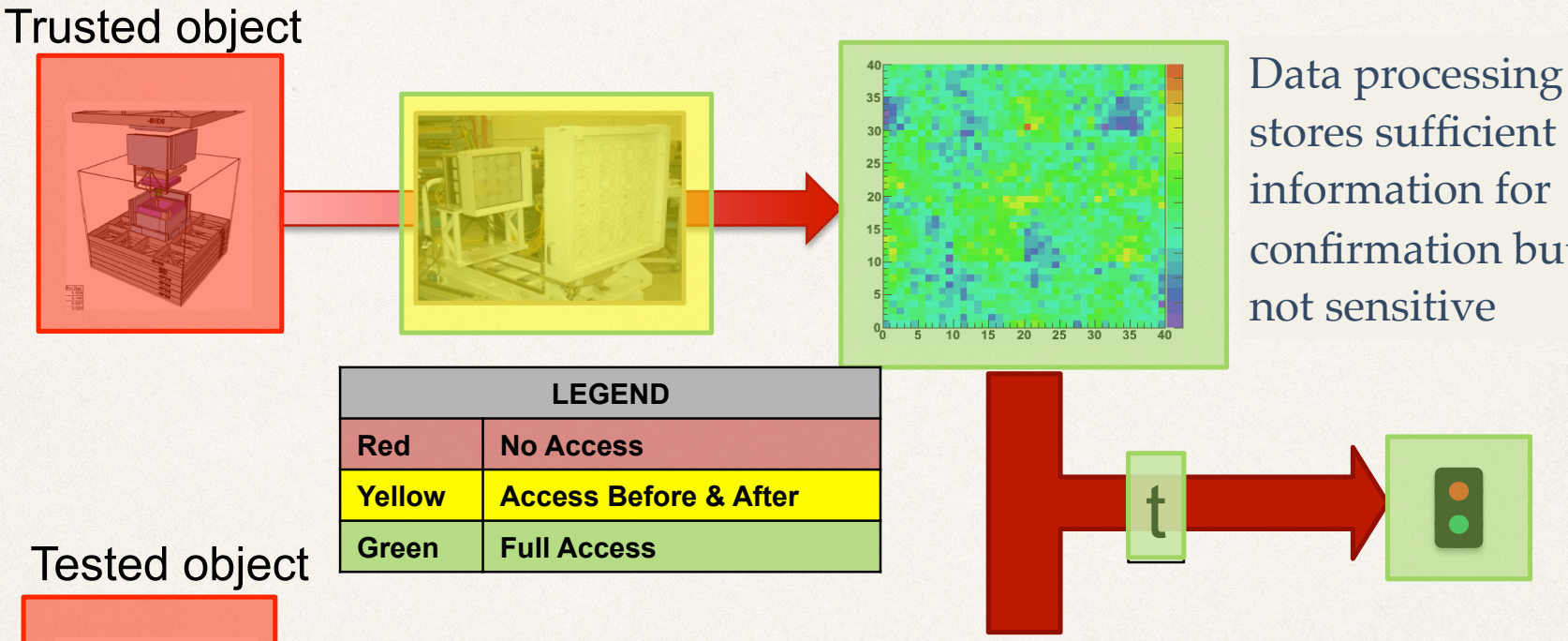
Red	No Access
Yellow	Access Before & After
Green	Full Access

Imaging and information

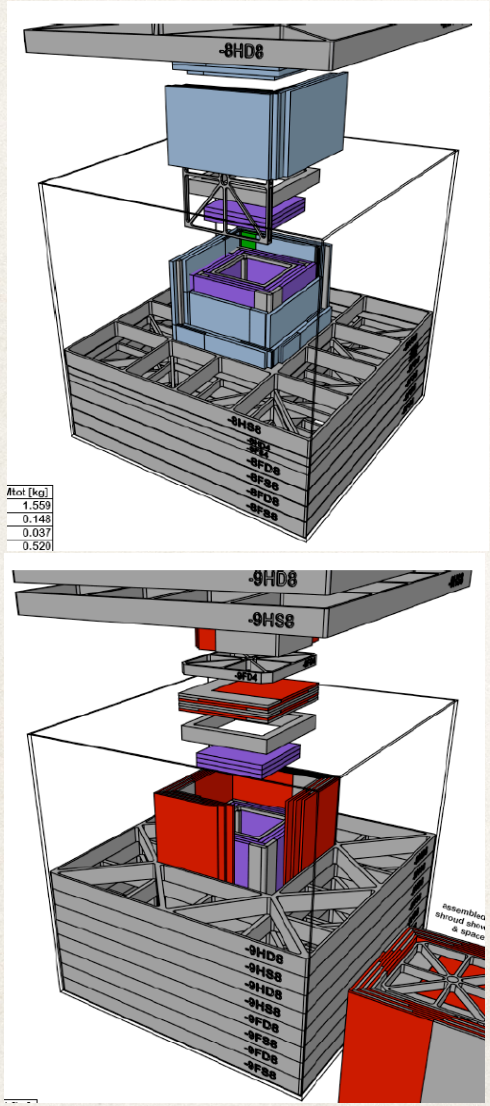


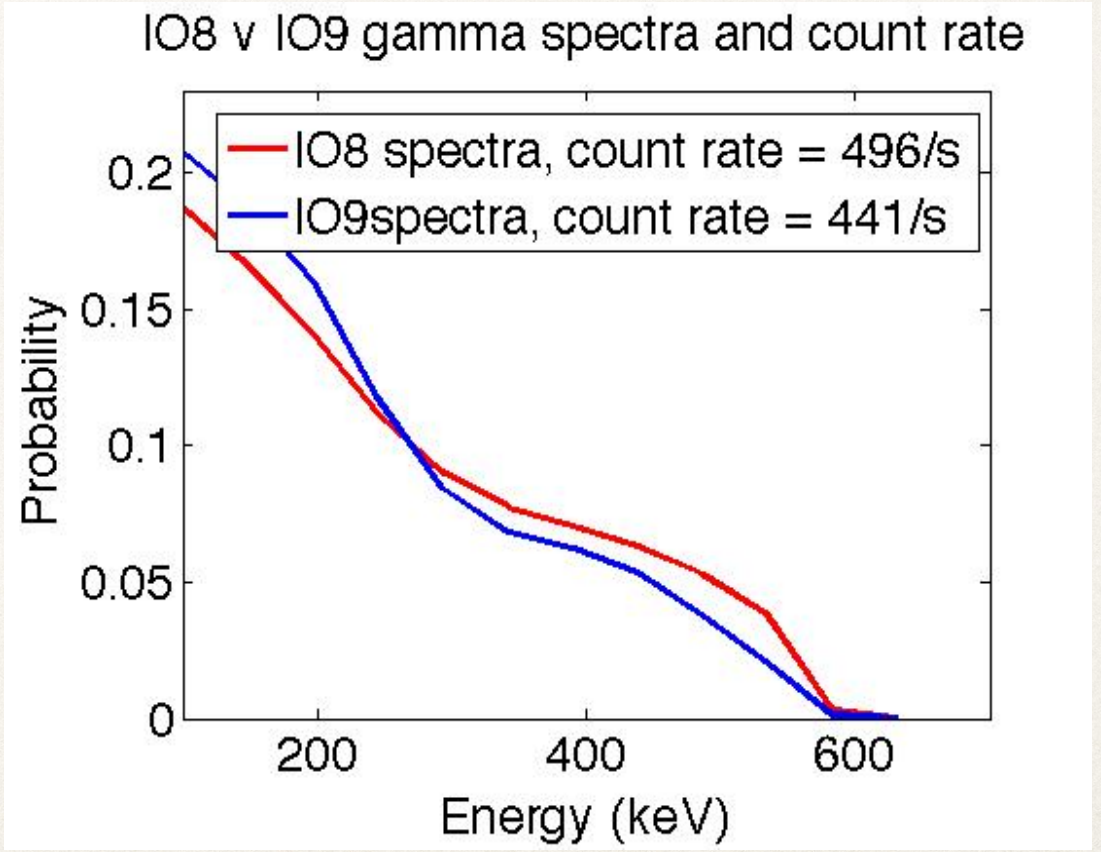
Data processing stores sufficient information for confirmation but is not sensitive

Testing data are processed event by event, only updating a single number.

Data not aggregated

Idaho inspection objects

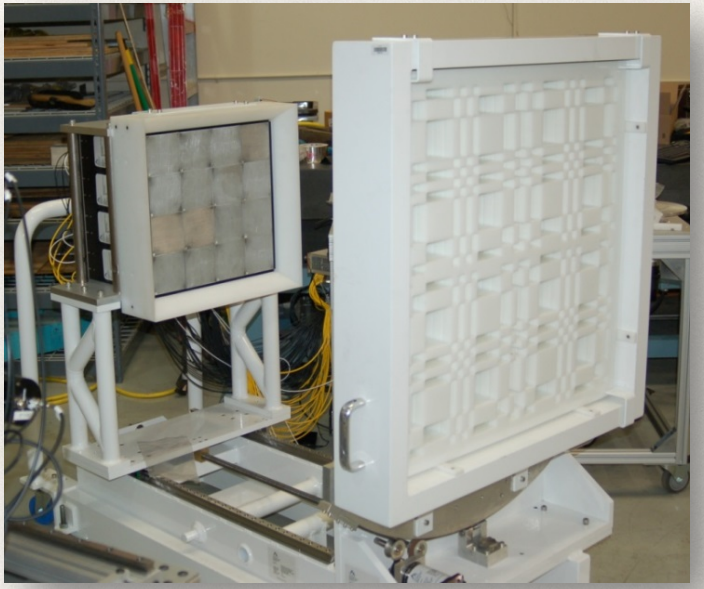


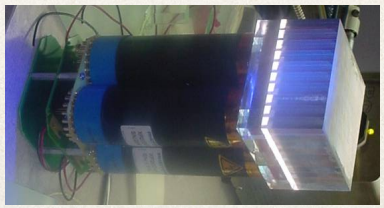


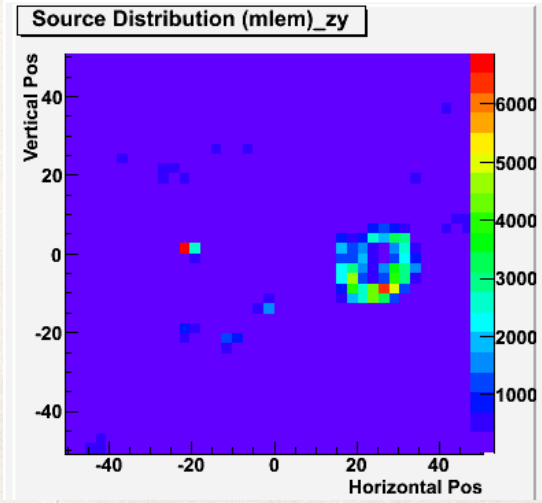
Fast neutron imaging system

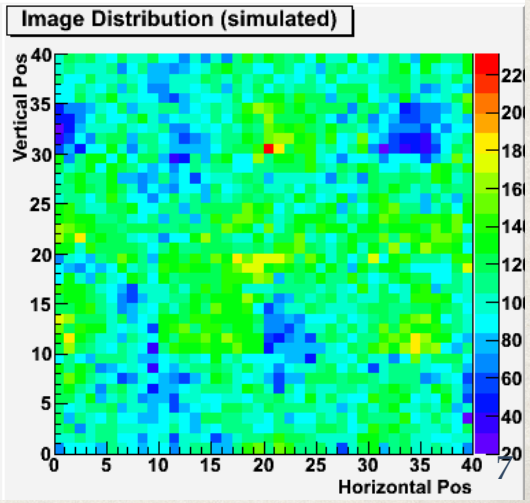
ORNL/SNL fast neutron coded-aperture imager developed for arms control treaty verification.

- 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.
- Coded aperture system.

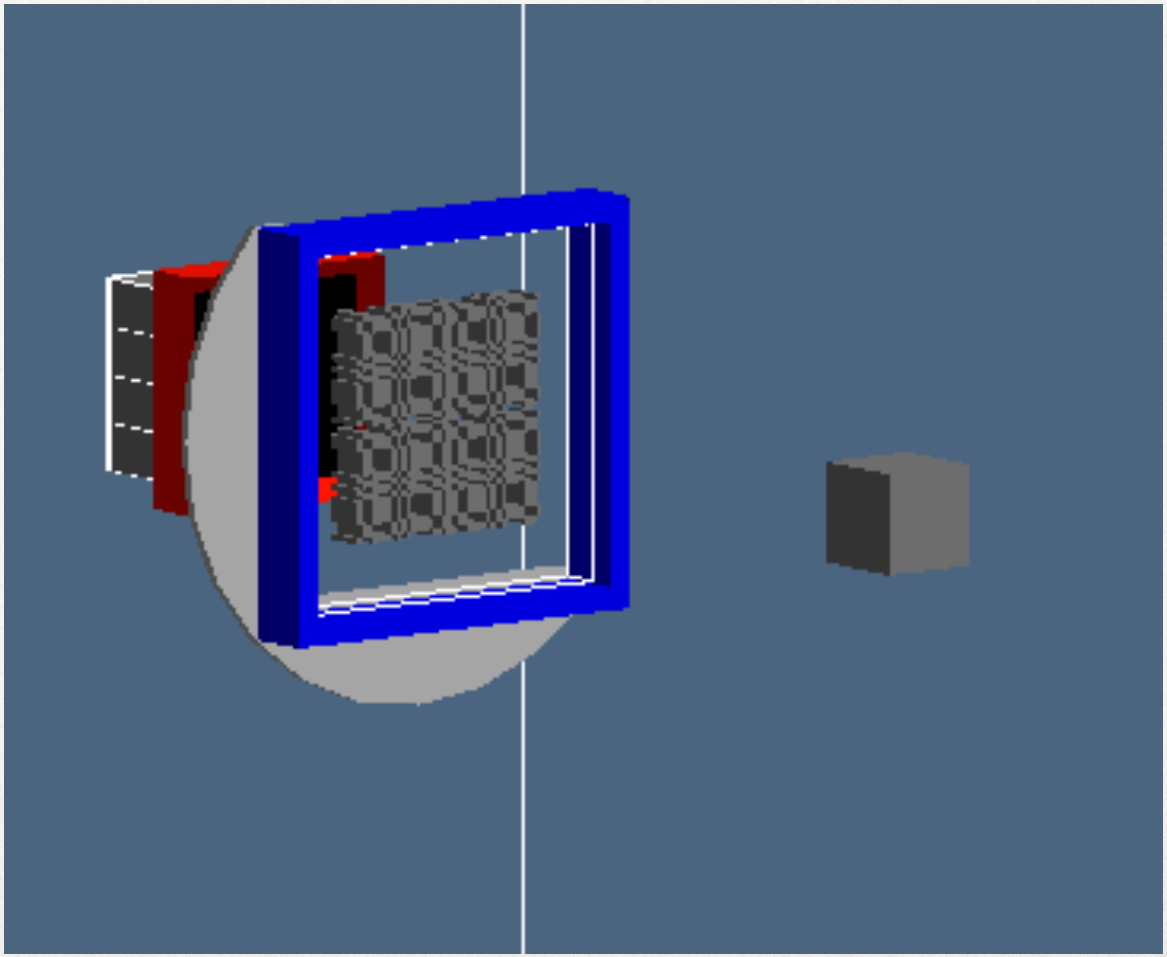








GEANT 4 models



Challenge 1

- How do we use an imaging system but not generate an image?

Solution 1: List-mode processing

- Method must process and not store list-mode events
- Output is a running sum that represents the likelihood of a signal being present
- Likelihood is thresholded to make a decision
  List-mode data A_n = {Estimated energy, position, and particle type}

Listmode processing

Event N

...

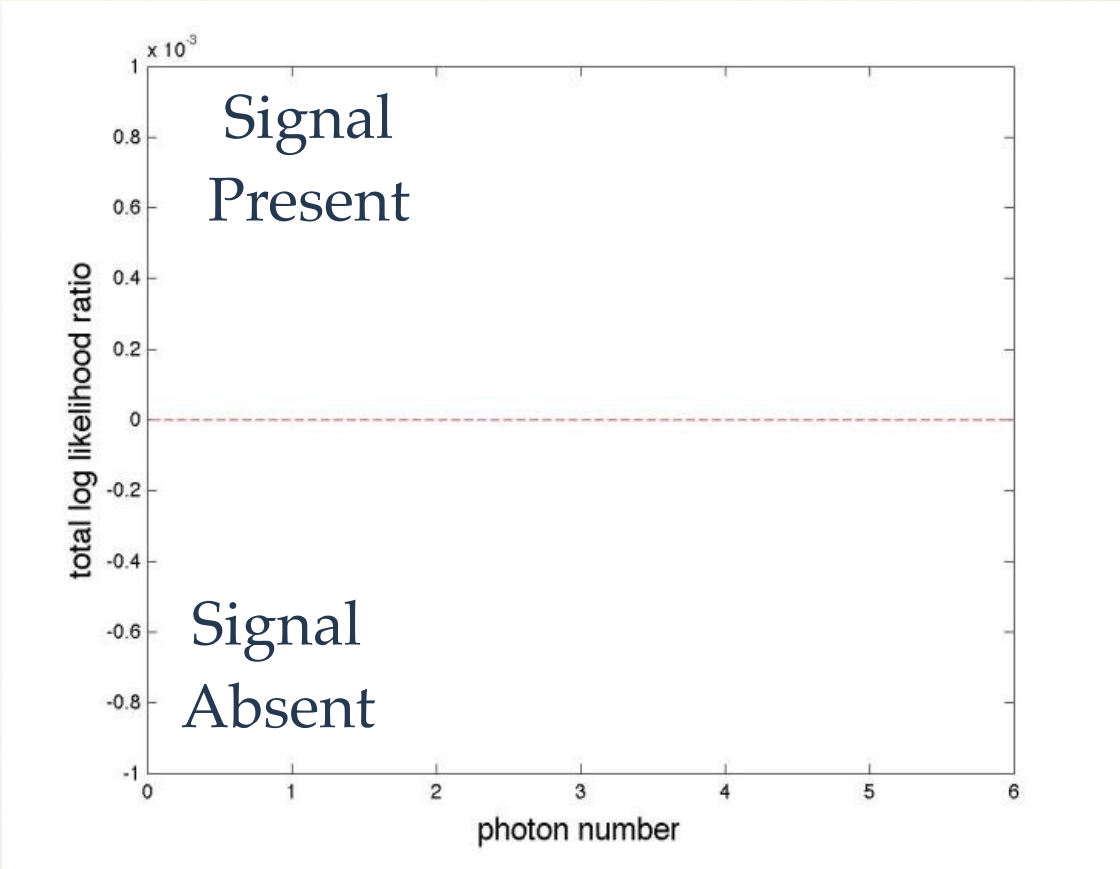
Event 3

Event 2

Event 1

Event 1

Likelihood of signal for 0 events



Listmode processing

Event N

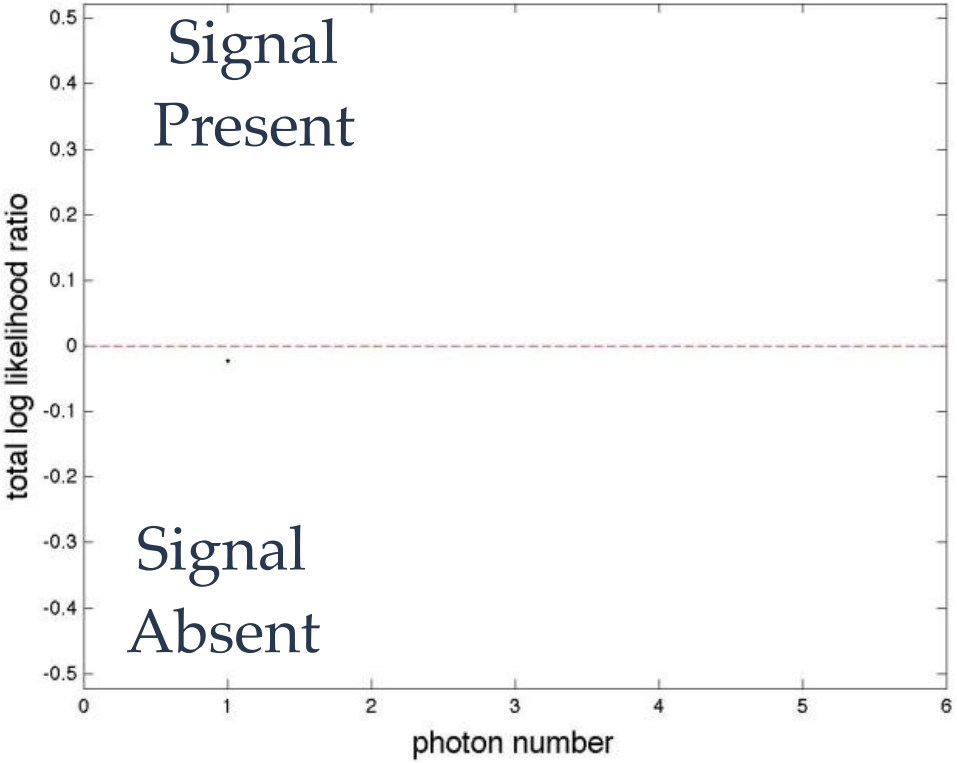
...

Event 3

Event 2

Event 2

Likelihood of signal for 1 event



Listmode processing

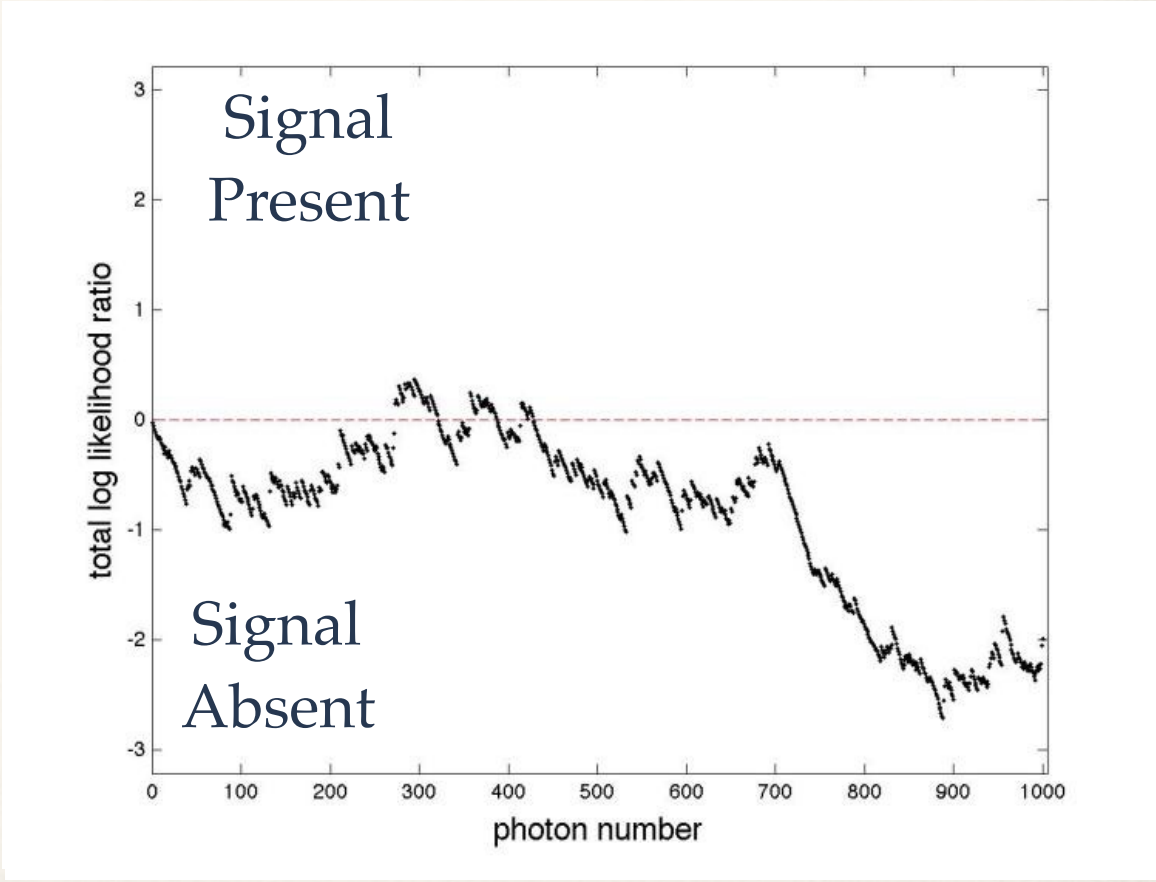
Event N

...

Events 1000-2000

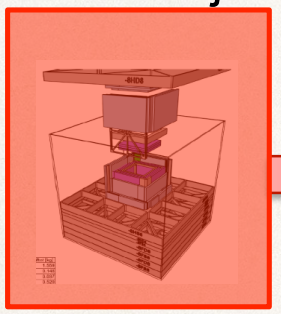
Likelihood of signal for 1000 events

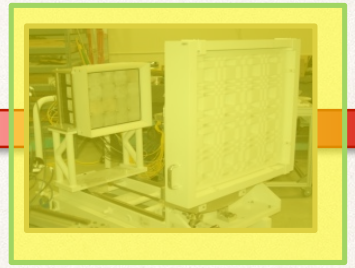
Events 1000-2000

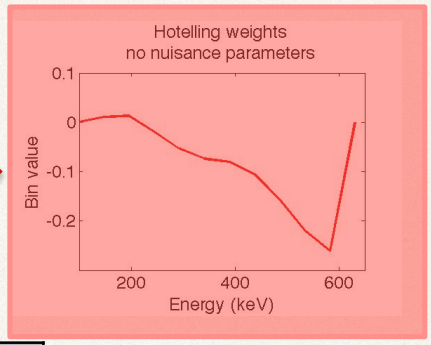


Solution 1

Trusted object

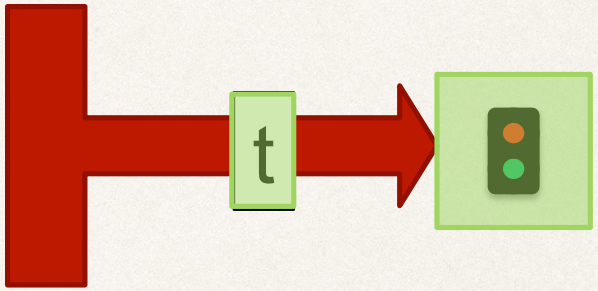




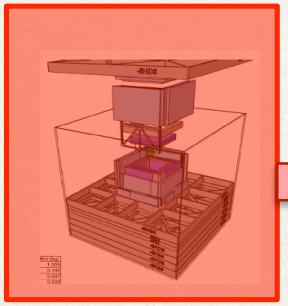


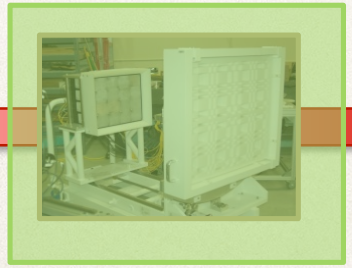
Data processing step uses sensitive information, but can't reconstruct object from *t* alone

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



Tested object





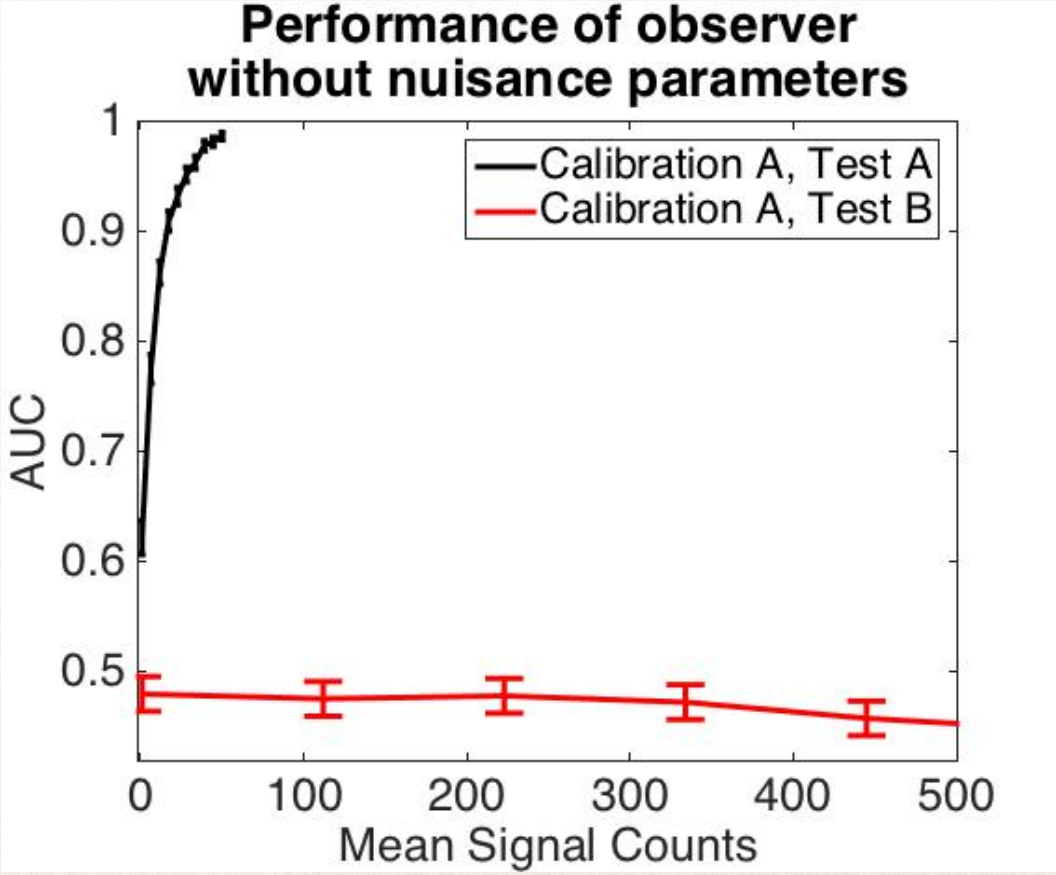
Testing data is processed event by event, only updating test statistic *t*

Challenge 2

- Problem is corrupted by a large set of nuisance parameters — things that change the data but are of no interest for the treaty-verification task
  - Material age, orientation, system calibration, background distributions, etc., etc.

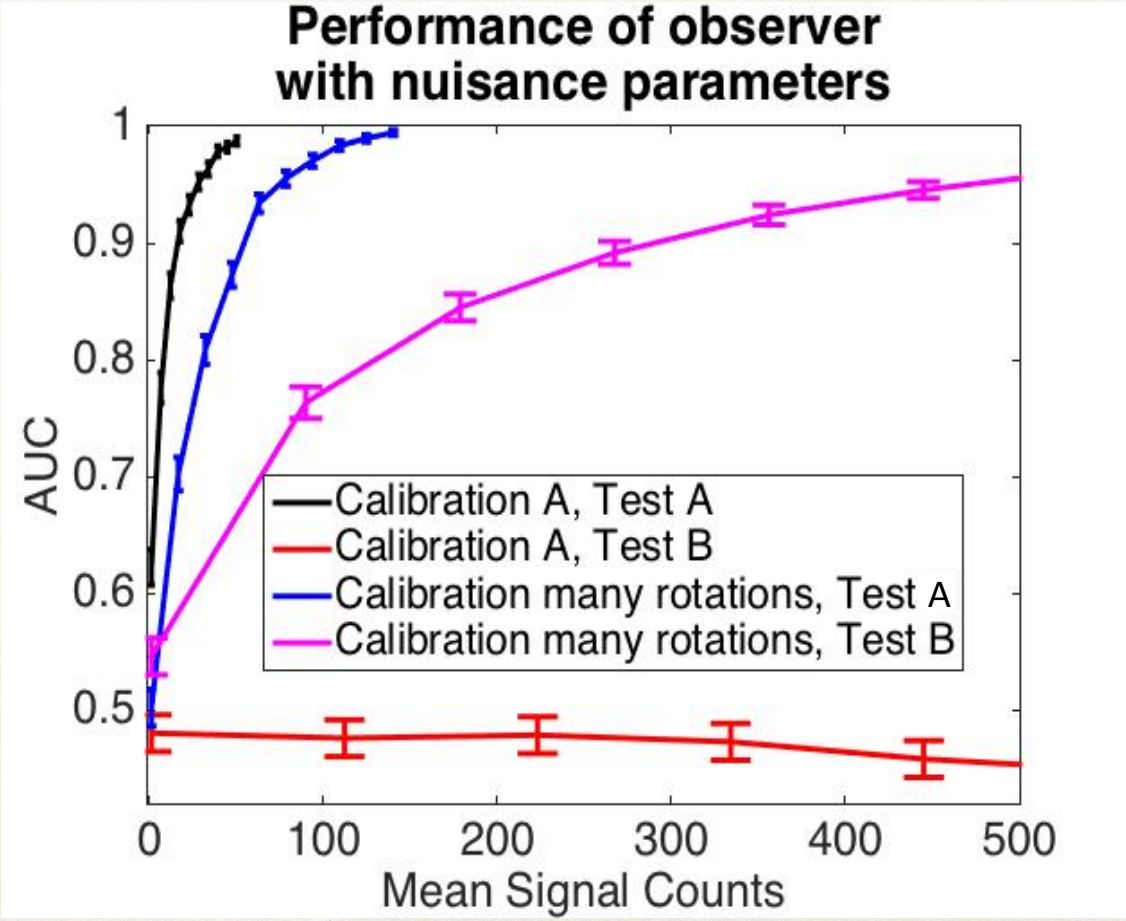
Challenge 2: Nuisance parameters

- How do we account for the many nuisance parameters?



Solution 2: Nuisance parameters

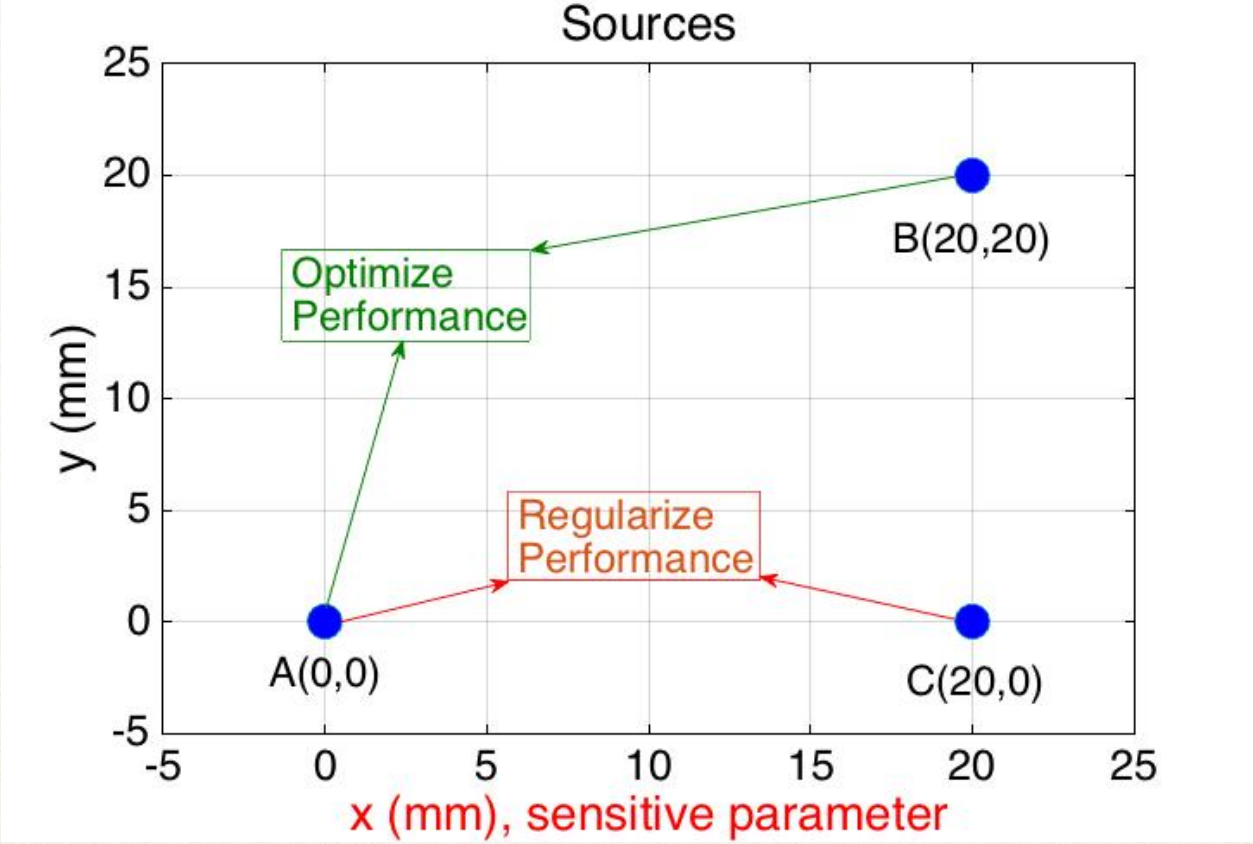
- Decision models that account for nuisance parameters.



Challenge 3: Sensitive observer models

- We have shifted the burden of information from the image to the method that makes the decision.
- Can we also hide the information the algorithm uses?

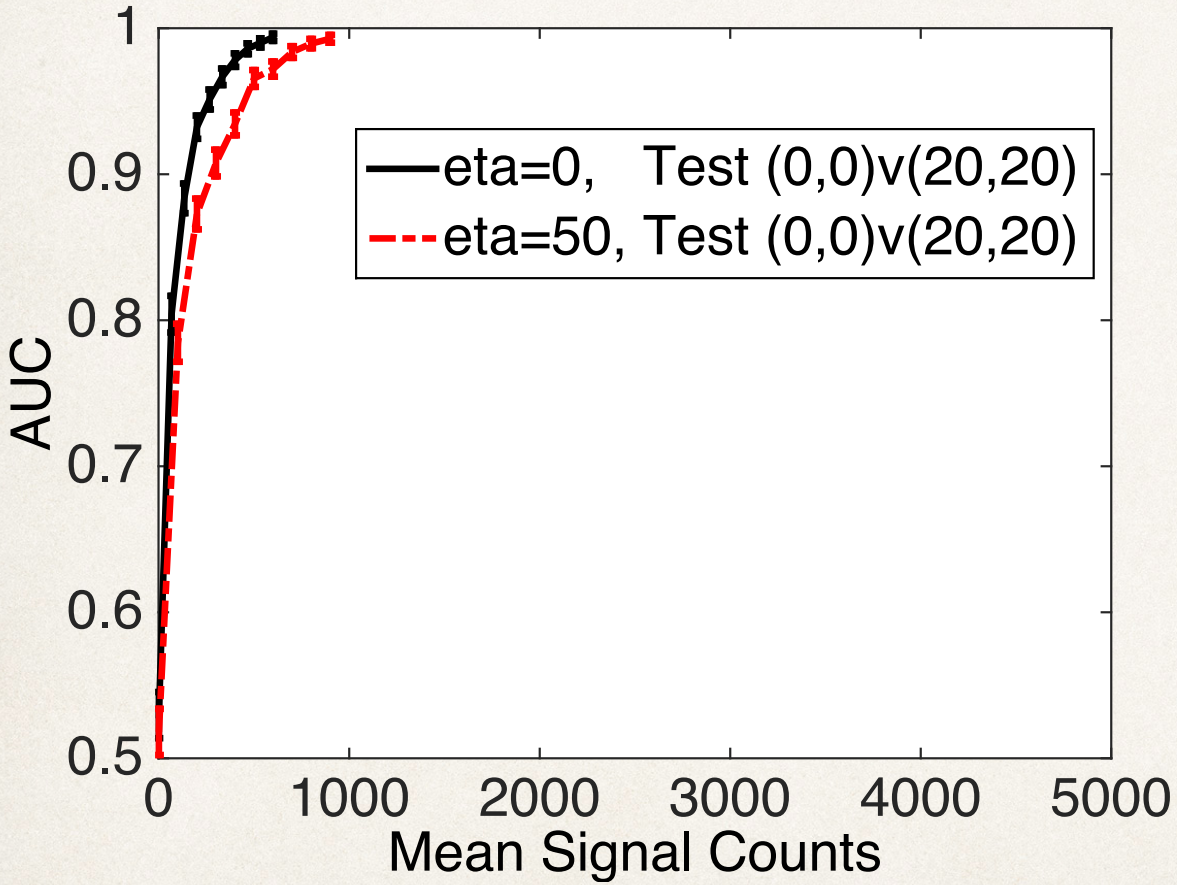
Solution 3: Penalize sensitive info

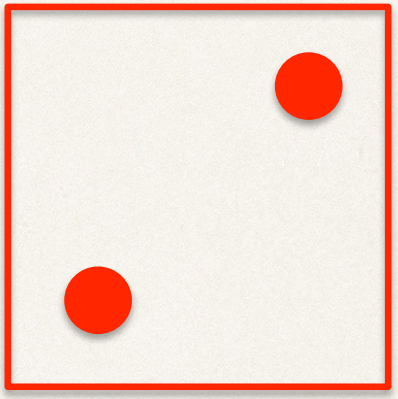


$$f_{obj} = SNR^2_{B,A} - \underbrace{\eta SNR^2_{C,A}}$$

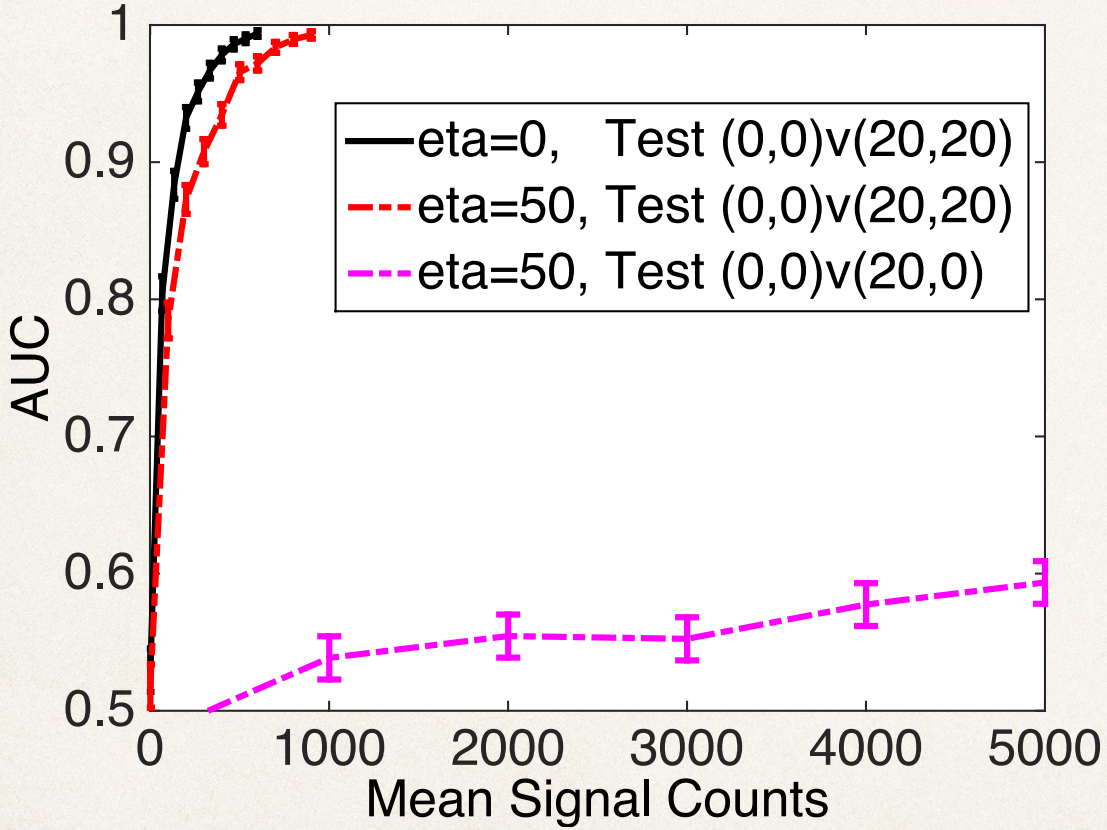
X differences

Results


1
0.9
0.8
0.7
0.6
0.5
AUC
0
1000
2000
3000
4000
5000
Mean Signal Counts
eta=0, Test (0,0)v(20,20)
eta=50, Test (0,0)v(20,20)



Results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eta=0, Test (0,0)v(20,20)
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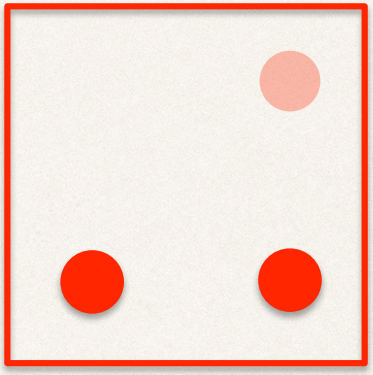
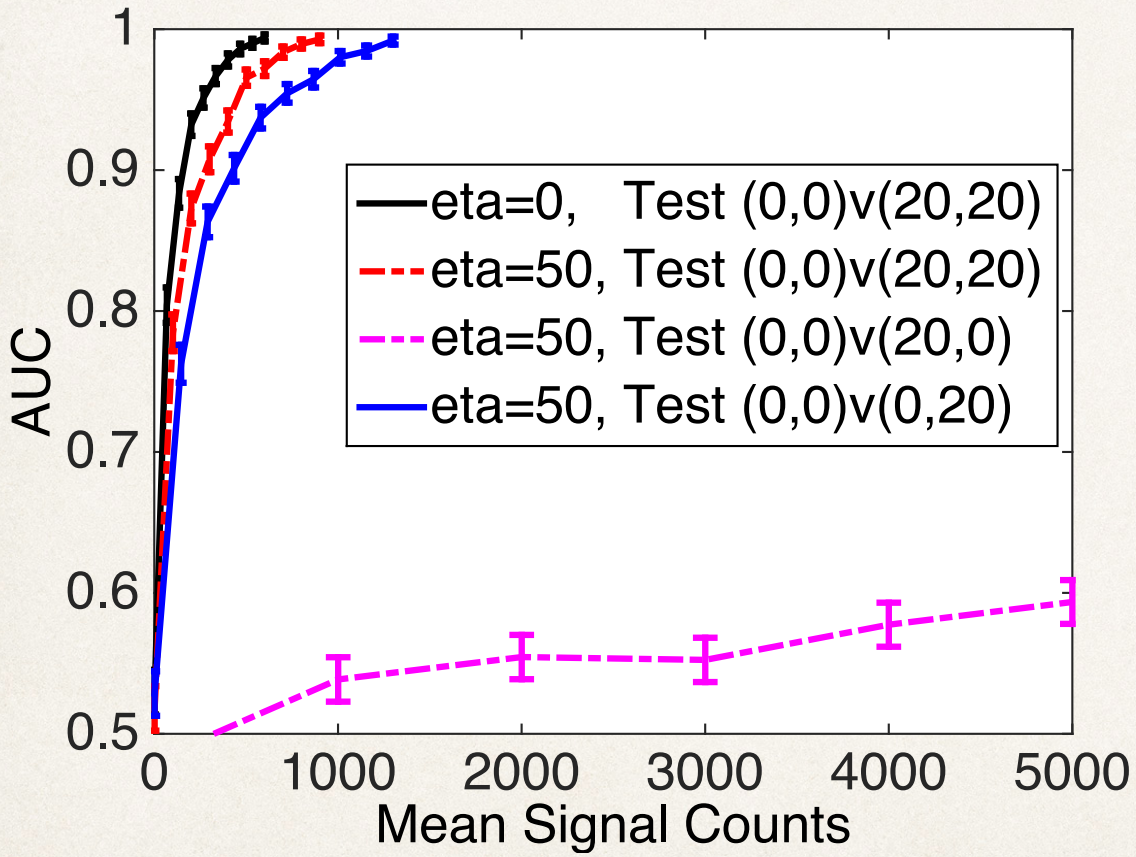


Results


AUC
Mean Signal Counts
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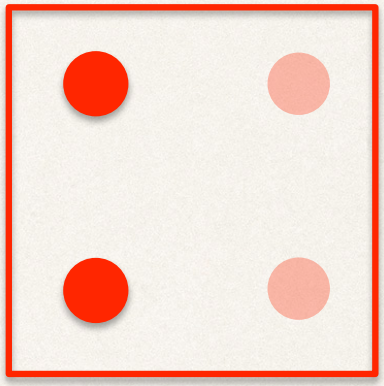
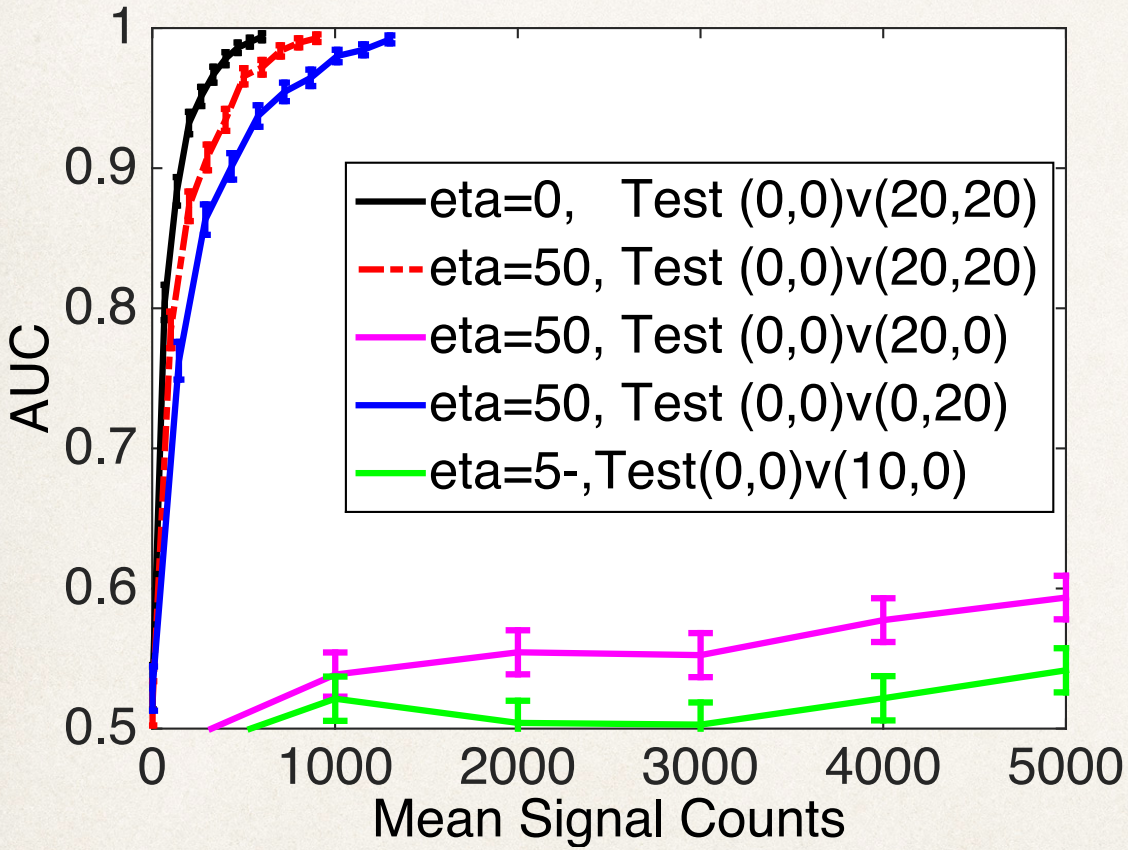
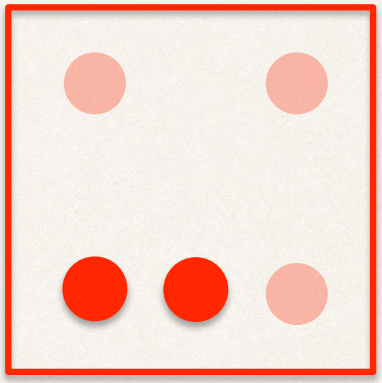
0.9
0.8
0.7
0.6
0.5
0
1000
2000
3000
4000
5000
eta=0, Test (0,0)v(20,20)
eta=50, Test (0,0)v(20,20)
eta=50, Test (0,0)v(20,0)
eta=50, Test (0,0)v(0,20)



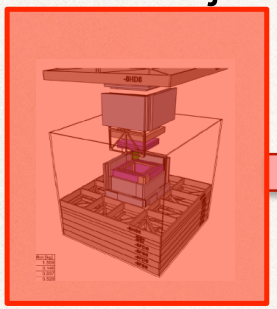
Results

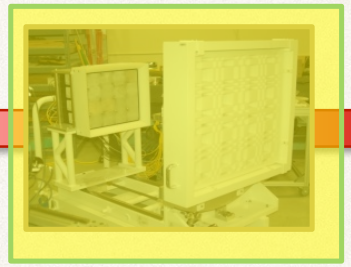

1
0.9
0.8
0.7
0.6
0.5
AUC
0
1000
2000
3000
4000
5000
Mean Signal Counts
eta=0, Test (0,0)v(20,20)
eta=50, Test (0,0)v(20,20)
eta=50, Test (0,0)v(20,0)
eta=50, Test (0,0)v(0,20)
eta=5-,Test(0,0)v(10,0)

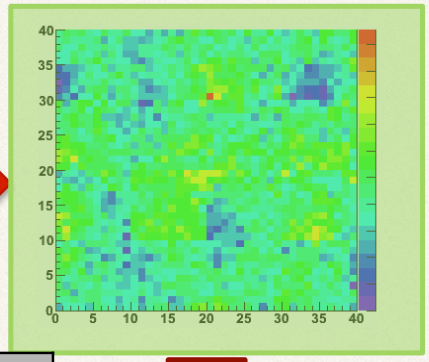


Solution 3

Trusted object







Hypothetical observer stores info sufficient for confirmation but not sensitive

LEGEND	
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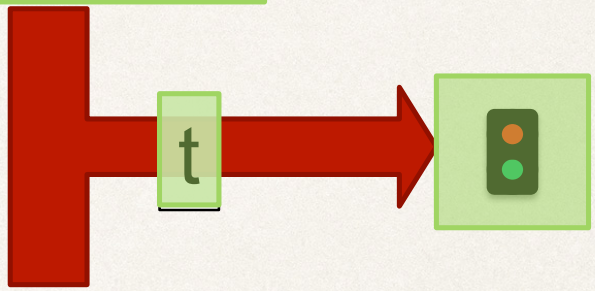
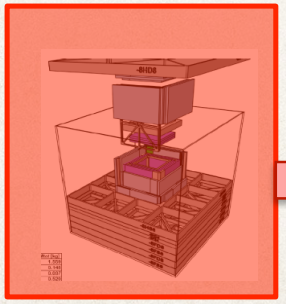
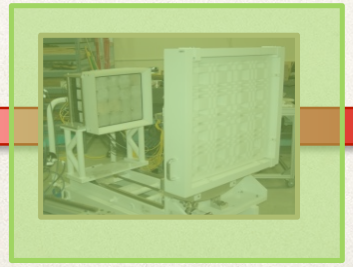


Tested object





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

Data not aggregated

Summary

- Imaging without images
- Nuisance parameters are key
- Generate decision models that contain no sensitive information

Key questions

- How well can we make decisions with only non-sensitive data?
- Can the imaging system itself acquire non-sensitive data?
  - As long as the detector measures sensitive data, we still require an information barrier. We have simply pushed that barrier further back.
- How well can we account for the many nuisance parameters present in the problem?

For more details…

Development of a Nonsensitive Template for a 2D Ring vs Square Classification Task

Christopher MacGahan, Matthew Kupinski, Erik Brubaker, Nathan Hilton, Peter Marleau

Wednesday 11:20-11:40
Session F: Nonproliferation and Arms Control: Treaty Verification
Marquis Ballroom A

Questions?