SAND2020-2949PE

Adaptive Imaging: Gimmick or Godsend?

MTV Workshop, 2020

March 10th, 2020

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Introduction and Motivation

Disarmament Verification

- Count warheads as opposed to delivery vehicles (upgrading New START)
- Verify SNM is separated from high explosives

Google Maps. (2018). 32.1502366, -110.821673

Treaty Verification

- Verify ICBMs are not carrying MIRVs
- START II style treaty

https://en.wikipedia.org/wiki/Multiple_independently_targetable_reentry_vehicle

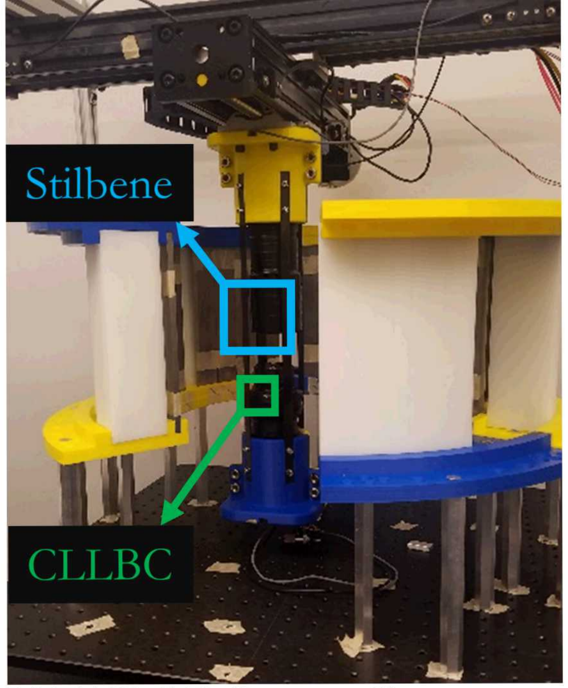
Nuclear Safeguards

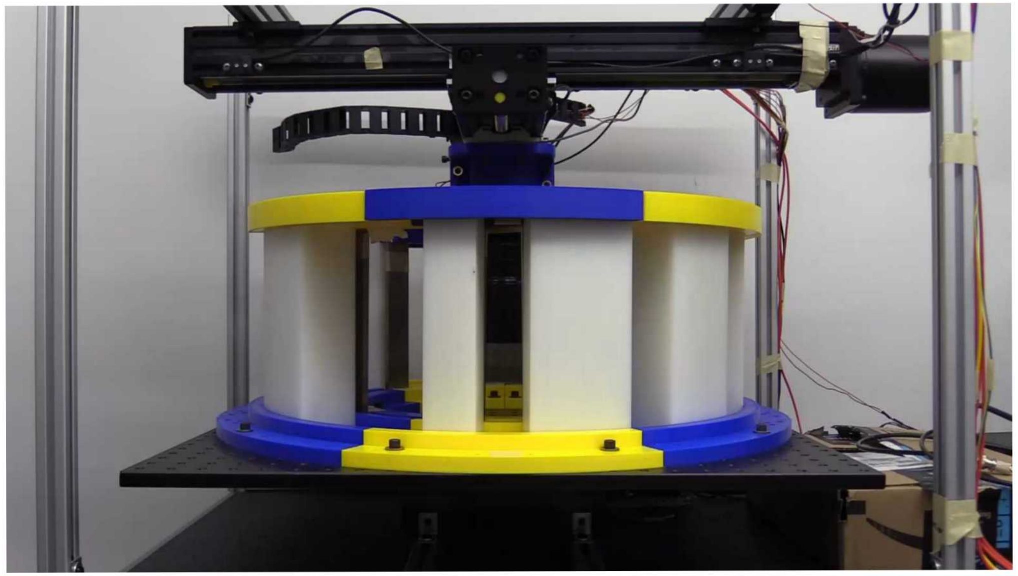
- Continuous surveillance and accounting of sources within a storage vault or vessel
- Search for undeclared sources in an access restricted setting

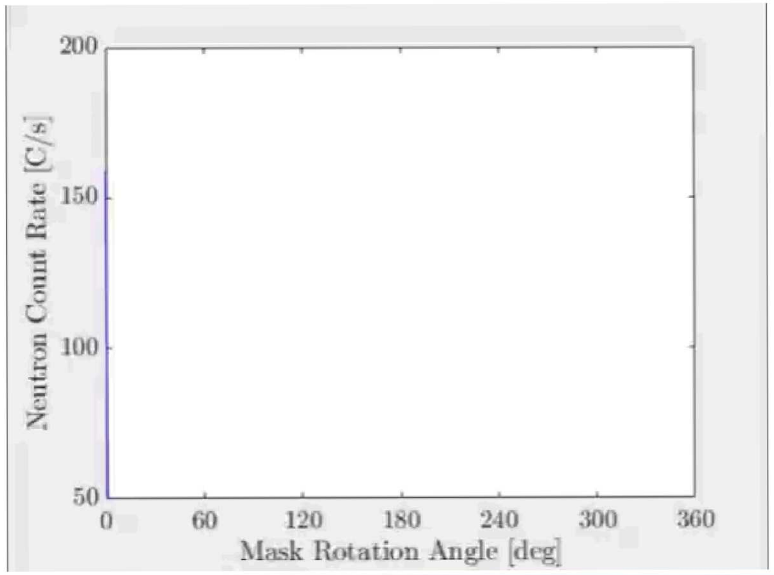
Monzano Alarm and Nuclear Material Consolidation Project

Cylindrical, Time-Encoded Imaging

- A detector is placed in the interior of a cylindrical mask with open and closed elements
- As the mask rotates, the count rate observed by the detector is modulated in time
- Temporal analog to spatial coded aperture





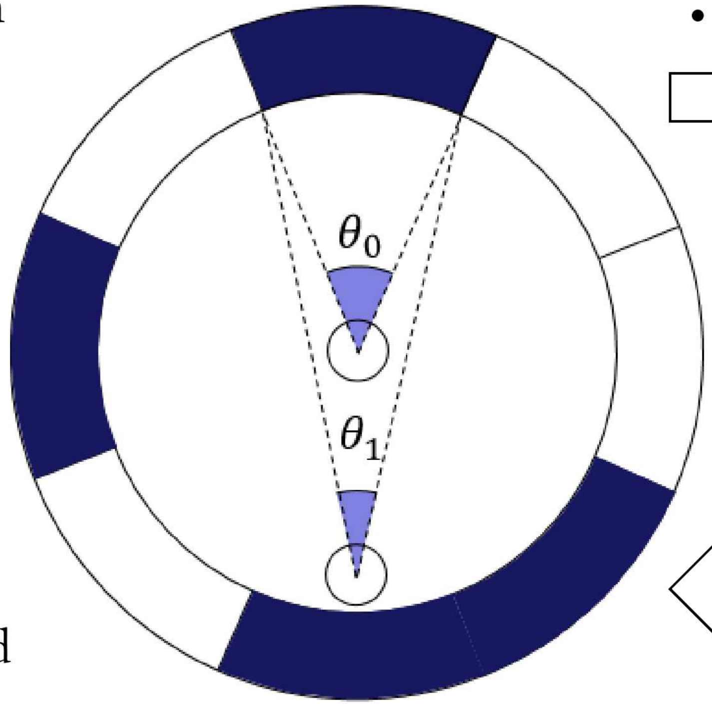


MATADOR System Parameters

Detector	2” Stilbene & 1” CLLBC
Mask Pattern	URA-35
Inner mask radius	17.5 cm
Tungsten thickness	0.635 cm
HDPE thickness	6 cm
Outer mask radius	26 cm

Adaptive Imaging

- Leverage collected data to inform where to collect next set of data
  - The detector hangs off of an x-y linear stage allowing it to move to any position inside the mask.
  - The mask position is controlled by stepper motor
  - Variable dwell times and rotation speeds
- Benefits
  - Tailor the system response matrix to achieve a goal
    - Angular resolution, source detection, quantification imaging
  - Some control over quality of measurements
  - Larger number of measurements instead of better statistics
    - Diminishing returns for each additional count



Experimental Data
- Raw digitized pulses

Reconstruction

Update Algorithm
- Defined task

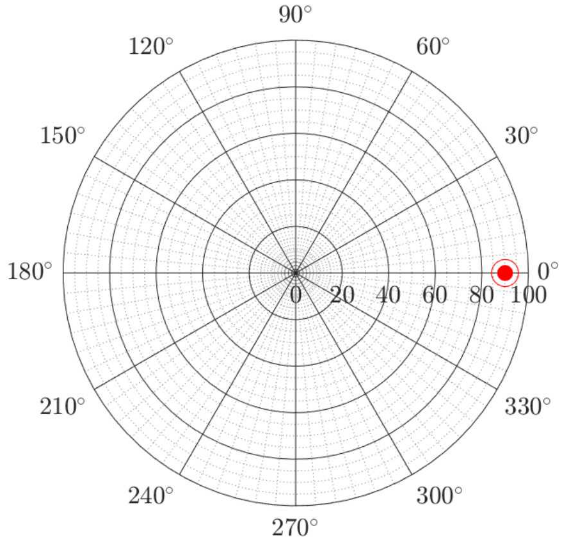
Adaptive Imaging
- Detector position
- Mask rotation

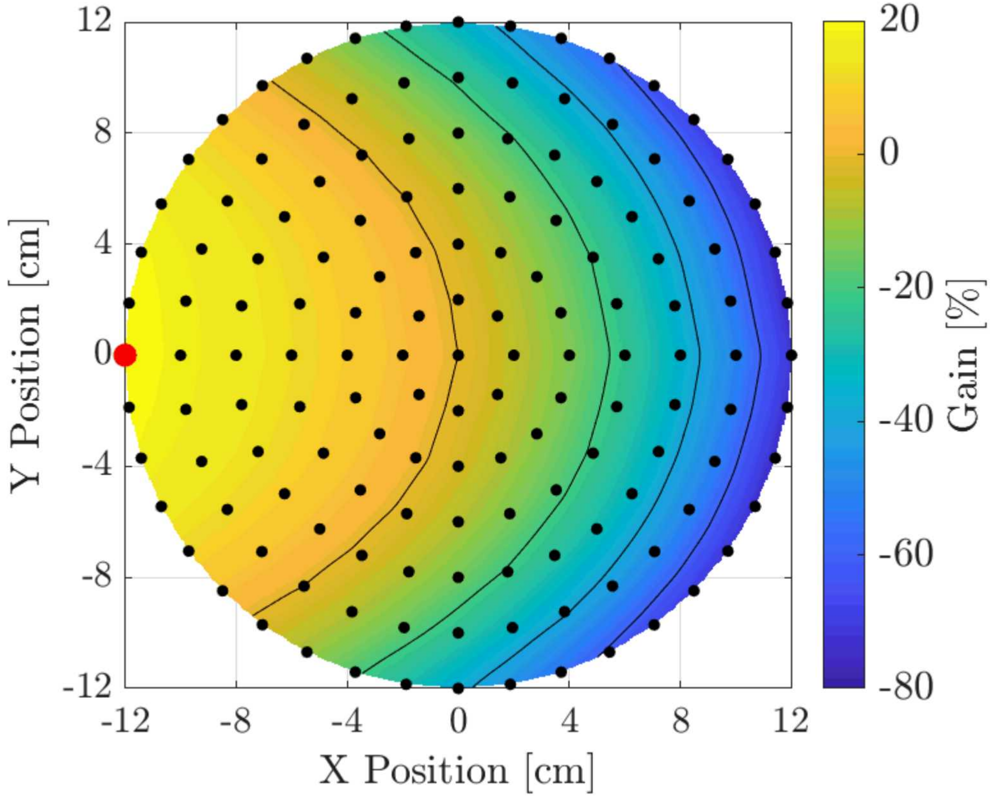
Focus

- What is the best that adaptive imaging can do compared to the conventional c-TEI?
- Task: Achieve best angular resolution – localization of a source
- Adaptive: Only concerned with adaptive detector movements – constant, full revolutions
  - Best detector position
  - Two best detector positions – optimize over time spent per position
- Scenarios: Only point sources
  - One point source, two point sources close together, two point sources distributed in the FOV, intensity differences
  - Sources at 90 cm away, S:B is 1:1
  - Neutrons only (> 40 keVee)
- Clairvoyant system: we know all source positions, intensities, and background.
- No cost to moving the detector.

One Point Source CRLB Predictions

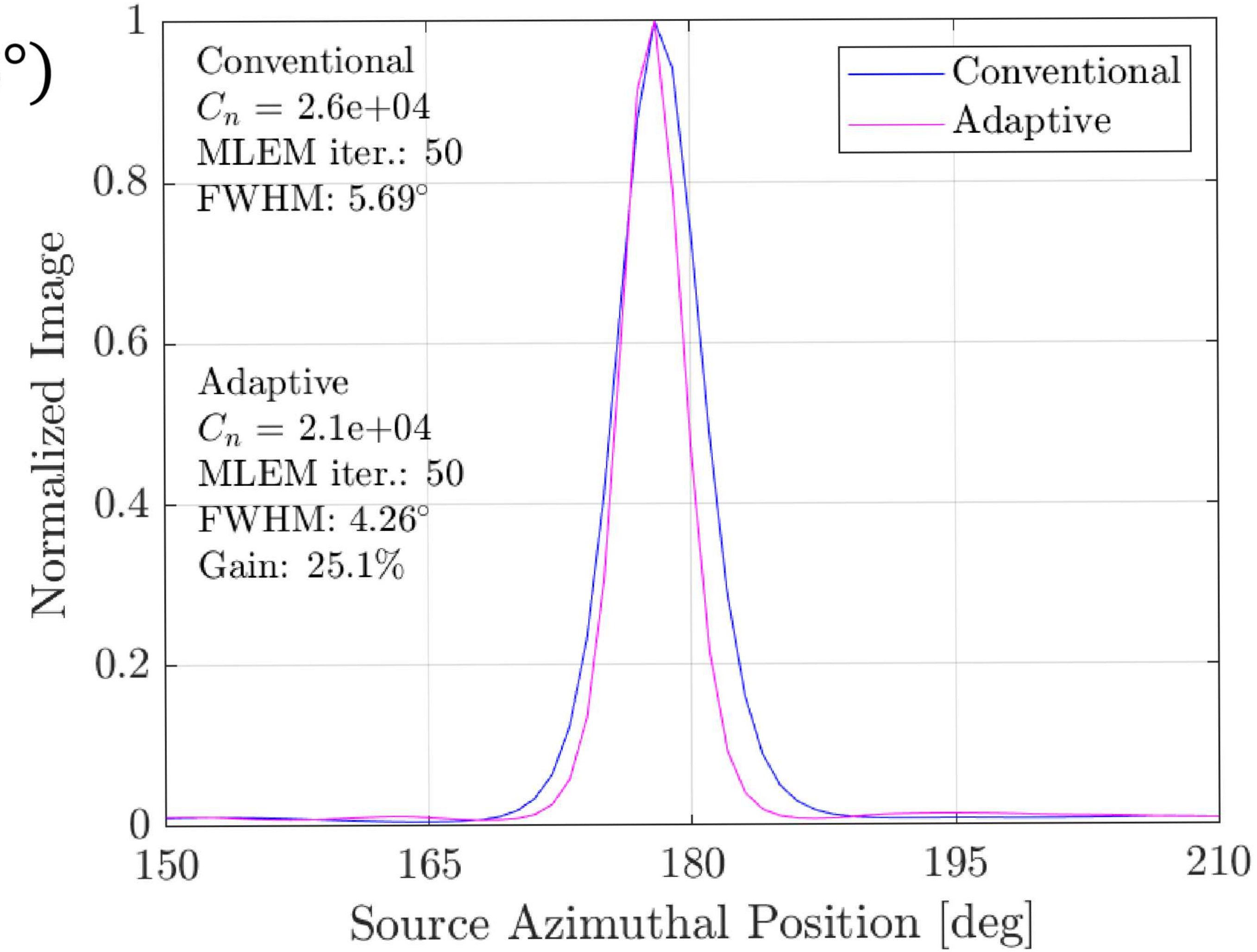
- Known point source at $(90\text{cm}, 0°)$
- $Gain = 1 - \frac{\sigma_{\phi,D(x,y)}}{\sigma_{\phi,D(0,0)}}$
- $\sigma_{\phi,D(x,y)}$:sqrt of CRLB of ϕ for a detector at $D(x,y)$





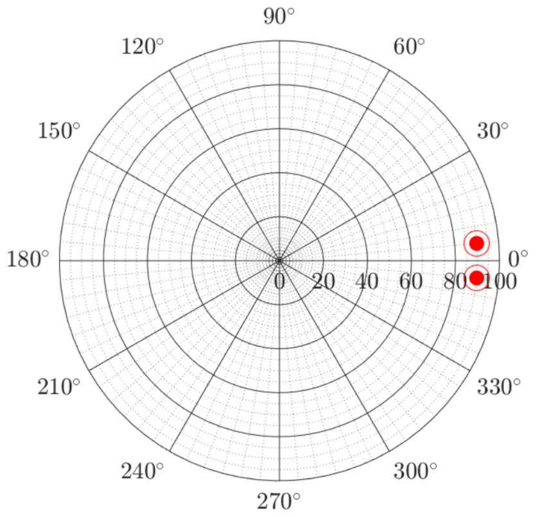
One Point Source MLEM Image

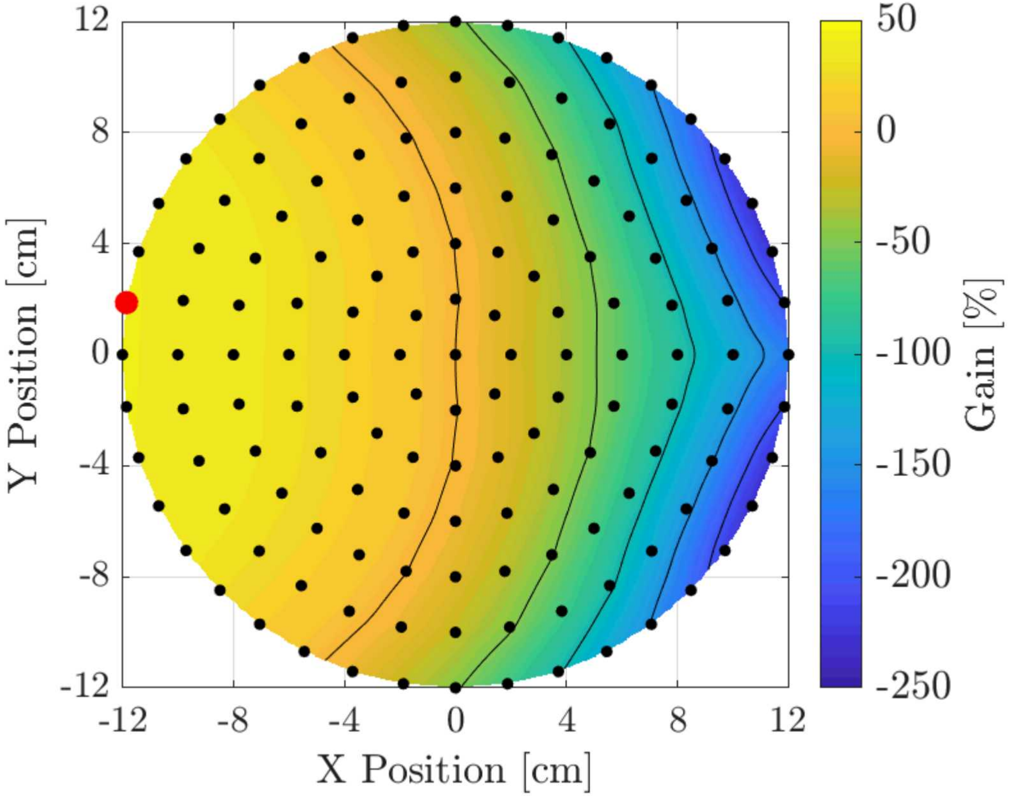
- Source: 1.85 mCi Cf-252 at (90cm, 178°)
  - Subsampled to 960 μCi
  - Total measurement time: 90s
- Expected S:B is 1:1
- Fast neutrons only
  - > 40 keVee
  - 99.9999% prob. of neutron
- 1 deg fidelity for response map
- Terminated by user when NRMSE plateaus



Two Equal Intensity Point Sources CRLB Prediction

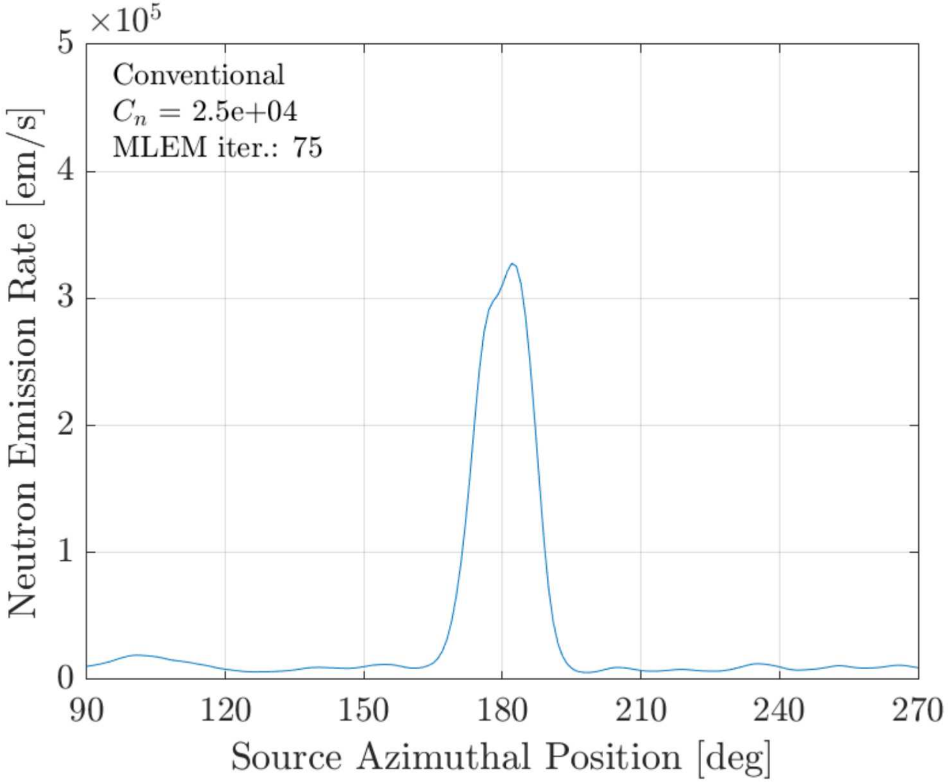
- Known point source at $(90\text{cm}, 5°)$ and $(90\text{cm}, 355°)$
- $Gain = 1 - \frac{U(\boldsymbol{\sigma}_{\phi,D(x,y)})}{U(\boldsymbol{\sigma}_{\phi,D(0,0)})}$
- $U(\boldsymbol{\sigma}_{\phi,D(x,y)}) = \sqrt{\sum_{s=1}^{N_s} \sigma^2_{\phi_j,D(x,y)}}$

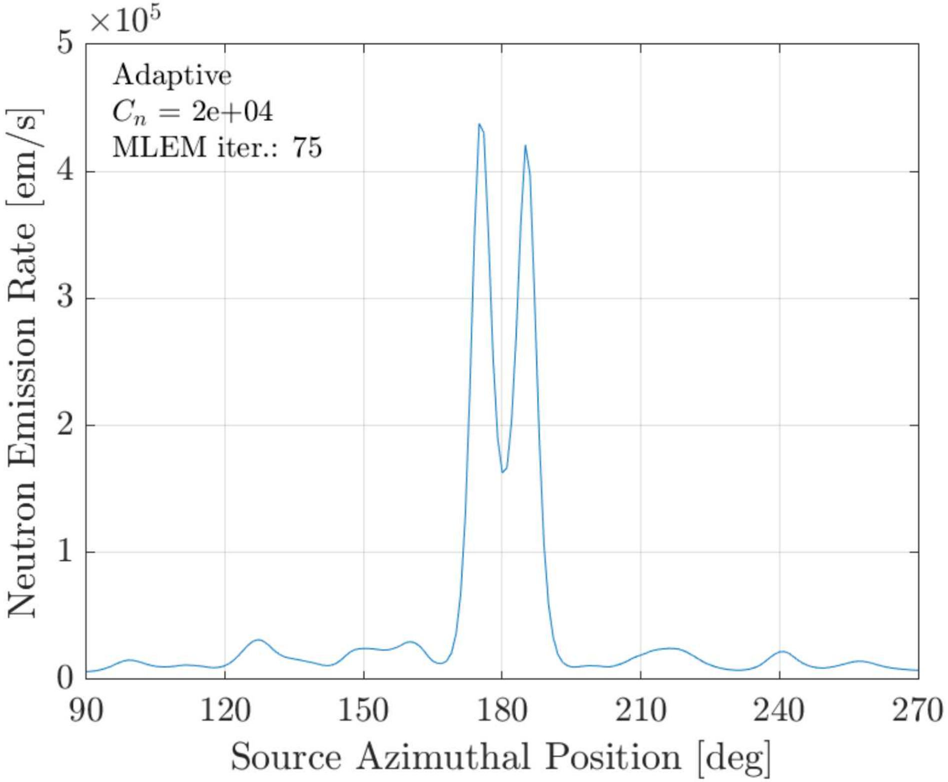




Two Equal Intensity Point Sources MLEM Image

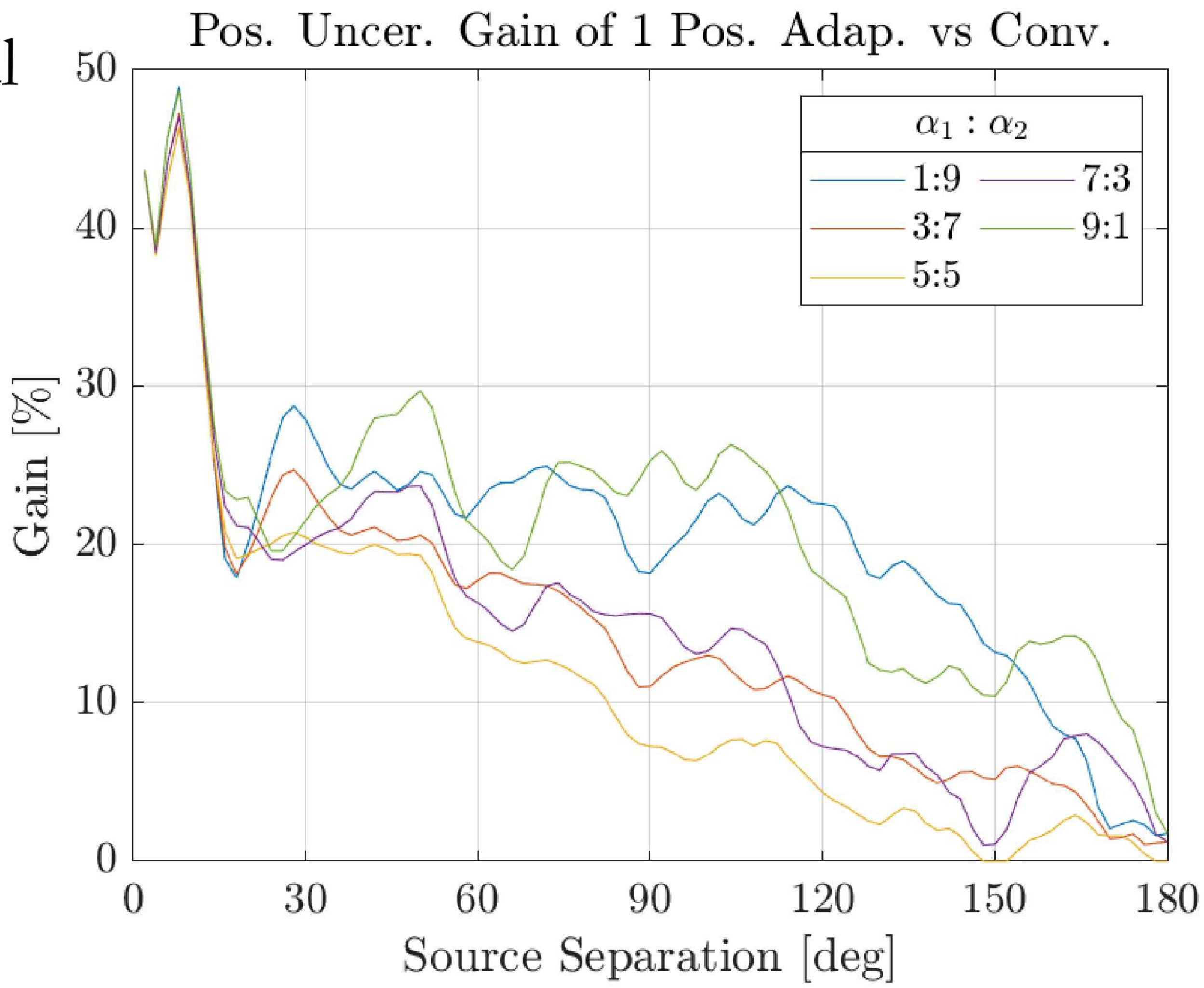
- Source: Two 1.85 mCi Cf-252 at (90cm, 175°) & (90cm, 175°)
  - Subsampled to 480μCi each - Total measurement time: 90s





Two Point Source CRLB Predictions

- Best one detector position vs conventional
- Various source separations
- Various intensity differences
- If sources are localized, gain is large.
- If sources are within 100°, relative intensity matters.
- If sources are distributed, gain is small.
- For fast neutrons, 90 cm away
  - S:B is 1:1



Conclusions and Impact

- Adaptive detector movements can provide some angular resolution gain BUT
  - If sources are localized, gain is large – up to 50% better angular resolution
  - If sources are within 100°, relative intensity matters – 10-30%
  - If sources are distributed, gain is small < 10%
- These results are all conditional on sources being 90 cm away…
- Great connection with Dr. Marleau at SNL
  - Work continues on adaptive imaging
- New project on a handheld neutron c-TEI system

Acknowledgements

- This research was performed under appointment to the Nuclear Nonproliferation International Safeguards Fellowship Program sponsored by the National Nuclear Security Administration's Office of International Nuclear Safeguards (NA-241).
- This work was funded by the Consortium for Monitoring, Technology, and Verification under Department of Energy National Nuclear Security Administration award number DE-NA0003920
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