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Demonstrating Adaptive Imaging on Complex Source Scenes made with Special Nuclear Material

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Motivation

Nuclear Non-proliferation and 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

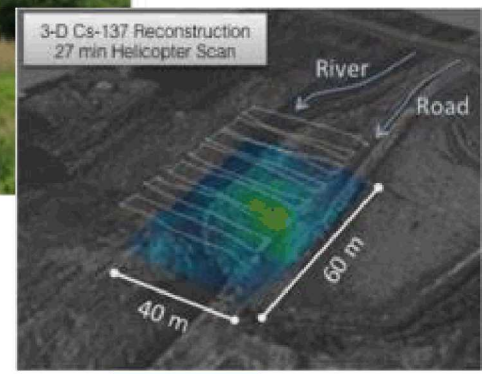
Treaty and Disarmament Verification

- Verify Russian missiles do not have multiple warheads
- Verify SNM is separated from high explosives

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

Homeland Security and Emergency Response

- Search for lost sources or black box scenarios
- Dose/contour mapping post detonation of an RDD



Vetter, "Multi-sensor radiation detection, imaging, and fusion," NIMA, 2016.

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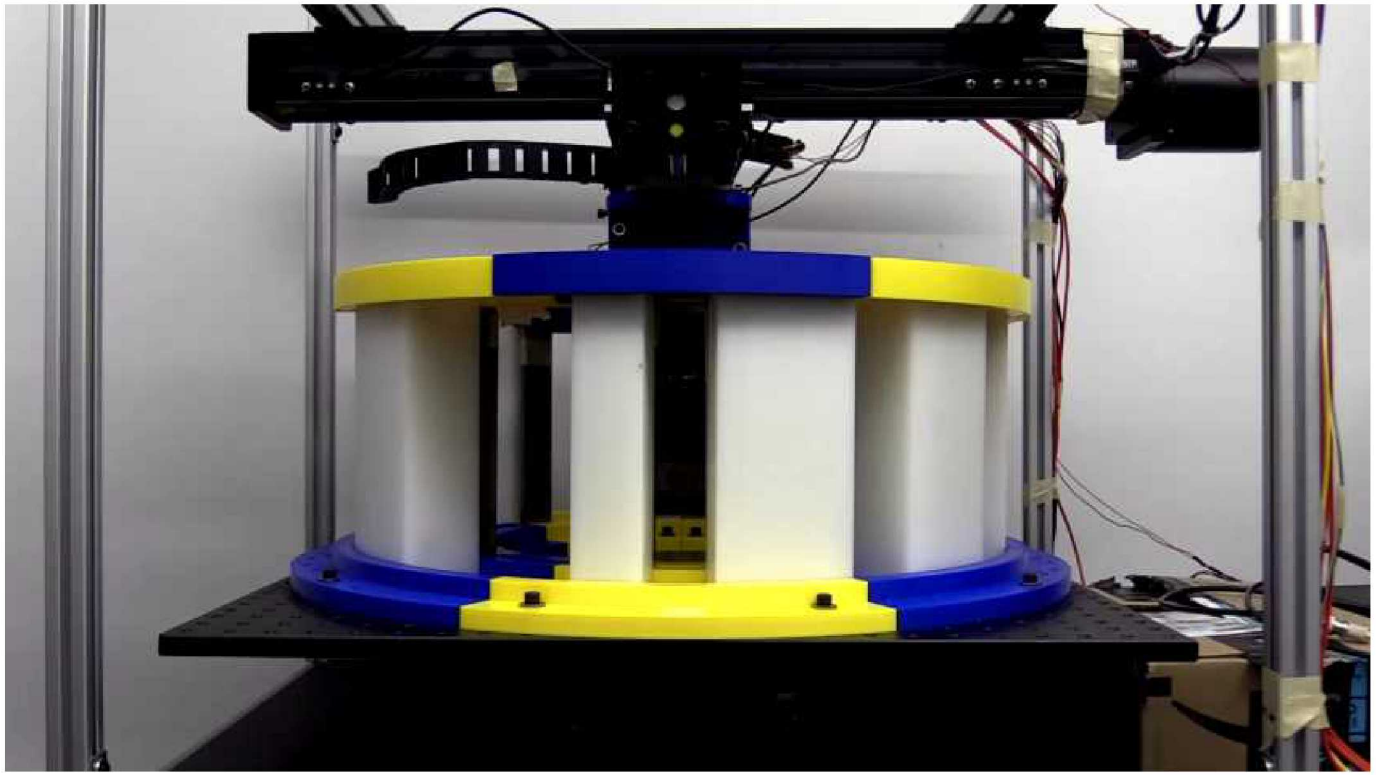
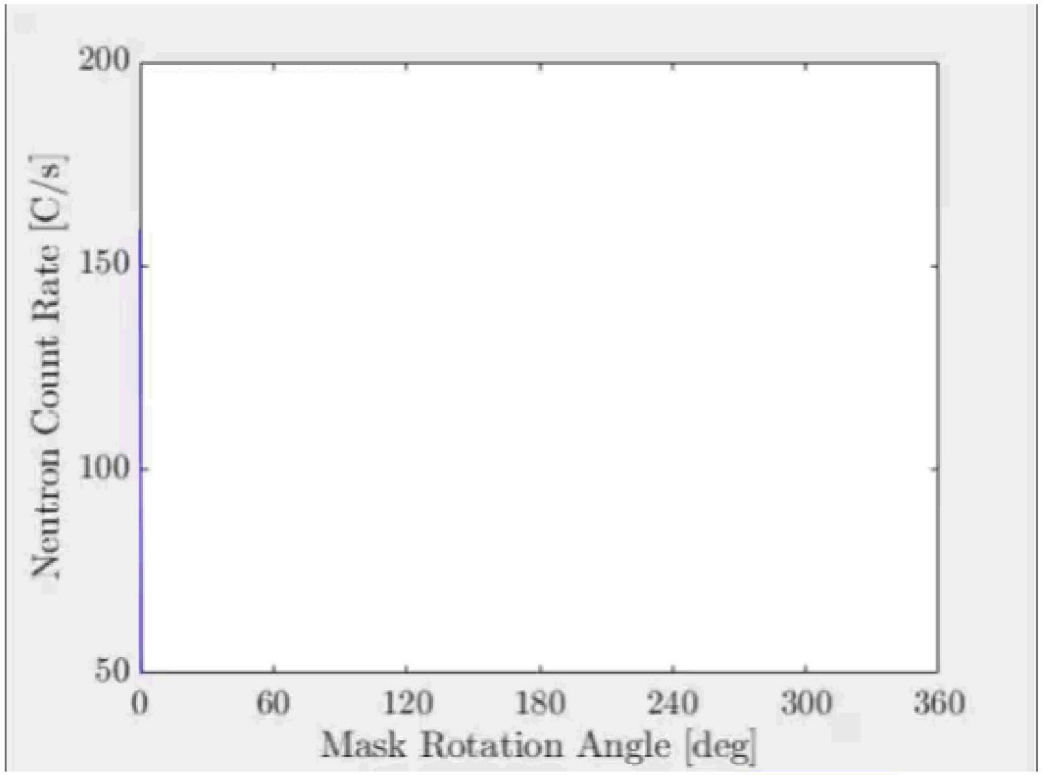
Cylindrical, Time-Encoded Imaging (c-TEI)

- Detector on the interior of a rotating, coded mask
  - Particles can freely travel through open elements but are attenuated by closed elements
  - Recorded data and information on the mask and orientation enables imaging





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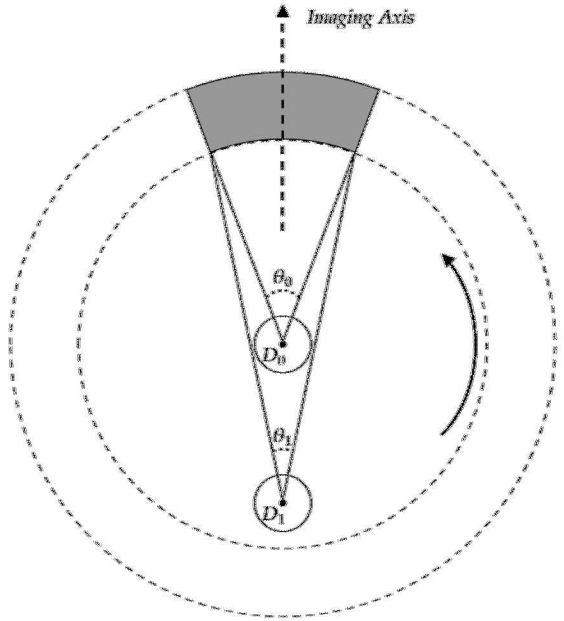
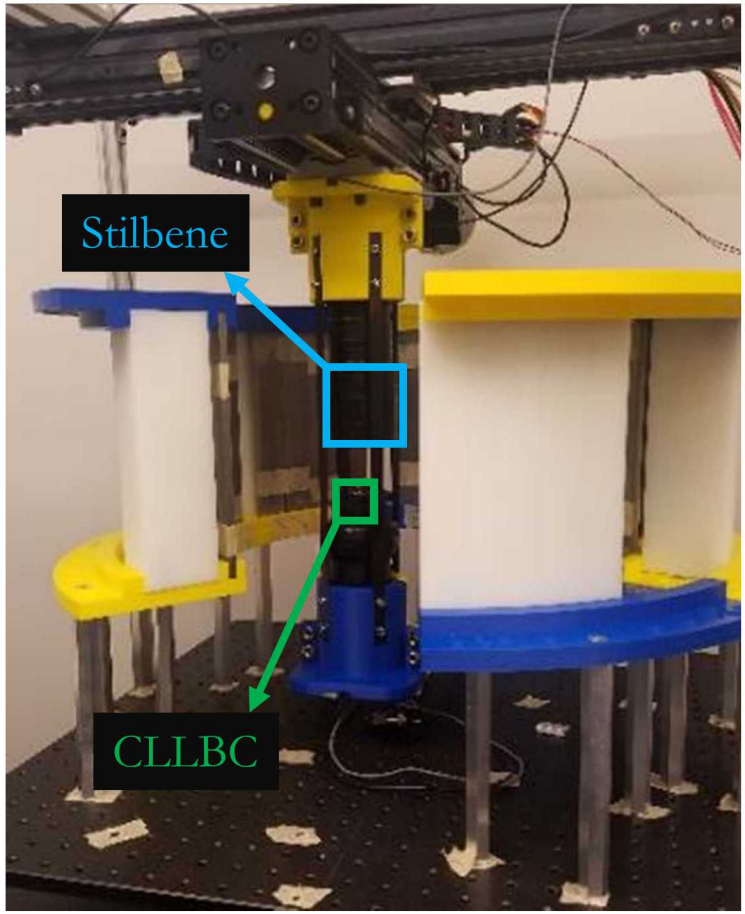
Adaptive Imaging with a c-TEI System

- Leverage collected data to decide where/how to collect more data
  - Scenario specific adaptation based on specified task
  - Control over quality of measurements
  - More unique information vs better statistics



MATADOR System Parameters

Detector	2” Stilbene & 1” CLLBC
Mask Pattern	URA-35
Inner mask radius	17.5 cm
Detector Position	R: [0:12] cm
Tungsten thickness	0.635 cm
HDPE thickness	6 cm
Outer mask radius	26 cm



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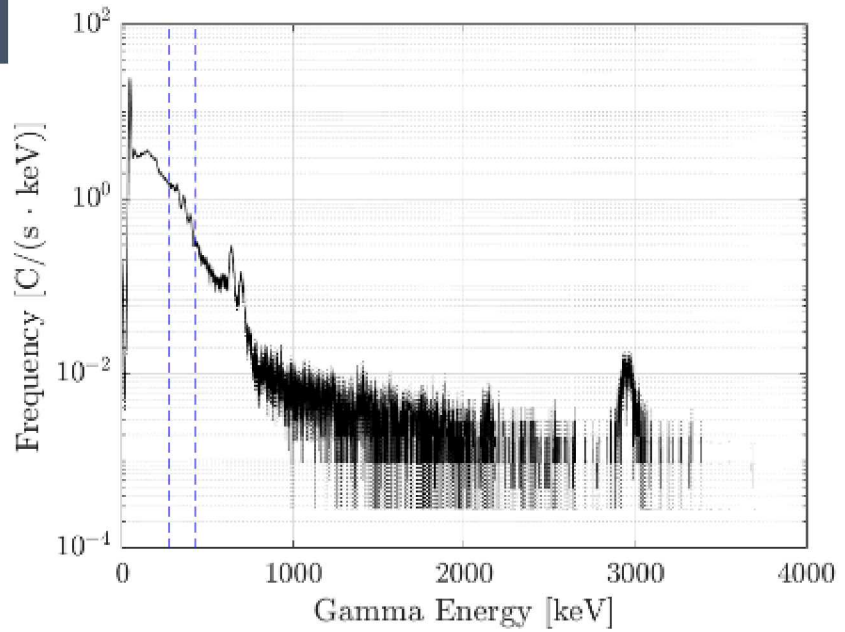
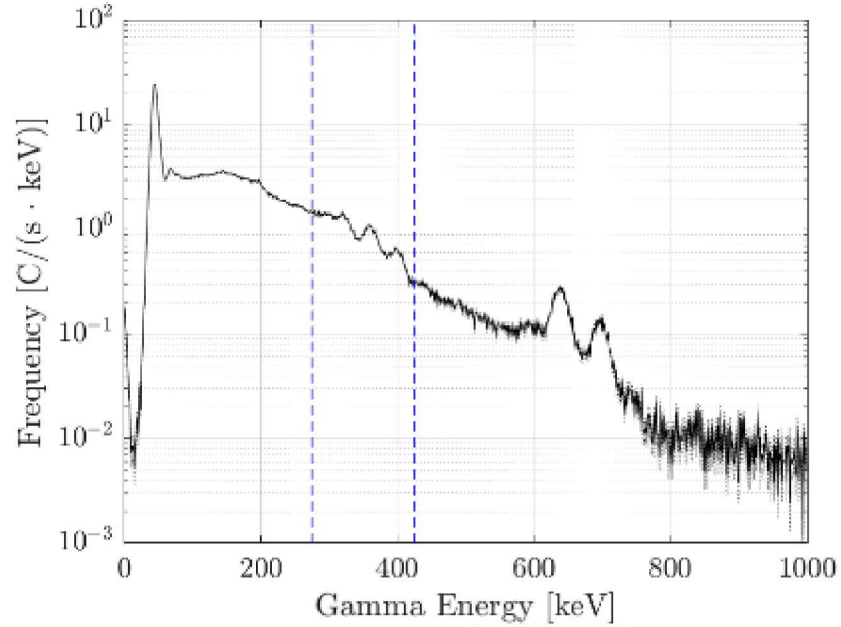
Demonstration: Complex Scenes

- Scenario: Reconstructing complex scenes made of special nuclear material (Pu-240 plates)
  - Gammas detected with 1” CLLBC only (275 - 425 keV)
- Conventional: detector centered, full revolutions
- Adaptive: detector movements only, no adaptive mask movements – uniform, full revolutions
  - User-selected detector positions – intuition
  - 10% of time at center, 90% time at user-selected
  - Data from many detector positions provides more unique information instead of better statistics
- Demonstration/preliminary work
  - Line Source
  - Split-Line Source
  - Multiple Source





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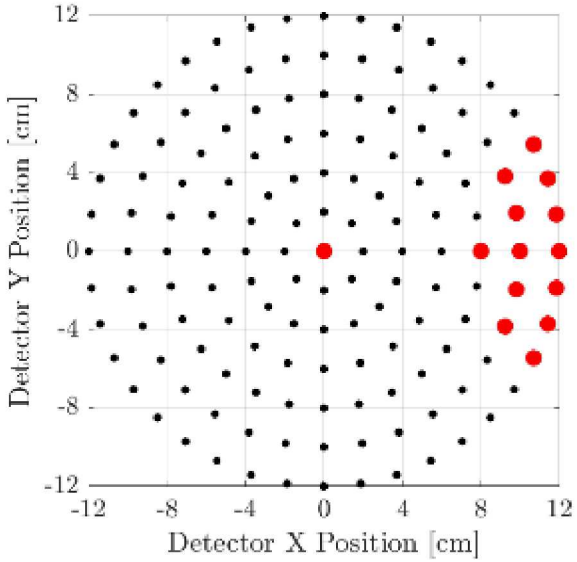
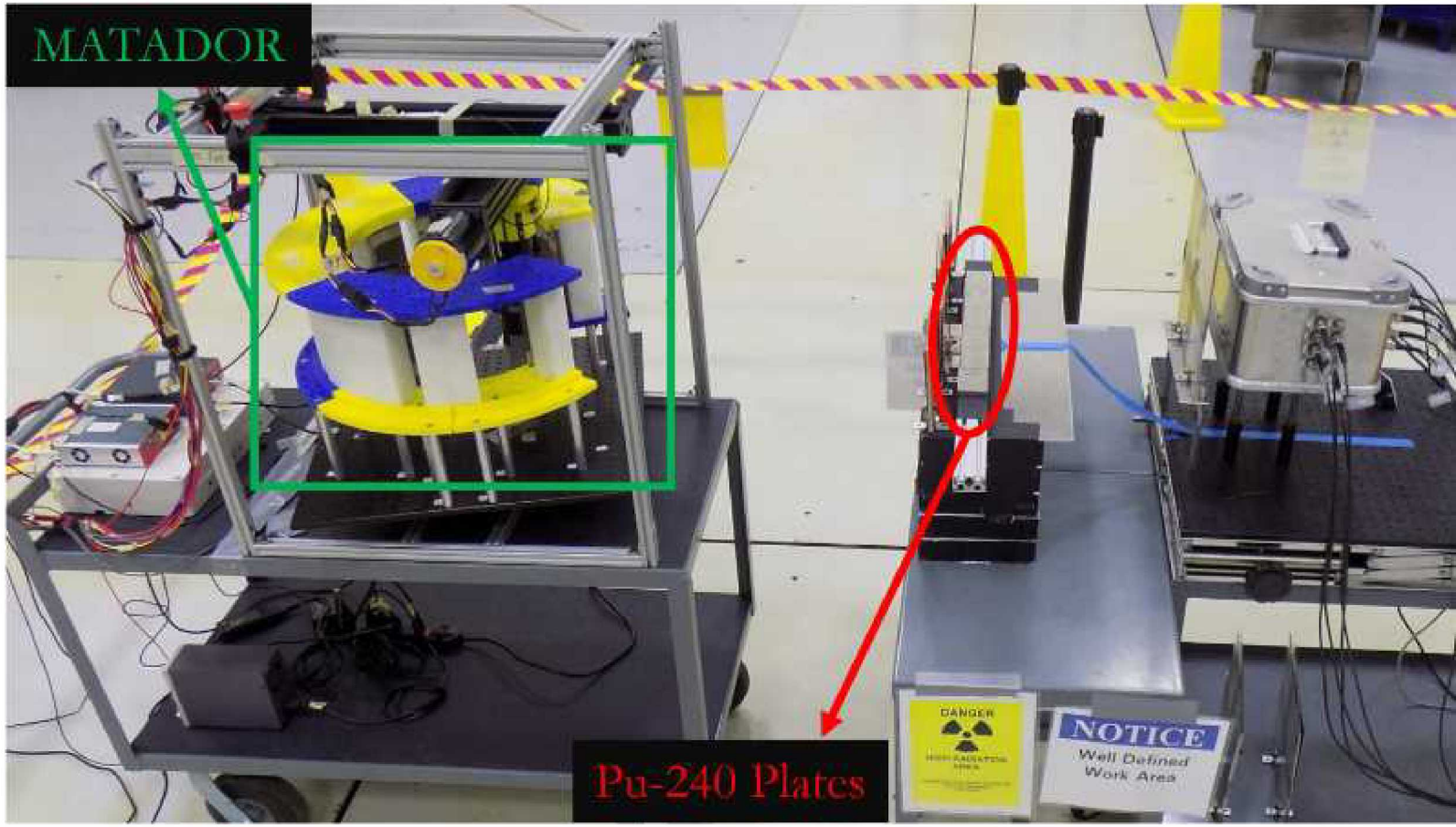
Line Source - Setup

- Line source is 28.5° wide and centered at $(90\text{cm}, 180°)$
- Composed of 6 stacks of 3 Pu-240 plates touching end to end
- Goal: show better uniformity and lower background noise
- For adaptive, collected data at:



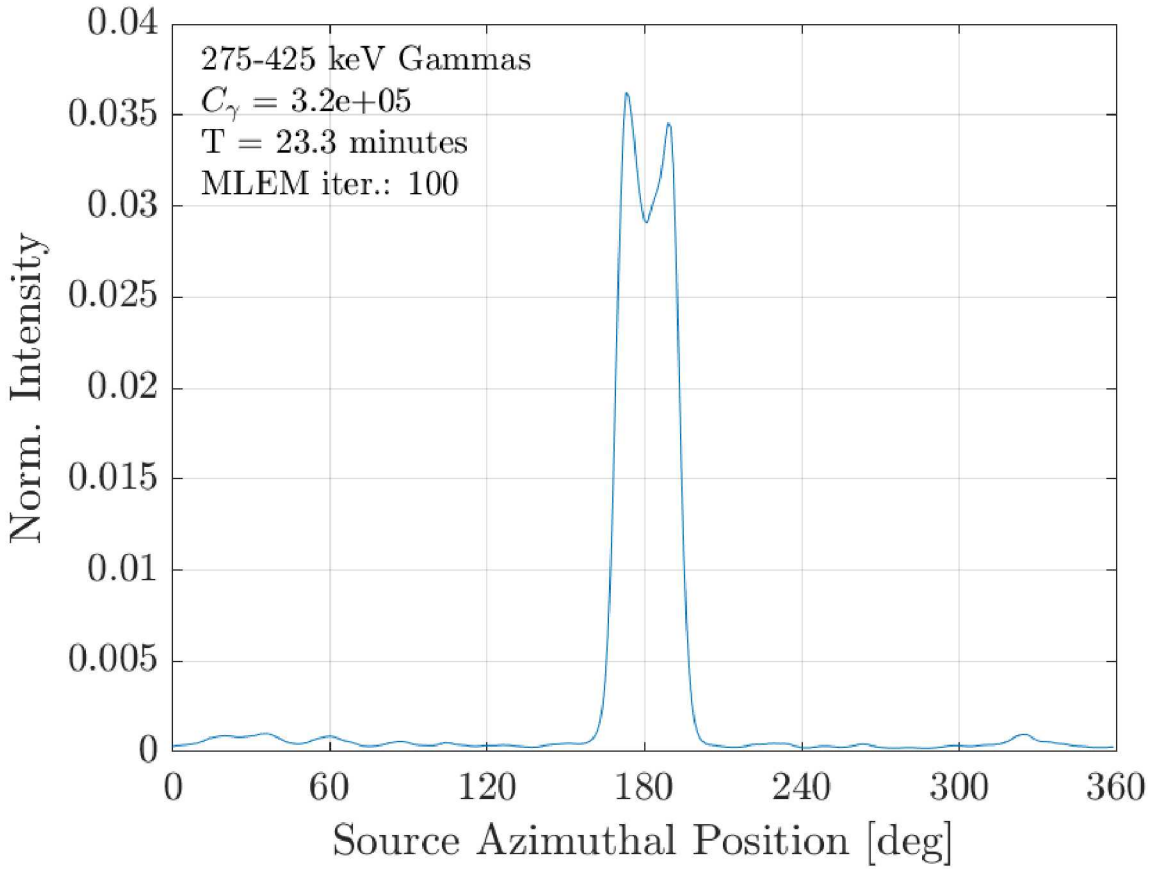


Line Source - Results

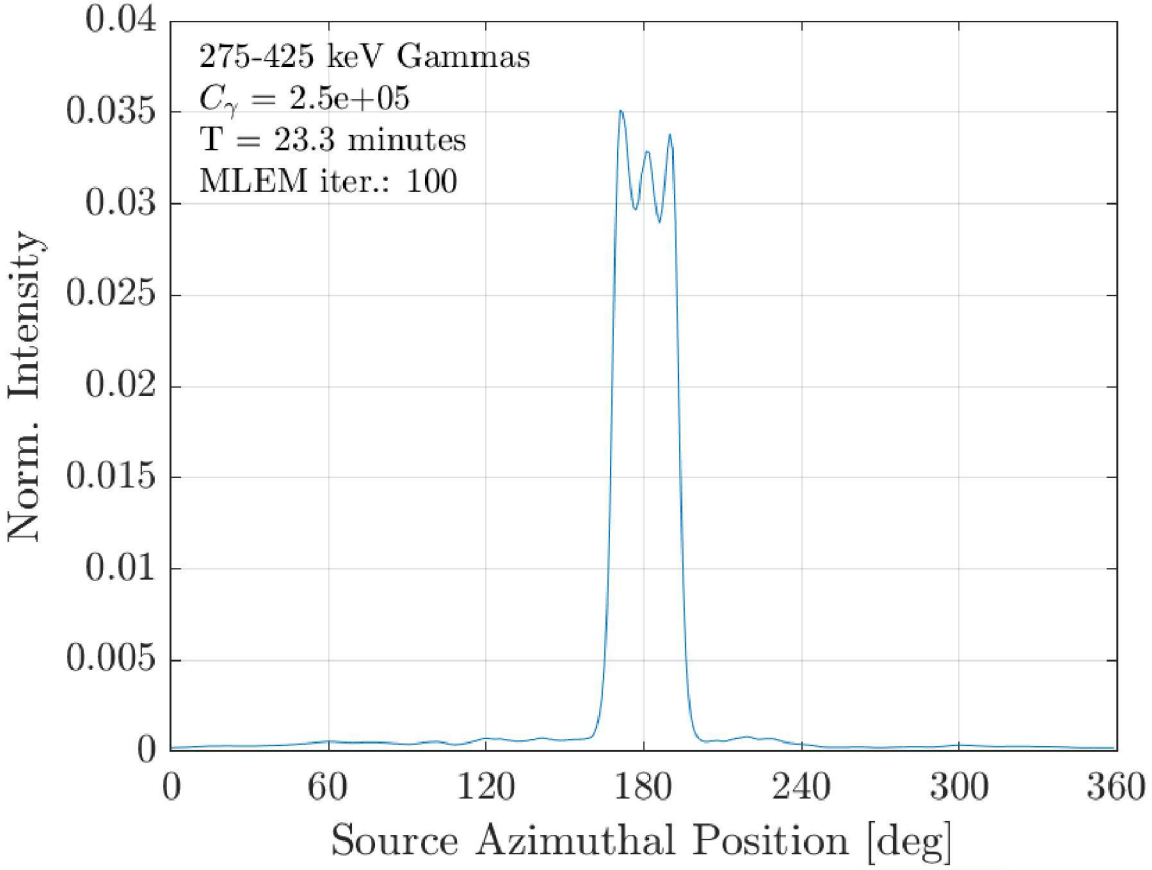
	Conventional	Adaptive
FWHM	25.8	26.5
Uniformity (10^{-3})	2.4	1.5
Noise (10^{-4})	2.2	1.1

- Adaptive reconstruction has 37.5% better uniformity and 50% less background noise

Conventional



Adaptive



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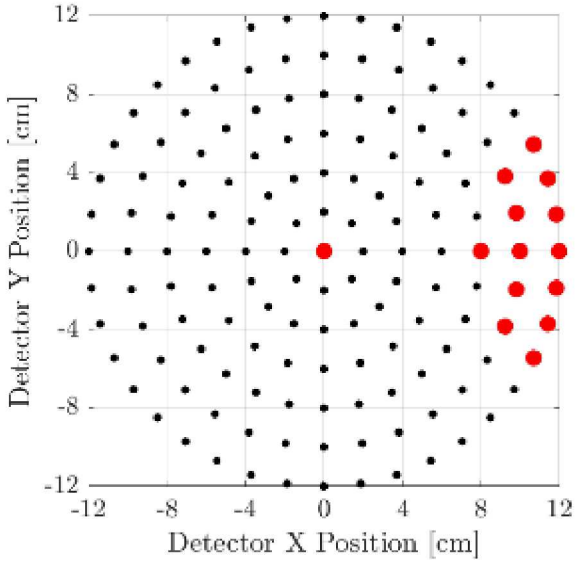
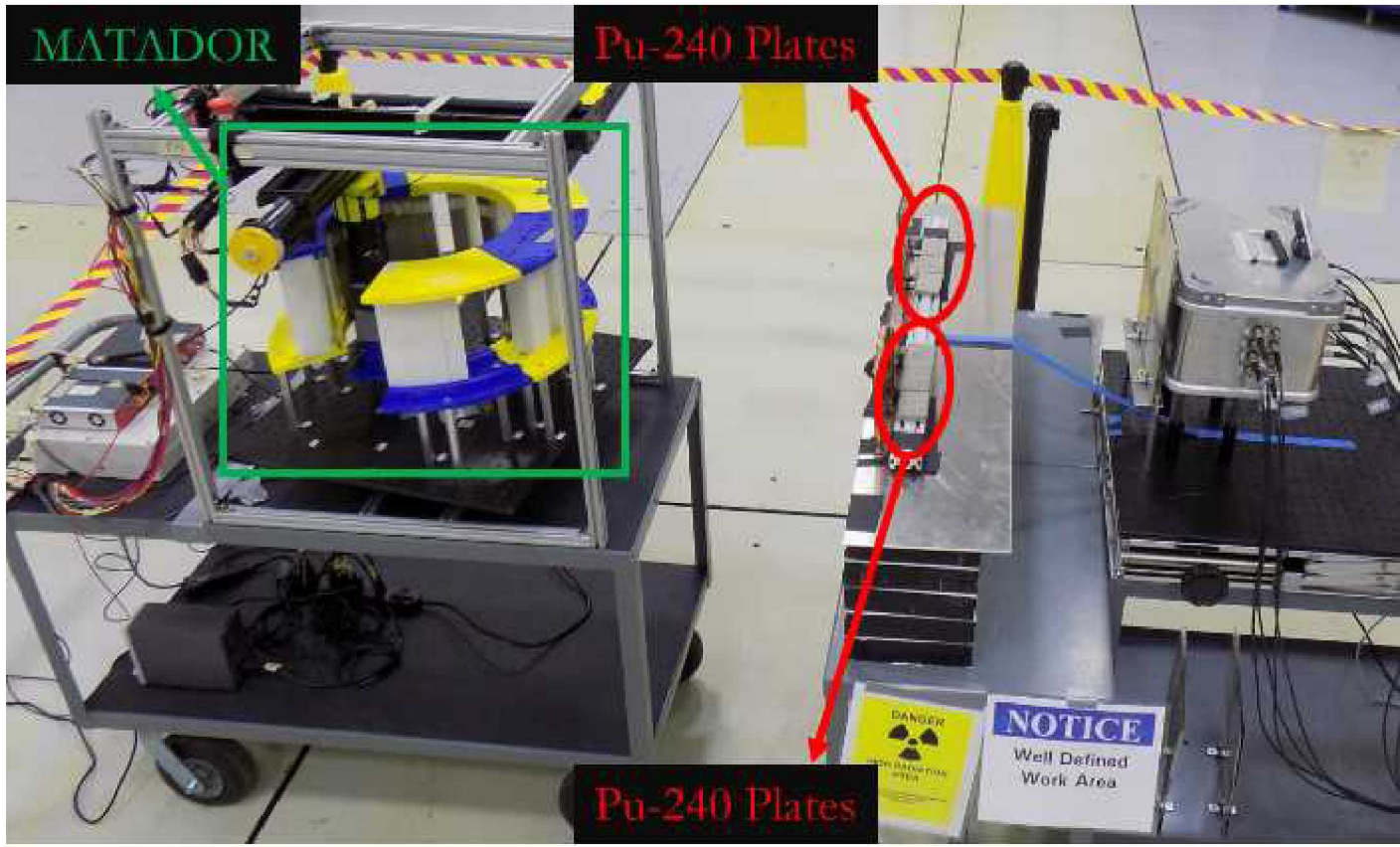
Split-Line Source - Setup

- Split-line source consists of two halves that are 13.7° wide separated by 12.7° (inside edge), and centered at **(90cm, 180°)**
- Each half is composed of 3 stacks of 3 Pu-240 plates touching end to end
- Goal: show better uniformity and lower background noise
- For adaptive, collected data at:



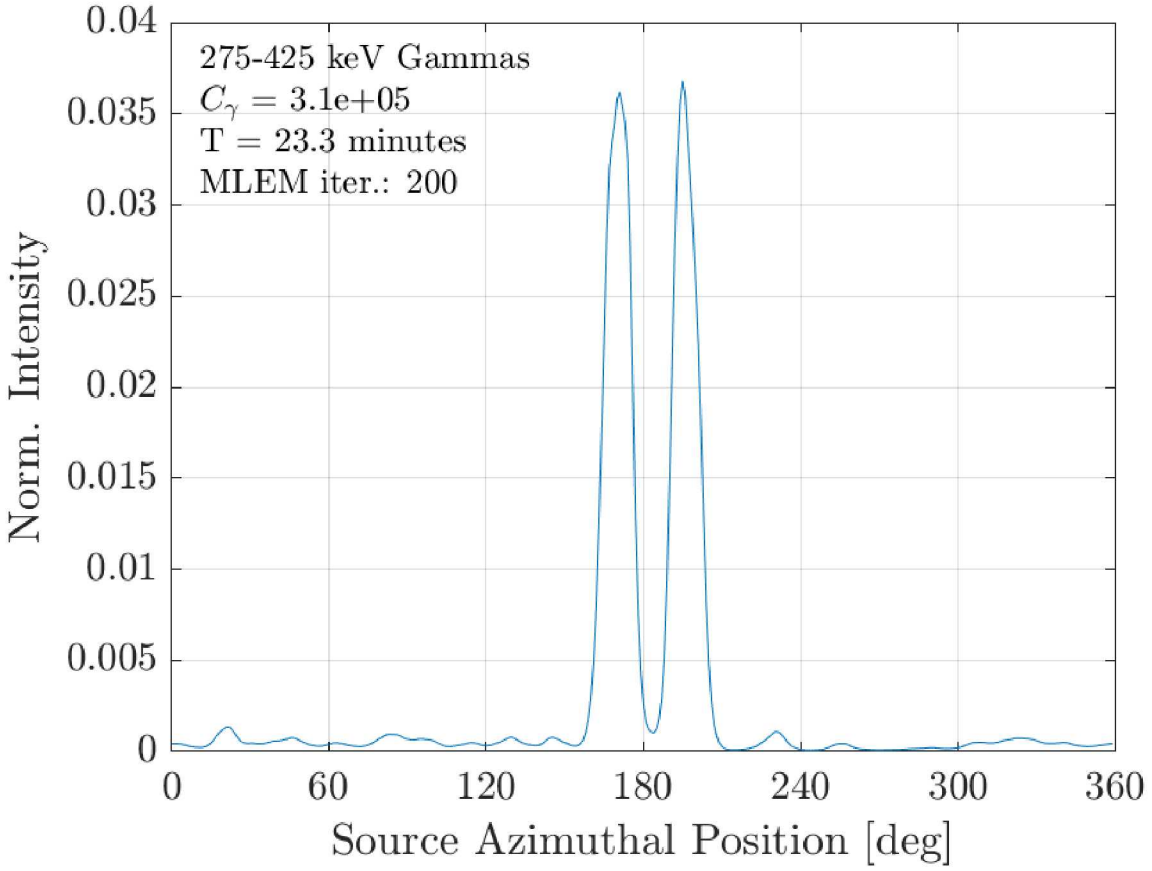


Split-Line Source - Results

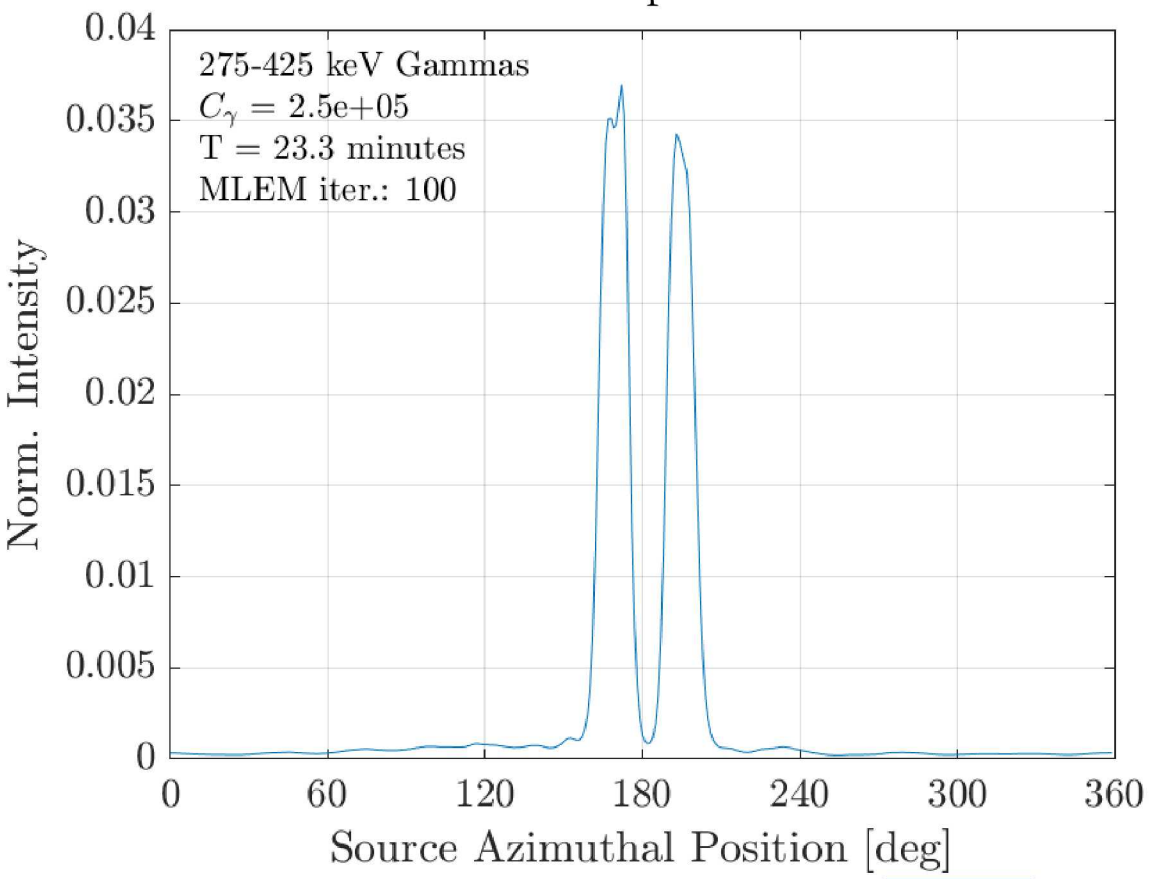
	Conventional	Adaptive
S_1 FWHM	12.5	12.5
S_2 FWHM	12.2	12.1
S_1 Uniformity (10^{-3})	2.5	1.9
S_2 Uniformity (10^{-3})	4.0	2.9
Noise (10^{-4})	2.4	1.5

- Adaptive reconstruction has 25% better uniformity and 37.5% less background noise

Conventional



Adaptive



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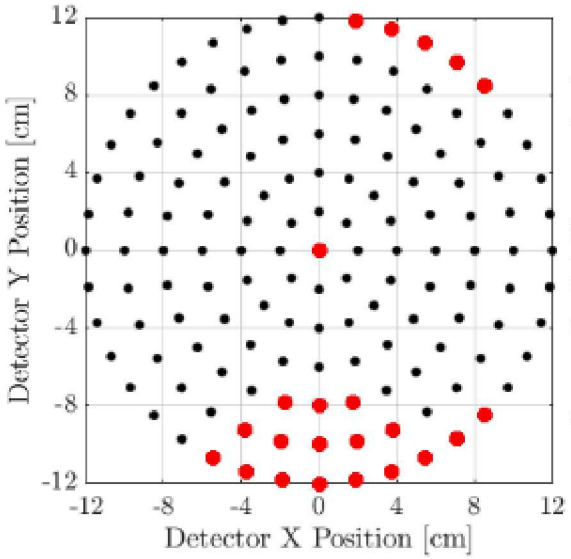
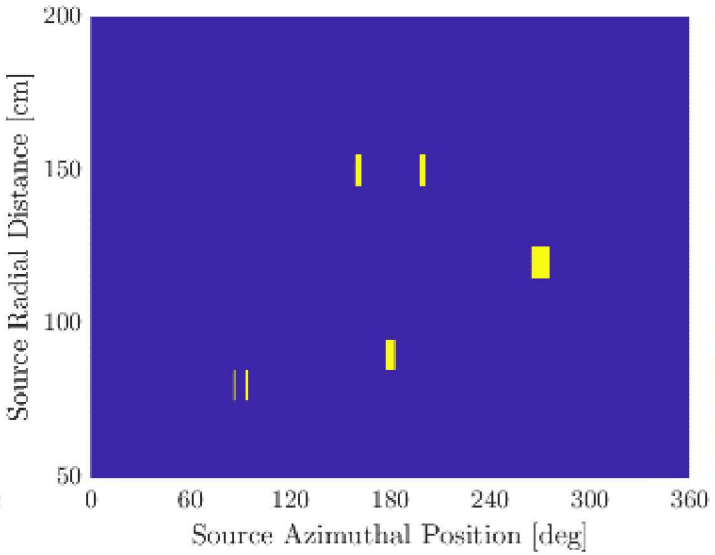
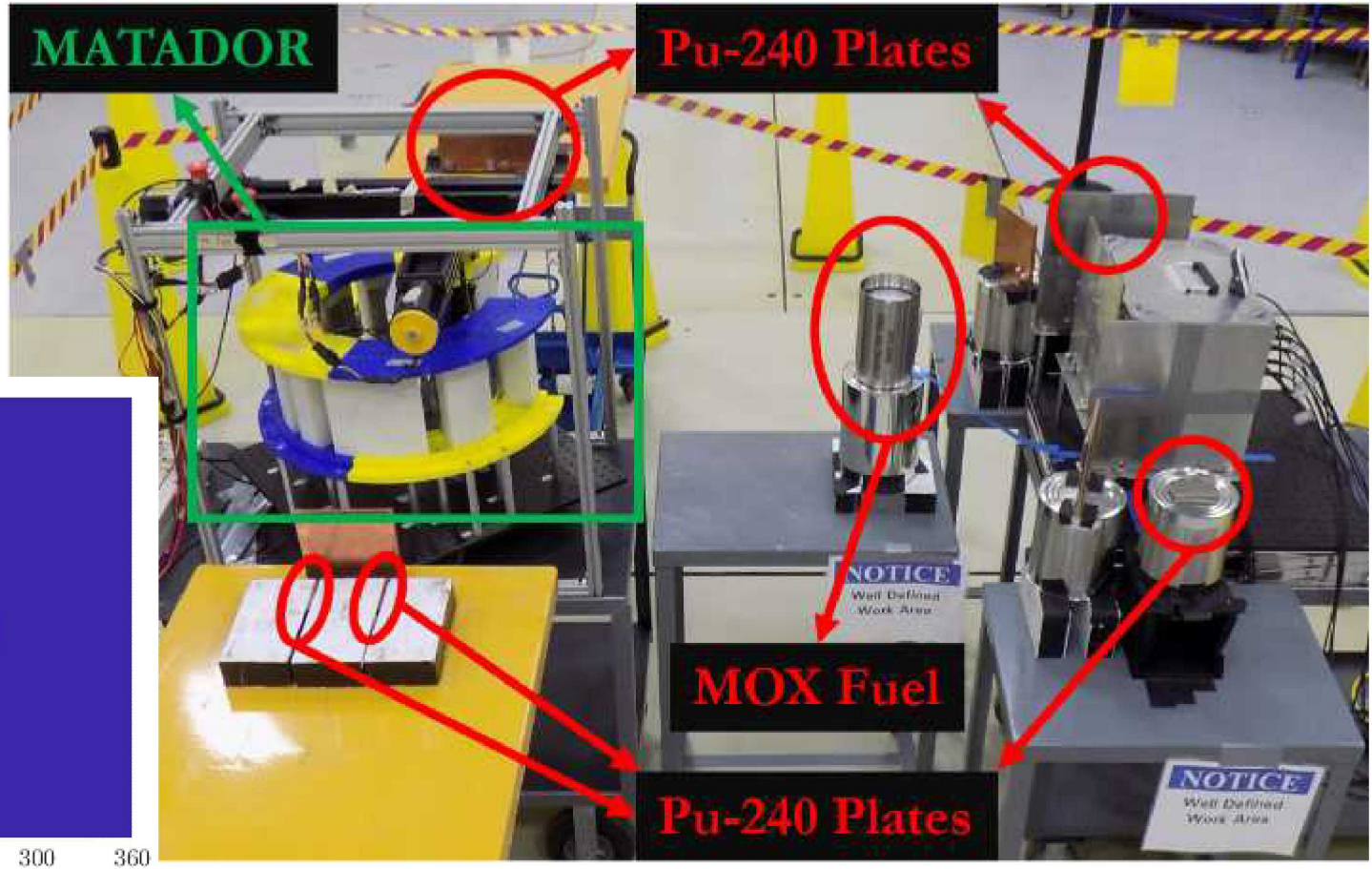
Multiple Source - Setup

- Complex arrangement of sources: point sources, two point sources close together, extended sources, different radial distances, and large activity differences
- Goal: show better angular resolution and 2D image reconstruction
- For adaptive, collected data at:

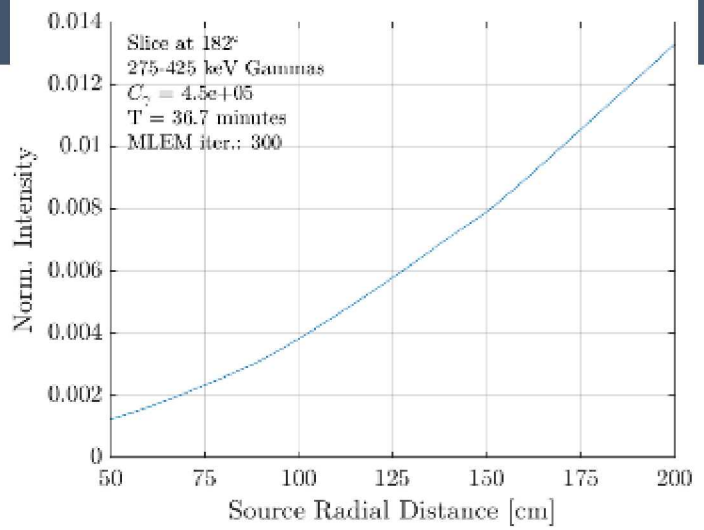


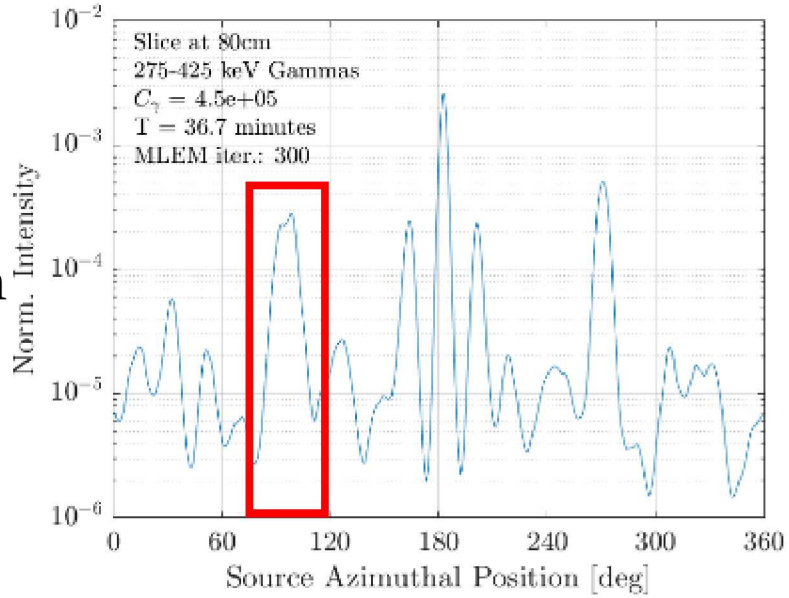


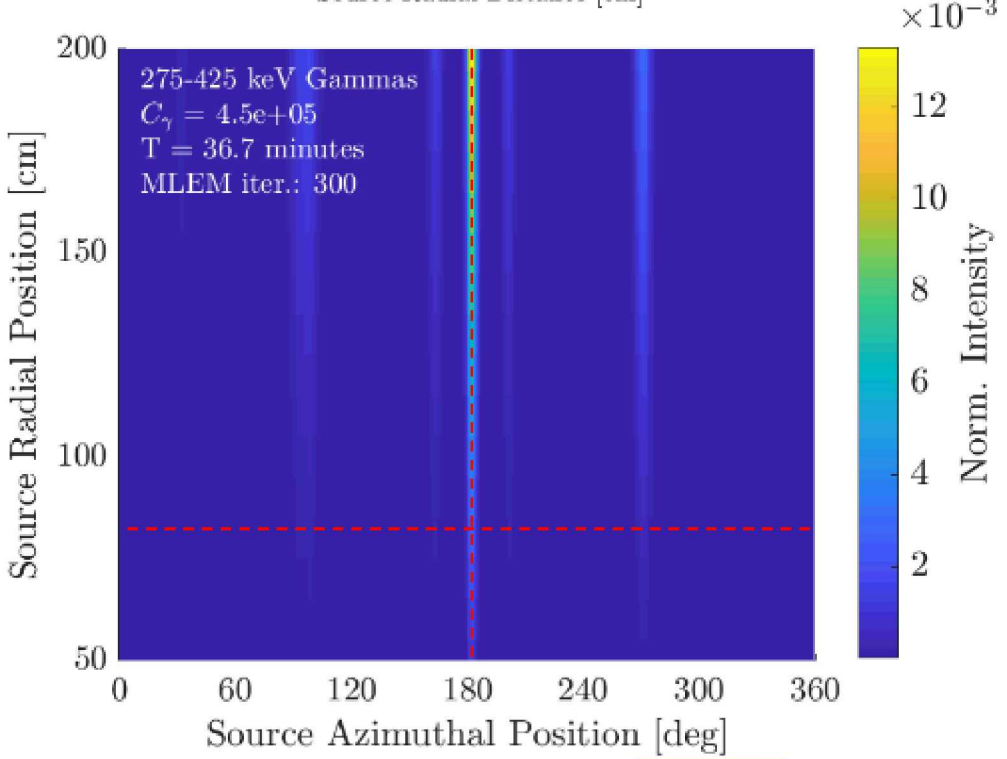


Multiple Source - Conventional

- Conventional c-TEI
- 1” CLLBC detector
- 275-425 keV gamma rays only
- No parallax → no 2D imaging
  - Sources are reconstructed further away because MLEM as inverse sensitivity of the response map
  - Also, 2D reconstruction is under-determined
- Cannot separate two source object

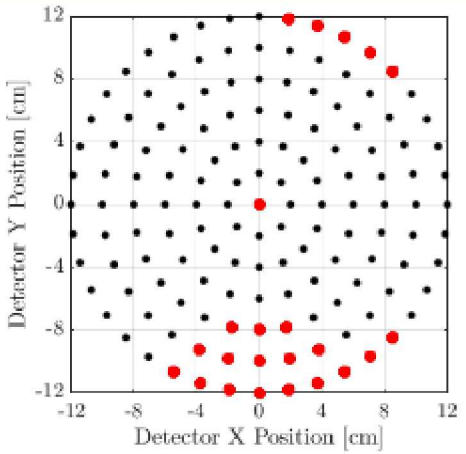


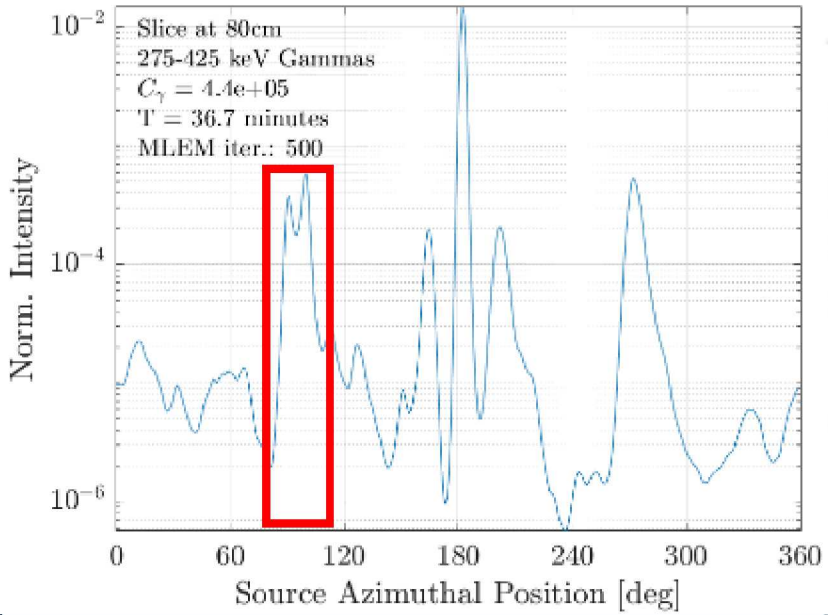


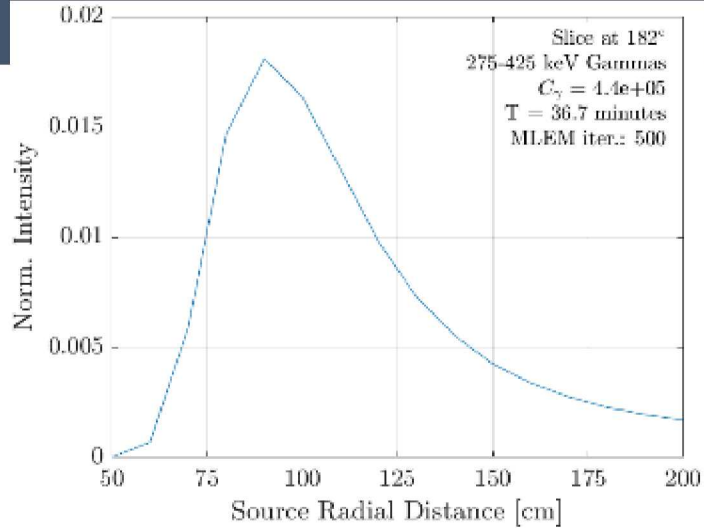


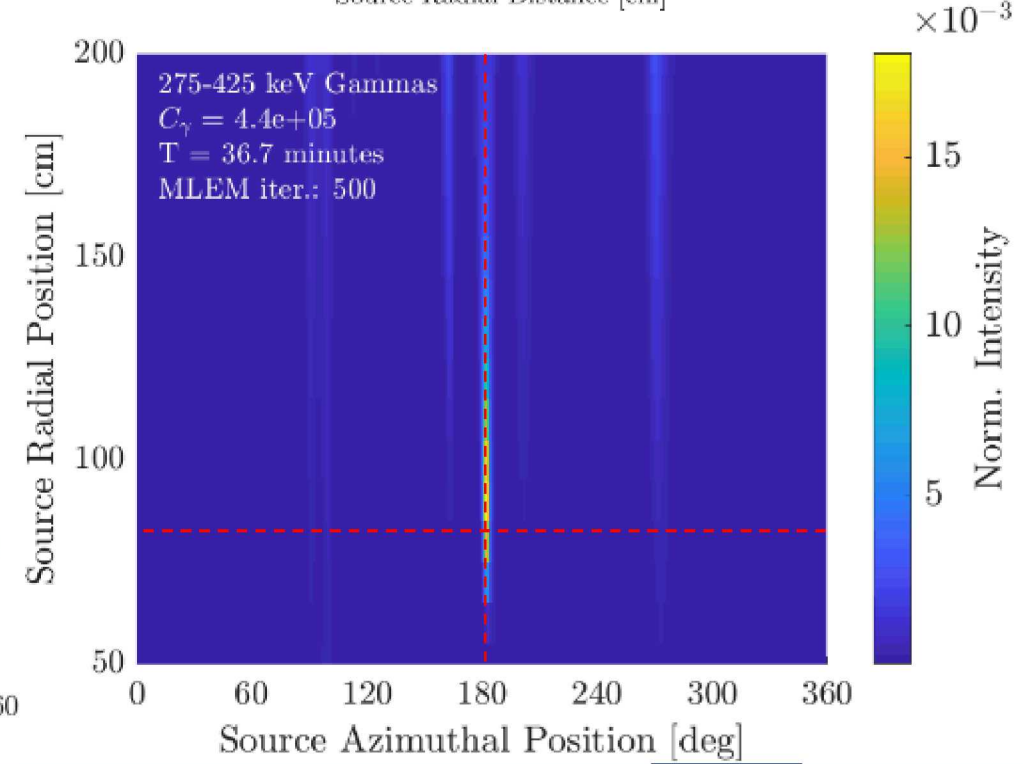
Multiple Source - Adaptive

- Adaptive c-TEI
- 1” CLLBC detector
- 275-425 keV gamma rays only
- MOX source can be localized
  - FWHM: 75cm – 125cm
  - Reconstruction suffers from initialization bias
- Can separate two source object









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Reconstructing Complex Scenes – Conclusions

- For extended sources, uniformity improves and background noise reduces
  - Line source: 37.5% better uniformity and 50% less background noise
  - Split-line source: 25% better uniformity and 37.5% less background noise
- In the multiple source experiment, we demonstrated
  - 2D imaging using parallax from detector movements
  - Improvement in angular resolution even in a complex scene

Acknowledgements

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