Characterization and Restoration of Mini-Muon Tracker Imaging System

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Mission Relevance

Muon imaging techniques can be used to…

- Ensure that all spent nuclear fuel at a facility is accounted
- Identify if nuclear material has been removed from storage containers

- *NNSA Mission*
  - *Website:* https://www.energy.gov/nnsa/missions/nonproliferation

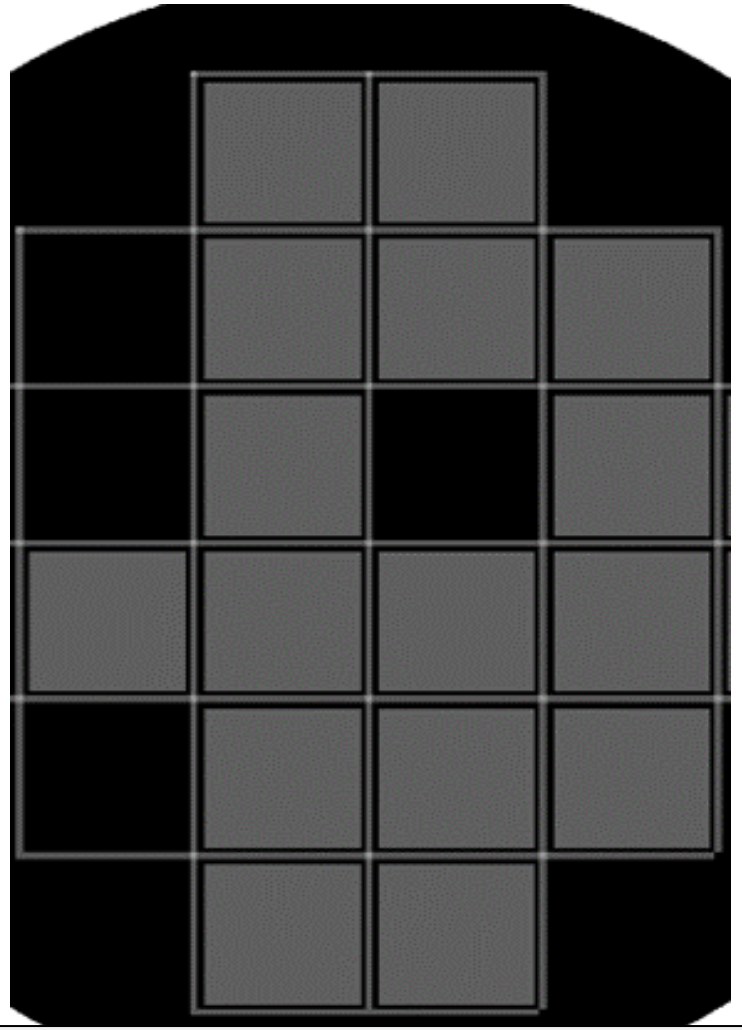
  Preventing nuclear weapons proliferation and reducing the threat of nuclear and radiological terrorism around the world are key U.S national security strategic objectives that require constant vigilance.

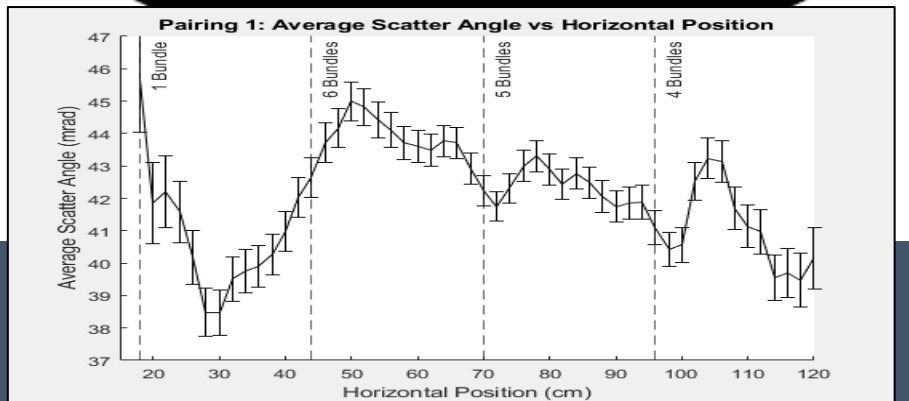
  NNSA's Office of Defense Nuclear Nonproliferation works globally to prevent state and non-state actors from developing nuclear weapons or acquiring weapons-usable nuclear or radiological materials, equipment, technology, and expertise.

Introduction and Motivation

Create multi-dimensional reconstructions to verify spent fuel cask loading

- Using cosmic-ray muons as radiographic probe
- Based on average muon scattering angle inside object (bigger θ = higher density, Z)
- Collection times are long
- Prior cask reconstruction have been limited to one-dimensional line images
- Optimize image reconstruction techniques for low data

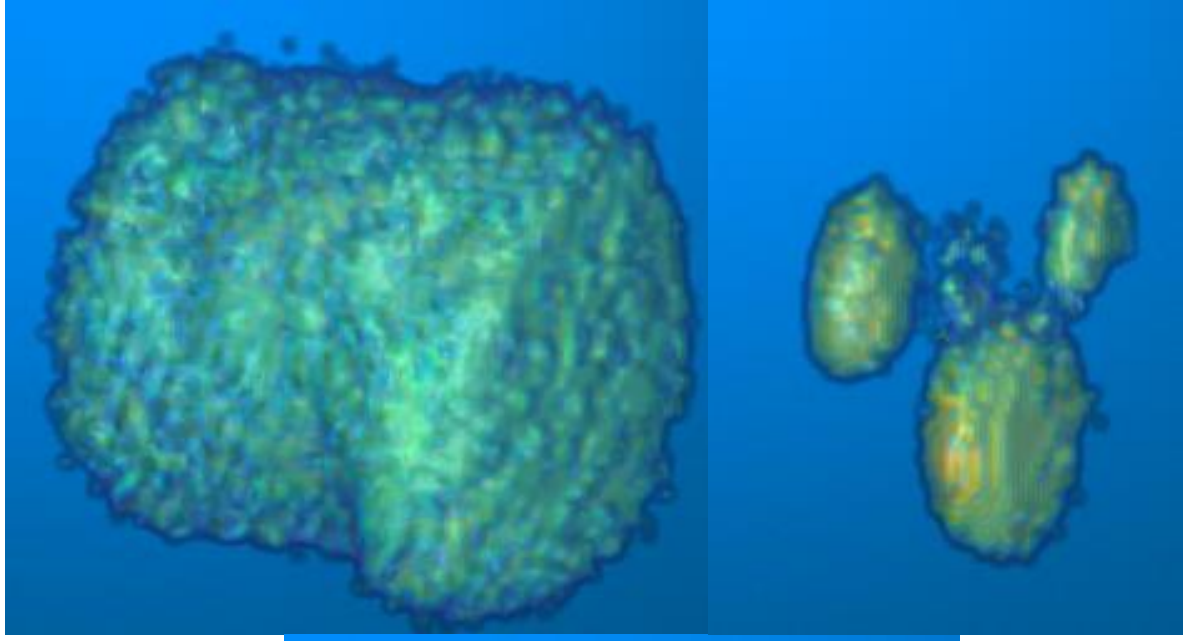


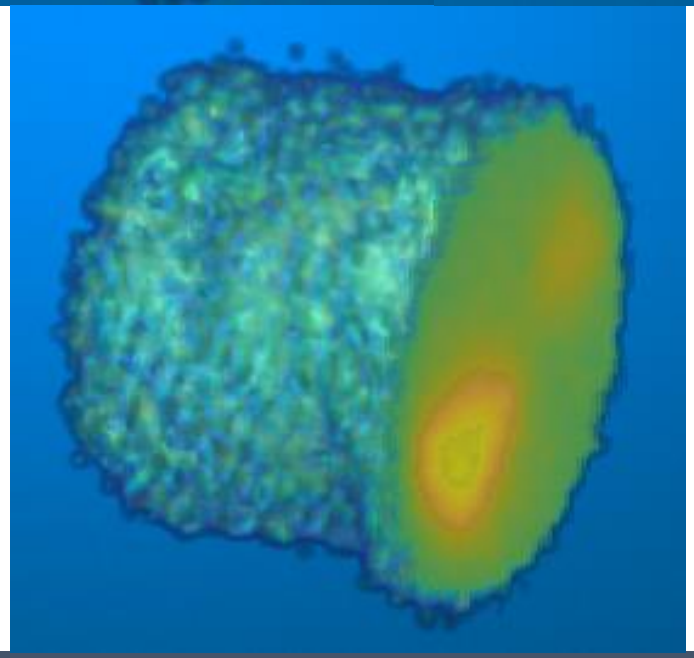


Multi-Dimensional Steel Drum Test Reconstructions

Comprehensive set of muon track information collected through a steel drum filled with concrete and triangular metal wedges

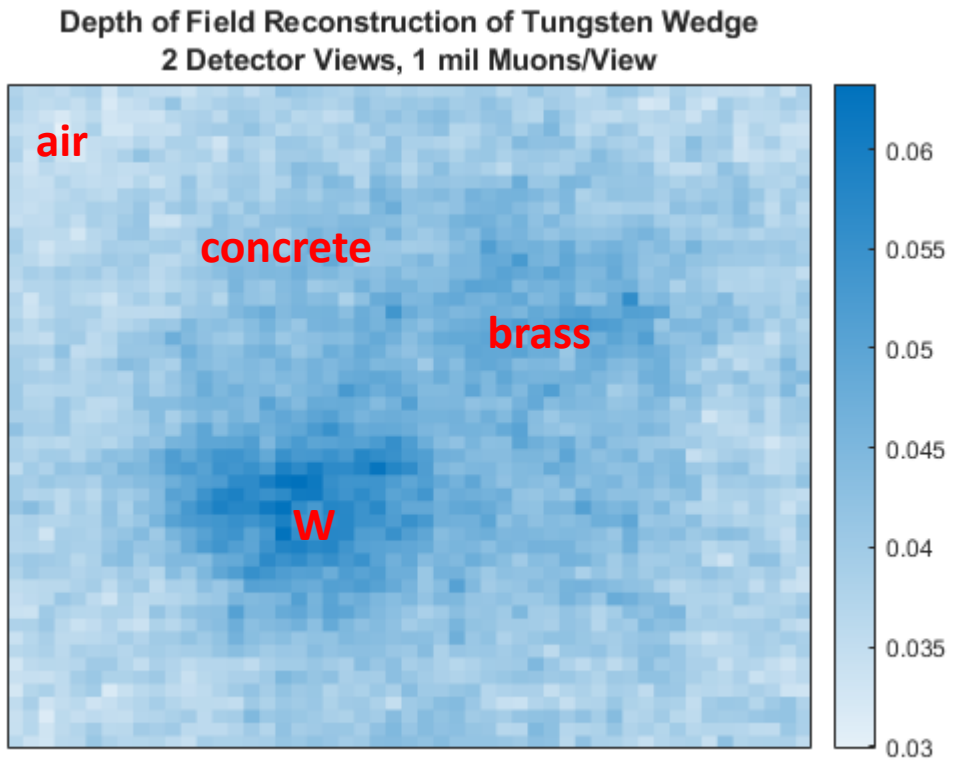
- Tomography using several detector-barrel orientation views
- Used to optimize reconstruction techniques. Created new depth-of-field combination technique
- Create useful images with low data levels



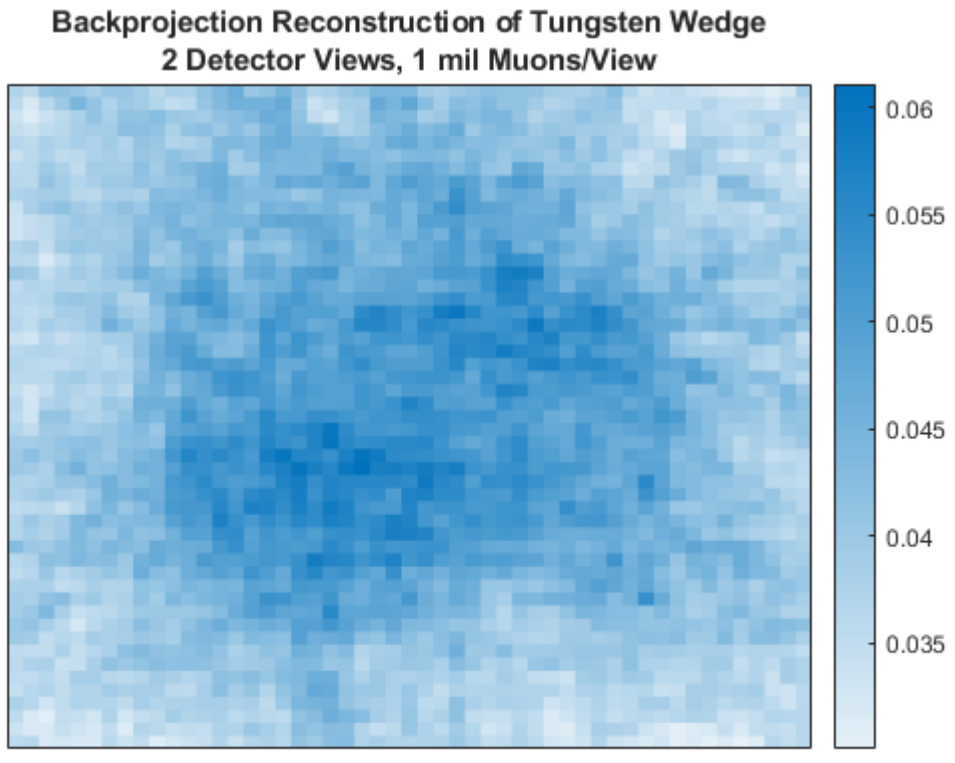


Comparison of New "Combined Depth-of-Field" and Traditional Backprojection Tomography reconstruction

Our Method



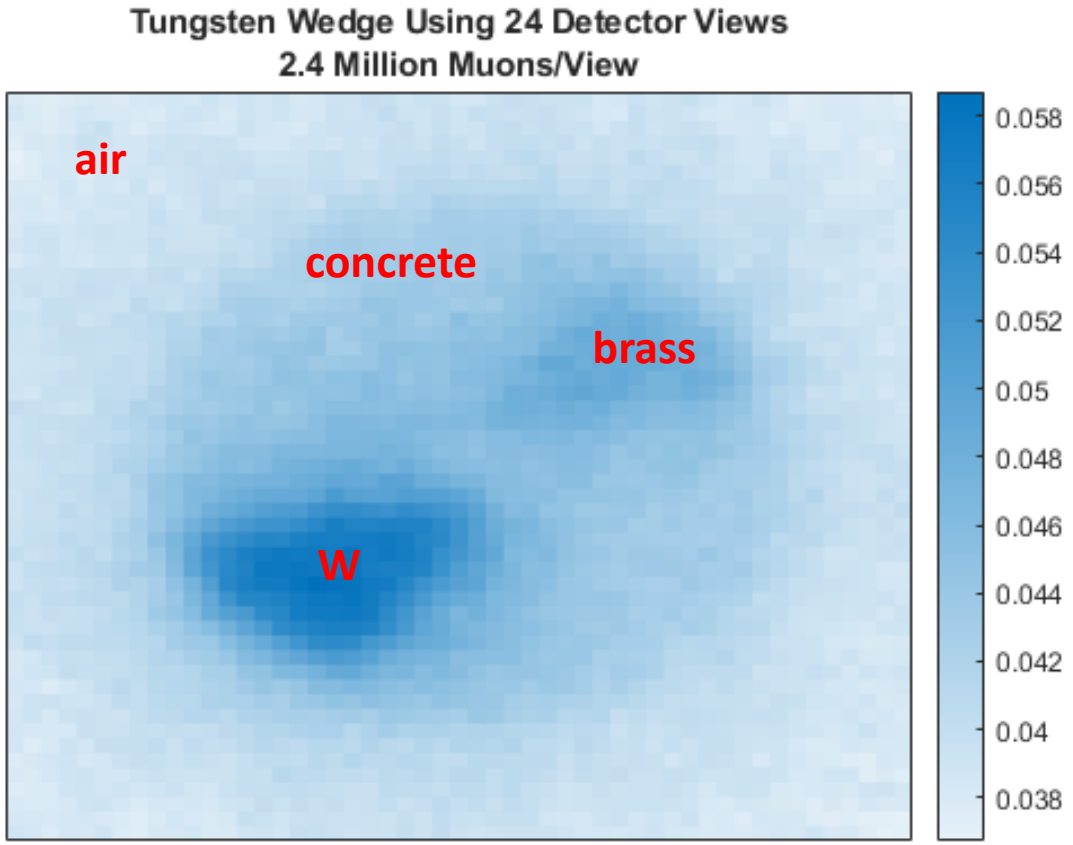
Backprojection Tomography

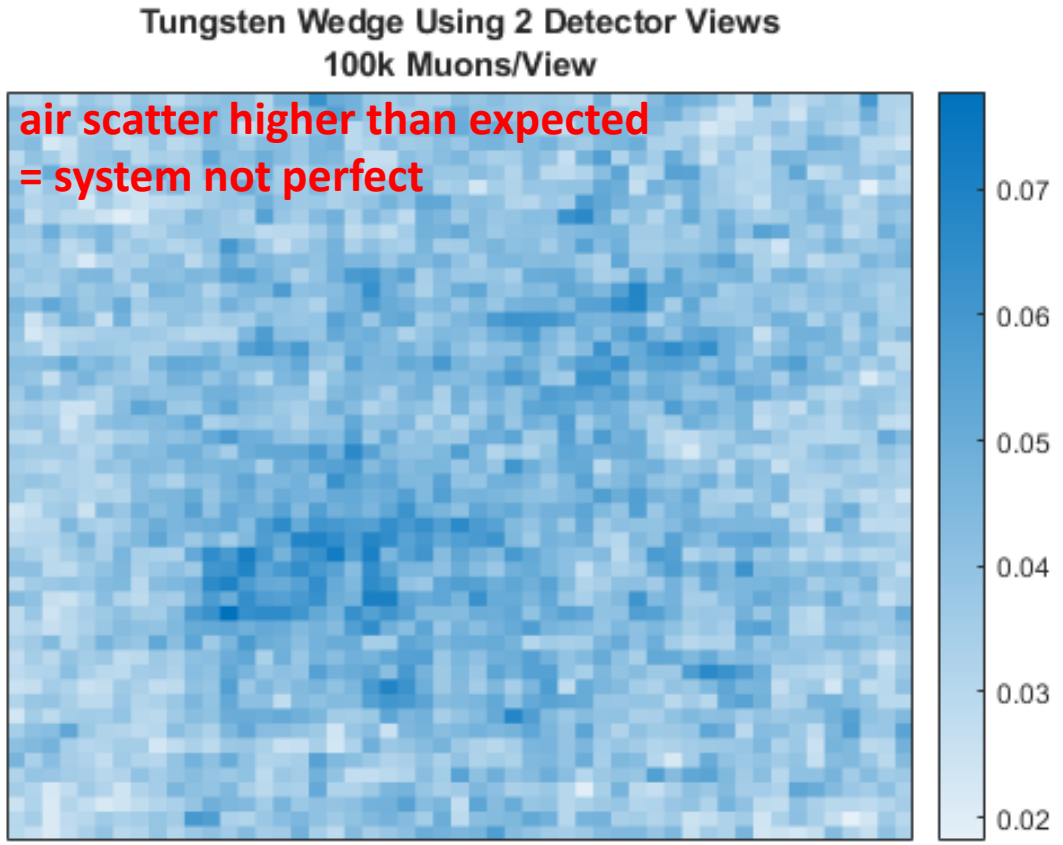


Reconstruction Using Limited Data

Experiment (~100k muons/hr recorded)

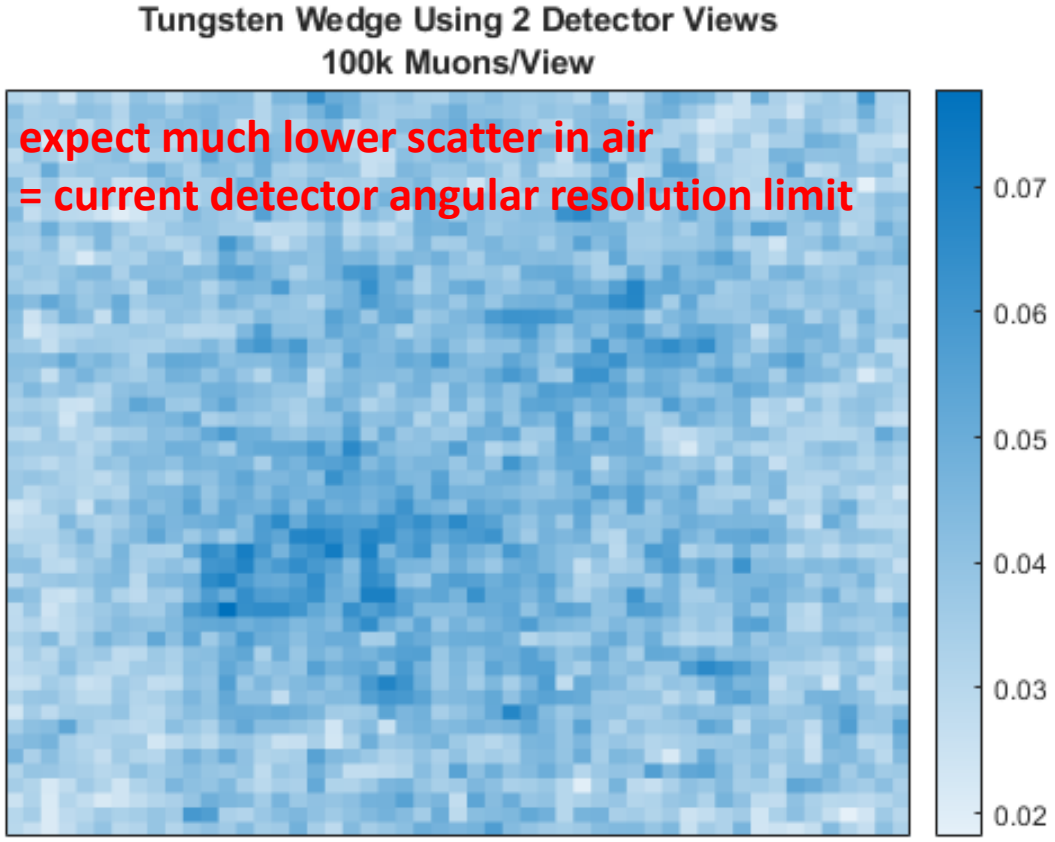
2.4M vs 0.1M muons per view



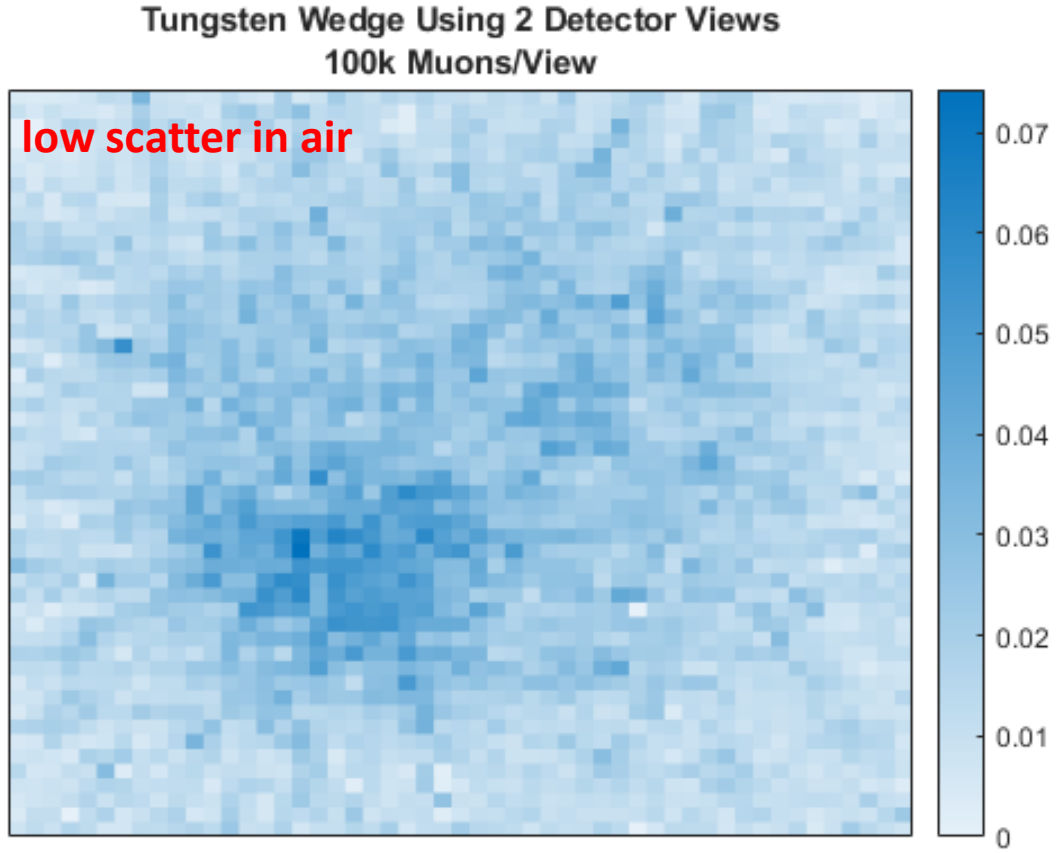


System resolution using very low data

Experiment

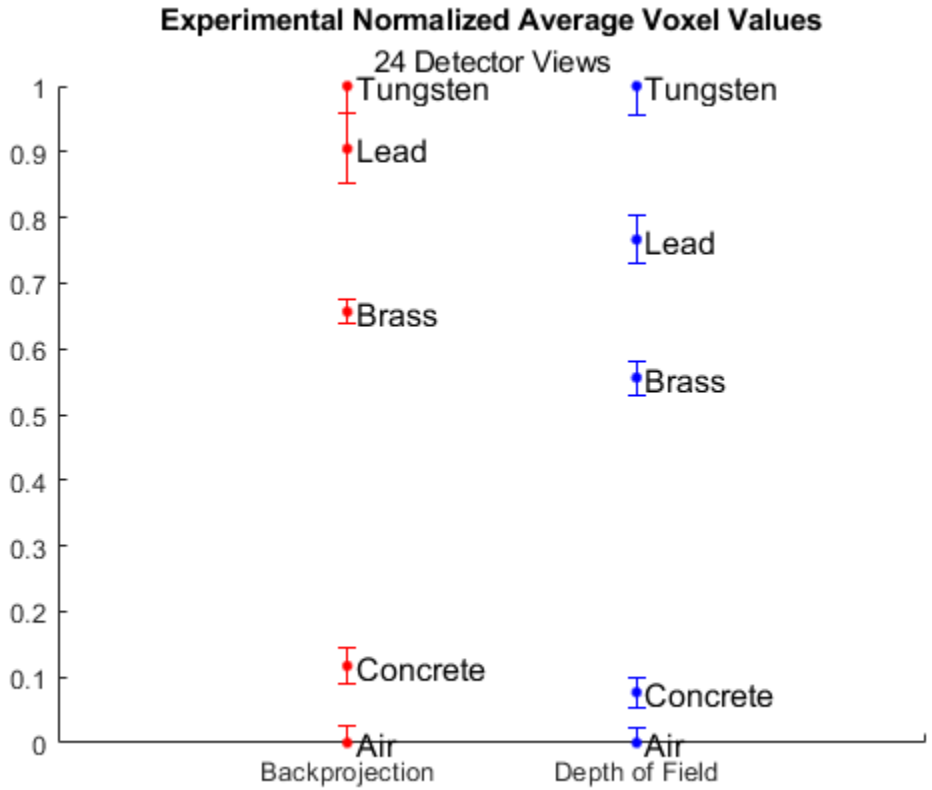


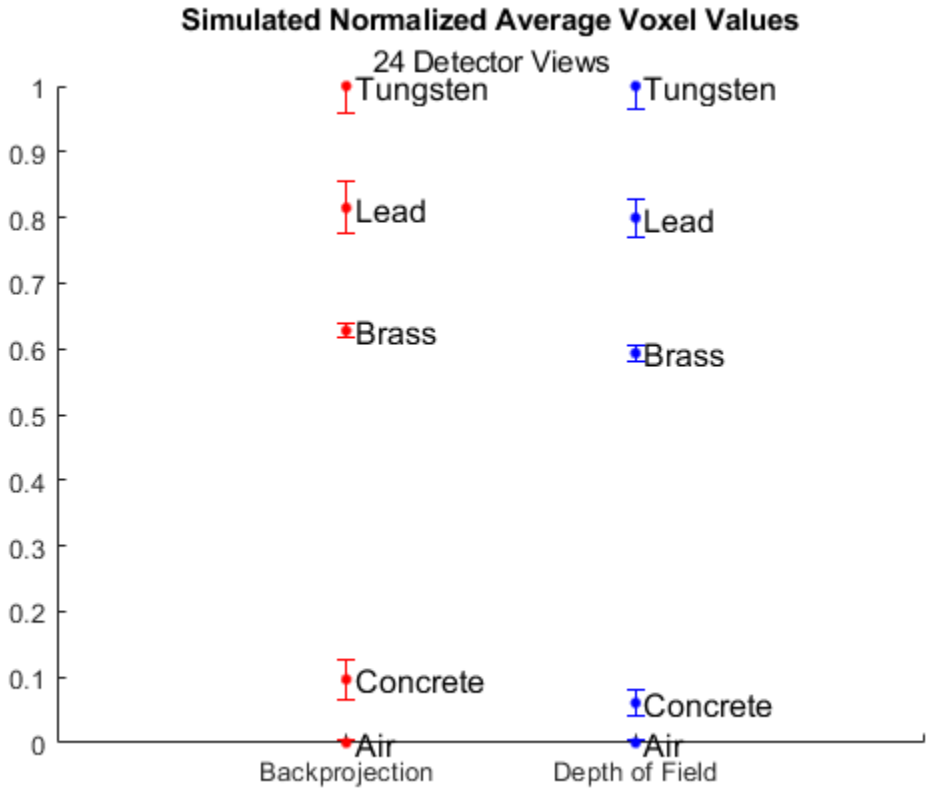
Ideal Simulation



Can improve low level random scatter readings by fixing radiation damage to gas from prior cask measurements.

Do resolution effects, create difficulties for material discrimination?





Results

- New reconstruction technique (combined depth-of-field) better than traditional tomography backprojection for low data reconstruction.
- Determined that reduced angular resolution of system adds baseline noise.
  - Material intensity values seem to be equally affected
  - Preserves the ability to discriminate materials
- Very low data reconstruction images appear noisier, causing difficulties for material localization
- Can fix low level random scatter angle reading by replacing old gas that was exposed to long cask measurements.

Conclusion

- Working towards low data image reconstruction
  - Tested and showed good material discrimination
  - Material localization is still possible for low data levels
  - At very low data levels localization difficult and images are noisy
    - Can fix low level random scatter angle reading by replacing old gas that was exposed to long cask measurements – should greatly improve very low data reconstruction images and system efficiency

- How does the work presented positively impact the NNSA mission?
  - Enabling in-situ tomographic reconstruction of spent fuel casks using cosmic-ray muons
  - Supports validation of loading in casks, to identify missing fuel bundle locations

Next Steps

- Larger and newer muon imaging system is being prepared for future cask measurement at INL this summer
  - New system does not show resolution degradation that is shown in the discussed results.
- Ongoing work is being performed to exchange the old gas in the older system with new gas, can use for more detailed tomography tests.
- New gas has new formulation that is more resistant to radiation damage, ideal for cask environment.

MTV Impact

- What is the impact of the MTV on your project development?
  - Student Jesus Valencia has been actively performing work on imaging with current data, and work at LANL to prepare imaging systems for upcoming measurements.
- Collaboration with Chris Morris, Matt Durham, Dan Poulson, Derek Aberle at LANL
- Plan to continue muon imaging activity with LANL
- Cohost UNM/LANL/Toshiba conference: Muography2024 in Santa Fe, NM
- Technology transitions
  - Technology used is created by Decision Sciences. Collaborating with them on setup, detector repair. Working on NDA to discuss continuing collaboration.

Acknowledgements

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