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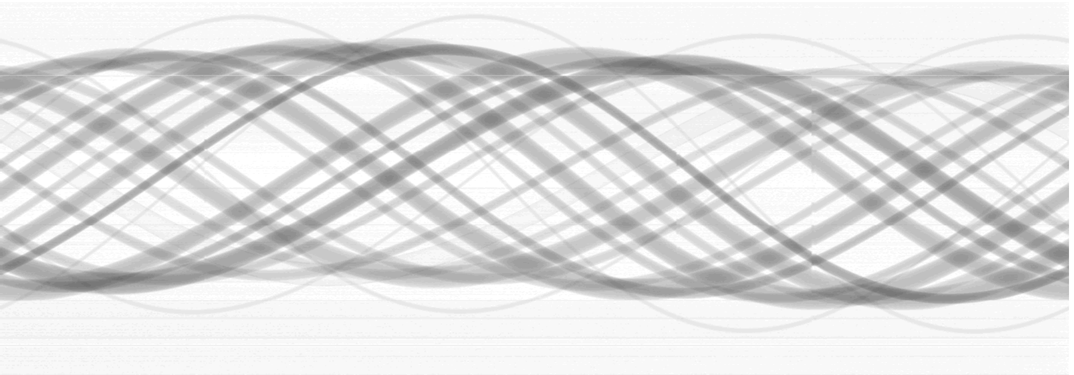
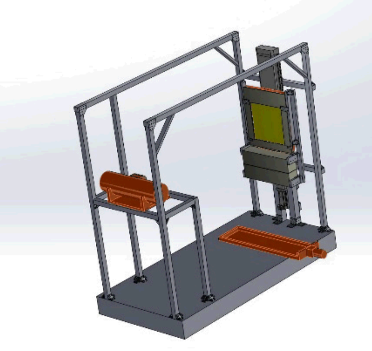

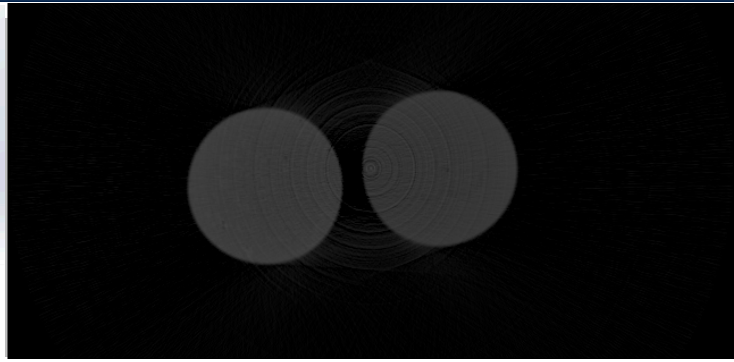

Leveraging Multi-Channel Detector Technology to Improve Quality Metrics for Industrial and Security Applications

Edward S Jimenez, Kyle R. Thompson, Adriana Stohn, and Ryan Goodner

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Objective

- Create advanced capability at Sandia National Laboratories
  - High-energy Color X-ray Computed Tomography for R&D in Industrial and Security Applications

- Industrial Applications
  - Verification and Validation
  - High-Mag Computed Tomography
  - Quality Assurance
  - Failure Analysis

- Security Applications
  - Checkpoint Screening
  - Materials Identification
  - Anomaly Detection

Introduction

- Sandia National Laboratories is developing a spectral CT capability for Industrial and Security Research
  - Nearly twice the energy of systems in existence at 300 KeV.
  - Current system can acquire a full polychromatic sinogram in approximately 30 minutes.

- Proc. SPIE 9969, Radiation Detectors: Systems and Applications XVII
  - E Jimenez et. Al. "*Comparing Imaging Capabilities of Multi-Channel Detectors to Traditional X-ray Detector Technology for Industrial and Security Applications*"

- This work will expand on the previous effort to include Computed Tomography
  - Acquire spectral sinogram data
  - Acquire 2D radiography data
  - Reconstruction of spectral sinogram data

Hardware

Sandia National Laboratories

- MultiX Detector:
  - 5 Modules
  - 0.8mm pixel pitch
  - 128 Channels
  - 300 keV maximum energy detection
- 4 axis motion control to allow for maximum flexibility.

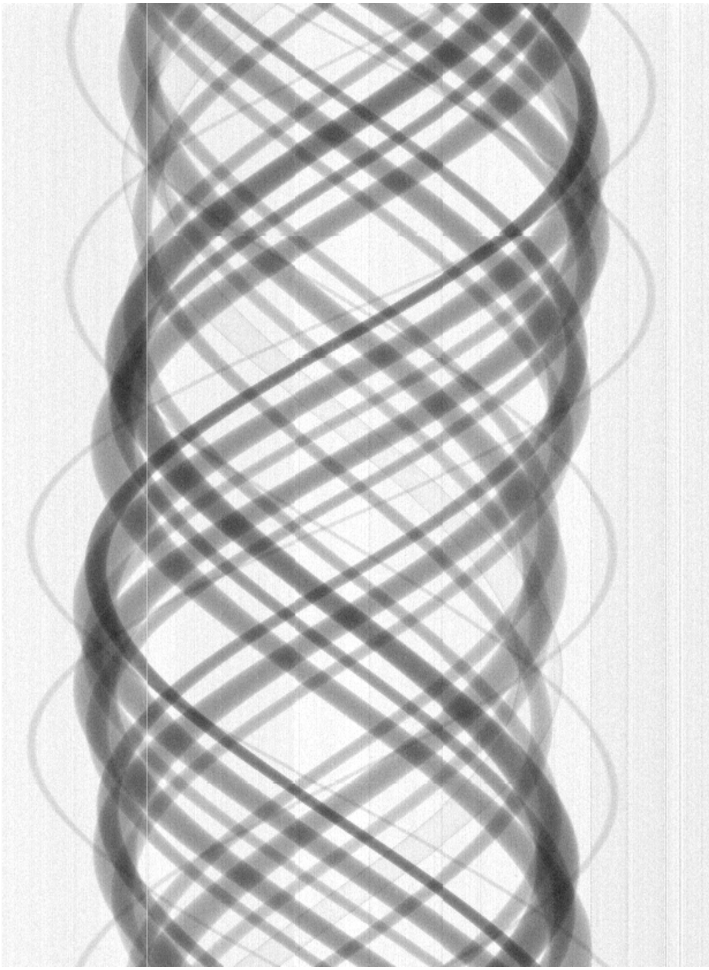
Hardware

- FOV
  - Half meter wide
  - Up to 9 meters tall

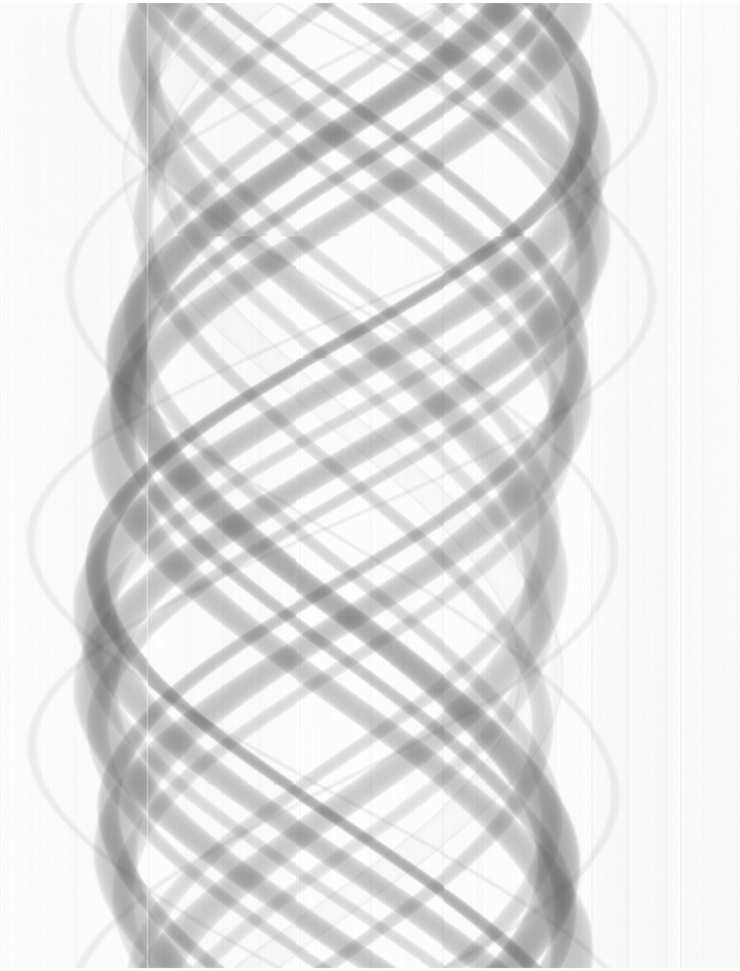
- System has been acquiring data as of May 2017.

Sinogram Data

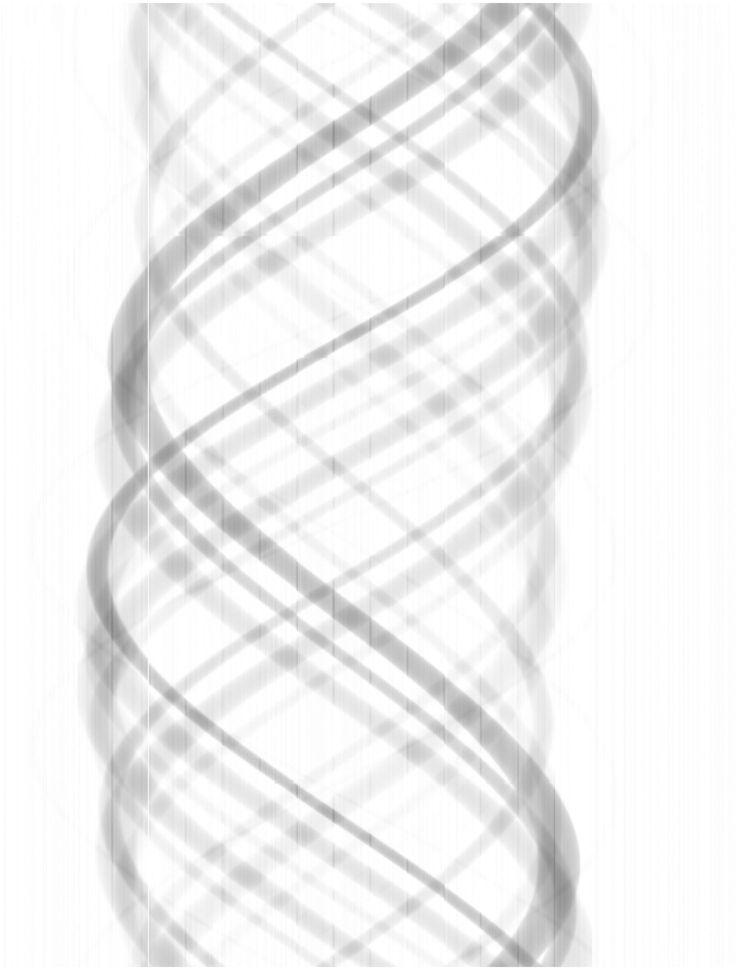
Bin 0



Bin 63



Bin 127



Expectations

Radiograph Data Quality Improvement

- Signal quality improvement
  - Long exposure
  - Varying perspectives from CT sampling
- Wide spectrum with narrow channels
  - Distinguish between similar compositions.
  - Higher capability than dual-energy methods or Computed Tomography

Challenges

- Acquisition Time
- This particular detector has many settings that are not user configurable or directly available
  - Gain
  - Deadtime
- Possibly difficult to calibrate
  - Gain Correction
  - Spectral Drift

Expectations

Materials Classification

- Multi-channel data
  - Signal that correlates to attenuation
- Wide spectrum with narrow channels
  - Distinguish between similar compositions.
  - Higher capability than dual-energy methods or Computed Tomography

Challenges

- In the previous work, the data was too noisy to reliably perform classification.
  - Will CT data mitigate this?
- This particular detector has many settings that are not user configurable or directly available
  - Gain
  - Deadtime

Expectations

Improved CT Reconstruction Quality

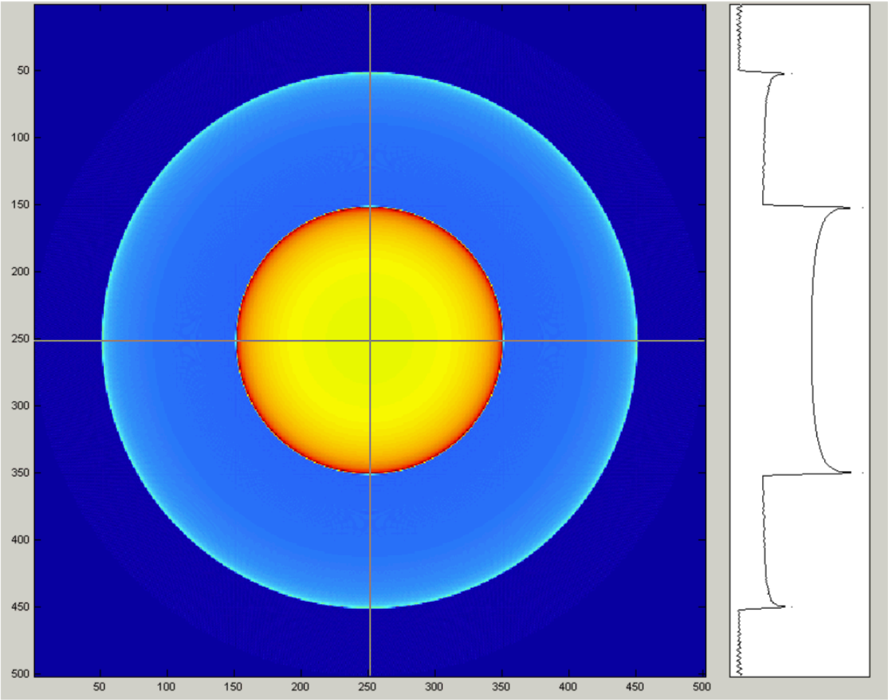
- Narrow energy channels
  - More linear than using entire spectrum
  - Imaging operator compatibility with reconstruction algorithm assumptions
- Artifact Reduction
  - Reconstruction of a single or few neighboring channel data will reduce beam hardening artifacts.
  - No extra pre-processing necessary.

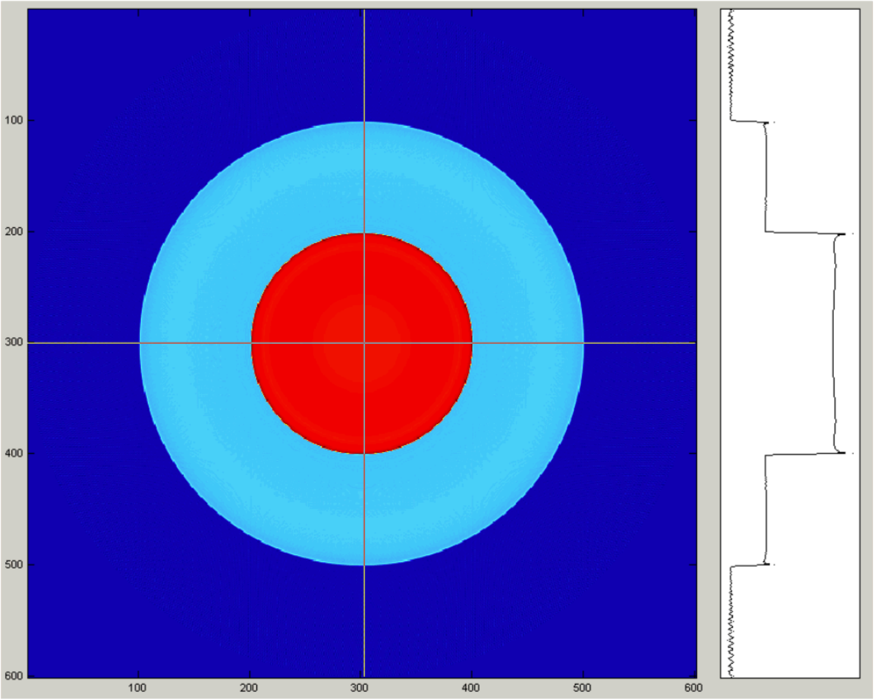
Challenges

- Will SNR overcome benefits
  - Photon Starvation for a single bin
- Will CNR overcome benefits?
  - High-energy channels will have no signal for low-density/attenuation regions.

Other Motivational Works

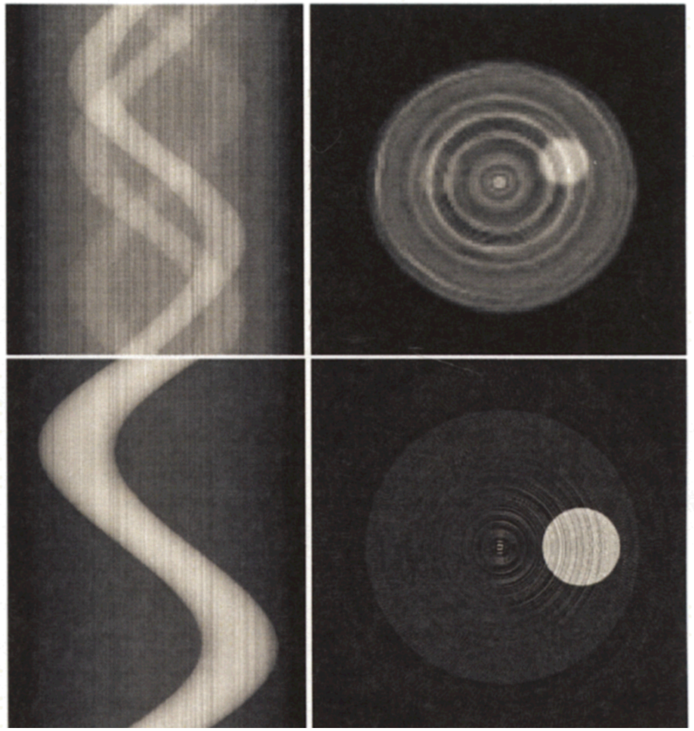
- James Hunter, *Dual Energy Beam Hardening Correction for Industrial X-ray Computed Tomography.* **2007 Masters Thesis New Mexico Institute of Mining and Technology**
  - Requires 2 scans and a Pre-processing step
  - Primarily demonstrated with dense cylindrical phantoms
  - Images below from Hunter’s work





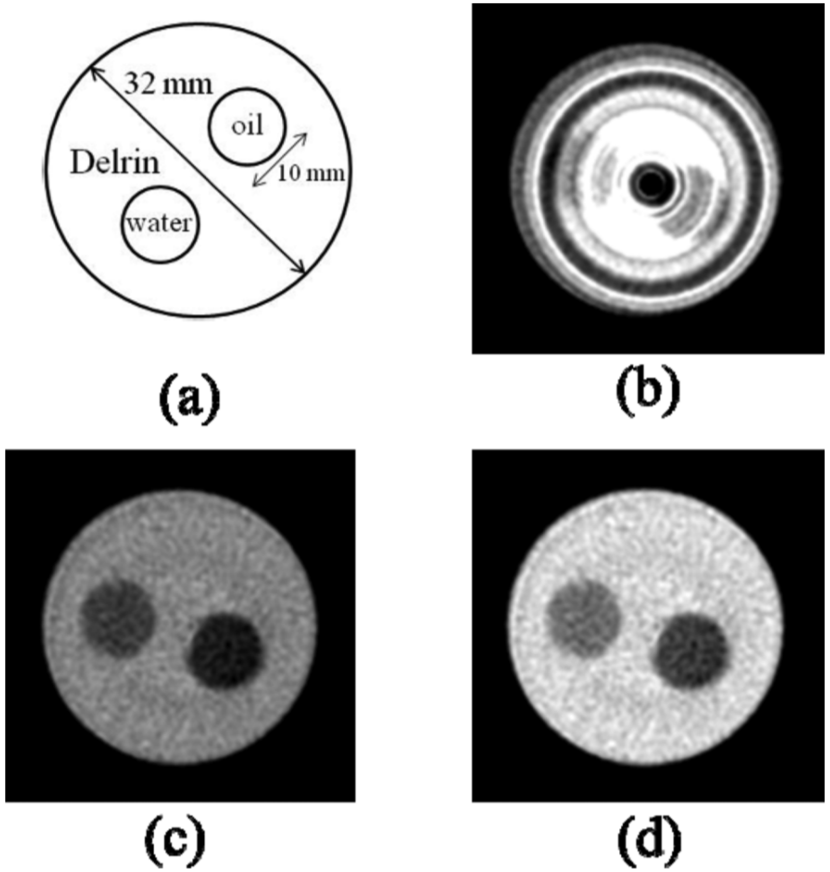
Other Motivational Works

- Wang et. Al., *Uniformity Correction in Photon-counting x-ray detector based on Basis Material Decomposition.* **2008 IEEE Nuclear Science Symposium Conference Record.**
  - Points out that there are severe CT ring artifacts in using photon-counting data
  - Random variations in cell (i.e. pixel) energy response
  - Image from Wang et. Al.



Other Motivational Works

- Din and Molloi, *Image-Based Sepctral Distortion Correction for Photon-Counting X-ray Detectors*
  - Image-based method to correct for distortions induced by various photon-counting artifacts
  - Claims reconstruction on raw data is essentially unusable.
  - Image from Din and Molloi

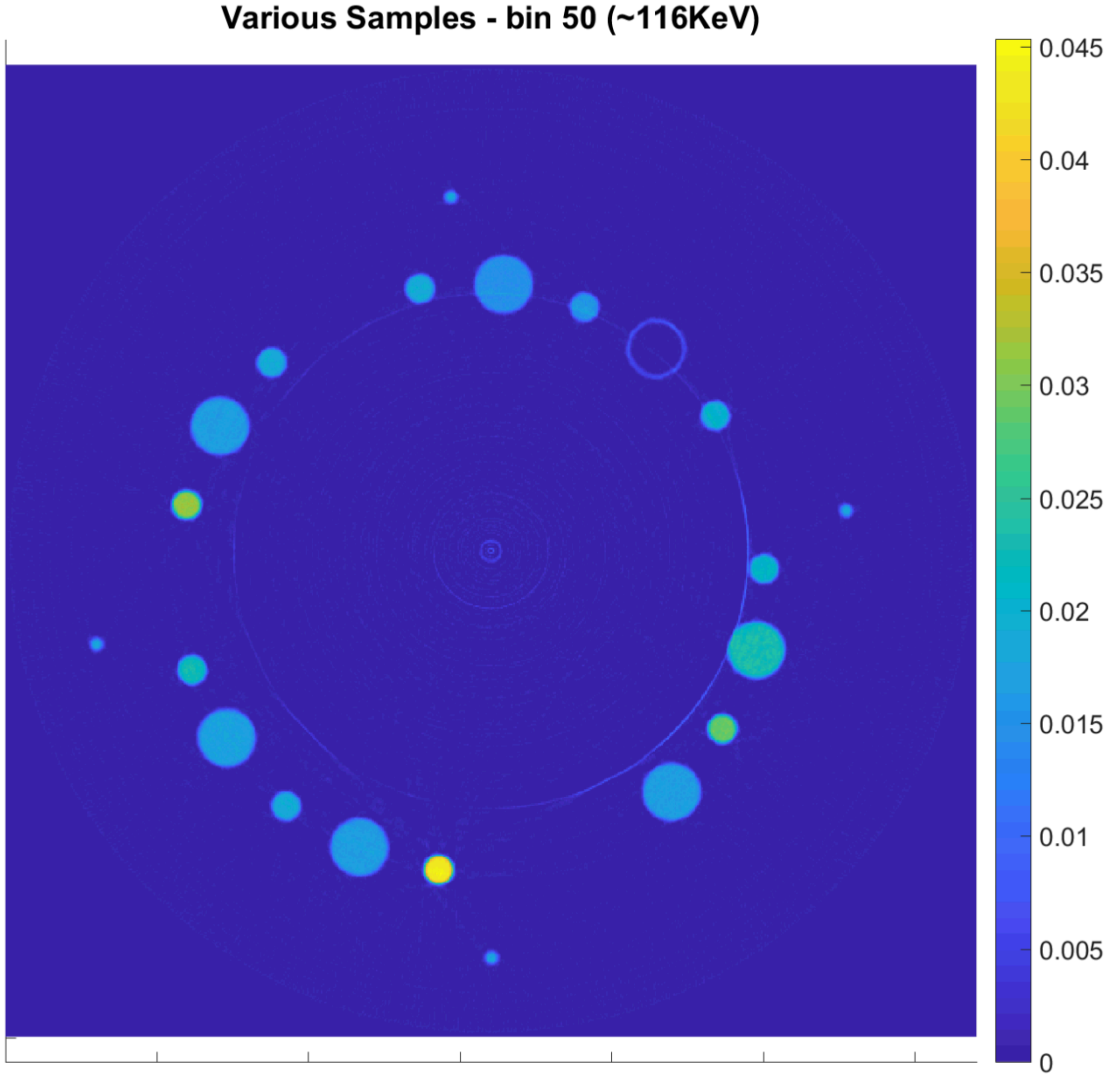


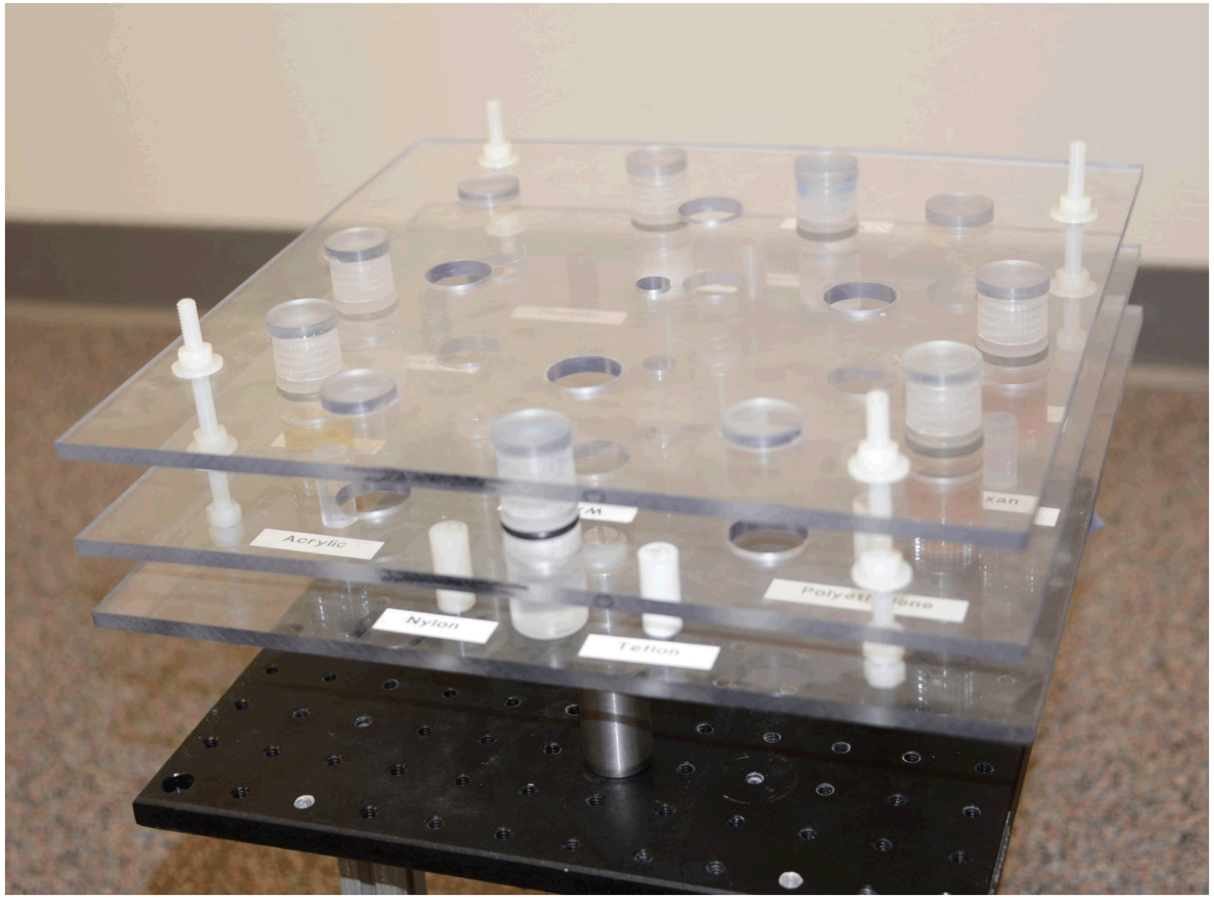
Experiments

- Scan simple configurations
  - Cylinders and Blocks
  - Uniform mixtures
- Various materials with similar properties
  - Study fidelity of system
- Simulant Scan
  - 2 Plastic Explosive Simulants
  - 3 Powder Explosive Simulants

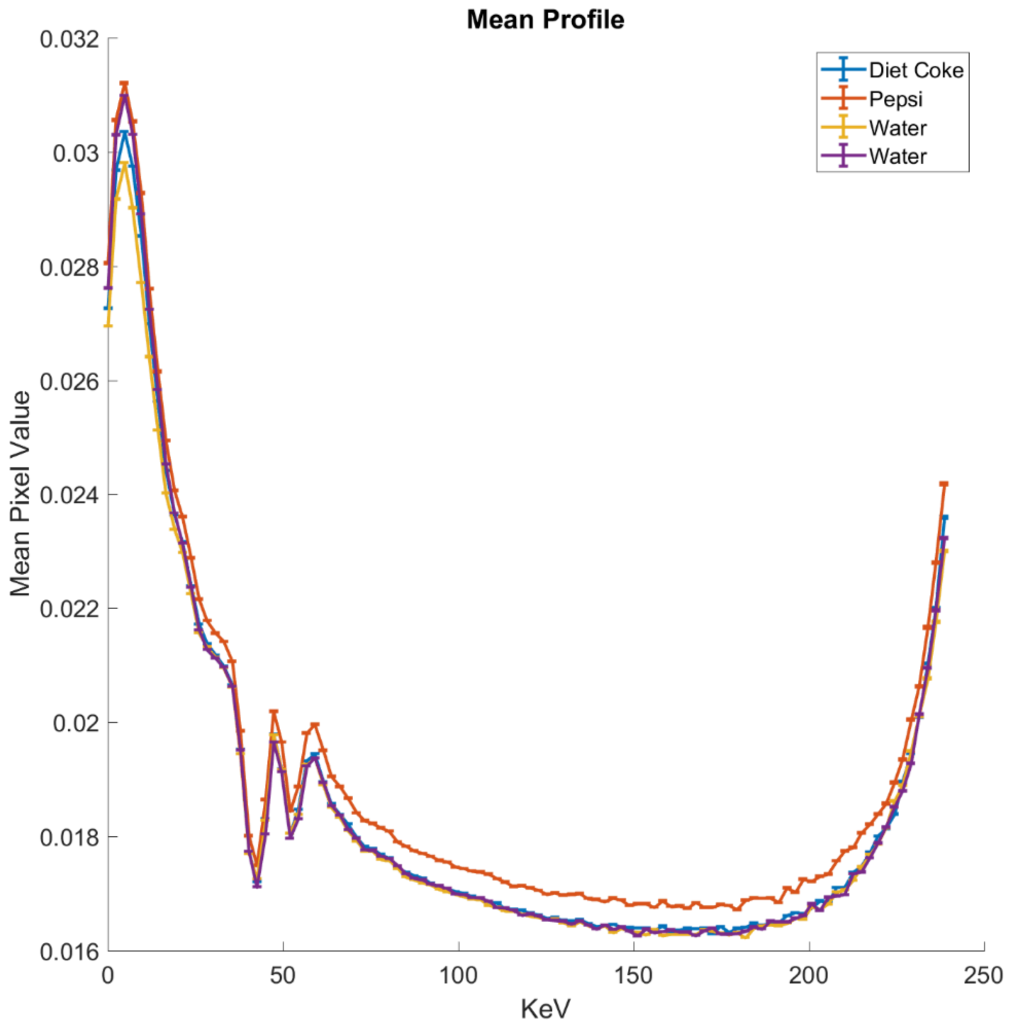
- Reconstruction
  - Recon (LANL and SNL Code)
  - Volume Graphics (Selectively)
  - Single Bin Reconstruction
  - Integrated Reconstruction (Selectively)
- Scan parameters
  - 250kVP
  - 720 projections
  - Single Slice
  - ~2m Source to Panel Distance
  - ~1.6m Source to Object Distance

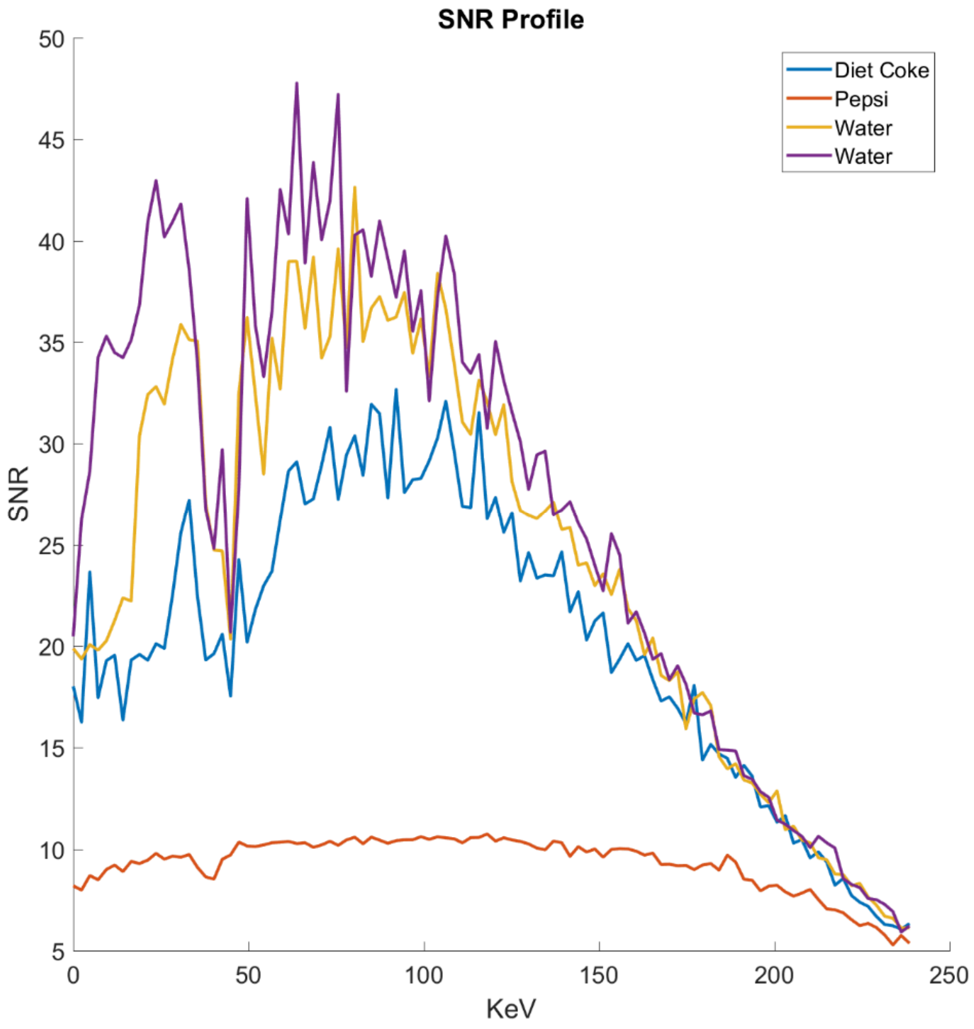
Data Acquisition: Various Samples



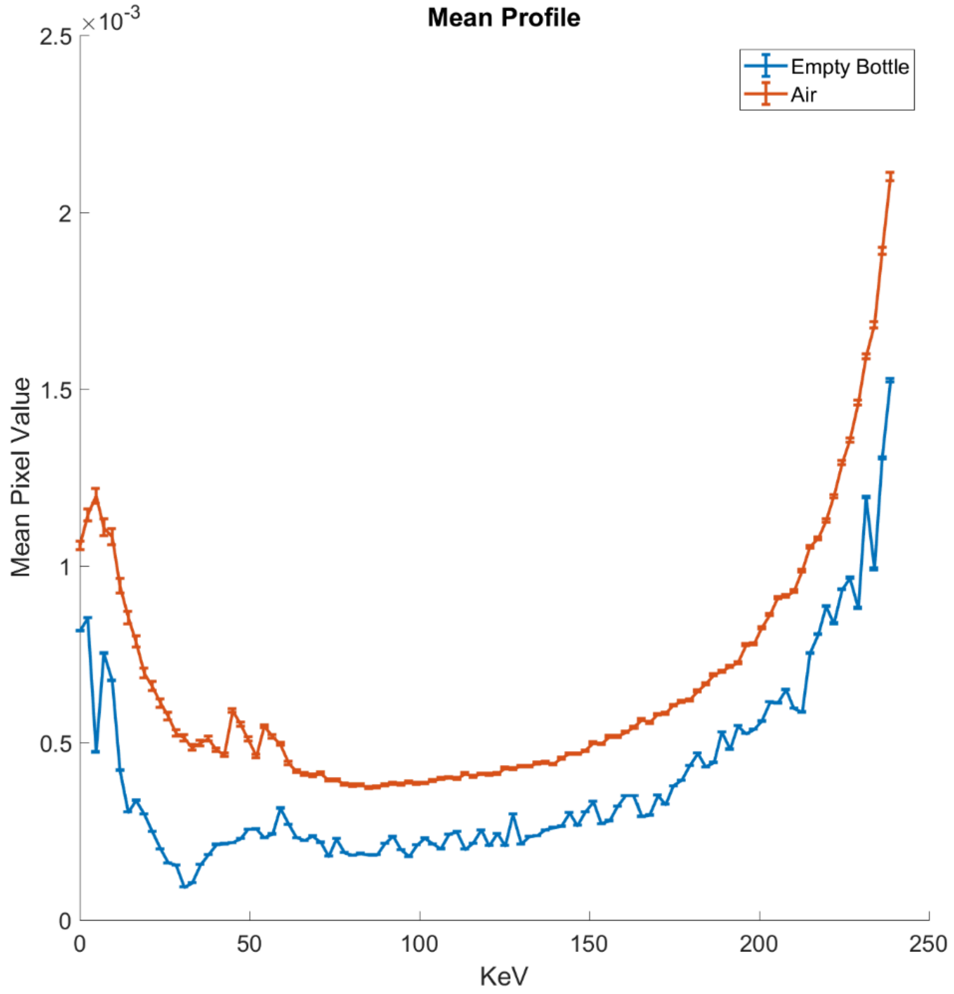


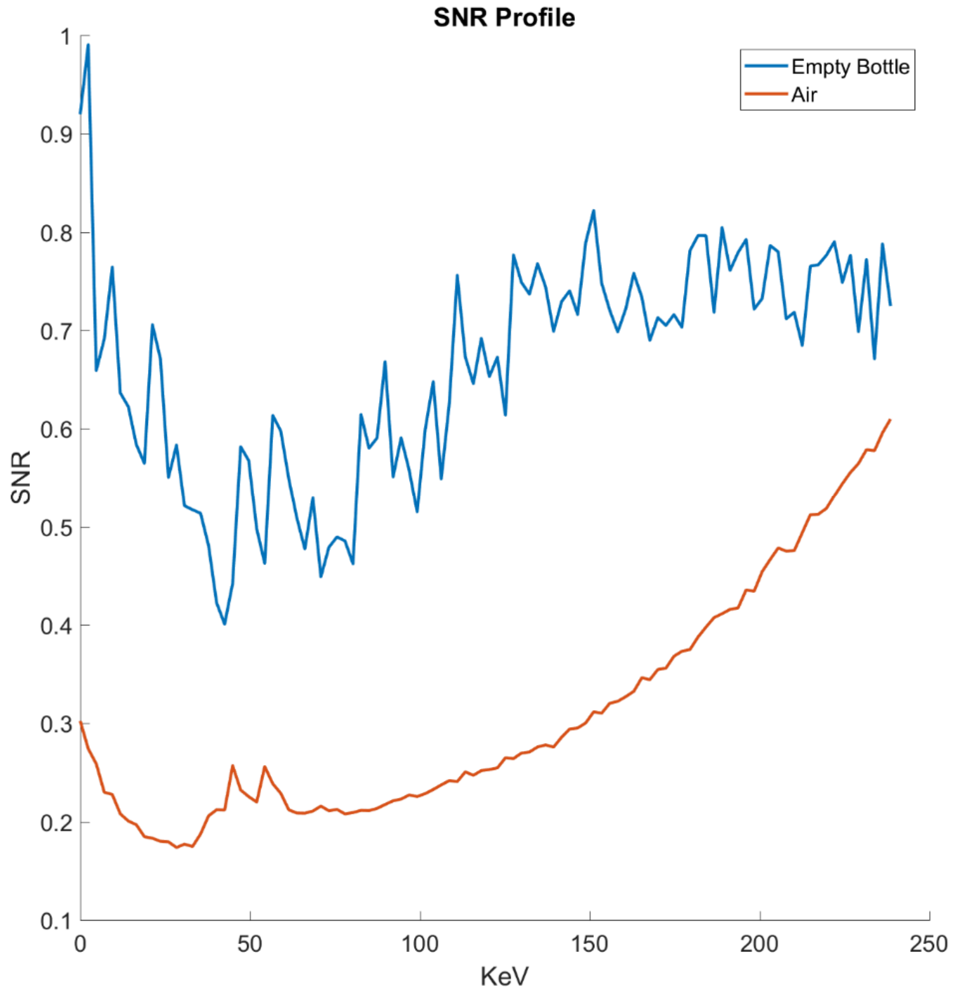
Mean Profile: Diet Coke, Pepsi, Water



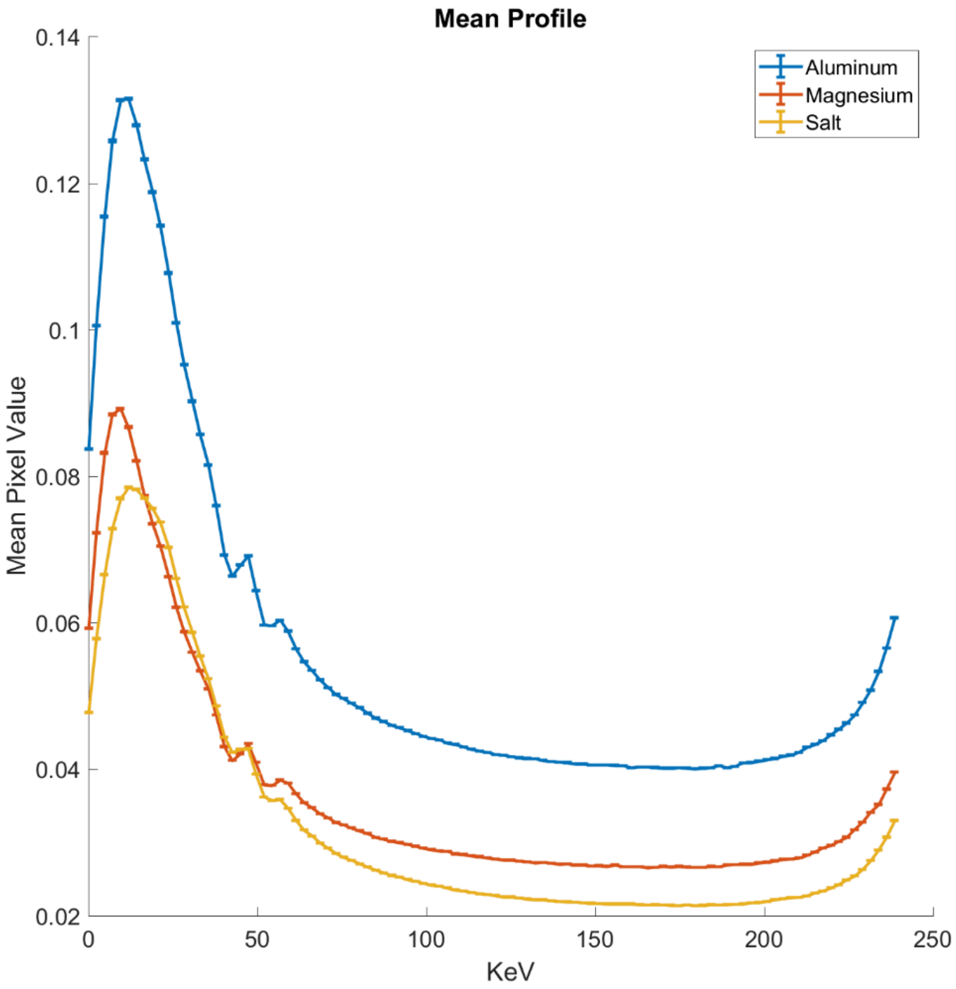


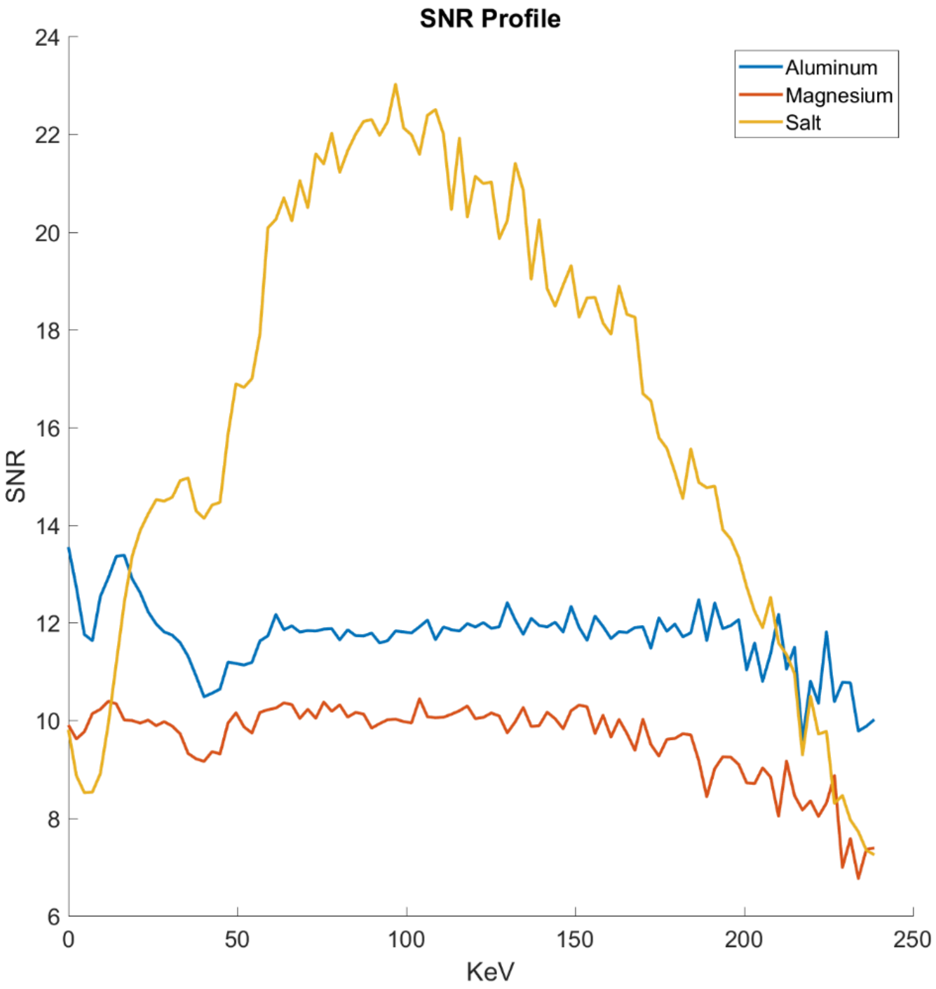
Mean Profile: Air



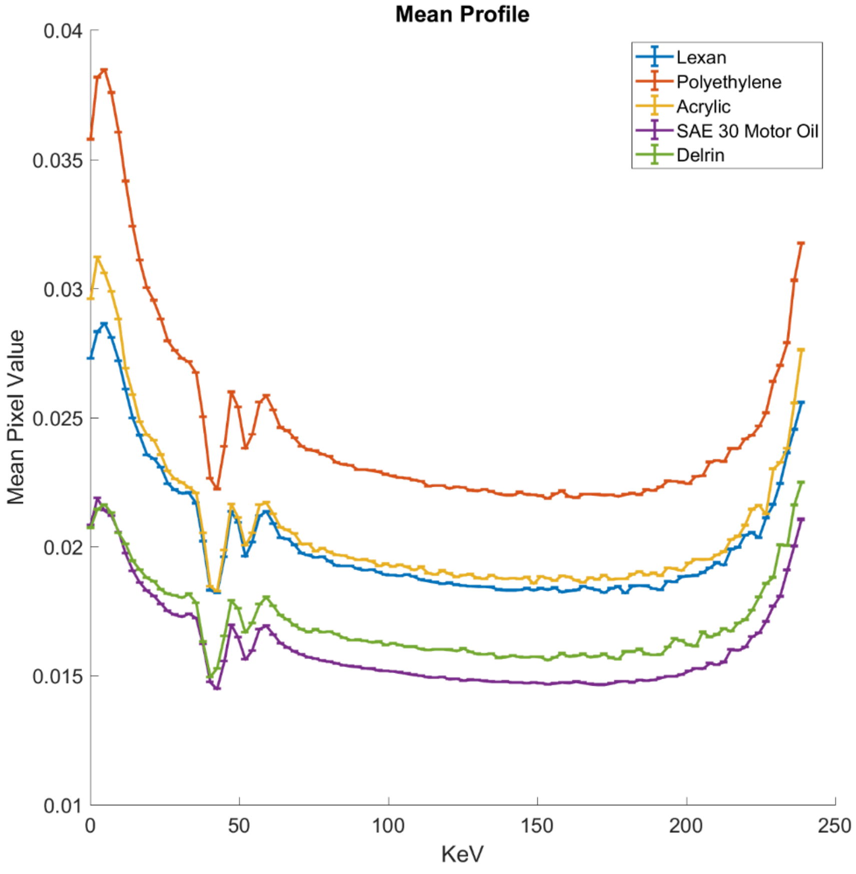


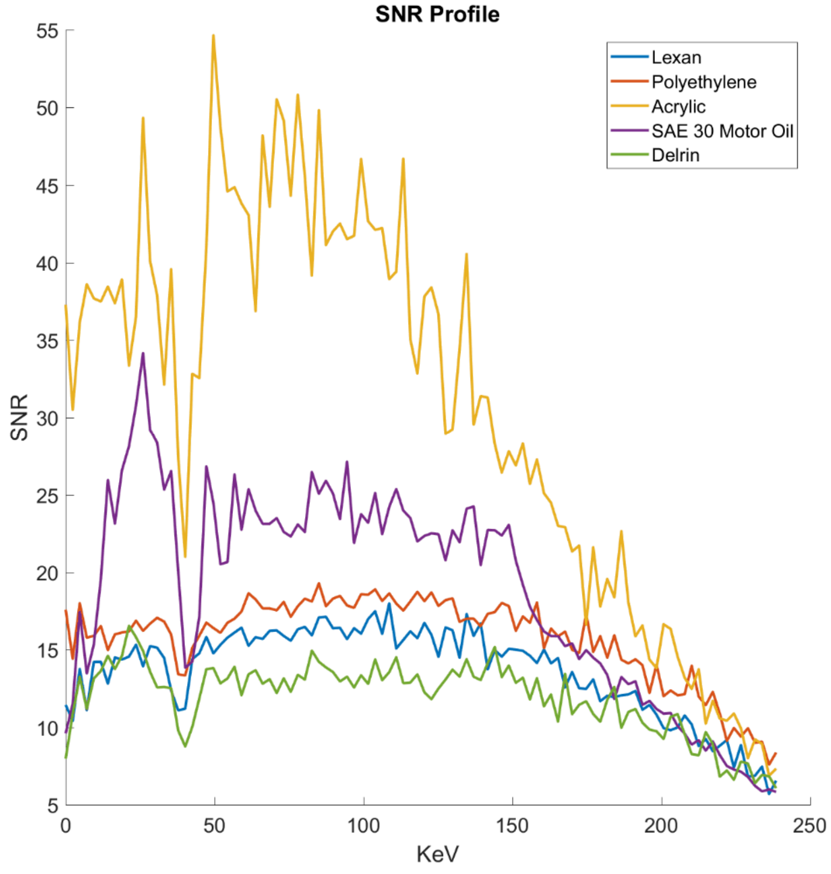
Mean Profile: Al, Mg, NaCl



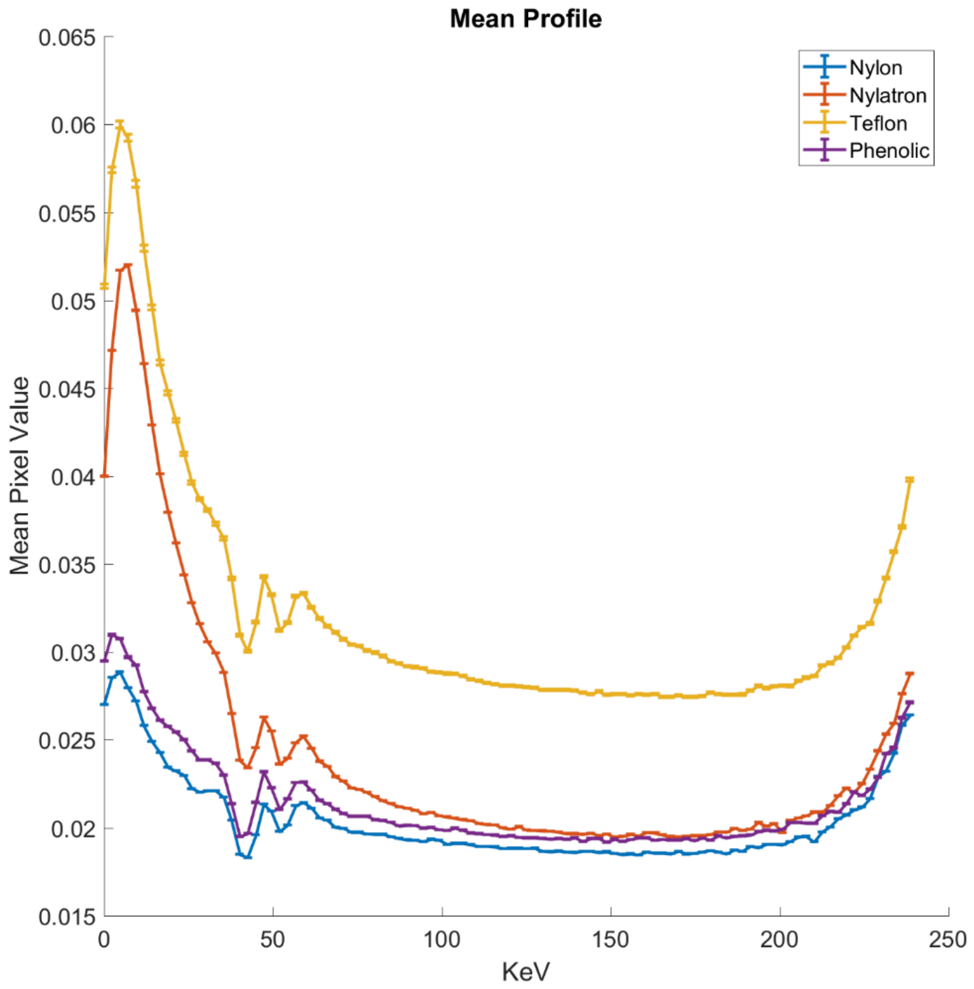


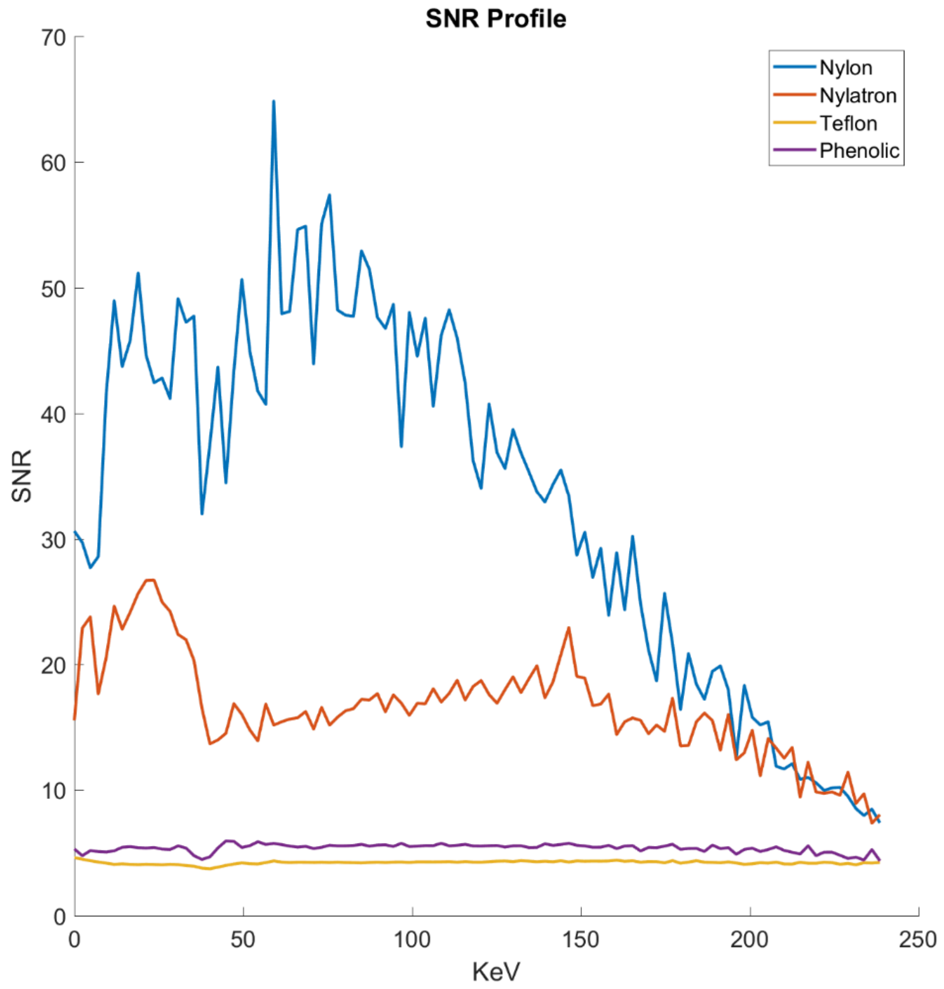
Mean Profile: Plastics



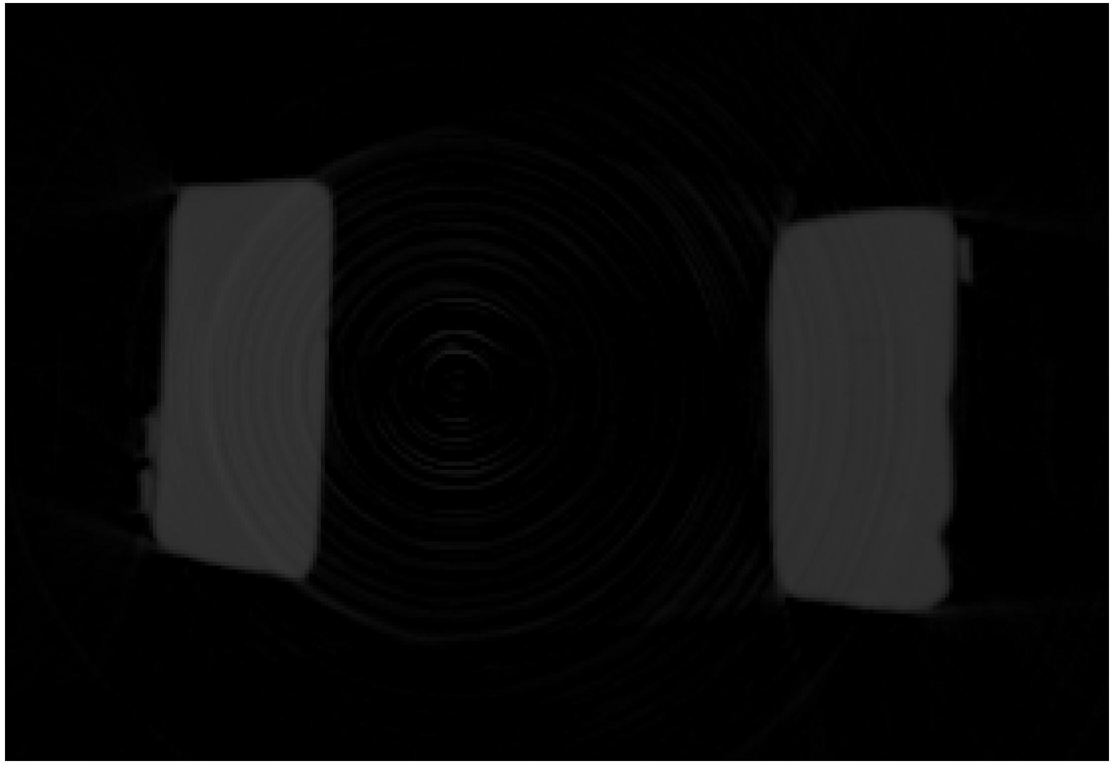


Mean Profile: Nylon



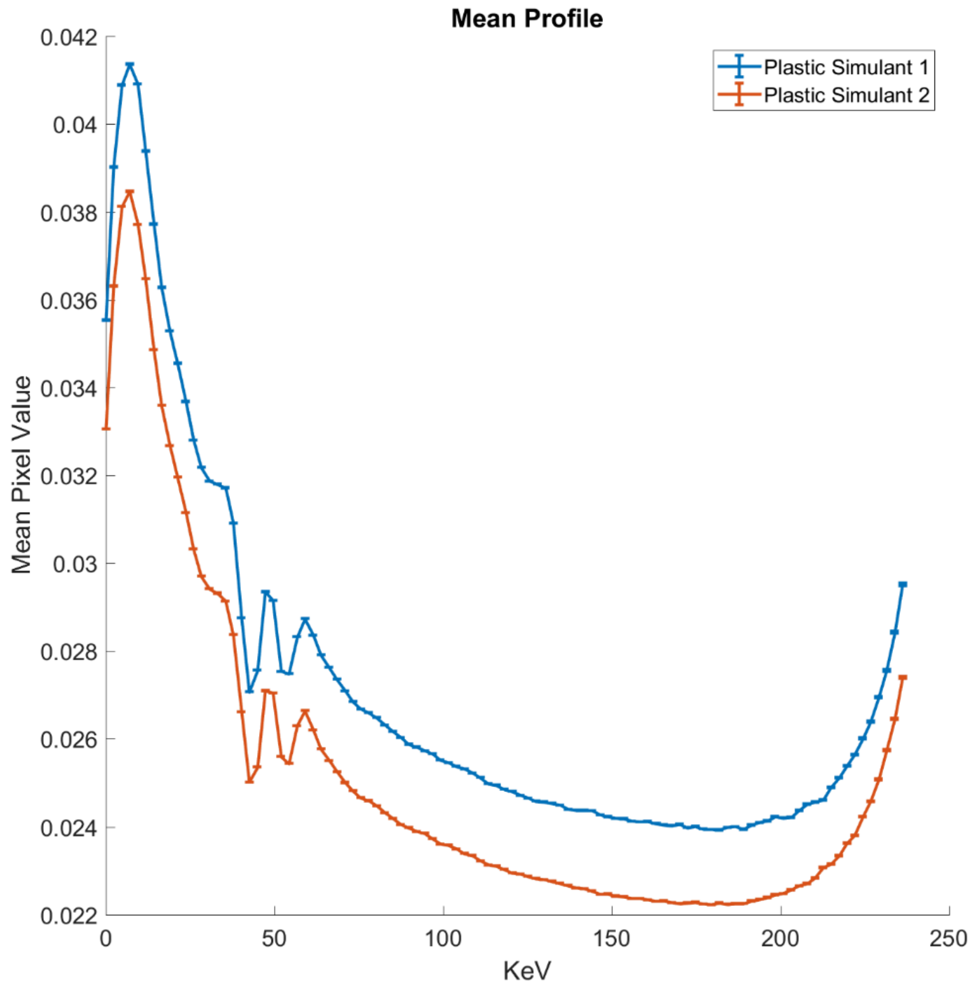


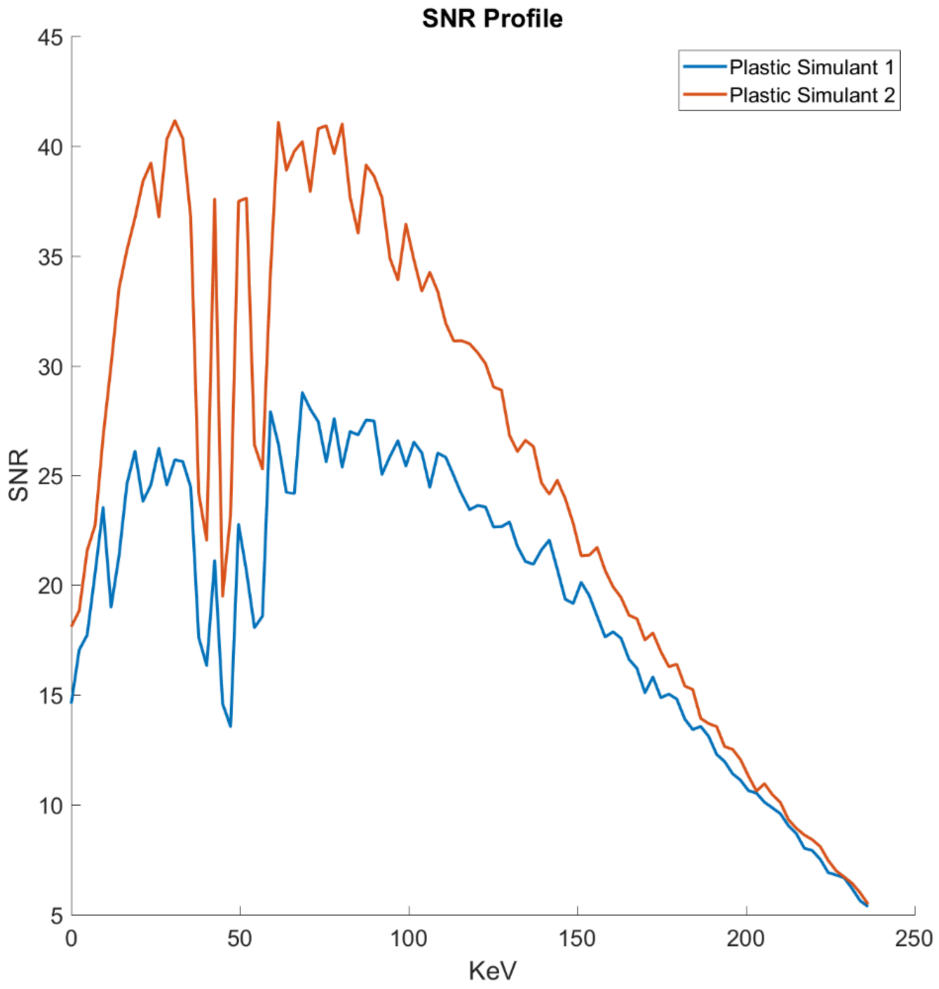
Data Acquisition: Plastic Explosives Simulant



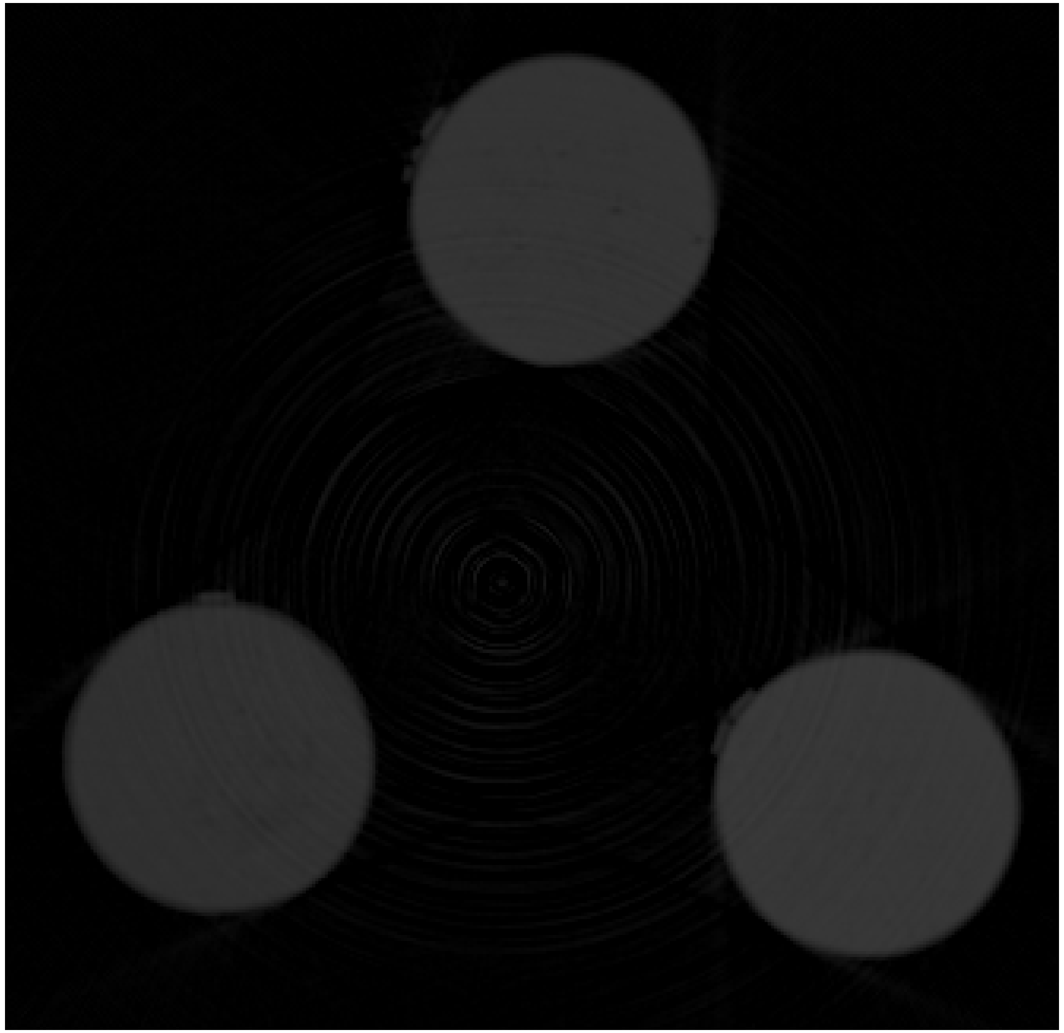
- Two 1 pound blocks of plasticized explosive simulant.
- Similar composition
- Used for various x-ray applications
  - Simulant has similar mass and density as material it mimics.

Mean Profile: Simulant-Plastic Explosive



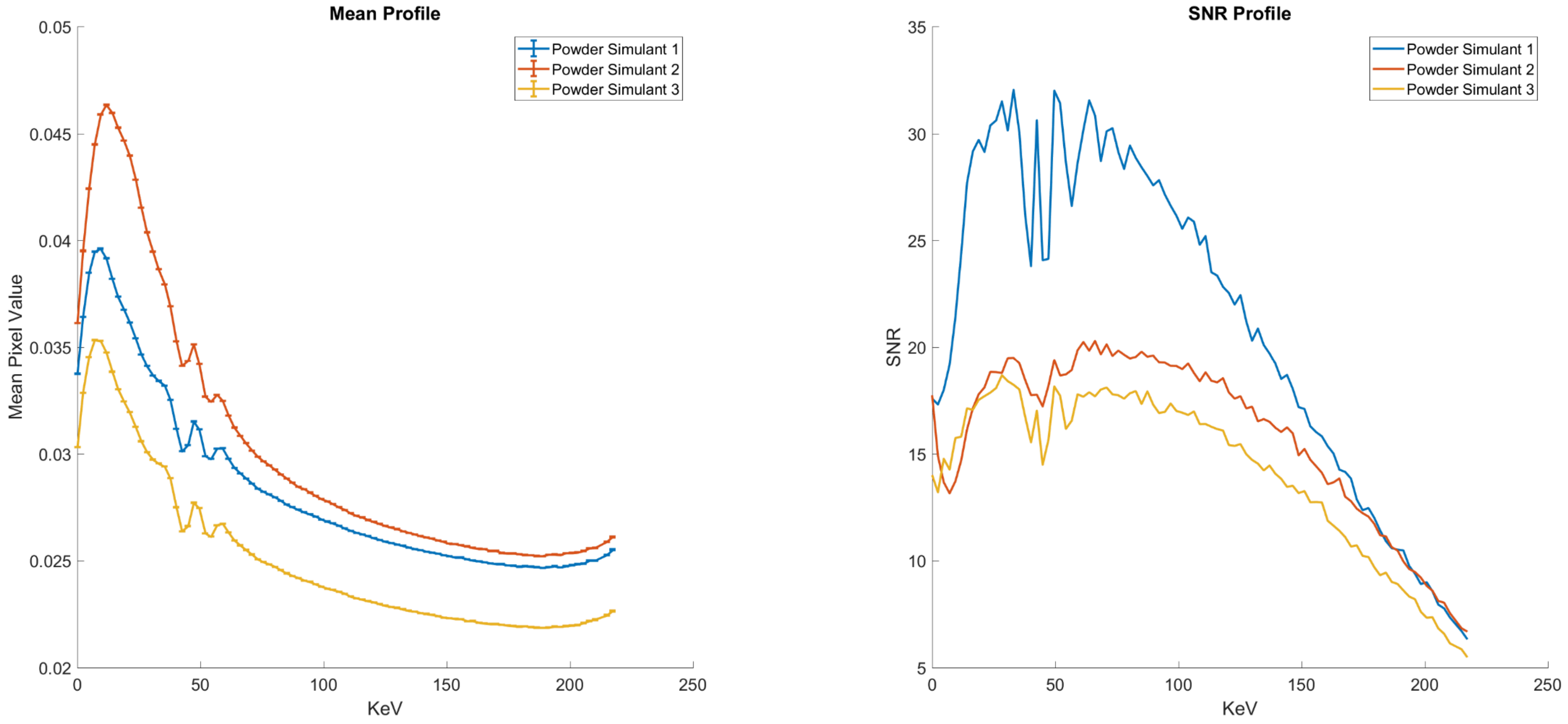


Data Acquisition: Simulant-Powder Explosives



- Three 1-inch diameter cylinders of powder explosive simulant.
- Three different compositions.
- Also used for various x-ray applications to mimic actual material of interest.

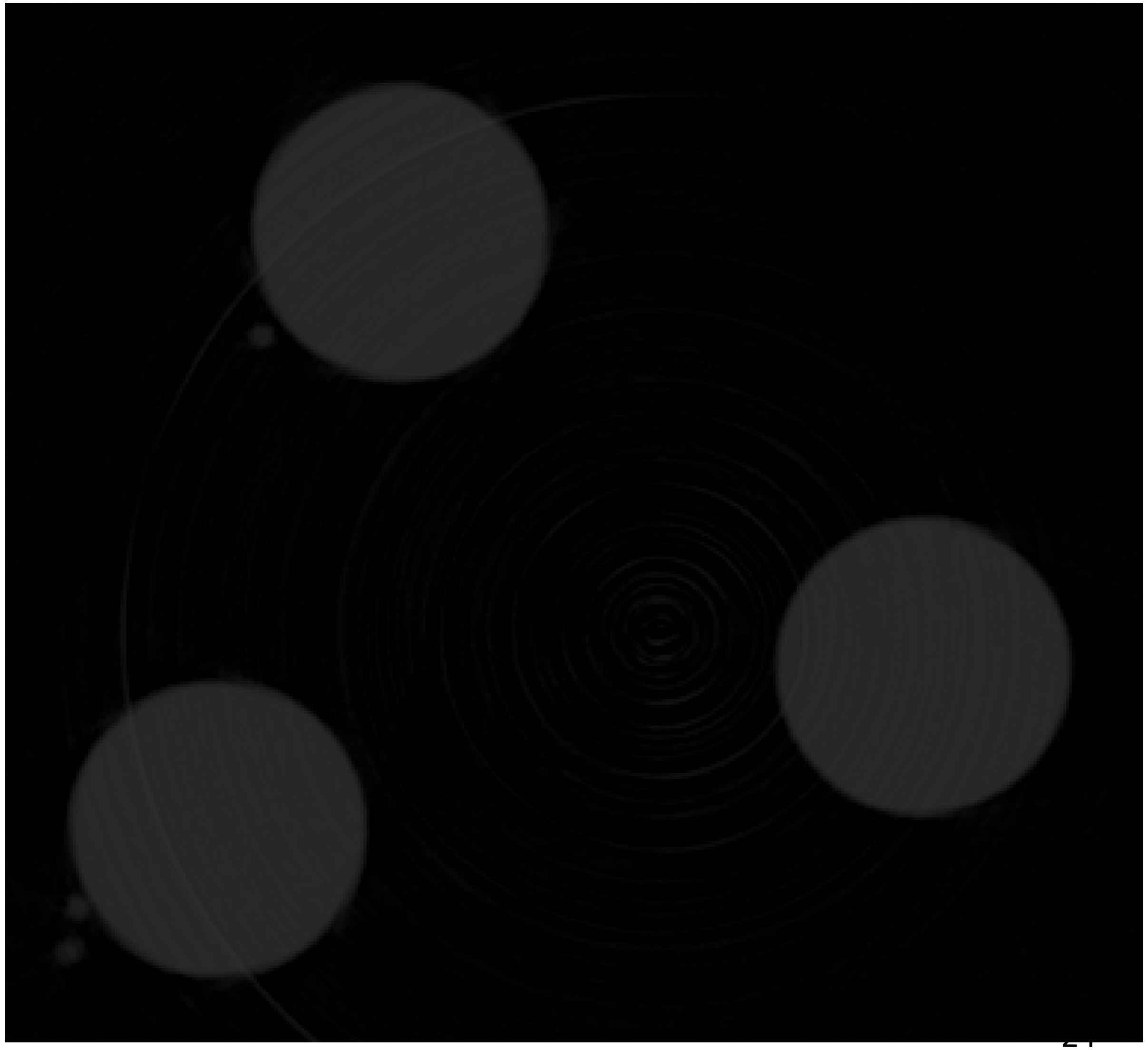
Mean Profile: Simulant-Powder Explosives



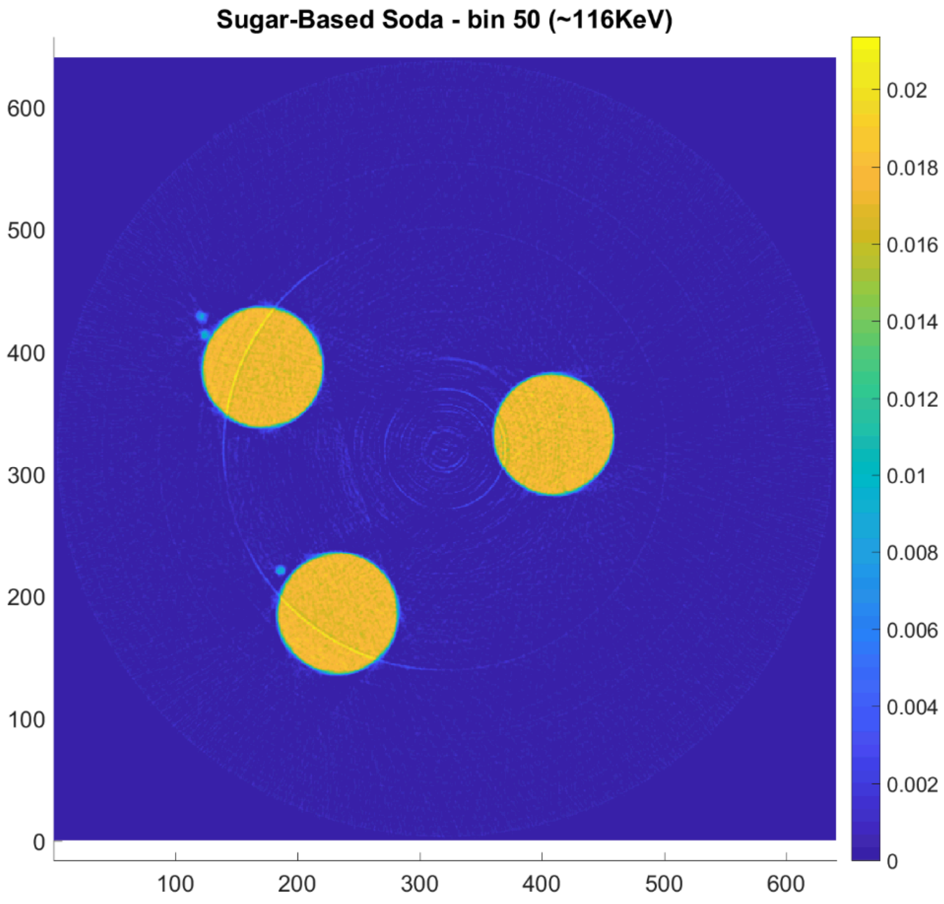
Data Acquisition: Sugar-Based Soft Drinks

- Three Sugar-based Soft drinks
  - Coke
  - Pepsi
  - 7-up

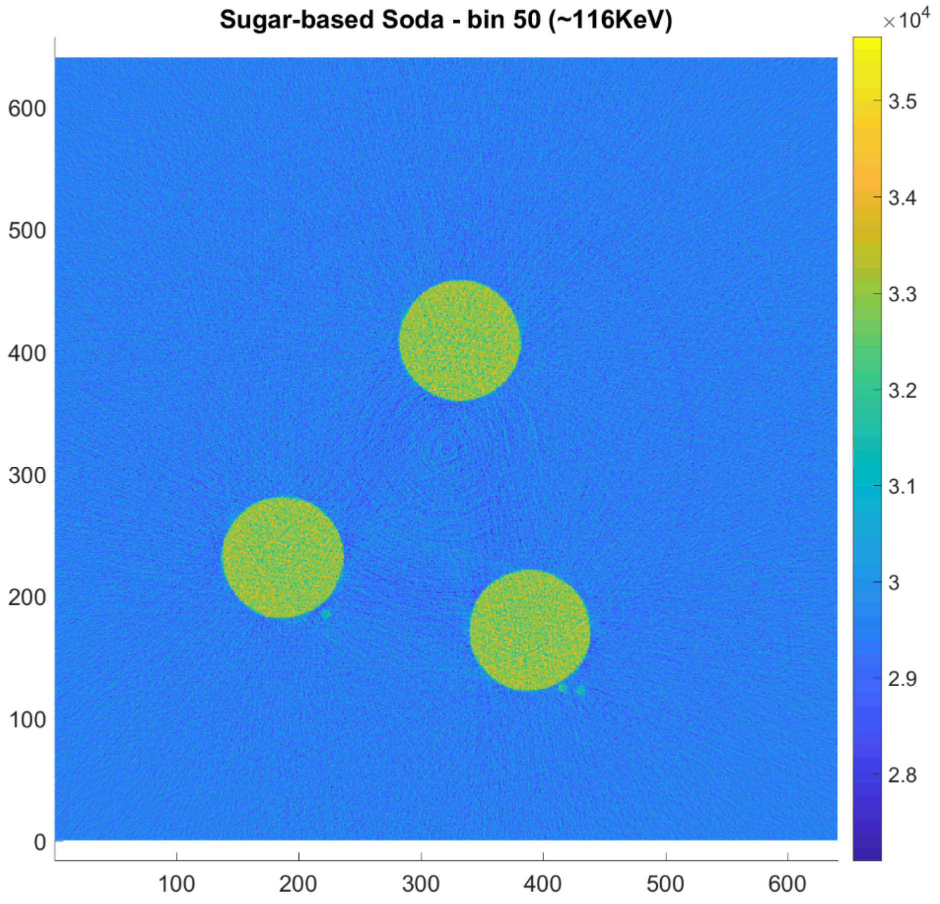
- As implied earlier, sugar seems to be the most distinguishing feature in the voxel profile.



Reconstruction: Sugar-Based Soft drinks

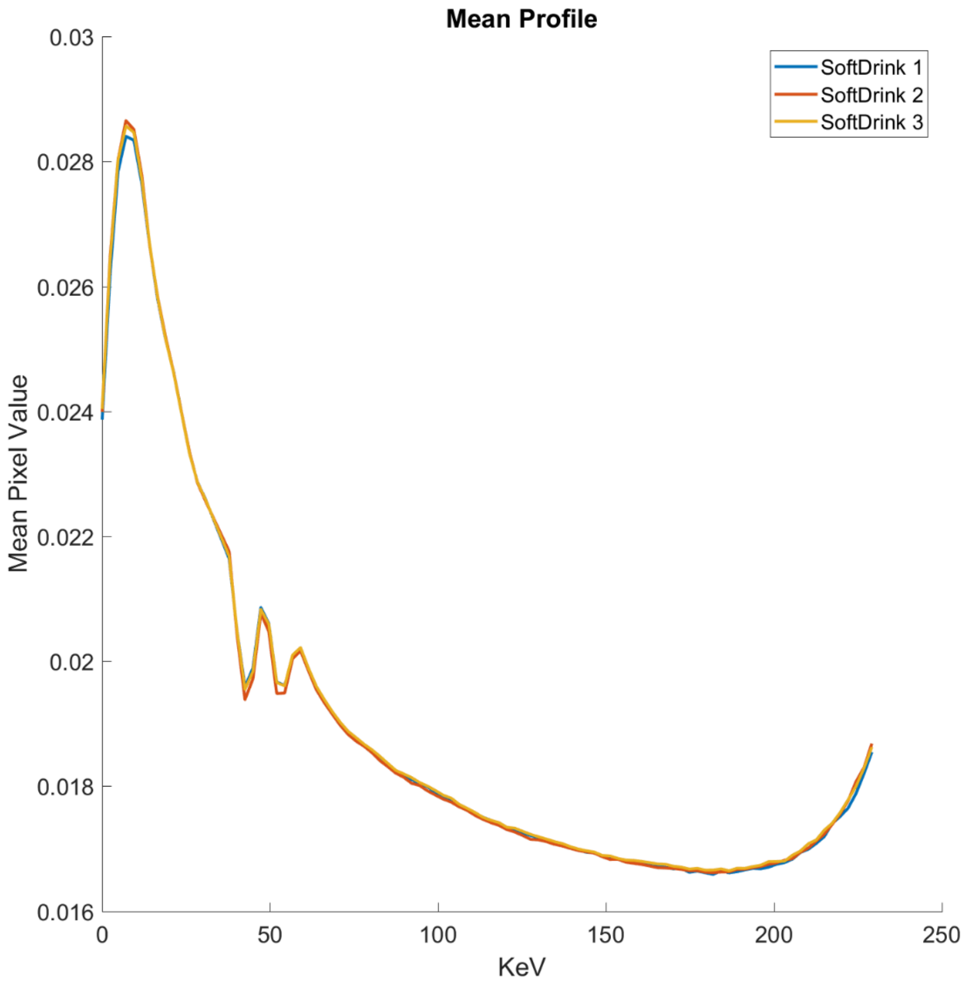


Recon

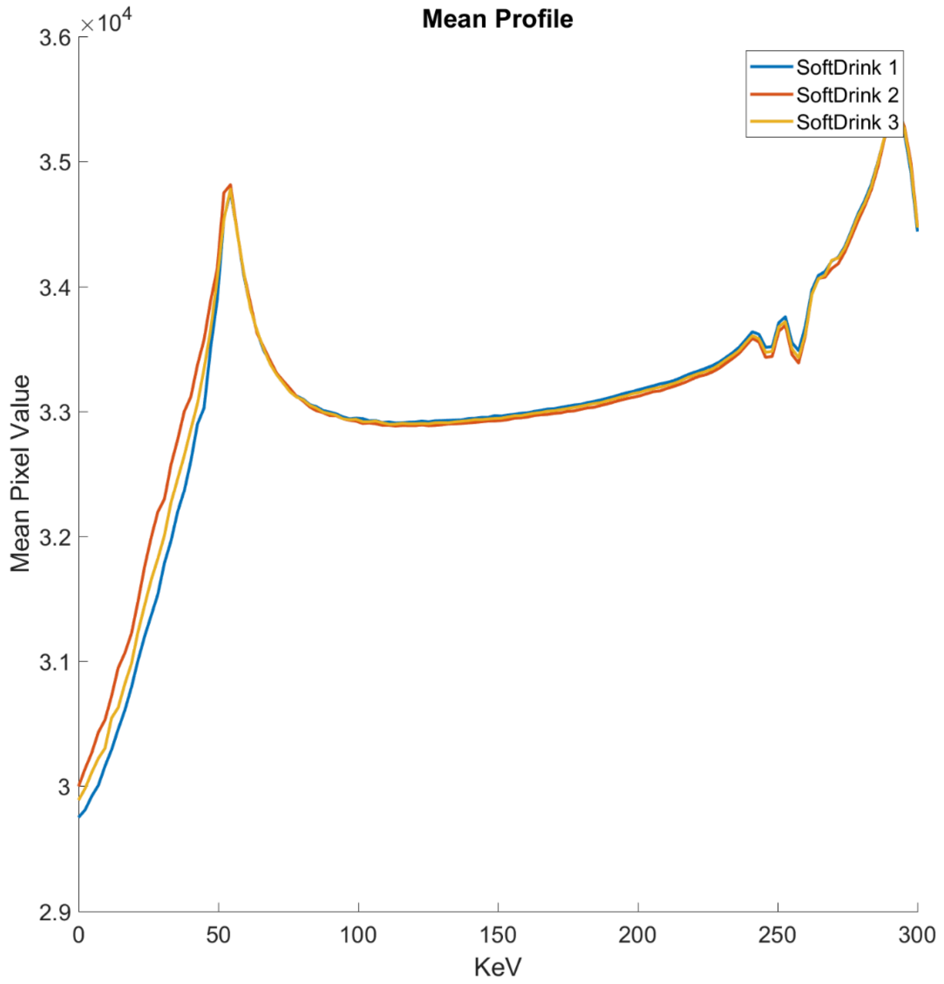


Volume Graphics

Reconstruction: Sugar-Based Soft drinks

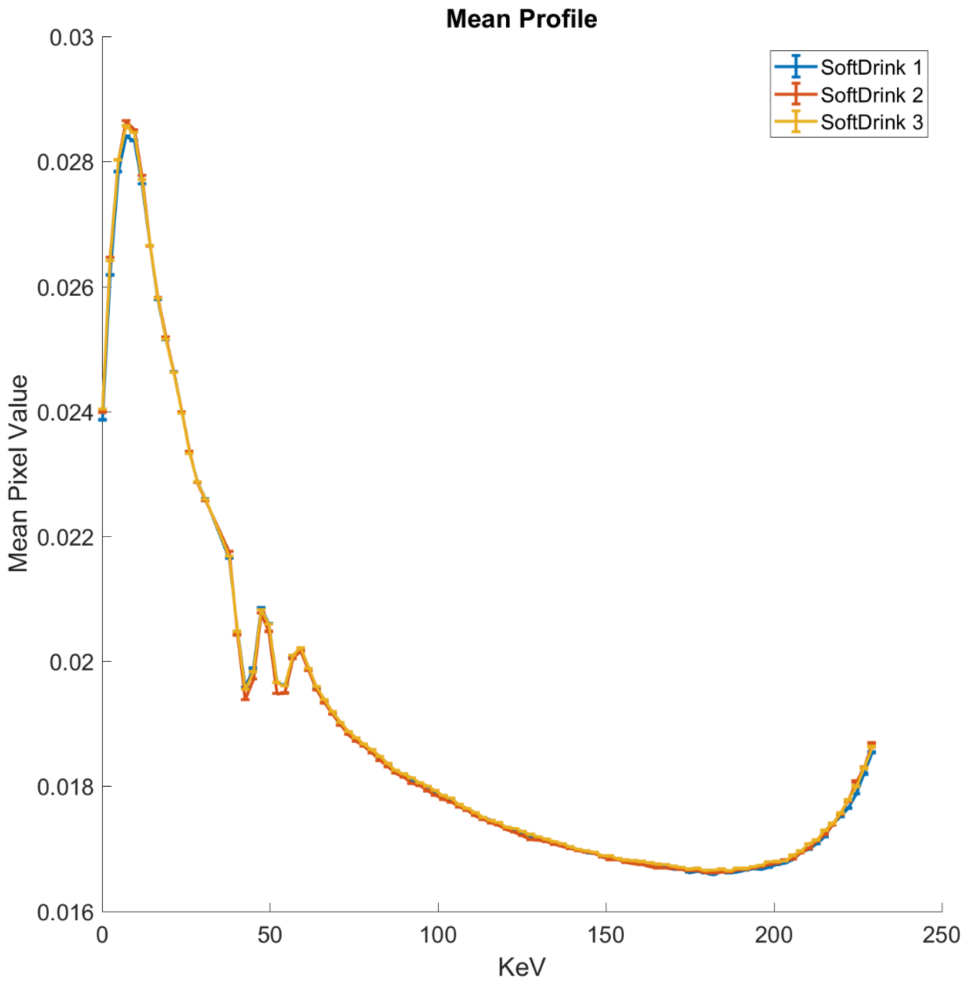


Recon

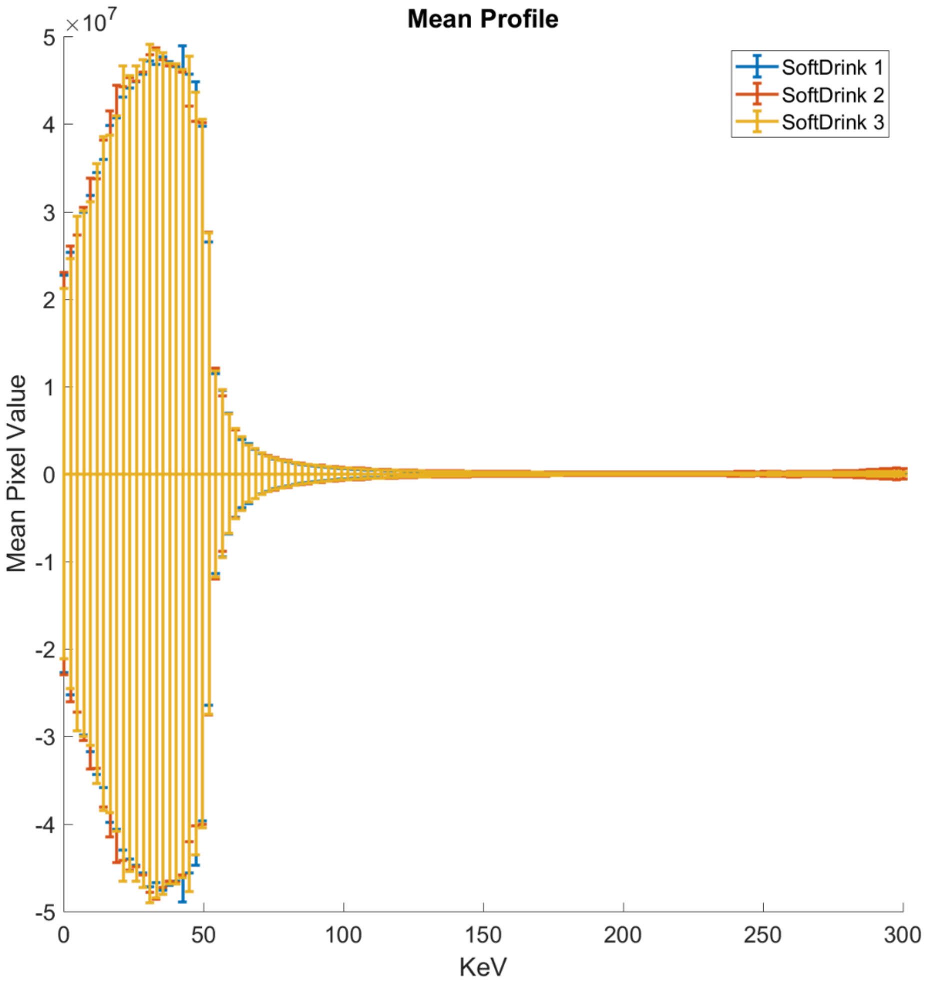


Volume Graphics

Reconstruction: Sugar-Based Soft drinks

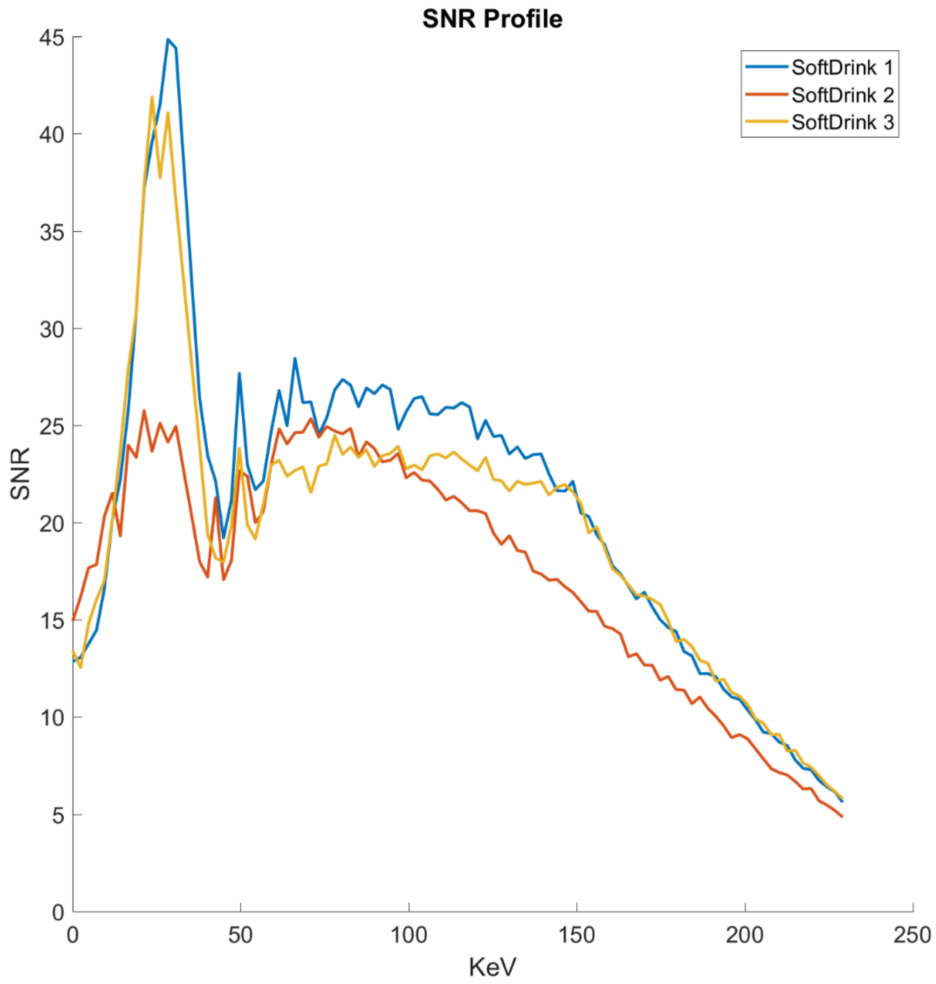


Recon

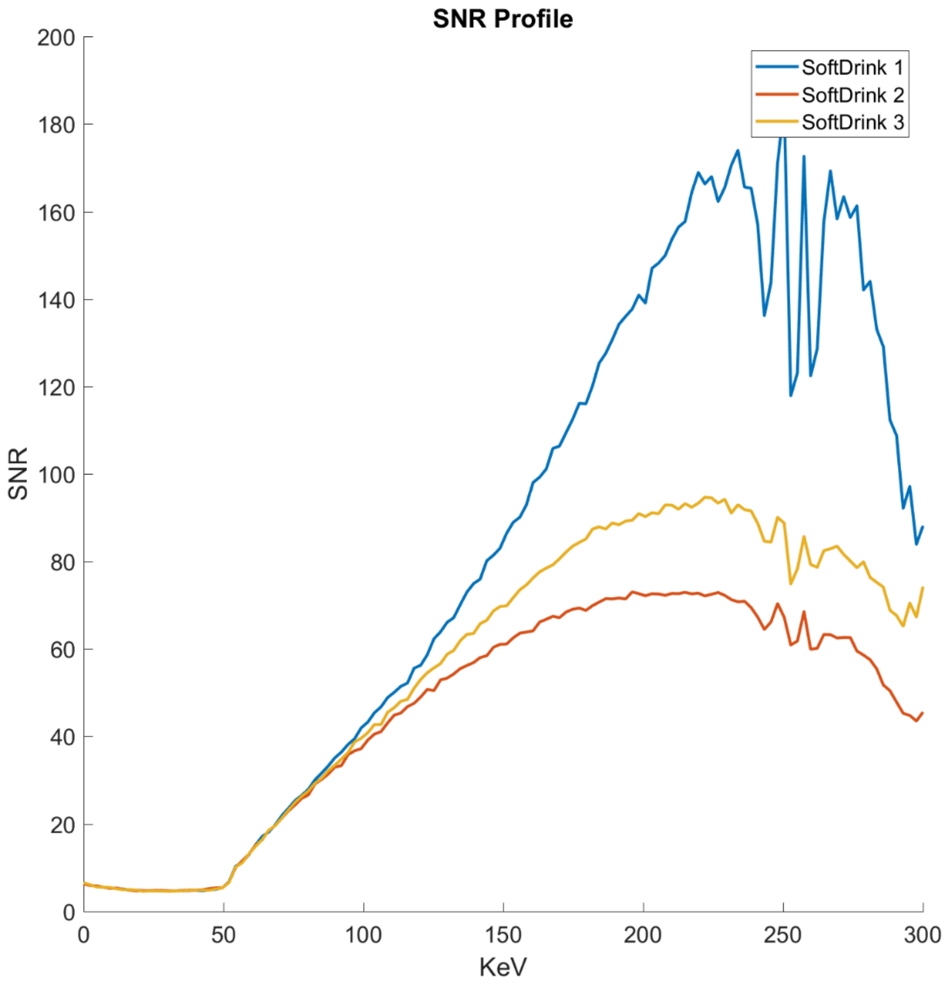


Volume Graphics

Reconstruction: Sugar-Based Soft drinks

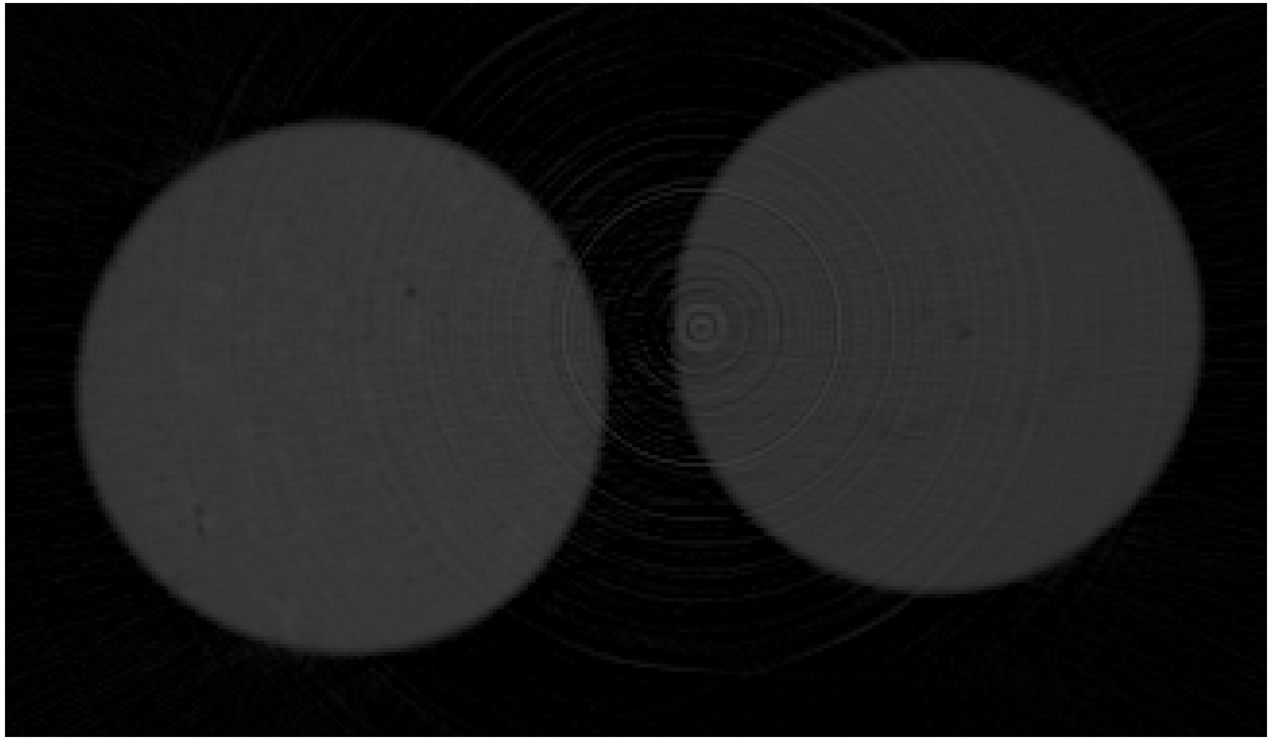


Recon

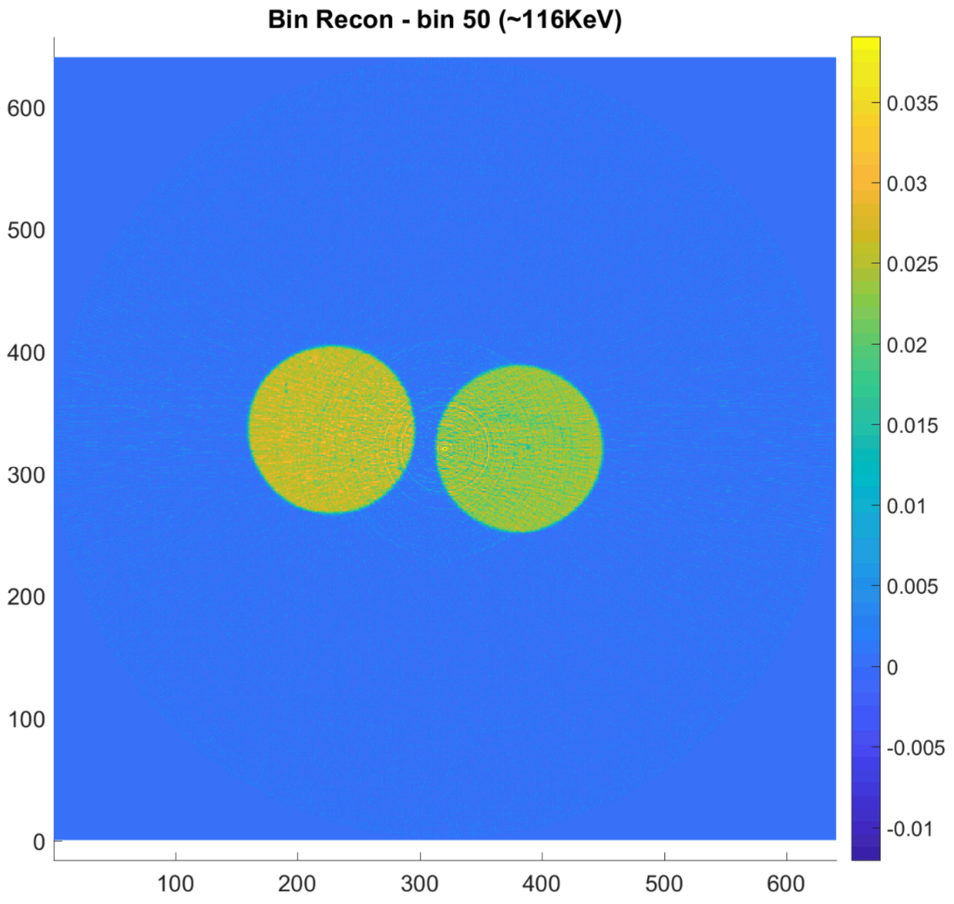


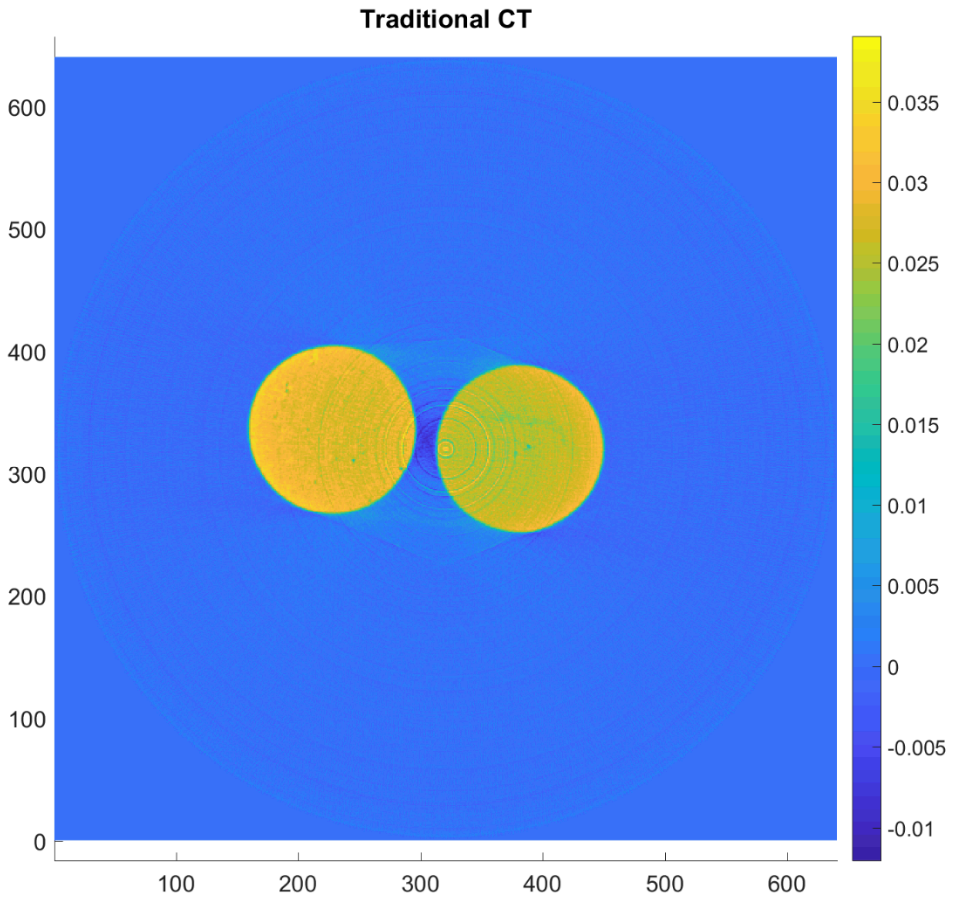
Volume Graphics

Data Acquisition: Wax Samples

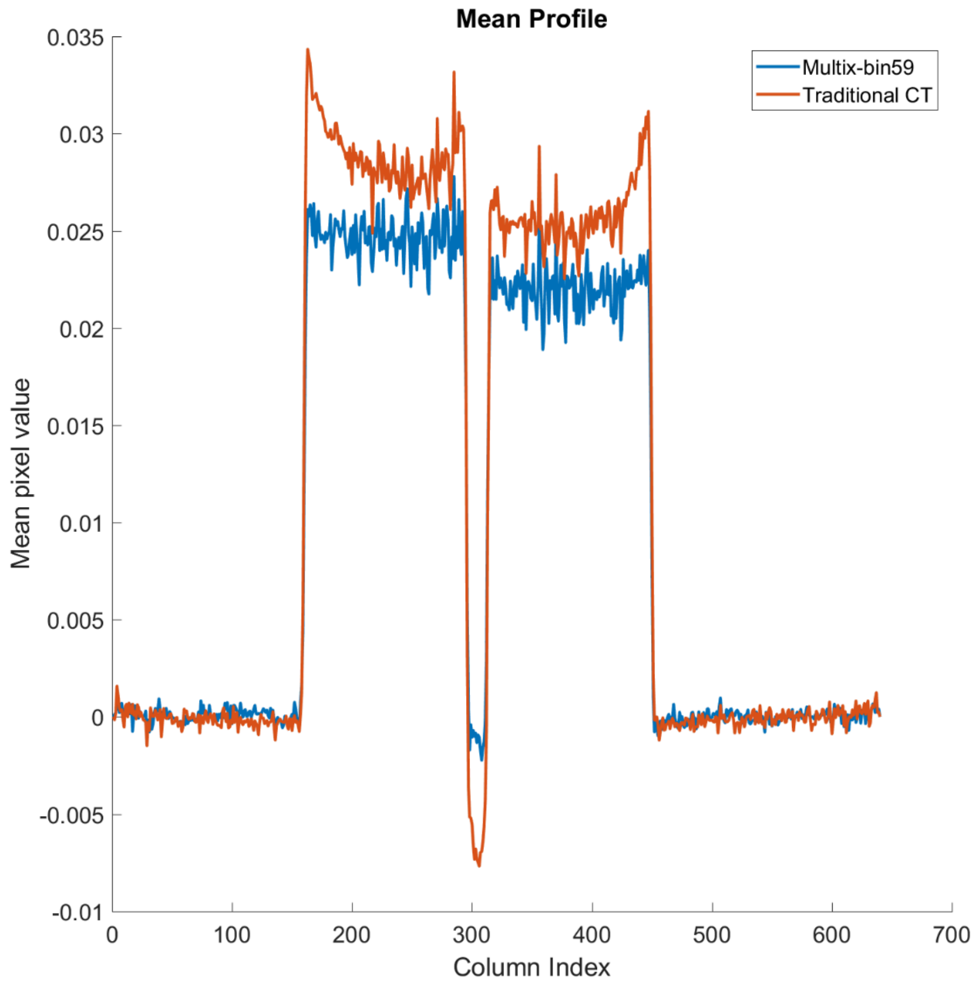


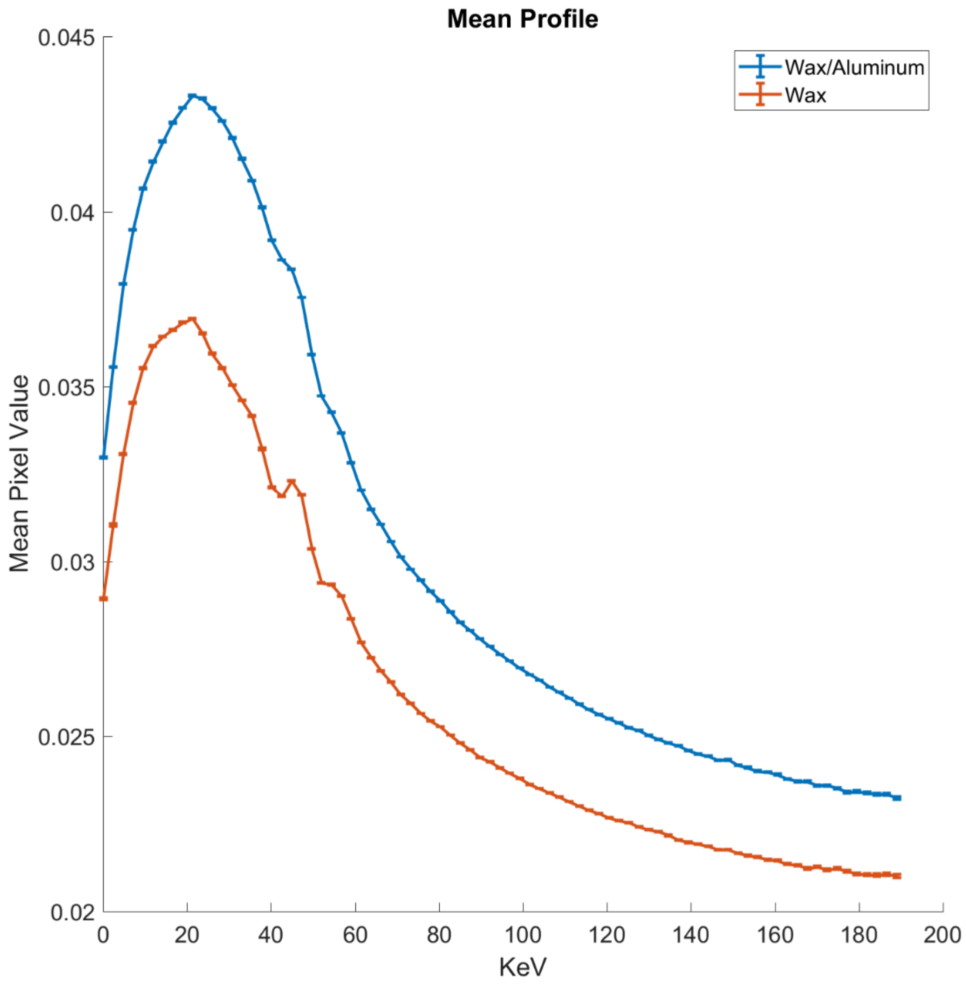
Reconstruction: Wax Cylinders





Reconstruction: Wax Profile



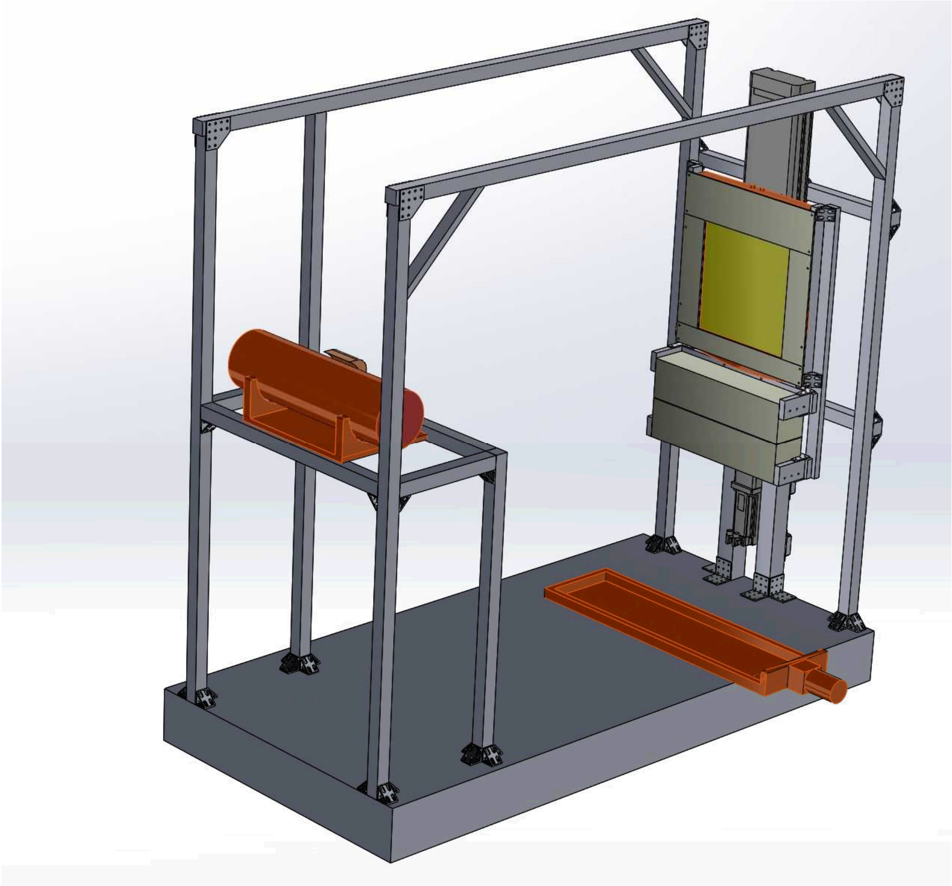


Conclusions

- Reconstruction of Raw data seems to yield usable data
  - Ring artifacts are present
  - While noise is significant, SNR is at reasonable levels for many applications
- Not all reconstruction algorithms are created equally
  - Can produce significantly different voxel statistics
  - Choice of algorithm may be application specific
- Use of spectral data can reduce artifacts
  - With cylindrical phantoms, beam hardening artifacts suppressed
  - Photon starvation results in somewhat noisy voxel information.

Looking to the future: Hardware

What we want…



Where we're at…

Looking to the Future: Reconstruction

- Calibration: Study potential methods
  - Limitations on calibrating with live sources
  - Limitations on access to tunable hardware parameters
  - Investigating Machine Learning-based methods to correction and calibration

- Investigate other methods
  - Can we integrate Hunter’s methods on spectral data to further realize improvements
  - Iterative reconstruction to further reduce artifacts
  - Investigate methods which simultaneously leverage information from several channels of data.

Thank you

- Questions?