Oak Ridge National Laboratory

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Radiation Scene Reconstruction with Multiple Gamma-Ray Imagers

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U.S. DEPARTMENT of ENERGY

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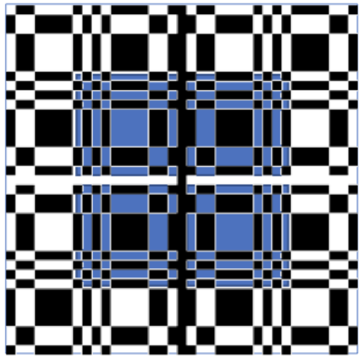
Gamma-Ray Imaging

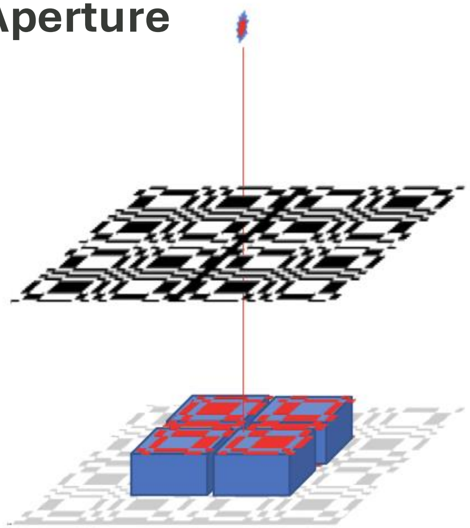
- Too high energy for focusing optics!
- Common imaging modes:

Coded Aperture:
Good Angular Resolution (~5°)
Limited FOV

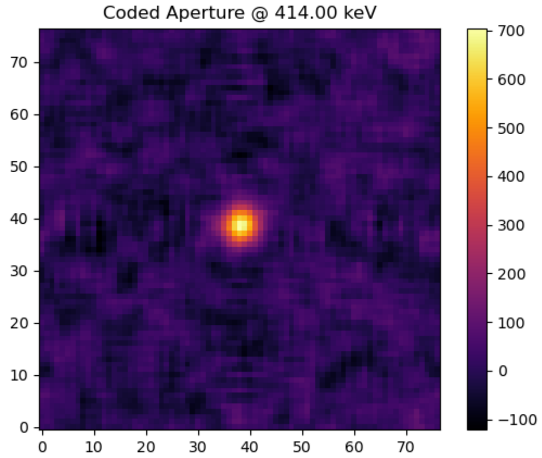
Compton:
Full-sky coverage
Poorer resolution (~15°)

Coded Aperture



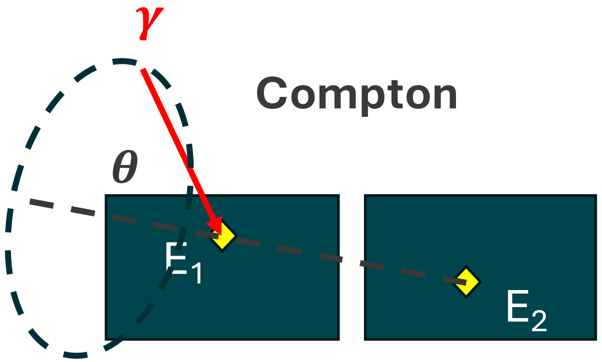


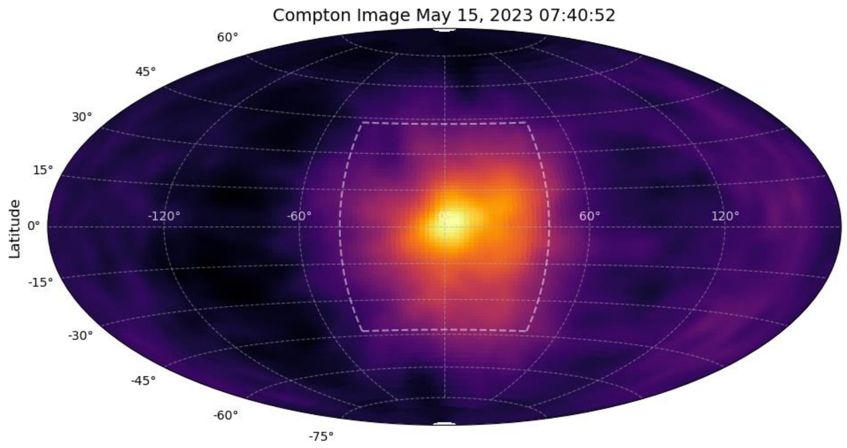
Source in the center of the FOV



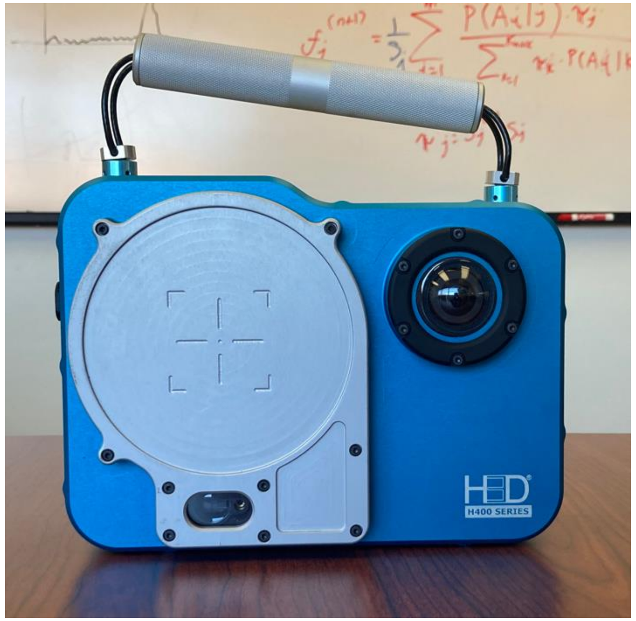
< 500 keV

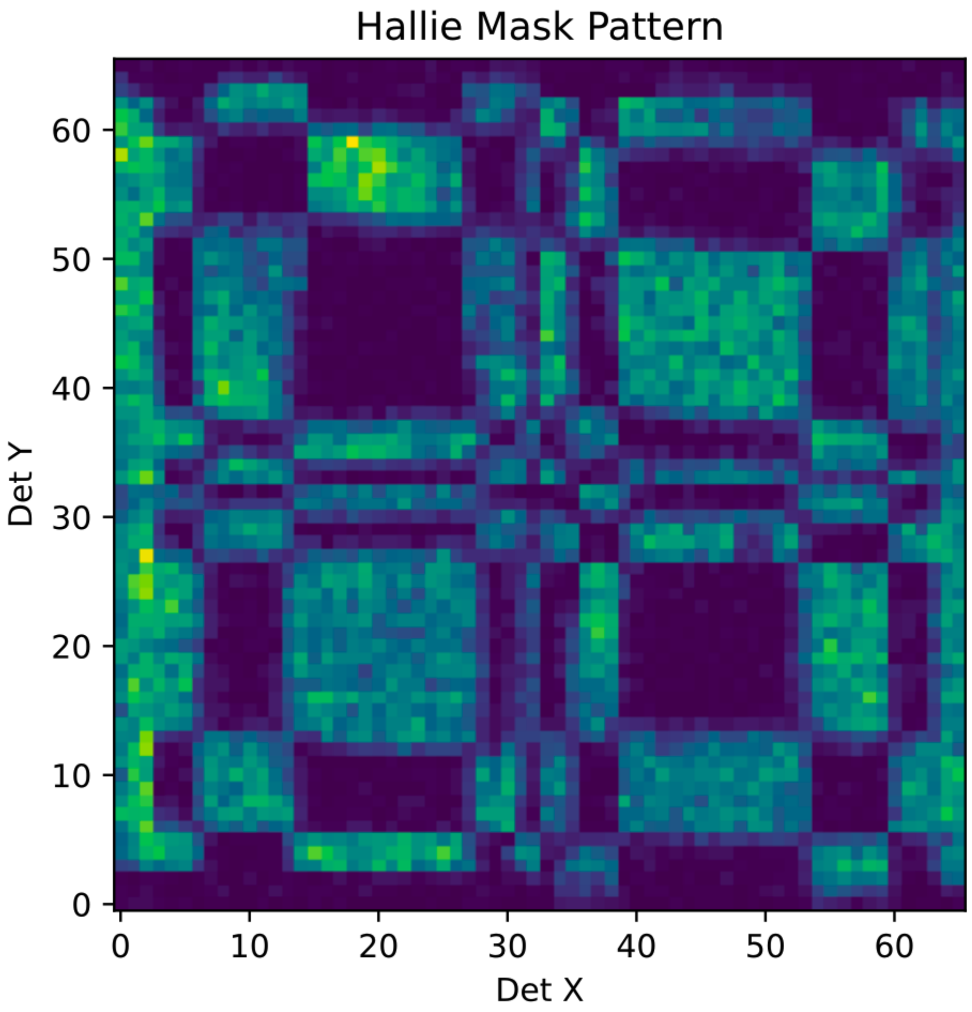
Compton





H3D CZT Imager



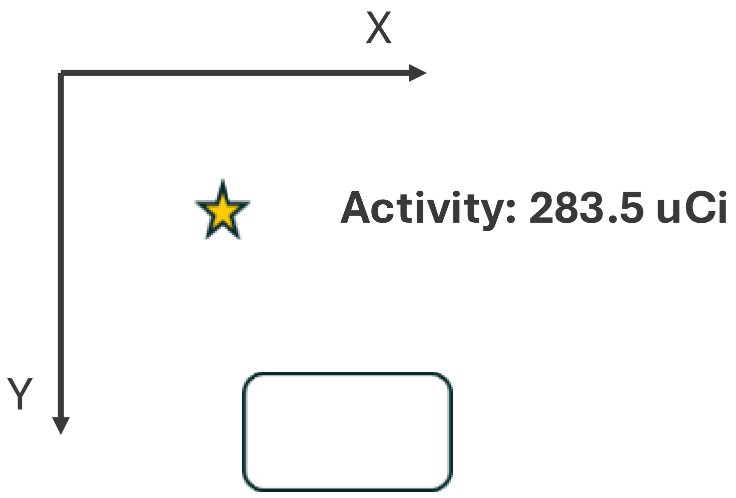


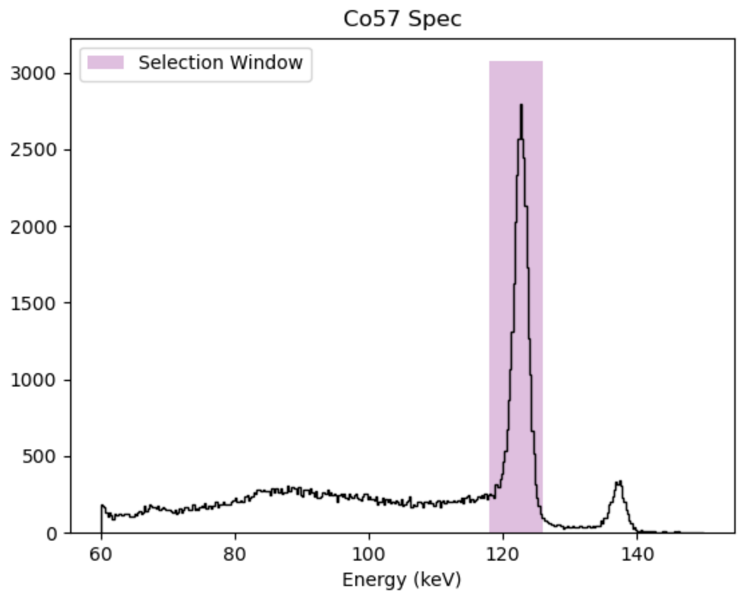
Mask Hit Pattern for Source Directly in Front of Imager

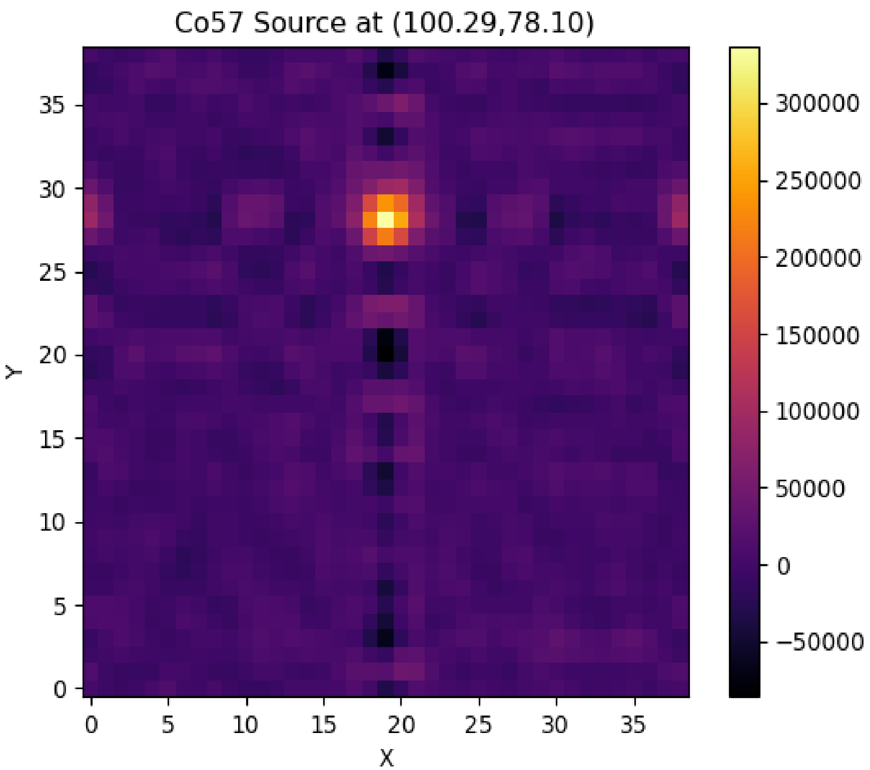
- H420 imager capable of coded-ap and Compton imaging.
- Detection element: 4 CZT crystals (2.2 x 2.2 x 1 cm).
- Position-sensitive (~0.5 mm spatial resolution)

Imaging a Point Source

- Co57 calibration source is scanned across the field of view of the detector at a distance of 1 meter.
- These calibrations are necessary for understanding the imaging efficiency as a function of location within the FOV.
- Image created using event selection about the 122 keV peak.







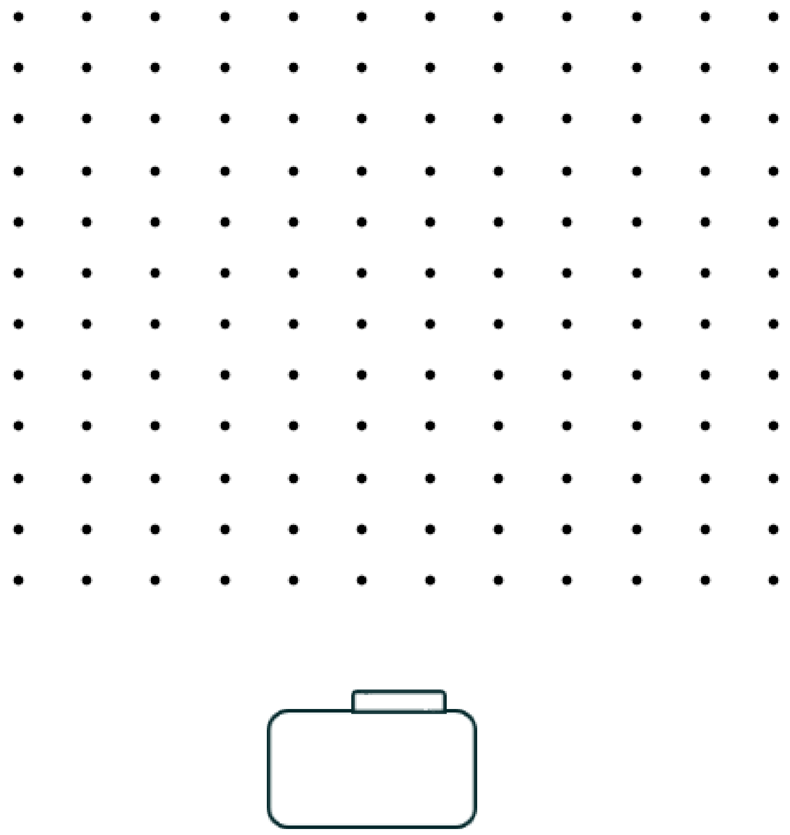
Linear Regression Reconstruction

Linear regression reconstruction seeks to reproduce the observed data using a combination of precalculated detector responses. It assumes the following:

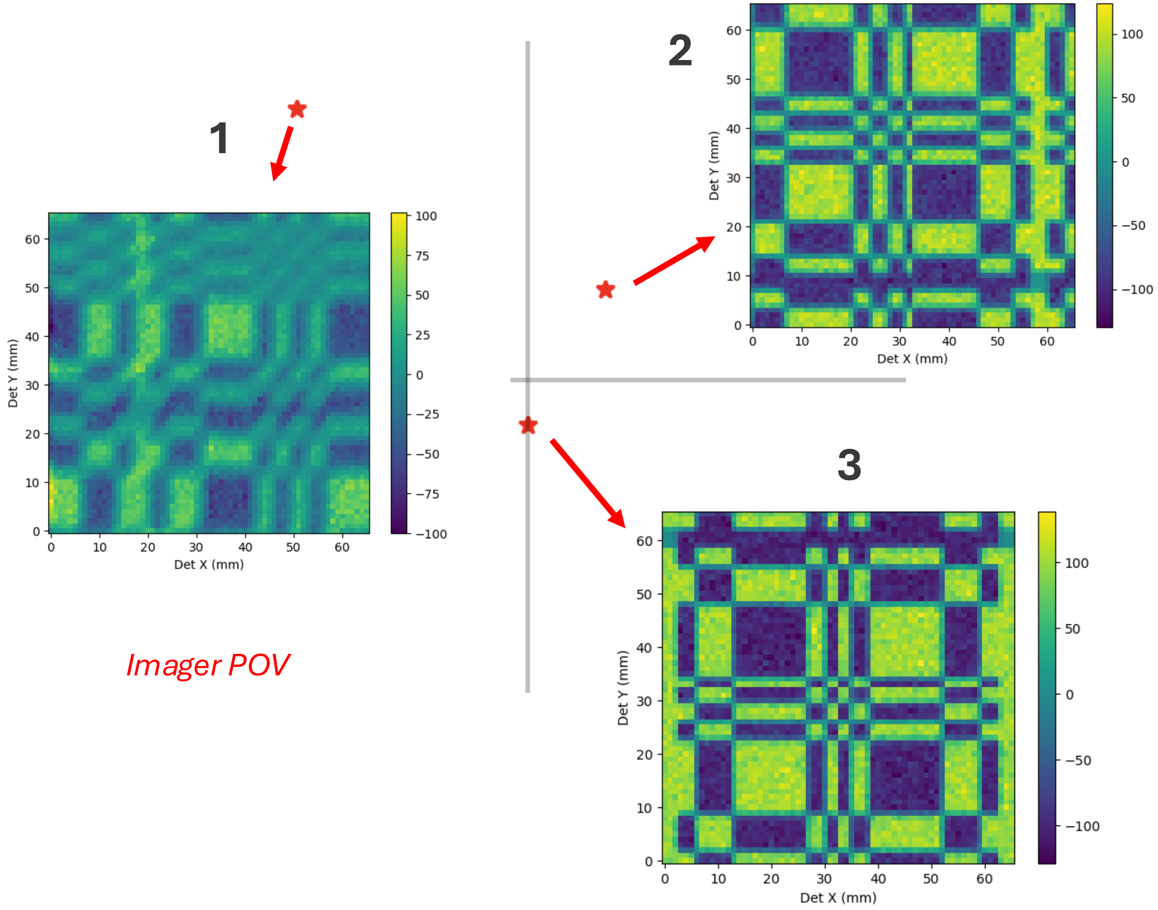
1. We can predict what the shadow pattern on the detector will look like for any arbitrary location in the field of view (via ray tracing or MC).

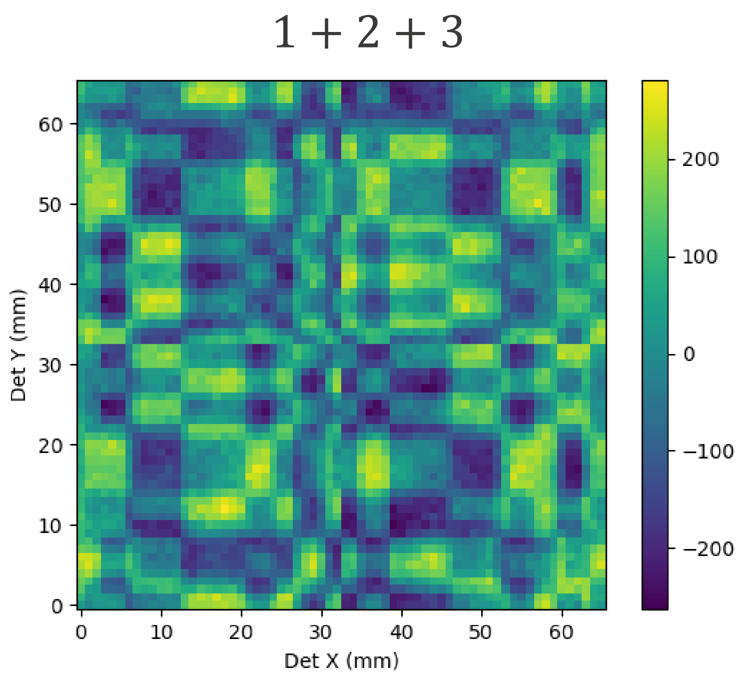
2. A basis set of possible patterns can be constructed that represents some volume in the FOV.

3. Any measured detector pattern can be described by some linear combination of the predicted patterns in the constructed basis set.



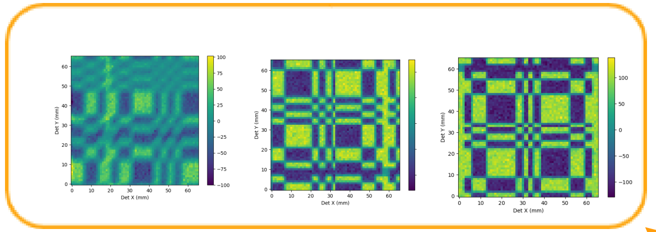
Linear Regression Reconstruction

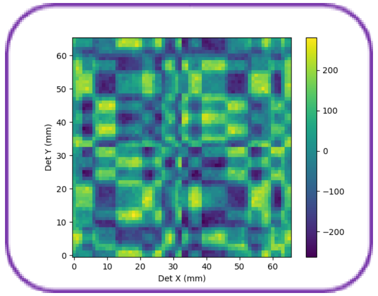




- Patterns from each basis point contribute with some weight w_i to generate a predicted detector pattern.
- At each iteration, the difference between the observed pattern and the prediction is calculated.
- Coefficients for the basis points (w_i) or updated until the overall difference between prediction and observation is minimized.

Elastic Net Model





L1 Norm (Sparsity)

$$\min_{w} \frac{1}{2n_{\text{samples}}}||Xw - y||_2^2 + \alpha\rho||w||_1 + \frac{\alpha(1-\rho)}{2}||w||_2^2$$

Ordinary Least Squares

L2 Norm (Collinearity)

Hou Zou and Trevor Hastie (2005)

α – penalty strength

ρ – L1 to L2 Ratio

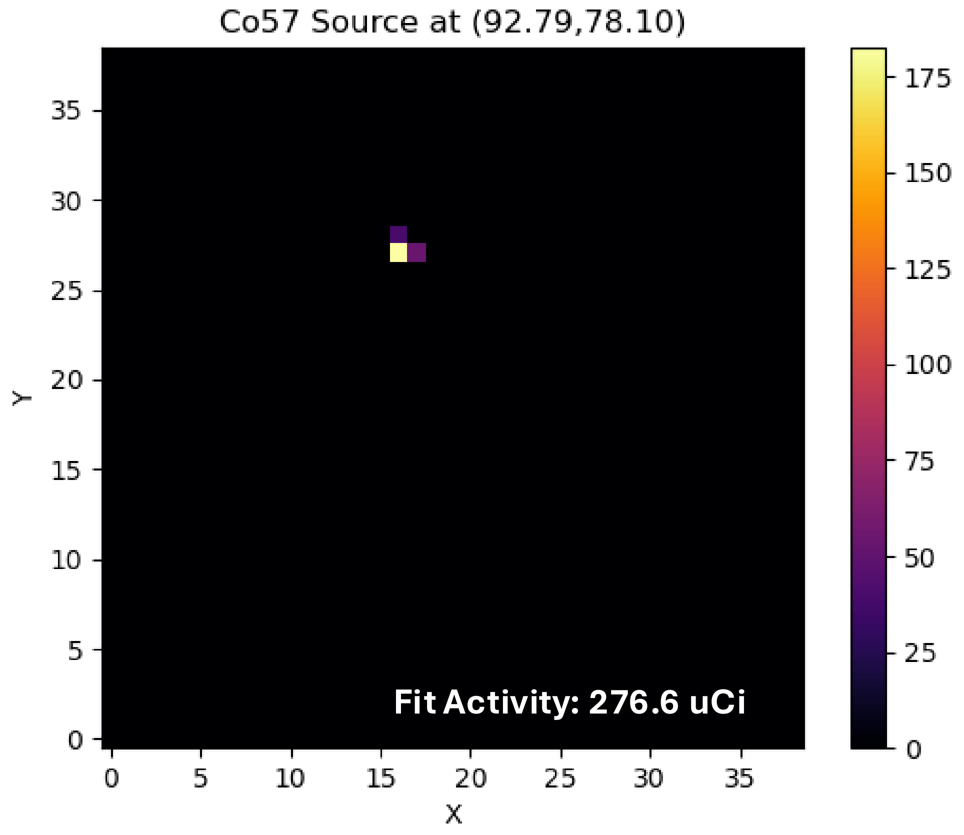
Elastic net uses two regularization terms to overcome issues that can commonly arise with OLS regression.

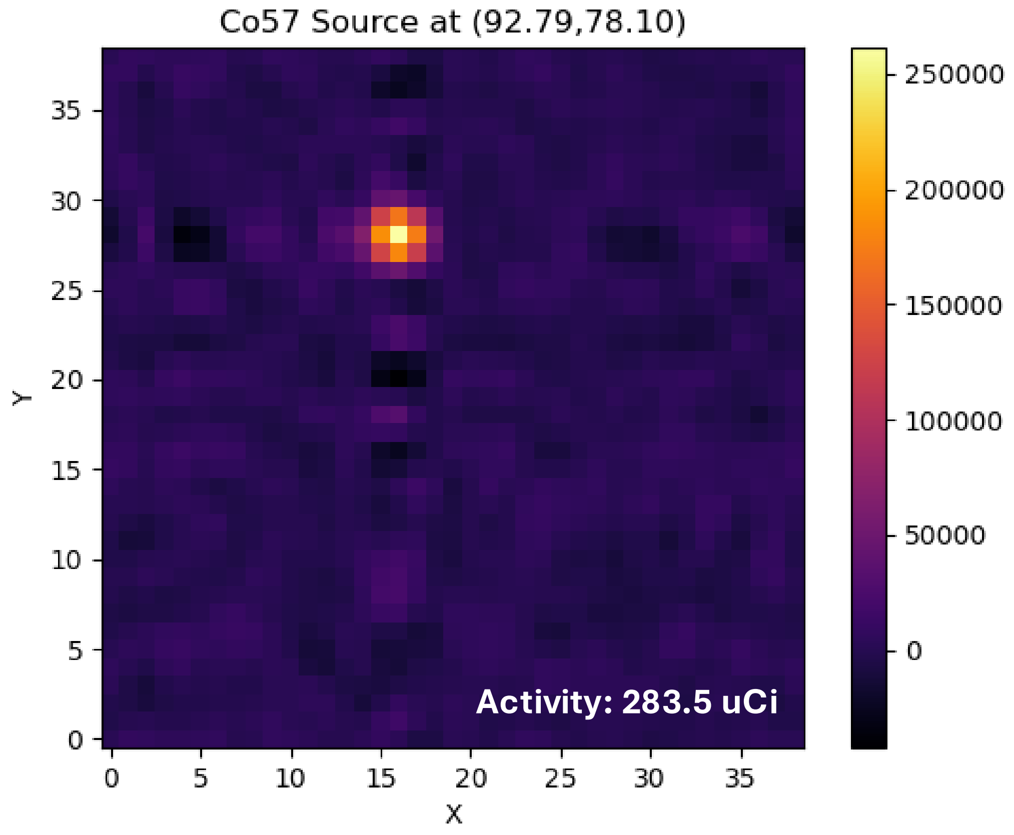
The L1 term seeks to keep the overall scale of the coefficients low (therefore concentrating on the most relevant).

The L2 term helps with feature selection and equal weighting to highly correlated predictors.

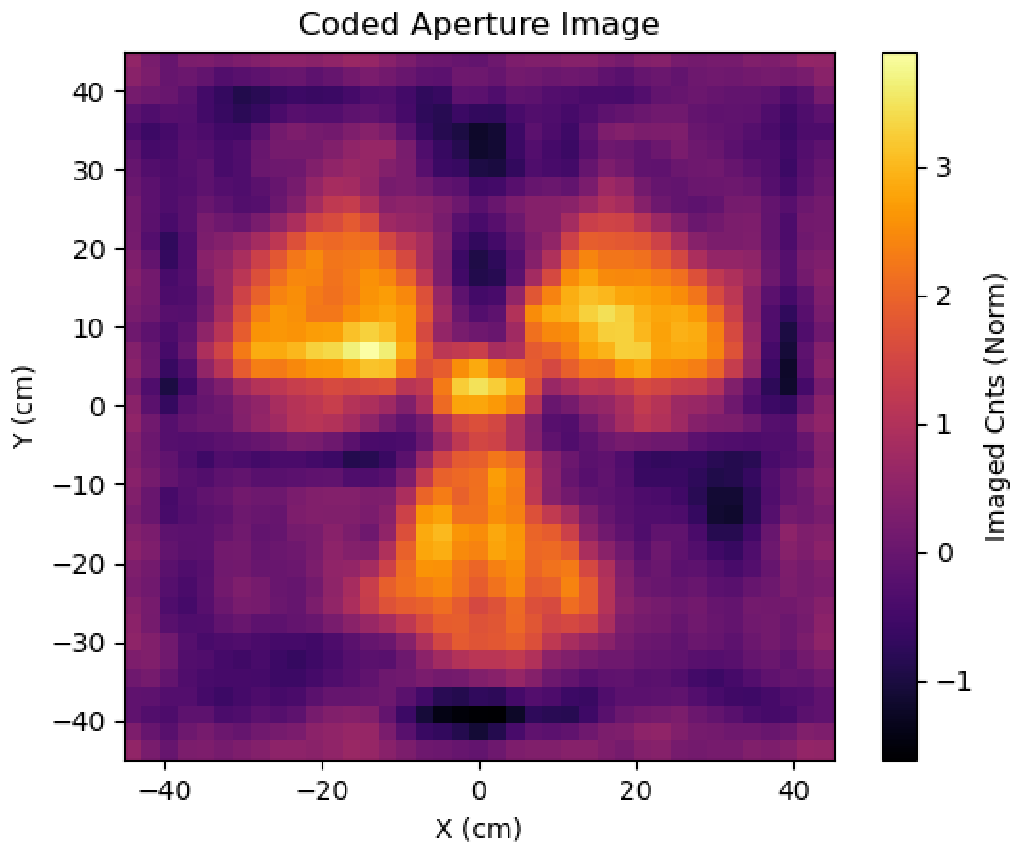
$\rho = 0 \rightarrow$ Ridge Regression
$\rho = 1 \rightarrow$ Lasso Regression

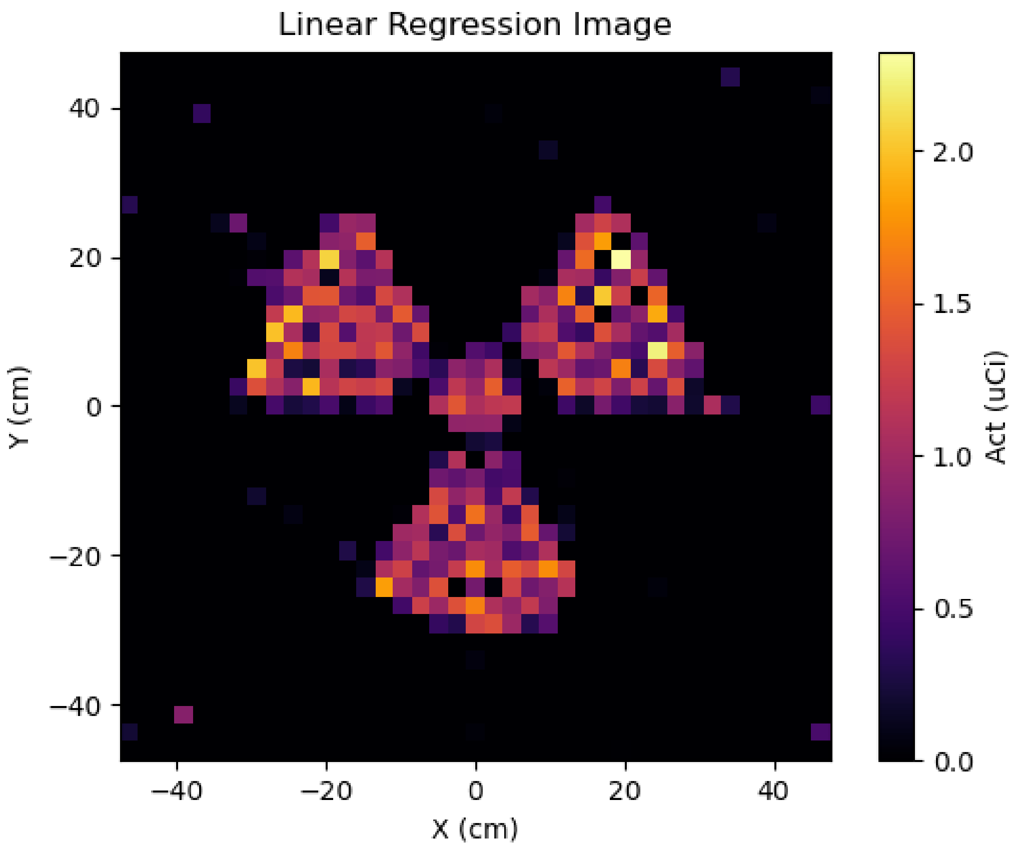
Calibration Point Source – LR Fit





Extended Source Test

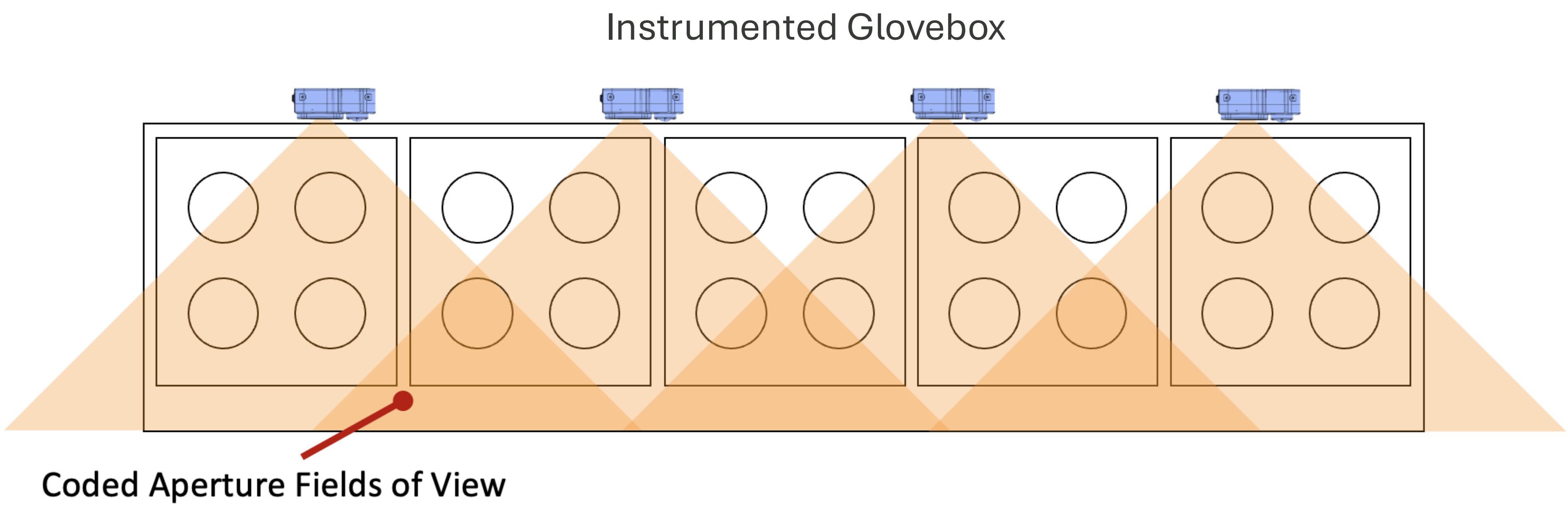




Fit Activity: 251.72 uCi

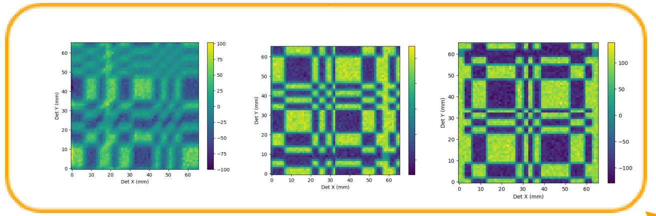
True: 283.5 uCi

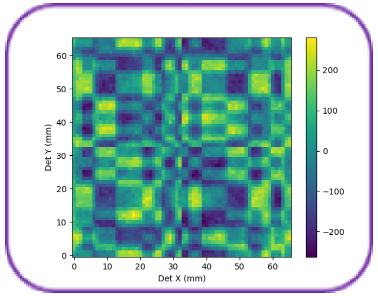
Multiple Imager System



- An instrumented glovebox could provide continuous monitoring of material that’s being processed.
- Each detector provides its own image – what’s the best way to combine this information?

Extending to Multiple Imagers





$$\min_{w} \frac{1}{2n_{\text{samples}}} ||Xw - y||_2^2 + \alpha\rho||w||_1 + \frac{\alpha(1-\rho)}{2}||w||_2^2$$

(M x B matrix)

(*B-length vector*)

M: Number of locations in basis set

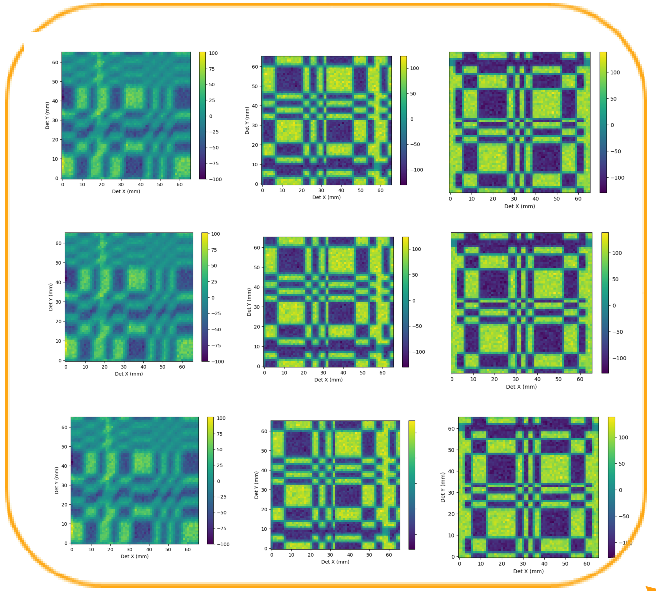
B: Number of bins in subtracted data histogram

Extending to Multiple Imagers

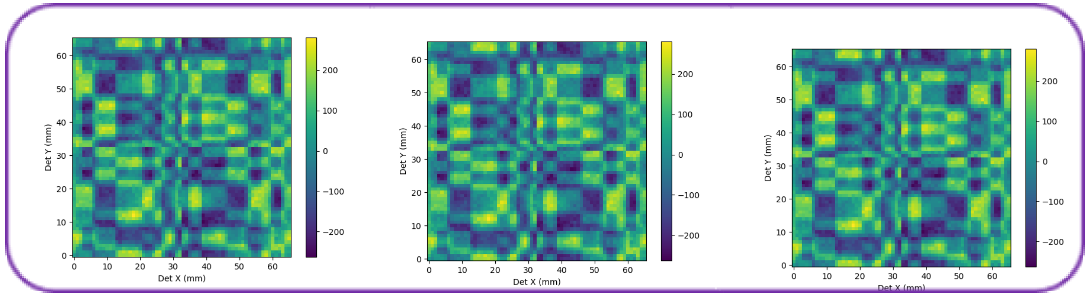
Imager *n*

Imager 1

Imager 1



Imager 1 | Imager 1 | Imager *n*



$$\min_{w} \frac{1}{2n_{\text{samples}}} ||Xw - y||_2^2 + \alpha\rho||w||_1 + \frac{\alpha(1-\rho)}{2}||w||_2^2$$

(M x (N·B) matrix)

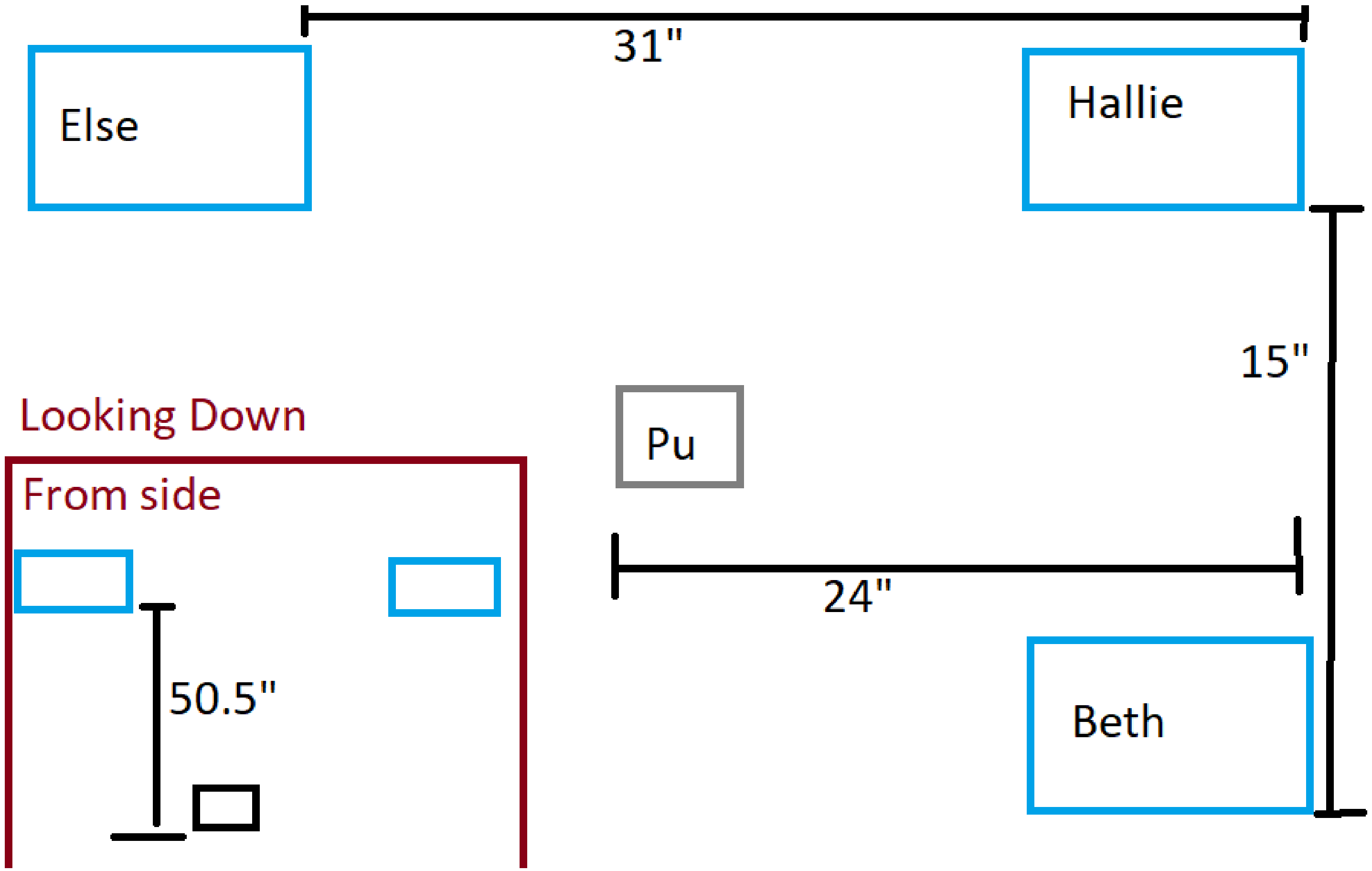
(N·B *-length vector*)

M: Number of locations in basis set

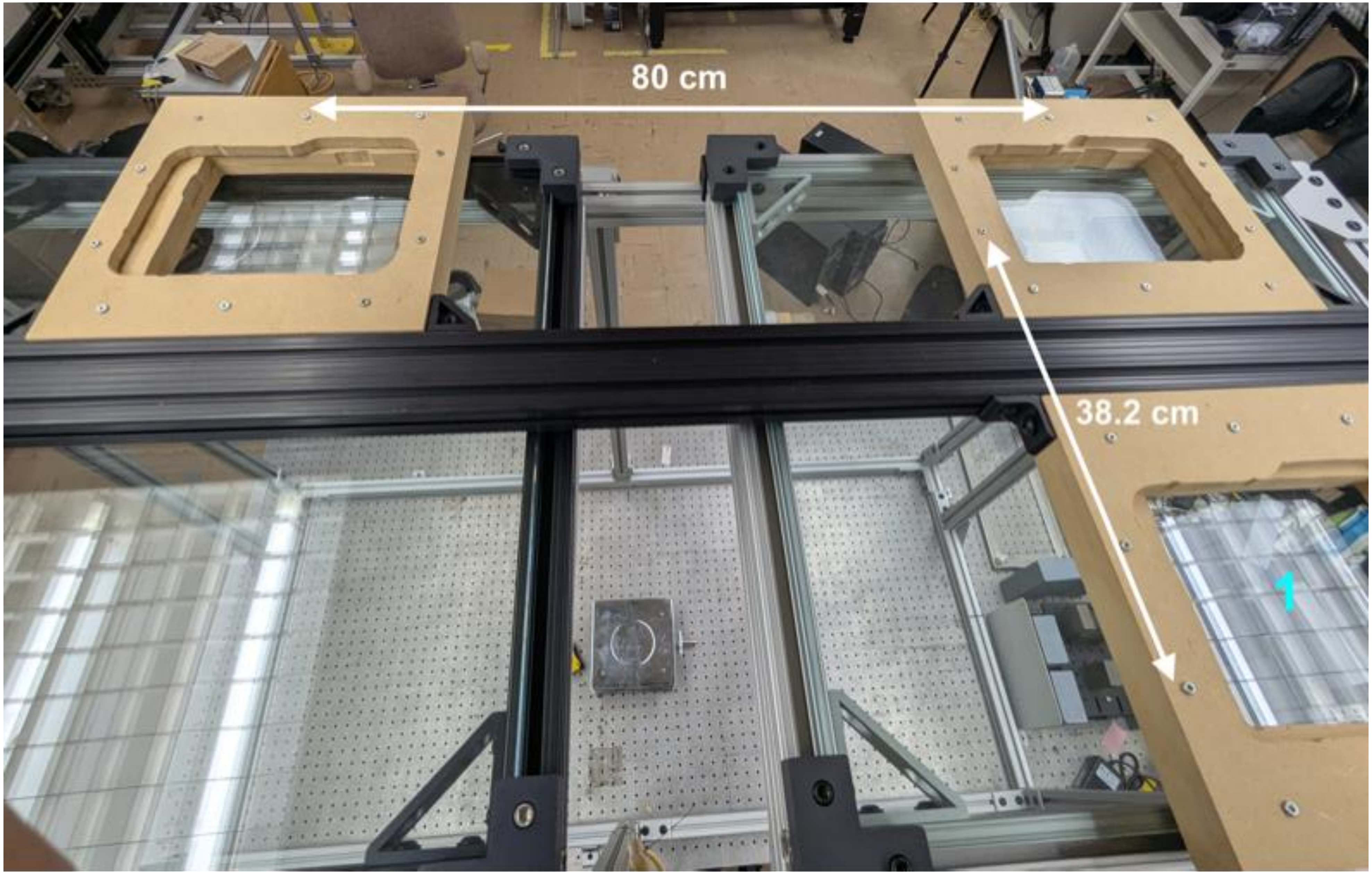
B: Number of bins in subtracted data histogram

N: Number of imagers in system

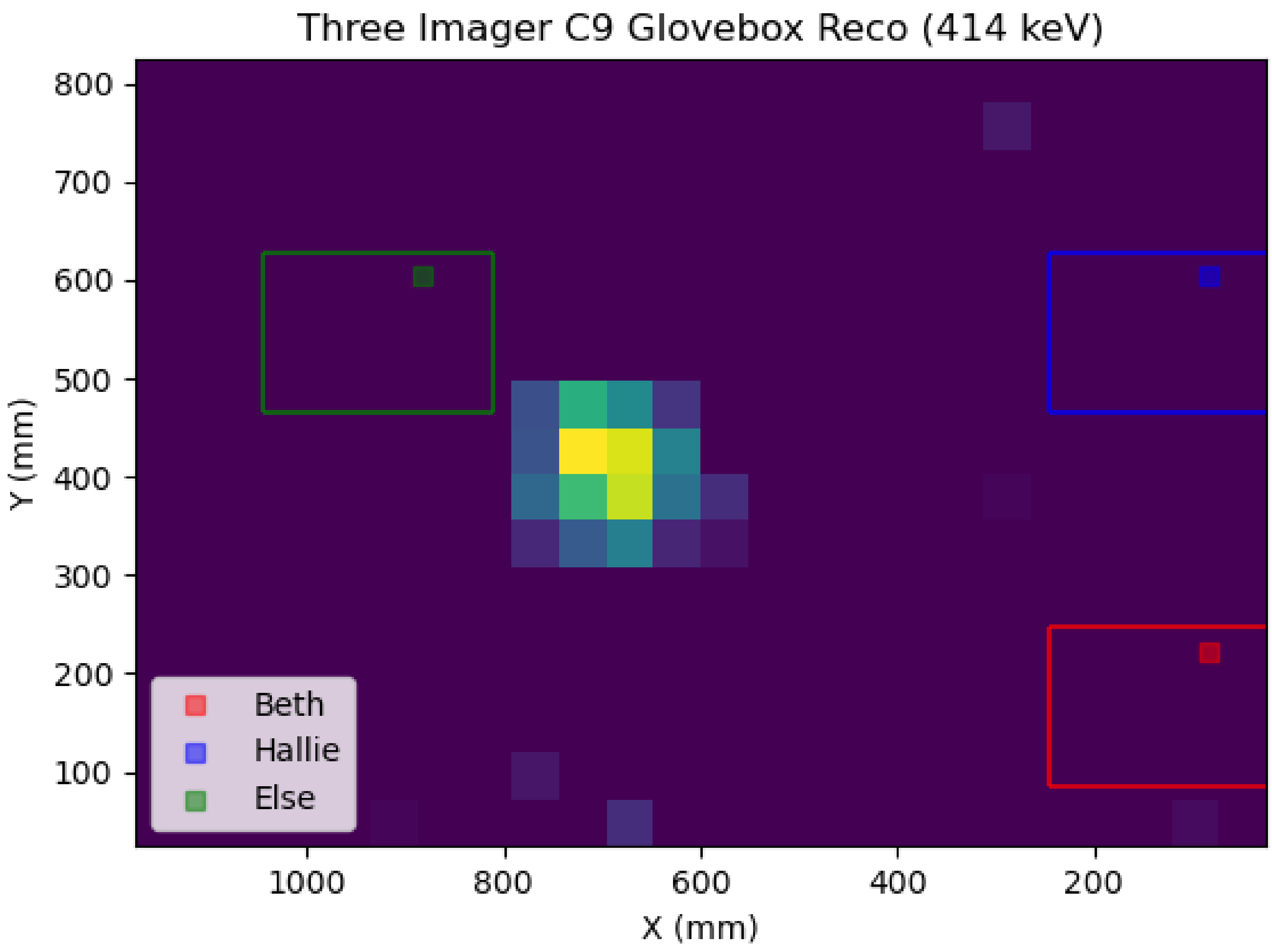
Three Imager Mock Glovebox



Three Imager Mock Glovebox

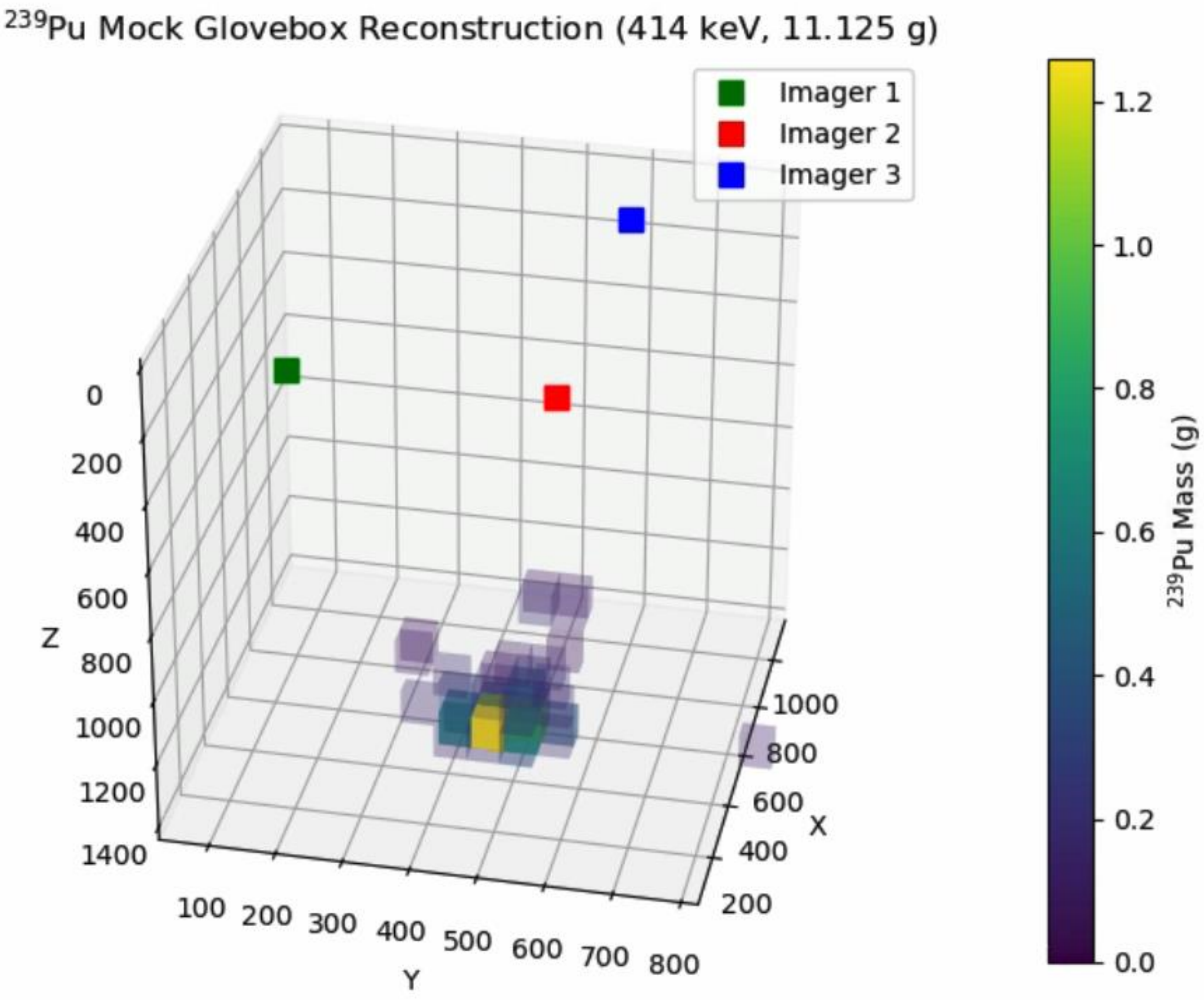


Multi-Detector Linear Regression Fit



Reco Mass: 12.2 g
Actual: 9.38 g

Multi-Detector Linear Regression Fit



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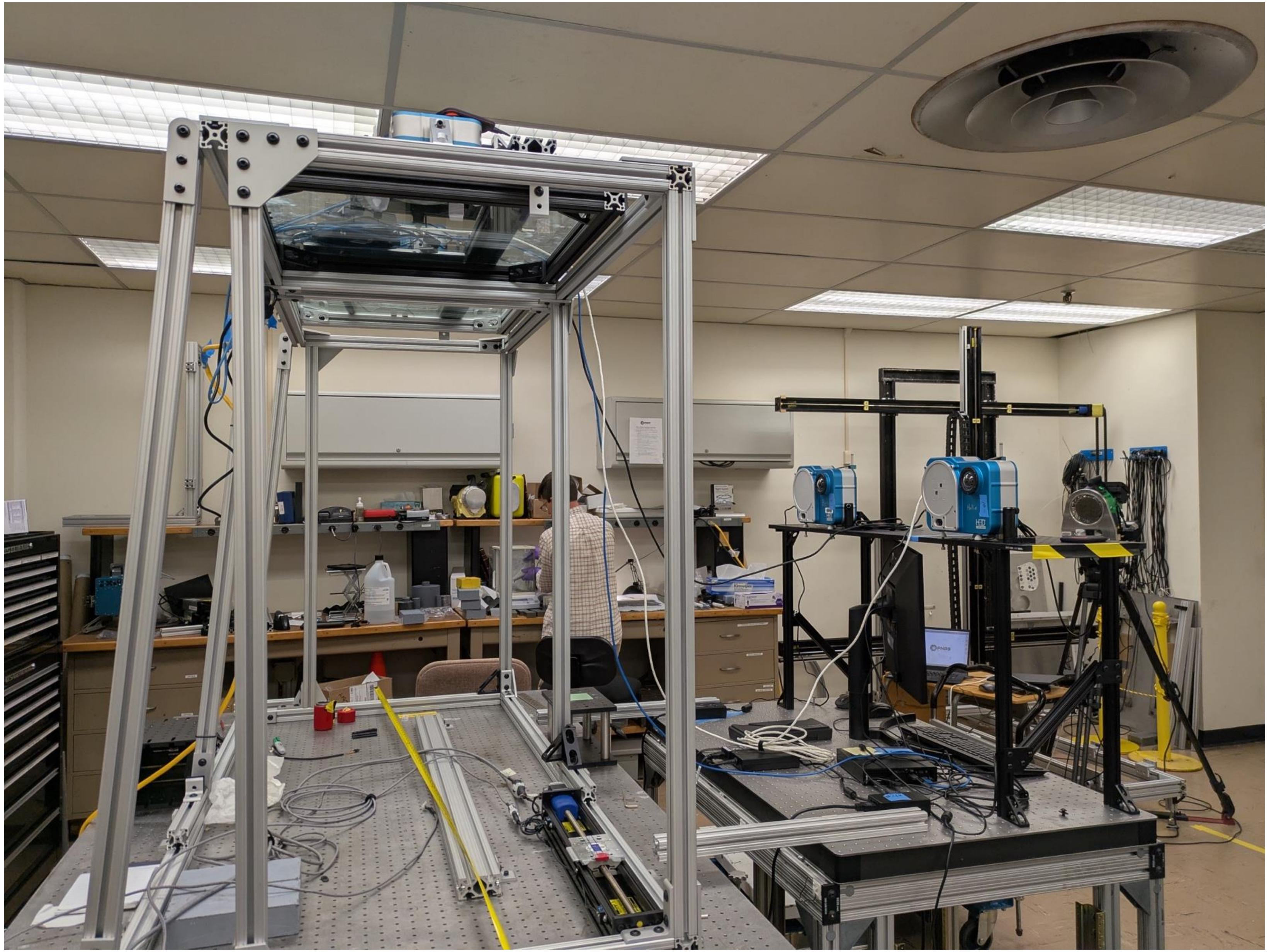
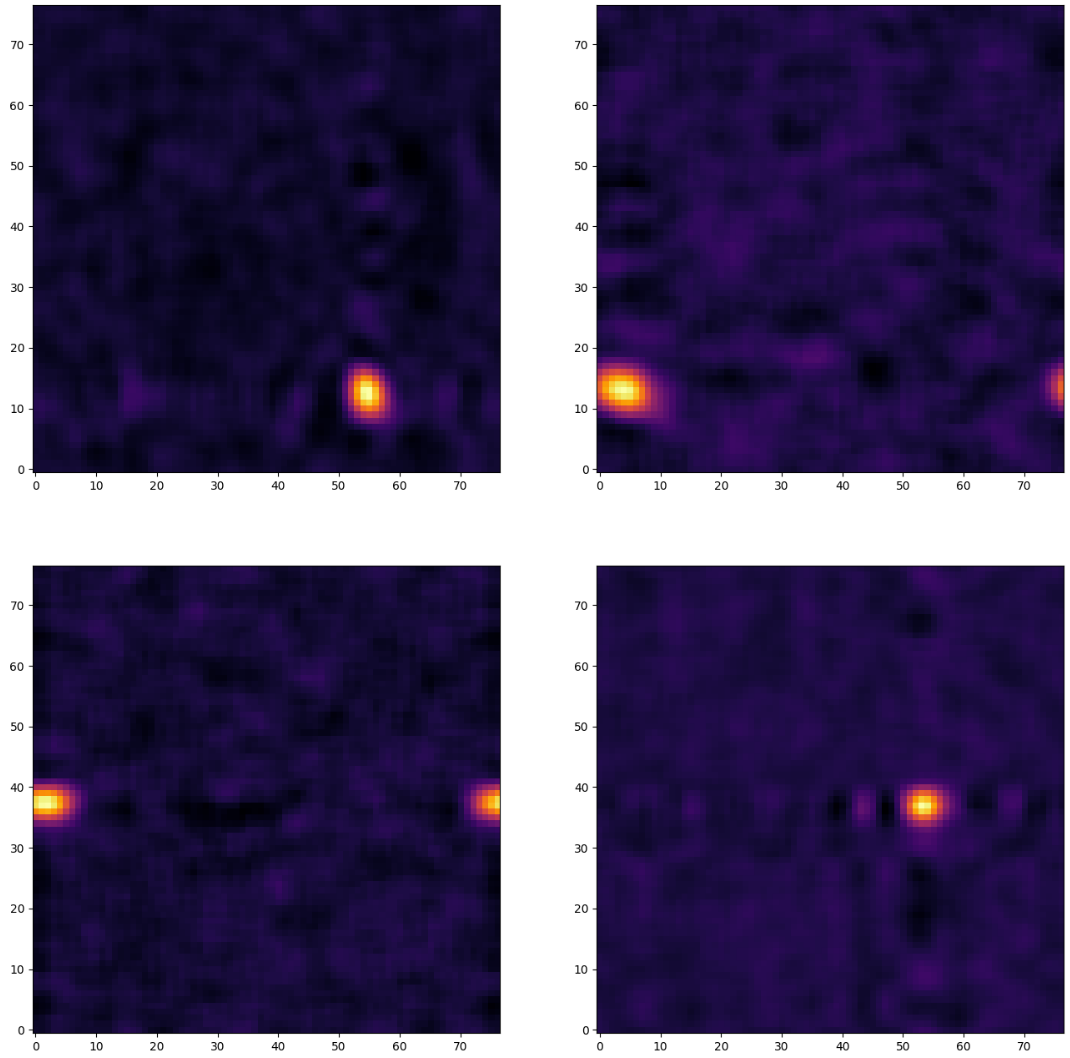
Ongoing Mockup Measurements



Ongoing Challenges

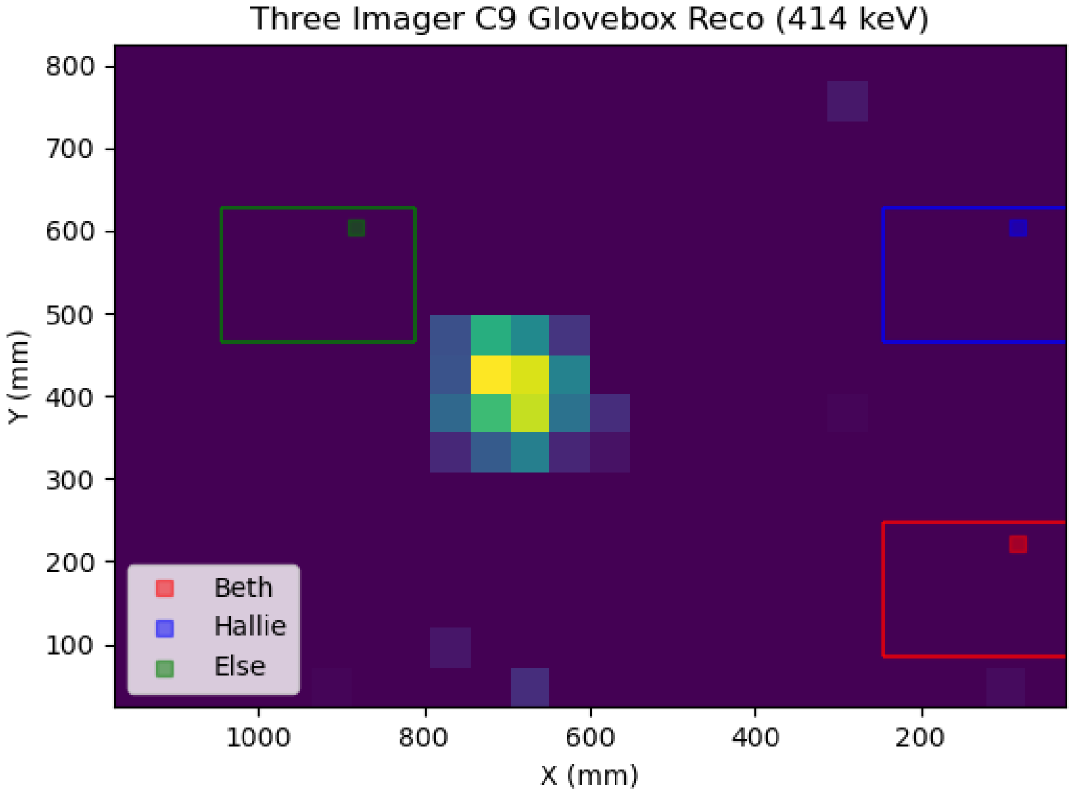
- Inclusion of all idiosyncratic detector behavior – each one has its own imperfections!
- Selection of hyper-parameters. Settling on values that *generally* work well, but adapting data-driven methods from literature has not been simple.
- Establishing performance (minimum detectable amounts, reliable error estimation, etc).
- Incorporation of Compton event information:
  - Use as a regularization term
  - Basis pre-selection tool
  - Direct addition to the basis

Coded-Ap Images (122 keV)



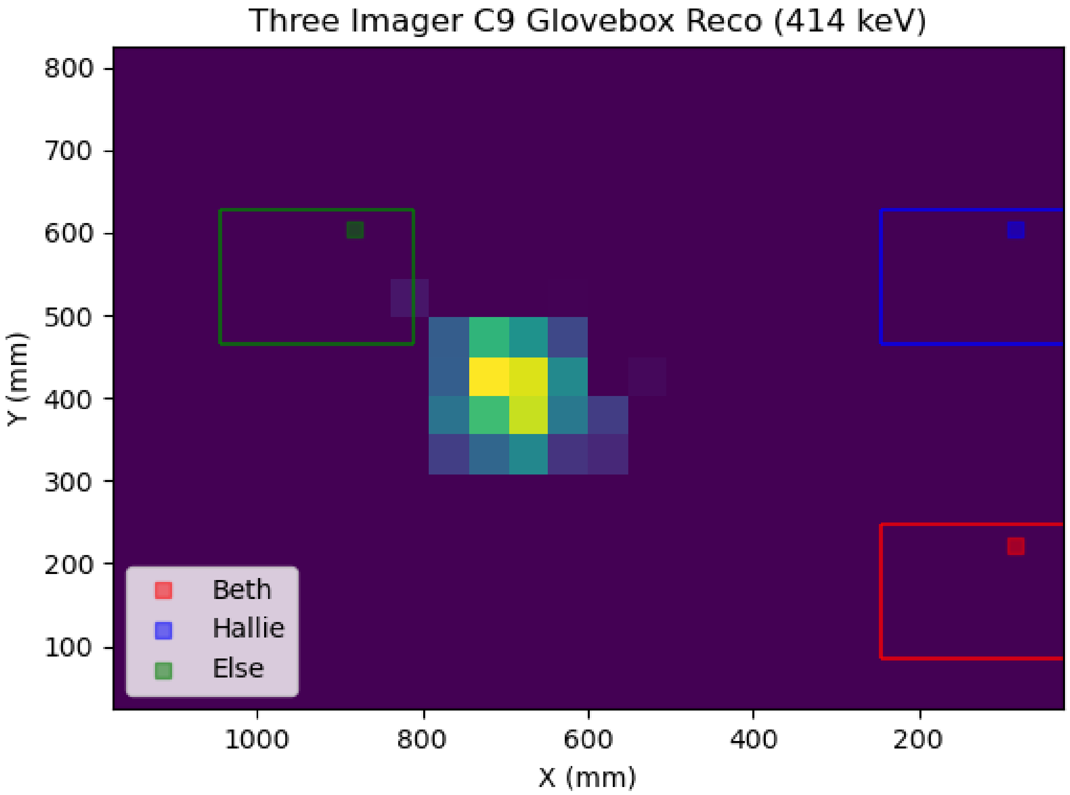
Compton Info as Preselect

Full Plane Reco



Reco Mass: 12.2 g

Restricted Plane Reco



Reco Mass: 13.1 g

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