Advanced MLEM Algorithm for Truncated Space Imaging of High Flux Photon Sources

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Introduction and Motivation

This work aims to show high-resolution image reconstructions of high flux photon sources. High energy and high flux gamma ray measurements were made using the 64-crystal, 3D position-sensing CZT detector system, H3DJ. This data was created using a high energy (> 50 MeV) proton beam incident on a plastic target, which causes a cascade of both prompt and delayed photon emissions on the order of 10^6 photons per second. To quickly image photon sources with millimeter precision a ROI (region of interest) MLEM (maximum likelihood estimation maximization) algorithm was developed.

Standard LM-MLEM in a Truncated FOV

The goal of this work is to improve the spatial resolution of the image while reducing the time it takes to reconstruct noisy data from high flux and high-energy measurements. However, standard MLEM converges sharply to the corners of the imaging space due to ill weighting of the Compton cones in a truncated FOV (field of view).

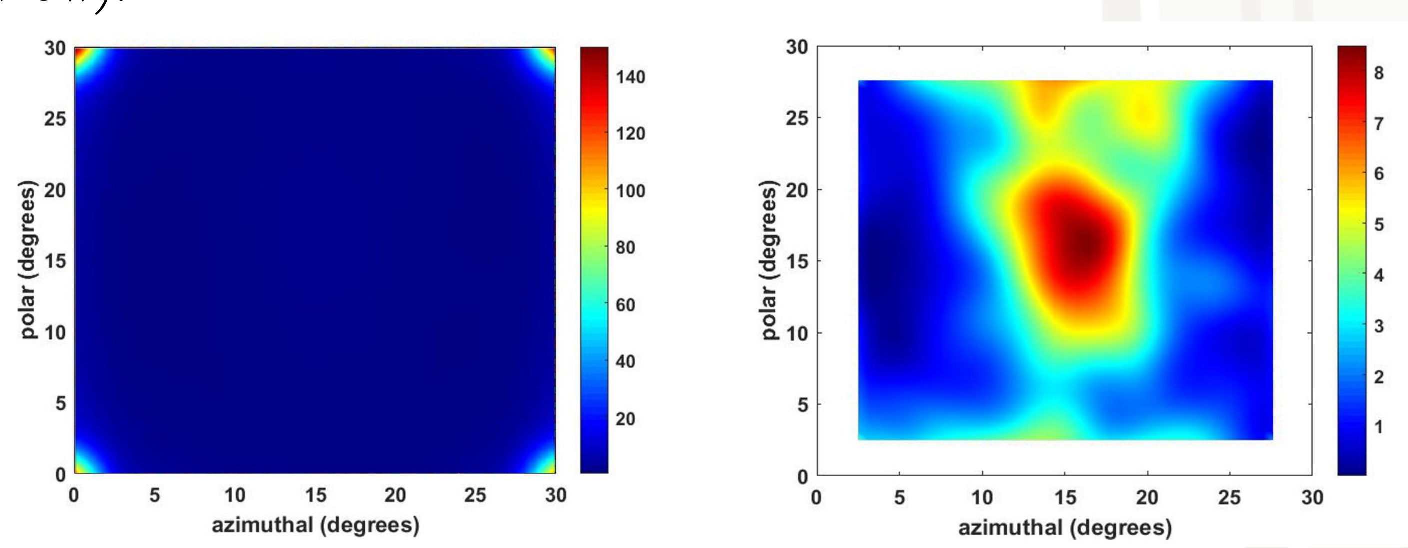

Fig. 1: MLEM reconstruction of 718 keV photopeak in a 30° FOV. The left image shows the inherit corner convergence of MLEM in a truncated FOV. The right image is the same reconstruction with the outermost pixels removed.

Table 1: Comparison of time to reconstruct 30,000 718 keV events given various image sizes with sub-cm resolution

Image size (Φ = θ)	Num Pixels	Reconstruction time (s)	pixel resolution (cm)
360°	720	**1450.8**	0.8
180°	606	**749.9**	0.05
90°	328	**29.09**	0.05
60°	222	**25.06**	0.05
45°	168	**11.77**	0.05
30°	112	**8.87**	0.05

ROI – MLEM Algorithm

ROI-MLEM allows for reconstruction in a truncated FOV while mitigating the effects of corner convergence. This is done by systematically reconstructing a low resolution background system matrix (**B**) and a high-resolution ROI system matrix (**R**), simultaneously. A cosine filter ($\mathbf{C_M}$) mask is applied to the ROI plus an outer perimeter background pixels to promote a smooth transition in the data between the background and ROI.

$$f_{Rf}^{n+1} = f_{Rf}^{n} \sum_{i}^{I} \frac{t_{ij}^{R+B_M}\,\mathbf{C_M}}{\sum_j^J t_{ij}^B \mathbf{C}_M + \sum_j^J t_{ij}^R f_{Rj}^n}$$

Where $\boldsymbol{t_{ij}^{R+B_M}}$ is the system matrix of the ROI and the outer perimeter pixels of the background system matrix. The background system matrix, $\boldsymbol{t_{ij}^{B}}$, is summed as a noise constant, where the ROI pixels are set to zero.

Simulated Line Source Image Reconstruction

ROI-MLEM is used to reconstruct a simulated 5cm and 10cm 662 keV line source in a 75° x 100° ROI.

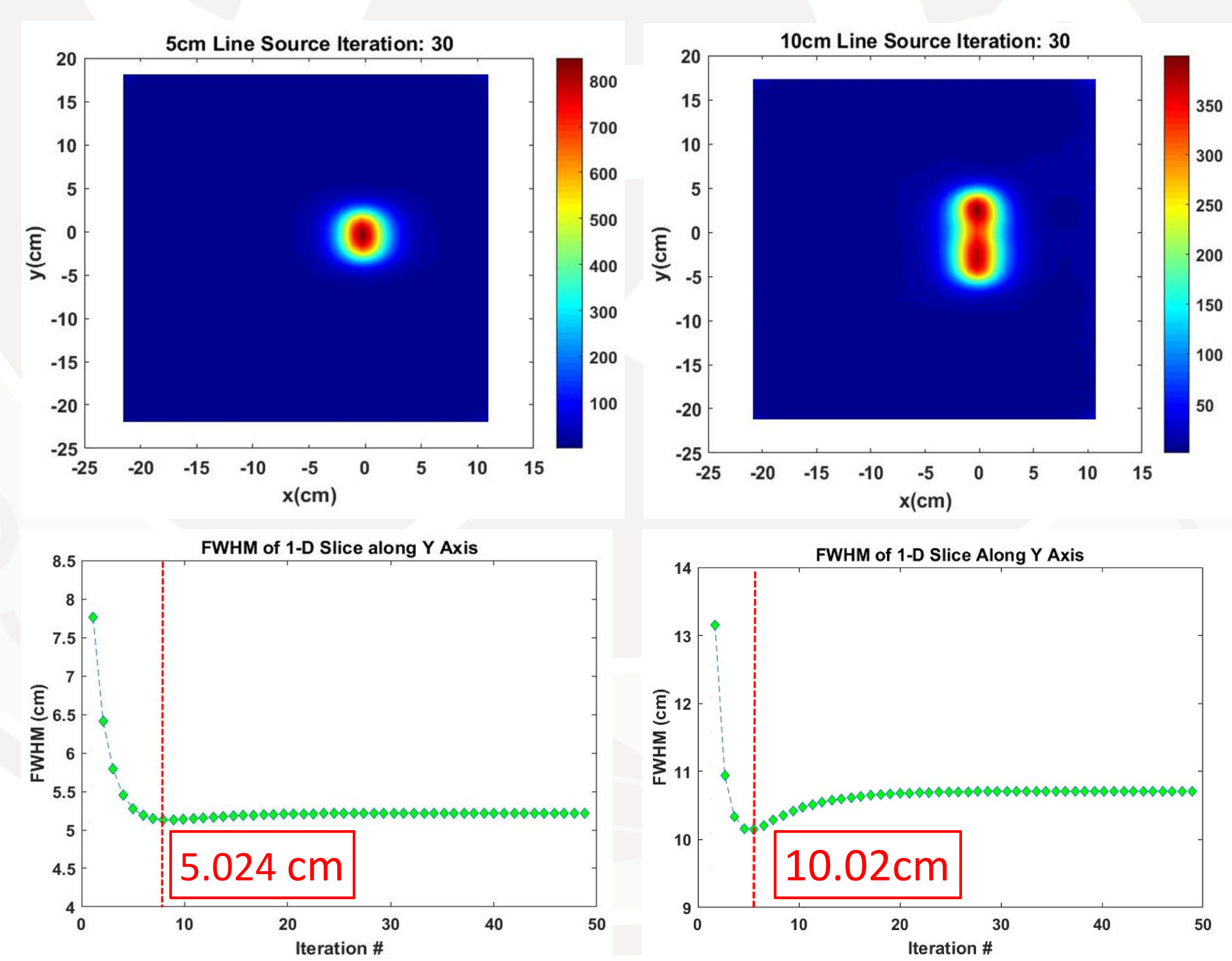

Fig. 2: 30,000 event ROI-MLEM reconstruction of 662 keV photon line source, 5cm (top left) and 10cm (top right). A 1-D slice is taken through the peak centroid of the hotspot to calculate the extent of the hotspot by finding the FWHM.

Prompt Gamma Ray Image Results

The 718 keV and 4.44 MeV photopeaks from the prompt gamma ray measurements taken at the Maryland Proton Therapy Center using H3DJ were reconstructed using ROI-MLEM within a 75° x 100° ROI. The prompt gamma rays were created by using a 70 MeV proton beam incident on a plastic target from two different trajectories.

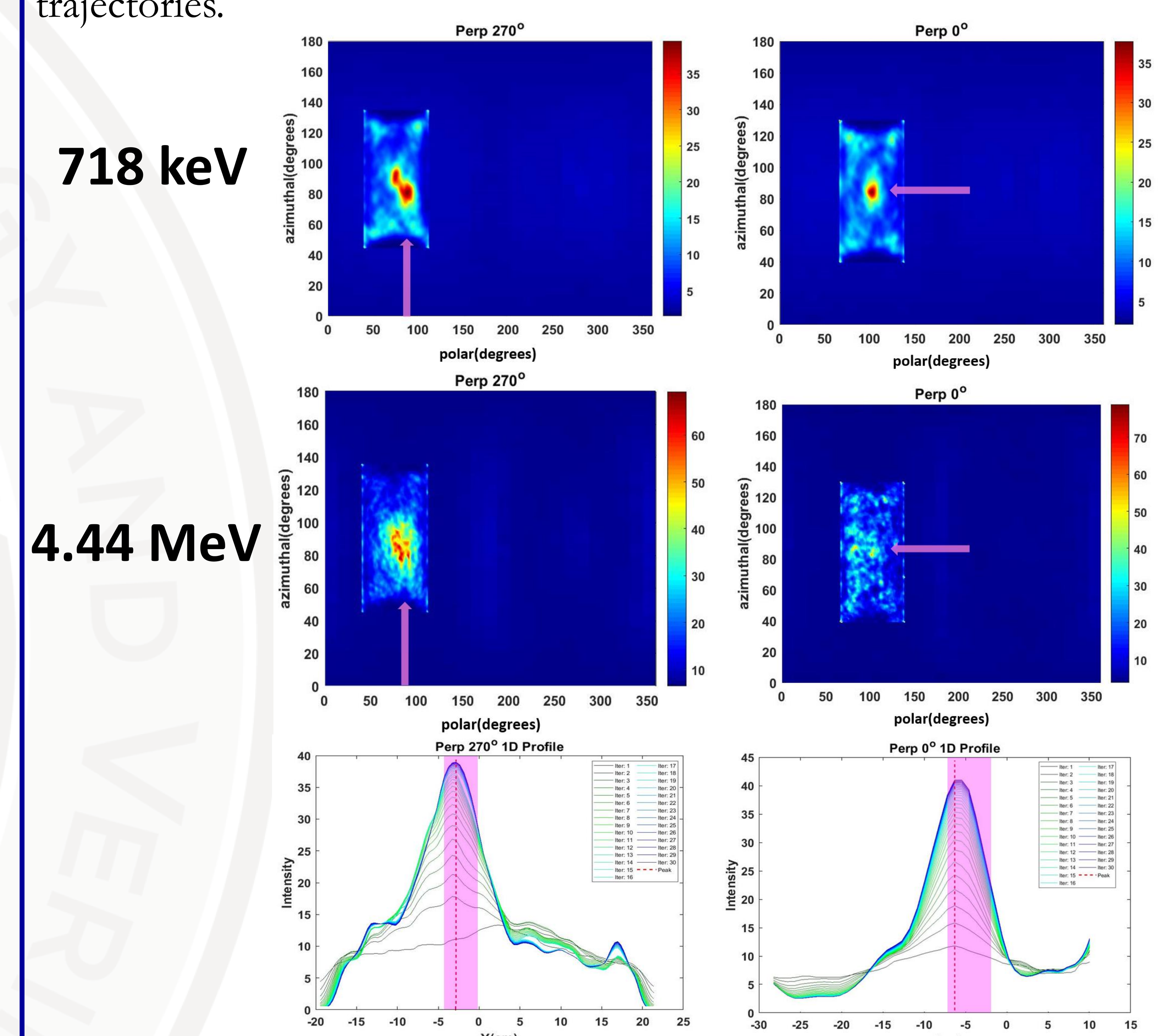

Fig. 3: ROI-MLEM image reconstructions of the 718 keV and 4.44 MeV from proton interactions with C^{12}. The 1D profile is taken through the peak centroid along the beam line for each 718 keV photopeak reconstruction. The pink arrows indicates the beam trajectory and the pink bar indicates the depth of the beam in the target.

Conclusion and Impact

The ROI-MLEM effectively reconstructs the high flux photon sources however, there is room for improvement at high-energies. This method aids in the reduction of time and improvement of spatial resolution of imaging hot sources typically found in nuclear safeguards applications.

This work was funded in-part by the Consortium for Monitoring, Technology, and Verification under Department of Energy National Nuclear Security Administration award number DE-NA0003920

National Nuclear Security Administration