

Experimental Demonstration of Coded Aperture Imaging using Thick 3D-Position-Sensitive CdZnTe Detectors

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Abstract – 3D-position-sensitive CdZnTe semiconductor detectors have demonstrated 4π Compton imaging capability and excellent energy resolution at room-temperature operation. However, Compton gamma-ray imaging is not feasible at low energies due to the small Compton-scatter cross-section. This work extends the current imaging capabilities to lower energies by utilizing coded aperture masks. Multiple coded aperture masks are applied to a single detector system of four 20mm×20mm×15mm CdZnTe detectors. Near- 4π coded aperture imaging has been demonstrated through Monte Carlo simulation. The correct source direction is consistently identified using measured data with one mask above the cathode side and another mask above the non-cathode side of the detector. Challenges related to electric field distortion due to space charge in the detector are discussed. The focus of this research is to image near- 4π field of view using coded apertures, ultimately, combining both Compton and coded aperture imaging techniques to expand the range of gamma-ray imaging.

I. INTRODUCTION

THE Polaris system is a detector unit consisting of two, 3×3 arrays using 20mm×20mm×15mm thick CdZnTe detectors, providing a total volume of 108cm³. This detector array yields the x, y, z position and energy deposition at each point of interaction, with less than 1% energy resolution, providing the information desired for excellent gamma-ray imaging capabilities.

Our current imaging capabilities include Compton imaging, which is most effective at energies above 300keV. However, below 300keV Compton imaging is not feasible due to the relatively low Compton-scatter cross-section in CdZnTe material. The solution to this limitation is a hybrid Compton-coded aperture imaging system, to extend our capabilities to lower energies.

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II. PREVIOUS RESULTS

In the past, simulated results of near- 4π coded aperture imaging using a single, large volume CdZnTe crystal were presented, demonstrating the theoretical capability of imaging far-field point sources over background through multiple masks applied to a single 3D-position-sensitive detector [1]. This is done by applying a MURA or random masks to five of the six sides of a single position sensitive detector, as shown in Fig. 1. Fig. 2 depicts the unfolding of a five-sided box, each side representing the image created through the particular mask.

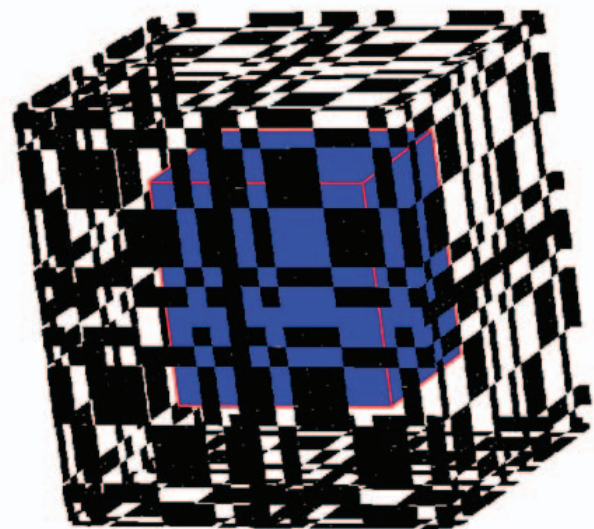


Fig. 1. Geometry of mask-detector system simulated in MCNP5. A MURA mask is applied to each side of the detector, except the anode.

The goal of this work is to measure multiple sources through multiple coded aperture masks applied to a single position-sensitive detector, as well as to identify any practical limitations of coded aperture imaging while using thick, large volume CdZnTe detector crystals.

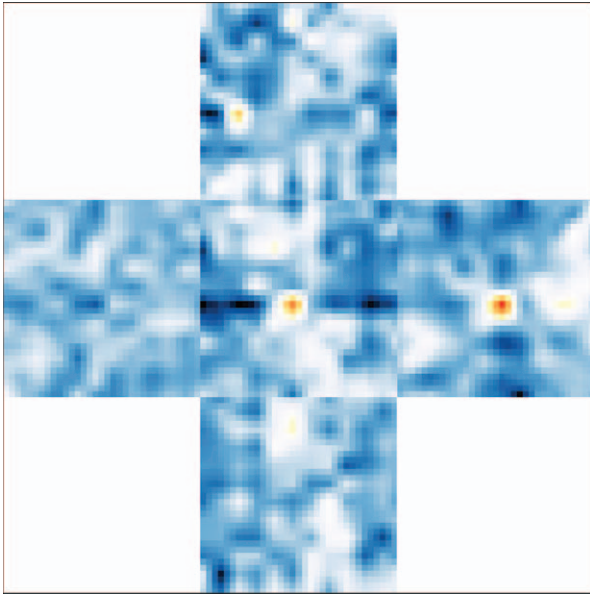


Fig. 2. Coded aperture imaging through five random coded aperture masks applied to a single thick CdZnTe detector crystal. Multiple far-field sources are accurately pinpointed over background. Simulations are performed in MCNP5.

III. EXPERIMENTAL SETUP

A. Detector Orientation

Each measurement is performed using an experimental imaging system consisting of four 20mm×20mm×15mm thick CdZnTe detectors, separated by a 2mm gap, as shown in Fig. 3. The 11×11 array of pixilated anodes have a pitch of 1.72mm, with a common steering grid between each pixel. Two of the four detectors were provided by eV Products and the other two by Redlen Technologies, oriented as shown in Fig. 4. All four detectors utilize the VAS_UM/TAT4 ASIC designed by Gamma Medica-Ideas. See Fig. 4 for more detector details.

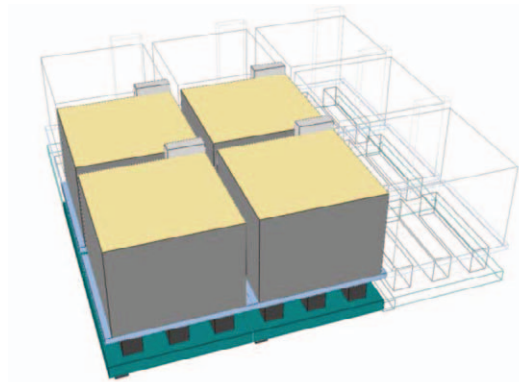


Fig. 3. Imaging system shown relative to a single layer of a three by three CdZnTe detector array.

Detector #11 4E5 – eV Products GMI ASIC Energy Resolution ~1.5% (1-pixel interaction)	Detector #21 4E10 – eV Products GMI ASIC Energy Resolution ~1.3% (1-pixel interaction)
Detector #12 4R8 – Redlen GMI ASIC Energy Resolution ~1% (1-pixel interaction)	Detector #22 4R2 – Redlen GMI ASIC Energy Resolution ~1% (1-pixel interaction)

Fig. 4. Orientation of four detectors as viewed from the cathode side.

IV. CATHODE-SIDE CODED APERTURE IMAGING

A. Mask Orientation

A single 1mm thick tungsten coded aperture mask is placed 4cm from the cathode sides of the detectors, centered on all four detectors. The current mask design consists of 21×21 random pixels, four times the area of the detector pixels with the dimensions 3.44mm×3.44mm.

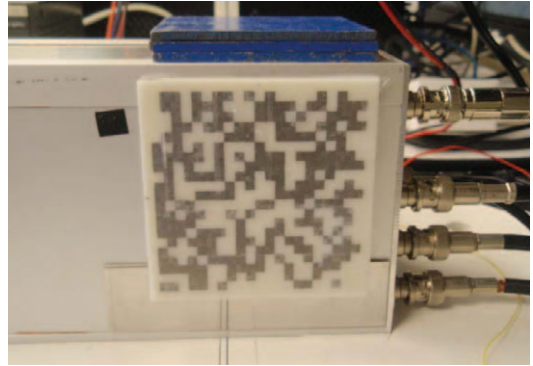


Fig. 5. Random patterned mask centered on four detectors, placed 4cm from cathode sides.

B. Source Orientation

A ^{57}Co source emitting 122keV gamma rays is positioned 20cm from the mask. As the source is placed near the detector-mask geometry, near-field corrections were implemented in the imaging algorithm. The source is moved from one end of the field of view to the other end in incremental steps. Images of these source positions are created using all four detectors, simultaneously.

C. Combined Cathode-side CAI

As previously mentioned, the source is moved along a plane 20cm from the cathode-side mask, across the approximately 60° field of view. The image of each source position is created with 1000 counts from each detector, using a back-projection coded aperture image reconstruction method.

The point source can be tracked in the coded aperture image as it is moved across the field of view. However, the artifacts are much more prominent than expected, based on simulated results, which may lead to misidentification of source positions, as shown in Fig. 6. Therefore, to better understand why the measured data provides such noisy results, it was necessary to examine the images formed by each individual detector.

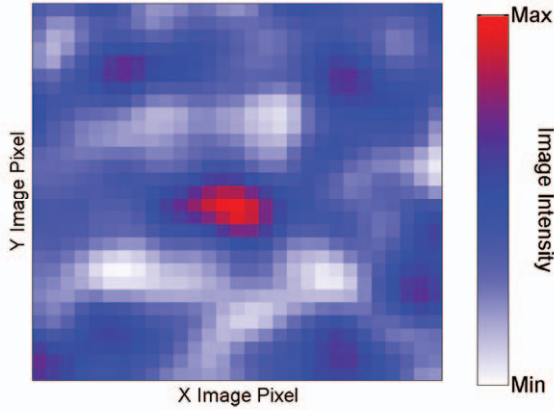


Fig. 6. Source located at center of field of view. Sidelobes are much more prominent than expected through simulated results.

D. Individual Cathode-side CAI

Counts from each individual detector are processed through the imaging code. Fig. 7 represents the same source position as depicted in Fig. 6. However, now the contribution of each detector is displayed independently. From the individually plotted images it is clear that only one of the four detectors is properly pinpointing the source direction (upper left).

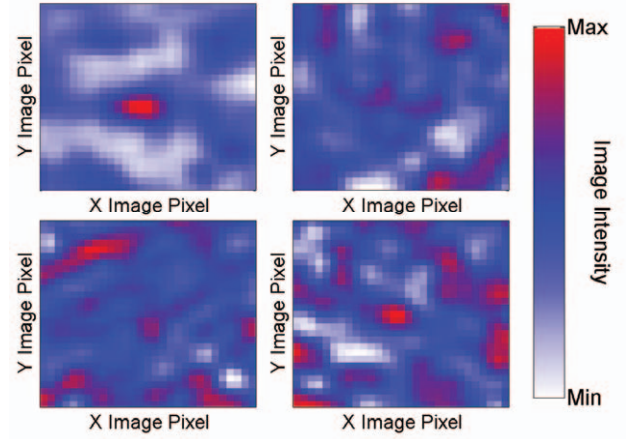


Fig. 7 Display of coded aperture imaging of individual detectors.

V. PIXEL JUMPING

What detector property could make one detector so much more effective at coded aperture imaging than the other three? A simple experiment was conducted to study this effect: all four detectors were irradiated uniformly from the cathode side with a near-parallel ^{137}Cs beam without an aperture mask. In the ideal case, a uniform count rate would be observed in each pixel. However, in Fig. 8, severe non-uniformities in the count rate are observed in all detectors except for the one in the upper left. This is surprising as this detector has the most severe trapping ($\sim 5\%$), as well as the worst energy resolution ($\sim 1.5\%$) of the four detectors.

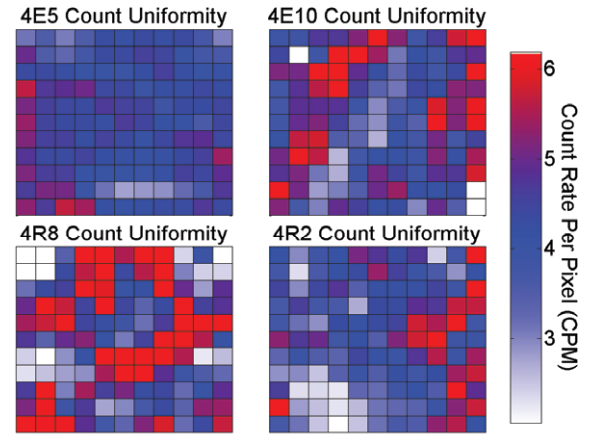


Fig. 8. Count rate of each pixel of four detectors under uniform ^{137}Cs irradiation without an aperture mask

Based on previous research, the measured efficiency matches the simulated efficiency across a wide range of energies, thus few counts are being lost. Instead, radiation interactions are occurring in one pixel and are being recorded in a neighboring pixel, a phenomenon called pixel jumping. This effect has been studied and is caused by space charge in the detector, yielding electric field non-uniformities, which ultimately bends the electron-cloud track [2],[3].

Experiments have shown that this problem cannot be resolved by a simple efficiency normalization of each pixel.

Generally, pixel jumping is not as pertinent due to the fact that coded aperture imaging is usually done with thinner CdZnTe detectors. However, it has become apparent that detectors of greater thickness will be more susceptible to pixel jumping. As the thickness of the crystal is increased, the greater the probability that the electron cloud will drift away from the original interaction pixel. This causes severe distortions in coded aperture imaging.

Pixel jumping has been a major surprise to our group as high quality Compton imaging has been implemented with the existing detector systems. In addition, the four imaging detectors utilized for this experiment were all tested as Compton imagers where excellent results were achieved. Due to this fact, it has been hypothesized that pixel jumping effects are much less severe in Compton imaging, since the effect would only slightly skew the axis of the Compton cone. In comparison, a simple shift in counts from one pixel to another could completely reverse the contribution of the count in coded aperture imaging. Also, the effects are less severe in Compton imaging since both interactions positions may shift in the same dimension by the same amount, yielding no change in the angle of the cone axis.

Two methods to overcome the effect of pixel jumping for coded aperture imaging include selecting detectors with uniform count distributions, and also trying to formulate an algorithm to reduce the effect of pixel jumping.

VI. SIMULATED RESULTS

To confirm that the coded aperture images are as expected, the detector-mask-source geometry is simulated in MCNP5 and processed through the imaging algorithm. Fig. 9 compares the measured image from the most uniform detector to a simulated image, showing that the two results are quite similar. The sidelobes are prominent in the simulated case, likely a property of the random mask design, rather than the product of effects such as pixel jumping, since the simulation of the detector contains no such physics. These results are promising as it also proves that there are no fundamental issues in using thick CdZnTe detectors for coded aperture imaging.

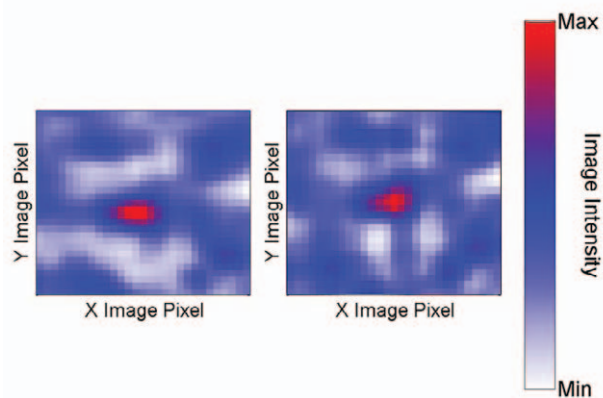


Fig. 9. Coded aperture image of measured data (left) and simulated data (right).

VII. NON-CATHODE-SIDE CODED APERTURE IMAGING

A. Mask Orientation

Now that cathode-side coded aperture imaging had been studied and proven possible, the next logical step is to apply a mask to one of the non-cathode sides of the detector. Since only one of the four detectors provided a uniform response, a single 1mm thick tungsten mask was placed on the side of that detector, orientation shown in Fig. 10. The 21×21 random design coded aperture mask was centered on this detector, with mask pixel dimensions of 1.72mm×1.72mm.



Fig. 10. Random patterned mask centered on single detector, placed 2cm from the non-cathode side.

B. Source Orientation

Similar to the non-cathode side, the ^{57}Co source is placed 20cm above the mask. Once again, near-field effects were accounted for in the imaging algorithm. The source is incrementally moved along a plane 20cm above the mask from one edge of the field of view to the other.

C. Individual Non-cathode-side CAI

As the source was imaged through the side of the detector the source direction is accurately pinpointed, but the images are observed to be significantly noisier than through the cathode mask. The image through the non-cathode-side mask is shown in Fig. 11.

There are three explanations for the noise in the image. First of all, there may be non-uniform charge loss of low energy gammas, which may be due to variable electric field on the outer edge of the detector. The second reason may be due to the fact that one of the 11 edge pixels is very noisy, and does not show a clear ^{57}Co photopeak. Lastly, the mask pixels are a quarter the area of the cathode-side mask pixels, allowing the image to be much more susceptible to the effects of pixel jumping.

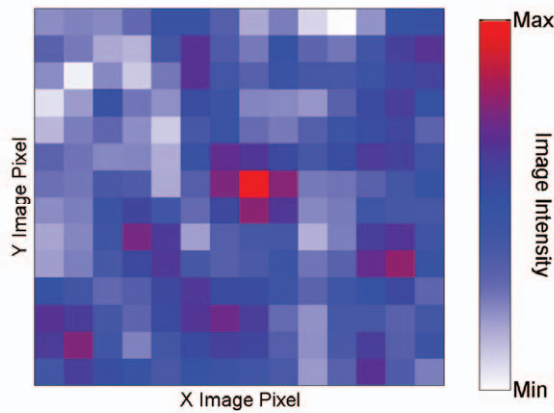


Fig. 11. Coded aperture image through a non-cathode-side mask on a single detector.

VIII. MULTIPLE MASK RESULTS

The ultimate goal of this project is to apply multiple masks to a single 3D-position-sensitive CdZnTe detector yielding near- 4π coded aperture imaging at low gamma-ray energies. Fig. 12 shows an image acquired using multiple sources and multiple masks. ^{57}Co is placed on the non-cathode side, while ^{133}Ba is placed on the cathode side of the detector. Proving that with the current algorithm, multiple mask coded aperture imaging is possible. However, the quality of the images is limited by the issues mentioned before, such as pixel jumping and side detector attenuation at low energies.

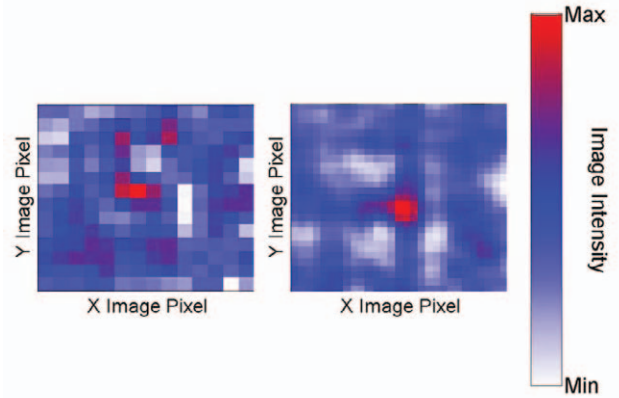


Fig. 12 Multiple side, multiple mask coded aperture imaging: non-cathode side CAI using ^{57}Co (left) and cathode side CAI using ^{133}Ba (right).

IX. SUMMARY

It has been proven that multiple coded aperture masks (one per side) can be applied to a single detector system formed by multiple 3D-position-sensitive pixilated detectors, and that near- 4π coded aperture imaging using multiple, thick pixelated CdZnTe detectors is achievable. However, it has been discovered that coded aperture imaging with thick CdZnTe detectors requires crystals with uniform electric fields, to prevent pixel jumping. In the next year, over one hundred detectors will be delivered to our group by Redlen Technologies. The hope is to select detectors with good energy resolution, minimal trapping, and minimal pixel jumping. Also, an attempt will be made to develop an algorithm to alleviate the pixel jumping effect.

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