Modeling of an Interwoven Collimator in a Gamma Camera for Intra-body-cavity Applications

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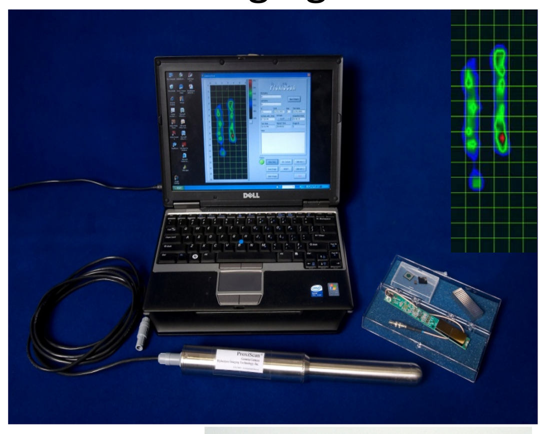
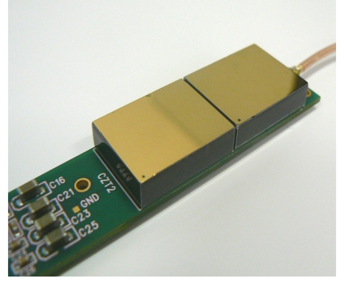
Introduction

With its improved material properties and detector performance, Cadmium Zinc Telluride (CdZnTe or CZT) radiation detectors are attractive in medical imaging applications. The detector modules can be very compact when fabricated in advanced pixilation and hybridization processes, and are finding applications in endo-cavity measurements. However, such applications have very limited space for operation; the traditional detector and collimator design and arrangement are not suitable, especially in 3D imaging applications. Here we present an interwoven collimator that can be employed with planar pixilated detectors to produce 3D images without rotation of detector module. In this presentation, we talk about the collimator design and report the Monte-Carlo simulation results.

Motivation of the Work

- Recently we developed compact trans-rectal gamma camera, ProxiScan™, for prostate cancer imaging based on CZT pixilated detectors.
  - The camera employed matched parallel hole collimator to generate 2D projection images.
  - The camera has gone through phase I clinical trials in 2011-2012 successfully and generated promising images indicating the focused high uptake regions in the prostate glands.

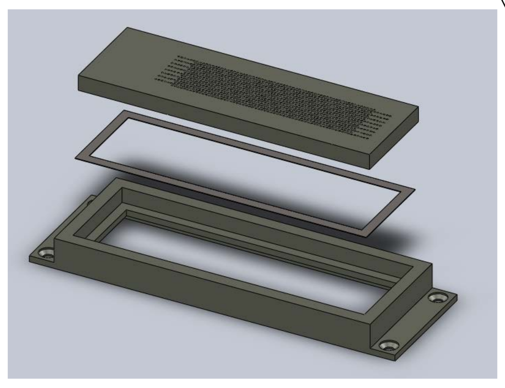




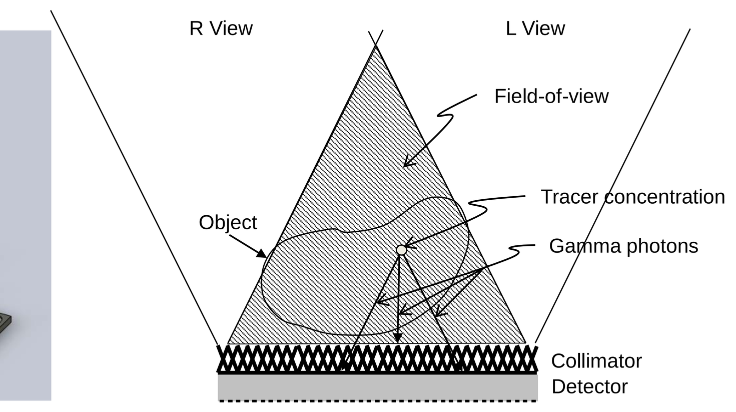
- 3D imaging capability is needed for interpreting the depth information of the foci.
  - Individual shot using parallel hole collimator can only generate 2D images.
  - Rotating parallel hole collimator can generate 3D images. However it has
    - Very limited focusing length (depth of field of view)
    - Long image acquisition time as more images are needed for image reconstruction
- Slanted parallel hole collimator could be useful in this specific application.
  - Traditional slanted hole collimator has separated groups of the parallel holes, and is not suitable for ProxiScan™ given the size of the prostate gland and the anatomical structure of rectum.
  - We proposed a fully interwoven collimator for 3D imaging.
    - Groups of parallel holes are fully mixed together.
    - All the holes are matched to the pixels in one pixilated detector plane.
    - We develop ML-EM algorithm for the 3D reconstruction.

Interwoven collimator

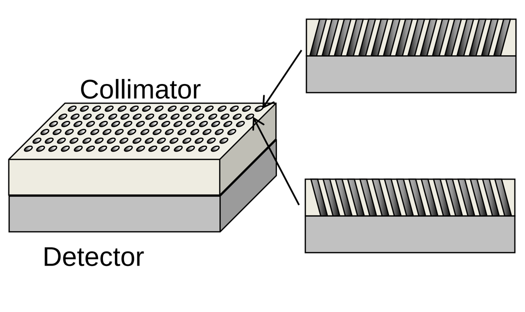
- **Design of the collimator**
  - The collimator has two or more groups of parallel holes.
  - The axis of the holes in one group have the same slanted angle.
  - Different groups have different slanted angles for multiple-view imaging simultaneously.
  - The rows of different groups are interweaved.
  - All groups are interwoven together so that the openings of all the holes match the pixels in one detector plane.
- **Advantages of the design**
  - Compact design
    - The dimensions of the collimator comparable to the size of the object
    - Highly demanded for endo-cavity probes
  - Very close working distance between the object and the collimator surface



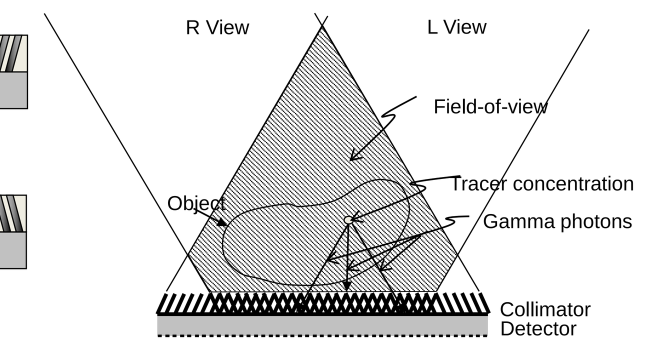
3D Modeling of Collimator



FOV of Fully Interwoven Collimator



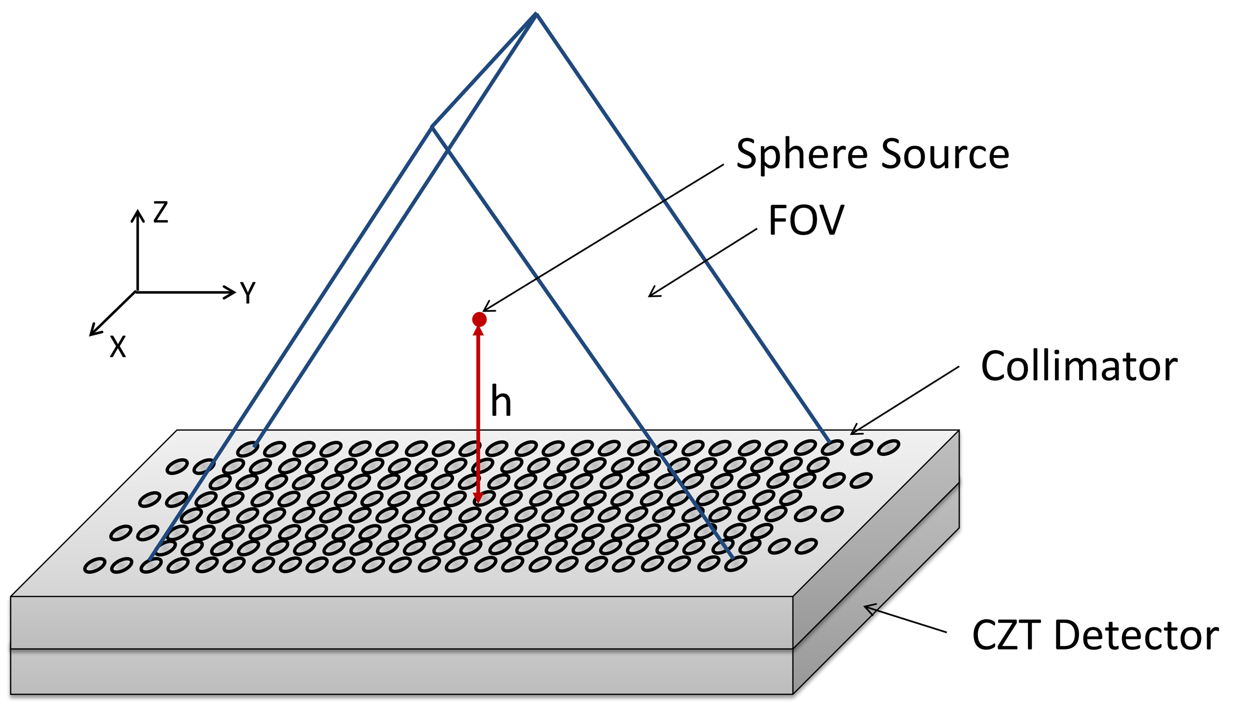
Detailed Sketch of the Collimator

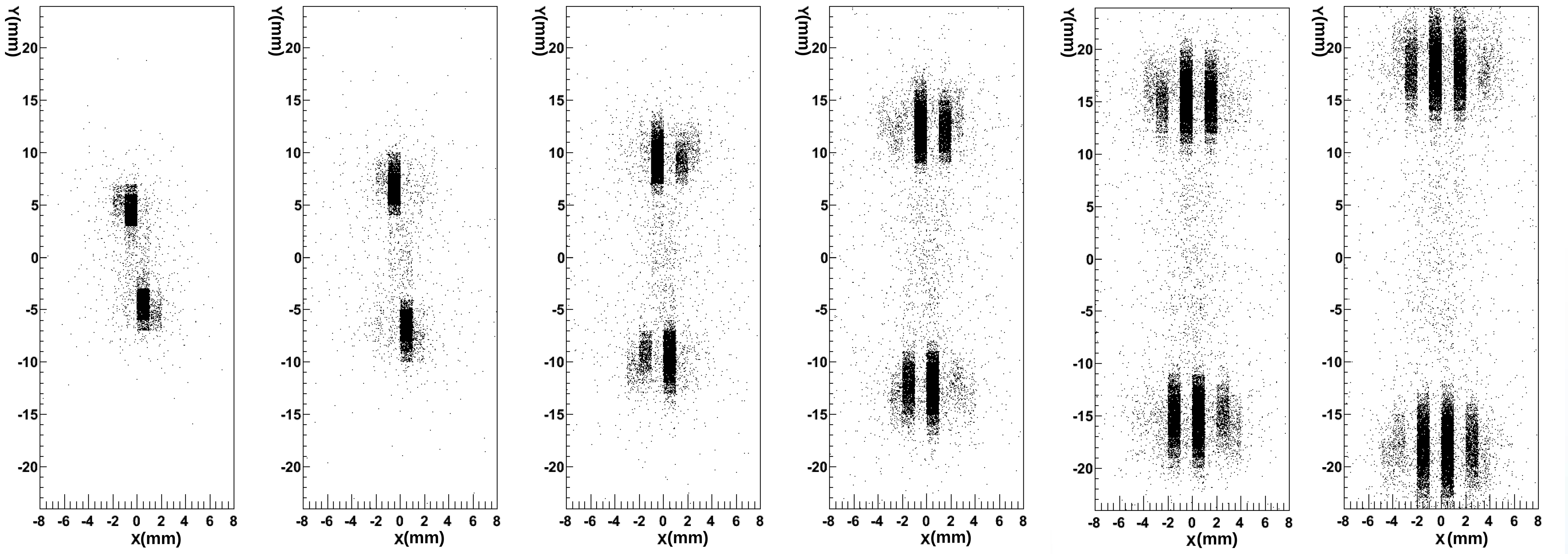


FOV of Partial Interwoven Collimator

Monte-Carlo Simulation of the Collimator with CZT Detector

- **Software package: Geant4 running on a 256-node cluster computer**
- **Collimator**
  - 5-mm thick tungsten plate
  - Two groups of slanted holes
  - 60° and 120° slanted angles
  - 0.5-mm diameter holes
- **Detector**
  - 16x48 pixel CZT detector
  - 5-mm thick
  - 1-mm pixel pitch
- **Radiation source**
  - Energy: Tc-99m (140.5-keV γ-ray)
  - Size: 0.5-mm-diameter sphere
  - We simulated the detector response to the source in each voxel (1-mm^3) within the FOV of the collimator
- **Detector response to a sphere source above the center of collimator plane with a distance of 6, 10, 15, 20, 25 and 30 mm.**

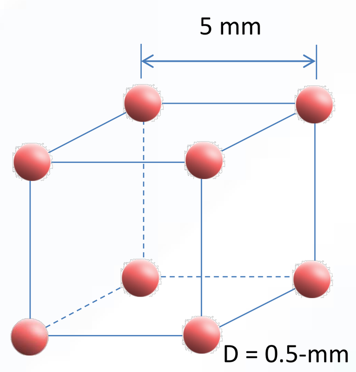




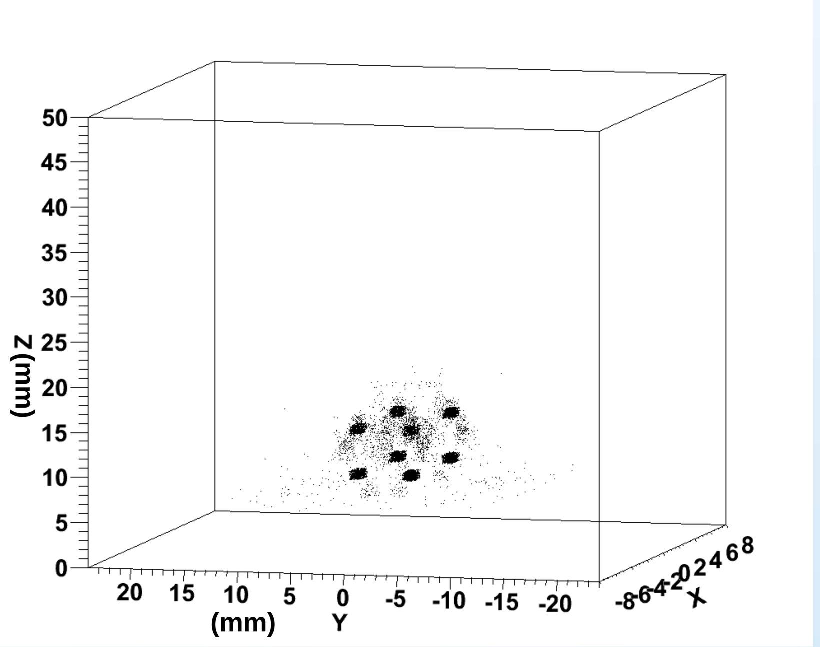
h: 6 mm 10 mm 15 mm 20 mm 25 mm 30 mm

First Reconstructed 3D Image using ML-EM Algorithm

- Phantom used for this study
  - Eight sphere sources distributed at each corner of a 5-mm cubic
  - Each sphere source has a diameter of 0.5 mm
  - Each sphere has the same radioactivity
  - The center of the cubic is located at (0, 0, 11) where the XY-plane is the top surface of the collimator
- ML-EM algorithm was developed for the 3D reconstruction
- In the reconstructed image as shown on the right, all the features (size of sphere sources and gaps between them) are well resolved.



Multiple-sphere Phantom



Reconstructed 3D Image of the Multiple-sphere Phantom

Conclusions

- We simulated the response of an interwoven collimator to gamma ray radiation and developed ML-EM algorithm for 3D image reconstruction.
- The Monte-Carlo simulation results demonstrated the 3D imaging capability of this novel collimator.
- The compact profile of the interwoven collimator make it suitable for intra-body-cavity imaging devices.
- A demonstration system with the same detector/collimator configuration is being built. More experimental results will be reported later.

For more information, please contact ycui@bnl.gov or 631-344-5351.

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