Simulation of Compton Reconstruction in Liquid Xenon PET

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Liquid xenon (LXe) is a promising technology for Positron Emission Tomography (PET). With its excellent capabilities for energy (<9% FWHM), position (1mm FWHM in 3-D), and timing (<1ns FWHM) resolutions, LXe allows the use of high efficiency Compton reconstruction to suppress random and scatter backgrounds to significantly improve image quality. To evaluate the potential performance of a LXe PET detector, a simulation of the system shown in Figure 1 was performed.

With the ability to resolve each photon interaction point in 3 dimensions as in a LXe Time Projection Chamber, it becomes possible to apply a Compton reconstruction algorithm to determine the correct line of response (LOR). Conceptually, this involves looking at all potential scattering sequences, and at each scattering location compare the apparent scattering angle with the expected value based on the deposited energy and Compton kinematics. In principle, the true sequence is most likely to have the smallest discrepancy, and thus identifying the correct line of response can be accomplished with high probability.

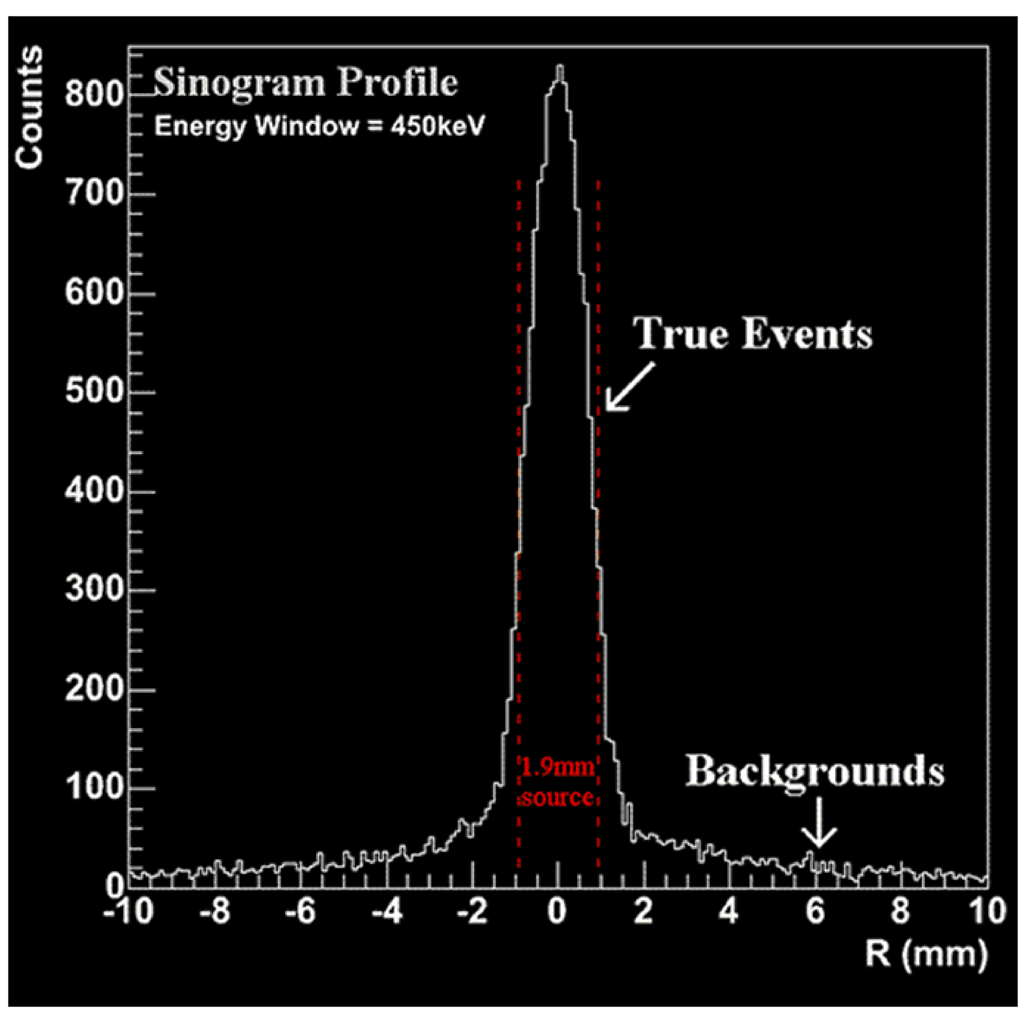

Figure 2 (left): Sinogram profile of a 1.9 mm diameter 1 mCi water line source inserted into the rat size phantom, at a 15 mm offset from the center. Sinogram projections were centered on the source peak and combined. All true events were assumed to be within a 9 mm narrow band centered on the source peak. Background events within the narrow band were assumed to be constant and interpolated as the average of the counts at the edge of the narrow band.

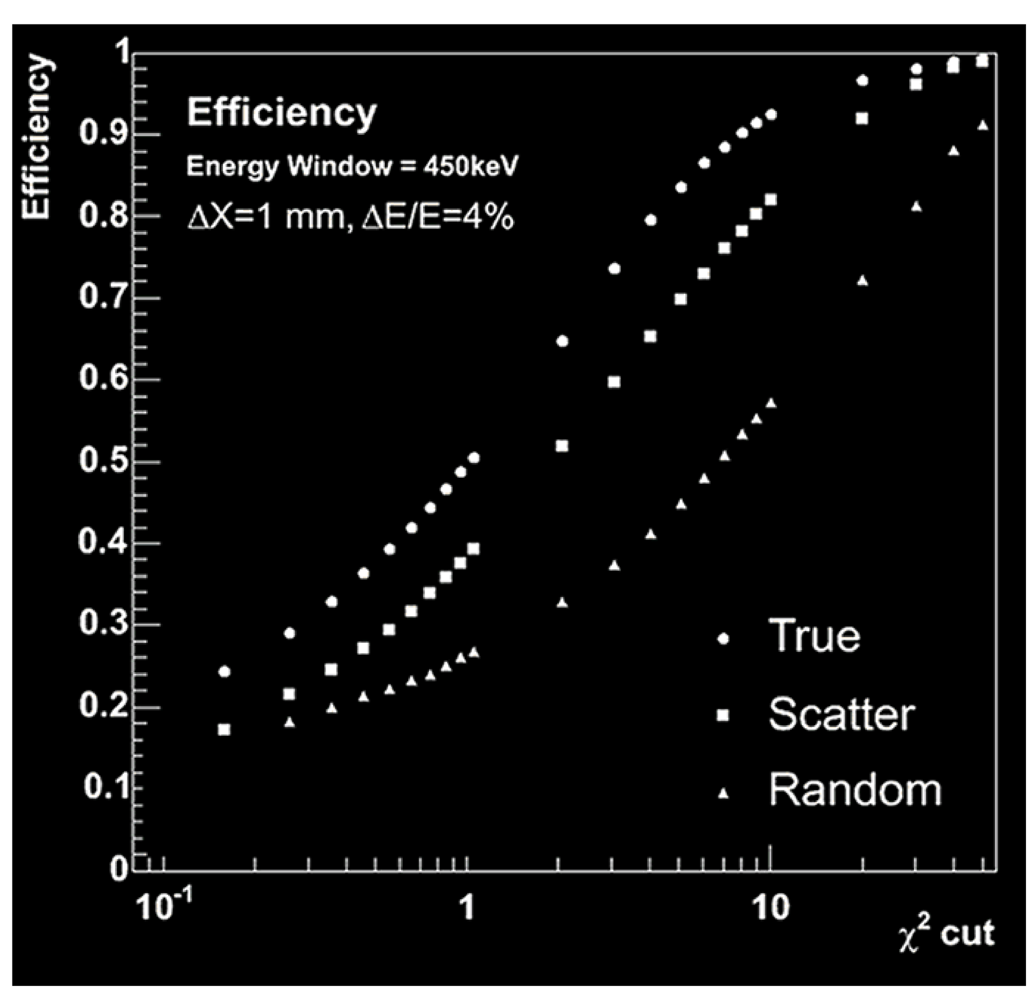

Figure 3: Efficiency v.s. $\chi 2$ statistics of the Compton reconstruction algorithm for True, Scatter, and Random events at 70 MBq. The difference in efficiency allows background suppression via an upper $\chi 2$ threshold cut.

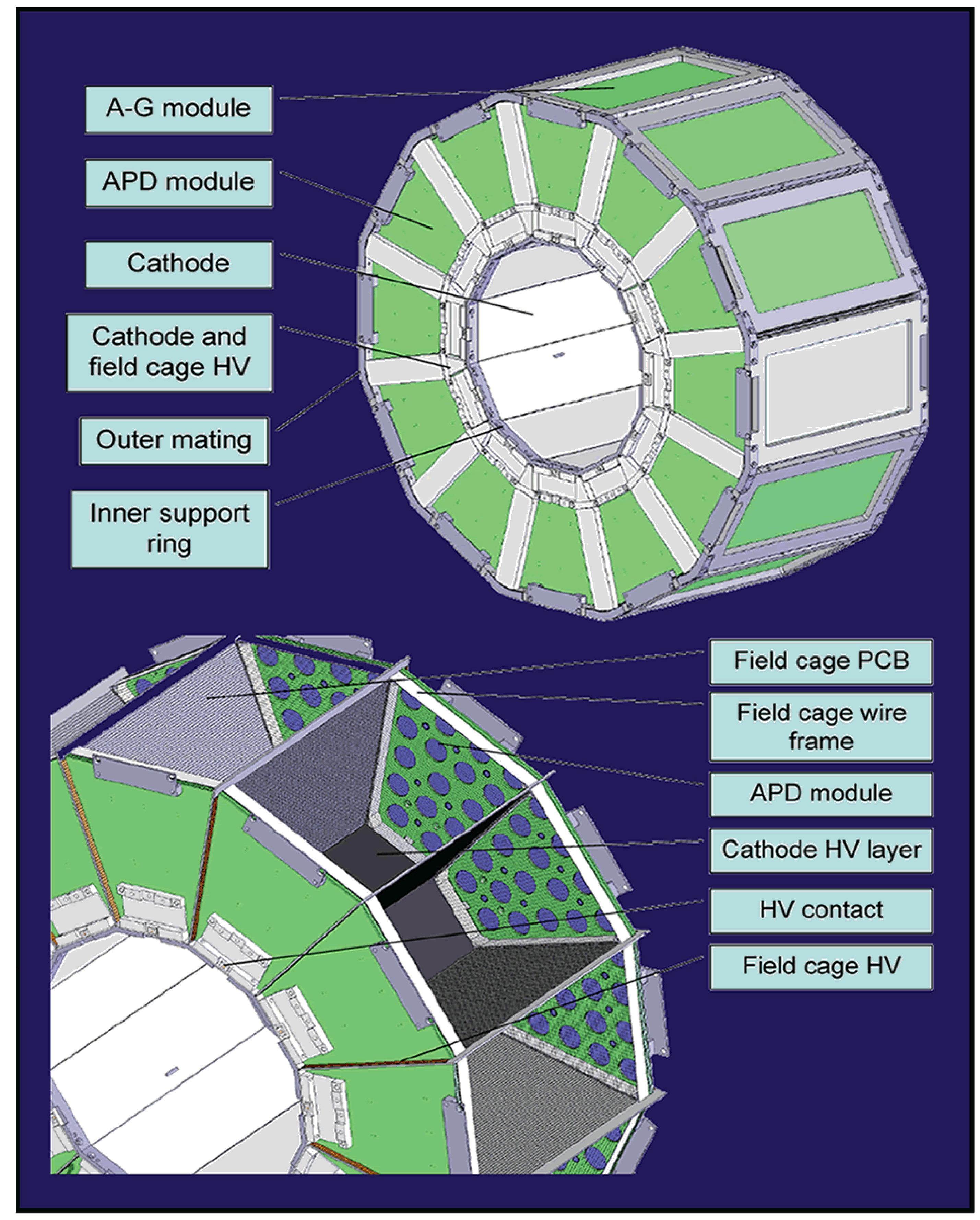

Figure 1: Schematic drawing of the simulated liquid xenon PET system.

Using Geant4, we simulated the performance of a LXe microPET detector (inner dia. 15cm, axial length 12cm) with a NEMA-like rat size phantom (5cm dia. x 15cm polyethylene with a 1.9mm dia. x 15cm water source offset radially by 15mm). The data were processed with the Compton reconstruction algorithm, and the resultant sinogram profile is shown in Fig. 2. The results for efficiency, scatter fraction and NECR are given in Table 1 for the same phantom with an energy window of 450-550 keV and coincidence window of 6ns.

In the reconstruction algorithm, true events are kinematically favored over scattered and random events, as illustrated in Figure 3. To demonstrate the image quality expected in a LXe PET scanner, we simulated a hot-rod phantom immersed in a 6 cm dia. water phantom (including effects of positron range) to produce the image shown in Fig. 4. These results indicated that LXe is a new approach which promises to provide high resolution diagnostic power with high sensitivity for future PET scanners.

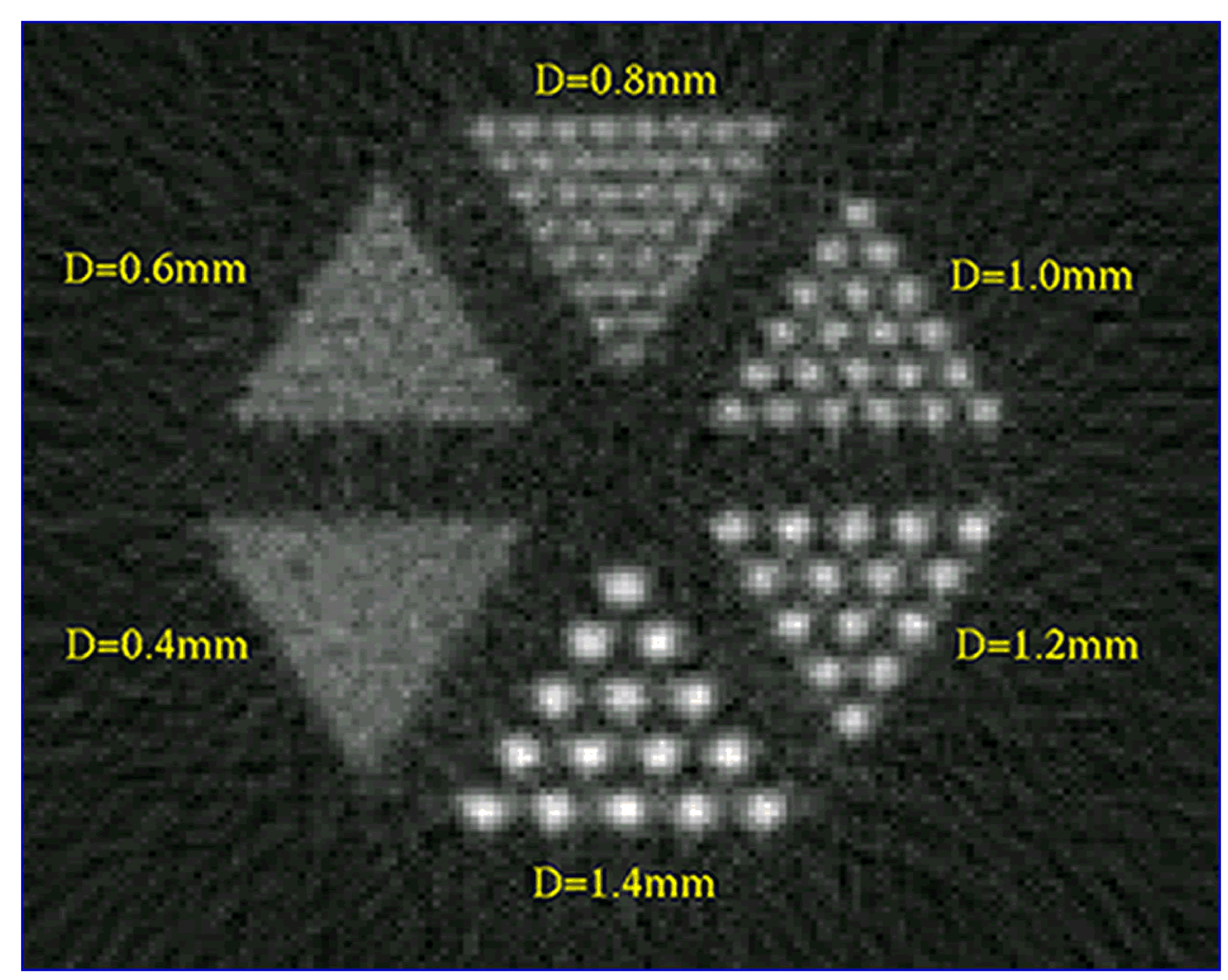

Figure 4: Image reconstructed for a simulated micro-Derenzo image constrast phantom with source rods of various diameters immersed in a 6cm dia. water phantom. Rod-to-rod separation was equal to twice the associated rod diameter. The image was reconstructed using a Filter-Back Projection algorithm with a modified Ramp filter having a cutoff at the Nyquist frequency. The data count rate was equivalent to a 20 min scan at 1 MBq total activity.*

**FBP algorithm for MATLAB adapted from http://www.owlnet.rice.edu/~elec431/projects96/DSP/index.html*

Table 1: Performance of LXe microPET with a NEMA-like rat size phantom, using a 450~550 keV energy window and a 6ns coincidence window

Property	System Perfomance	Description
Sensitivity	12%	Attenuation-less true coincidence rate divided by the activity with a simulated point source at the center of the field of view.
Scatter Fraction	18%	Scatter events divided by the total number of events at low activity obtained by assuming constant scatter background in the sinogram projection using NEMA-2001 standards.
Maximum NECR	510 kcps @ 70 MBq	Noise-Equivalent Count Rate = (True Coincidence Rate)^2 / (Total Coincidence Rate)

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