Simulations of Scintillation Events in a High-Resolution Liquid Xenon Micro-PET System

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1. Purpose

A high-resolution micro-PET system based on liquid xenon (LXe) is under development. The system employs LXe time projection ionization detectors (TPC) and large area avalanche photodiodes (LAAPDs) light sensors. The energy and positions of interactions in liquid xenon are measured by combining signals received from ionization charge in the TPC with scintillation light from the LAAPDs, improving the energy resolution, spatial resolution, and sensitivity.

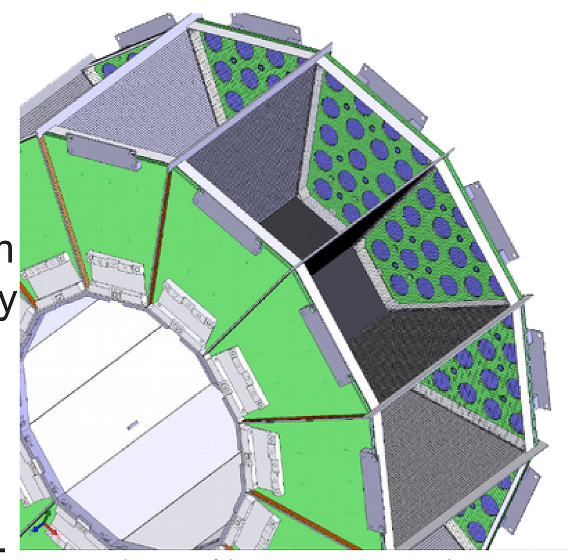

Figure 1: Schematic of the LXePET prototype. The prototype consists of 12 concentric TPC sectors filled with liquid xenon. LAAPD detectors are shown on the inner walls of the sector.

The energy from scintillation light is used to select events in the 1st-stage of a 2-stage selection. We investigated methods of determining interaction locations from the LAAPD data by employing neural network (NN) computation algorithms. The position resolutions of interaction locations achievable by these methods under various degrees of reflectivity of the surfaces within the detector were studied.

2. Methods

Simulations were performed using GEANT4, and analysed with the ROOT analysis package. A simulated isotropic point source of 10220 optical photons (representing scintillation light from 511 keV gamma photons) was located at various points within the sector. The scintillation signal on the LAAPDs was calculated for all points within the sector on a 2x2x2 mm three-dimensional grid for various levels of reflectivity.

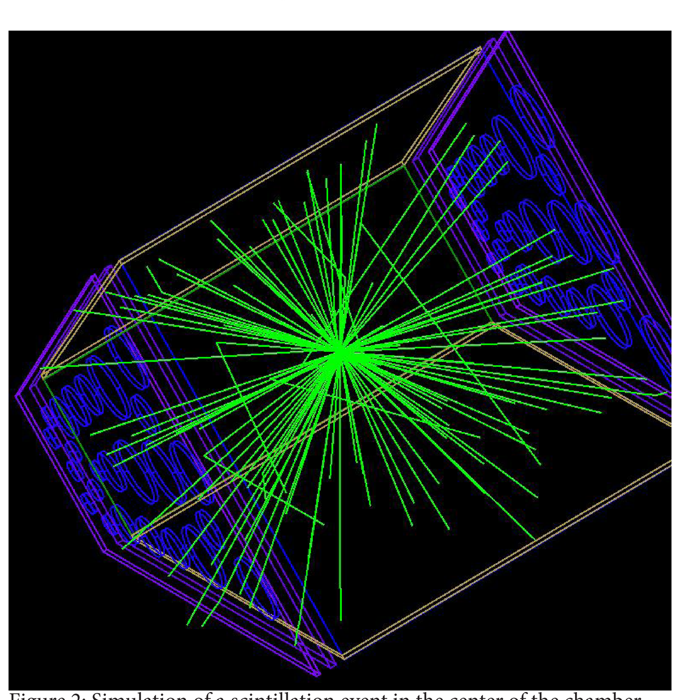

Figure 2: Simulation of a scintillation event in the center of the chamber. The number of optical photons reaching the surface of the LAAPDs are measured.

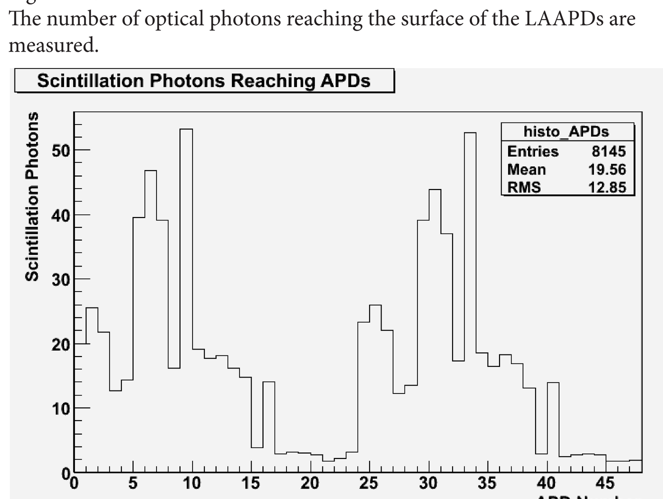

Figure 3: Histogram of the number of photons reaching each LAAPD from a scintillation event of 10220 photons generated at the center of a LXePET sector.

A distribution of interactions within the sector was evaluated with the NN algorithm.

3. Neural Network Specifications

The Neural network was constructed with the ROOT class TMultiLayerPerceptron. It consists of a simple feed-forward network with 160 hidden layers and a structure as indicated by the following diagram:

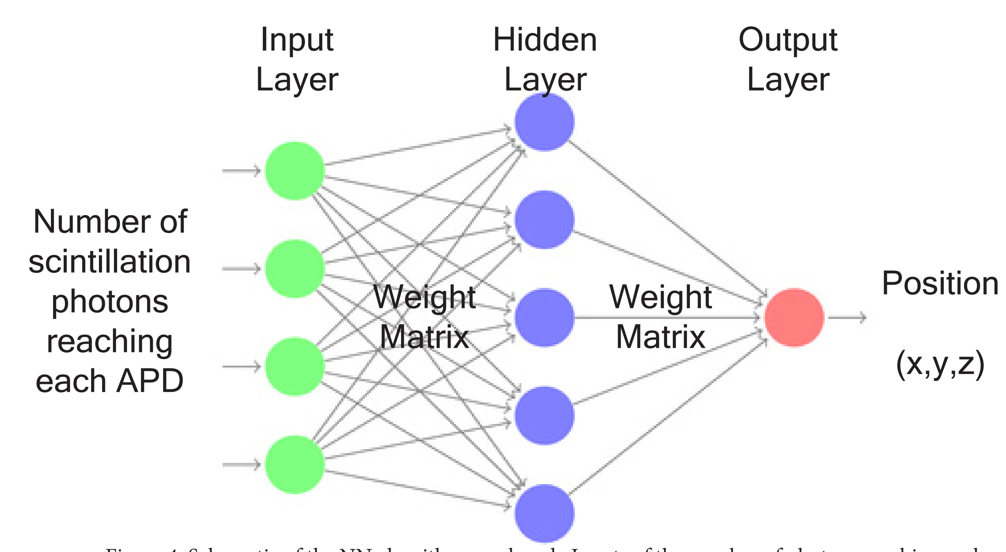

Figure 4: Schematic of the NN algorithm employed. Inputs of the number of photons reaching each APD are evaluated with 160 hidden layers to find the position of scintillation within the sector.

The network employed 200 iterations using the Broyden, Fletcher, Goldfarb, Shanno (BFGS) method. The number of photons reaching each APD for a particular interaction location was input and the resulting output gave the interaction location. This was done for a configuration of zero reflectivity within the detector and for a configuration of a typical amount of reflectivity on surfaces within the sector.

4. Results - Zero Reflectivity

Simulations performed using no reflective surfaces within the sector showed that the NN algorithm was successfully able to reconstruct interaction positions in 3 dimensions within the sector. Under optimal conditions of no electronics noise, the 3-D spatial resolution of reconstructed points was approximately 4 mm FWHM.

Position Reconstruction Results

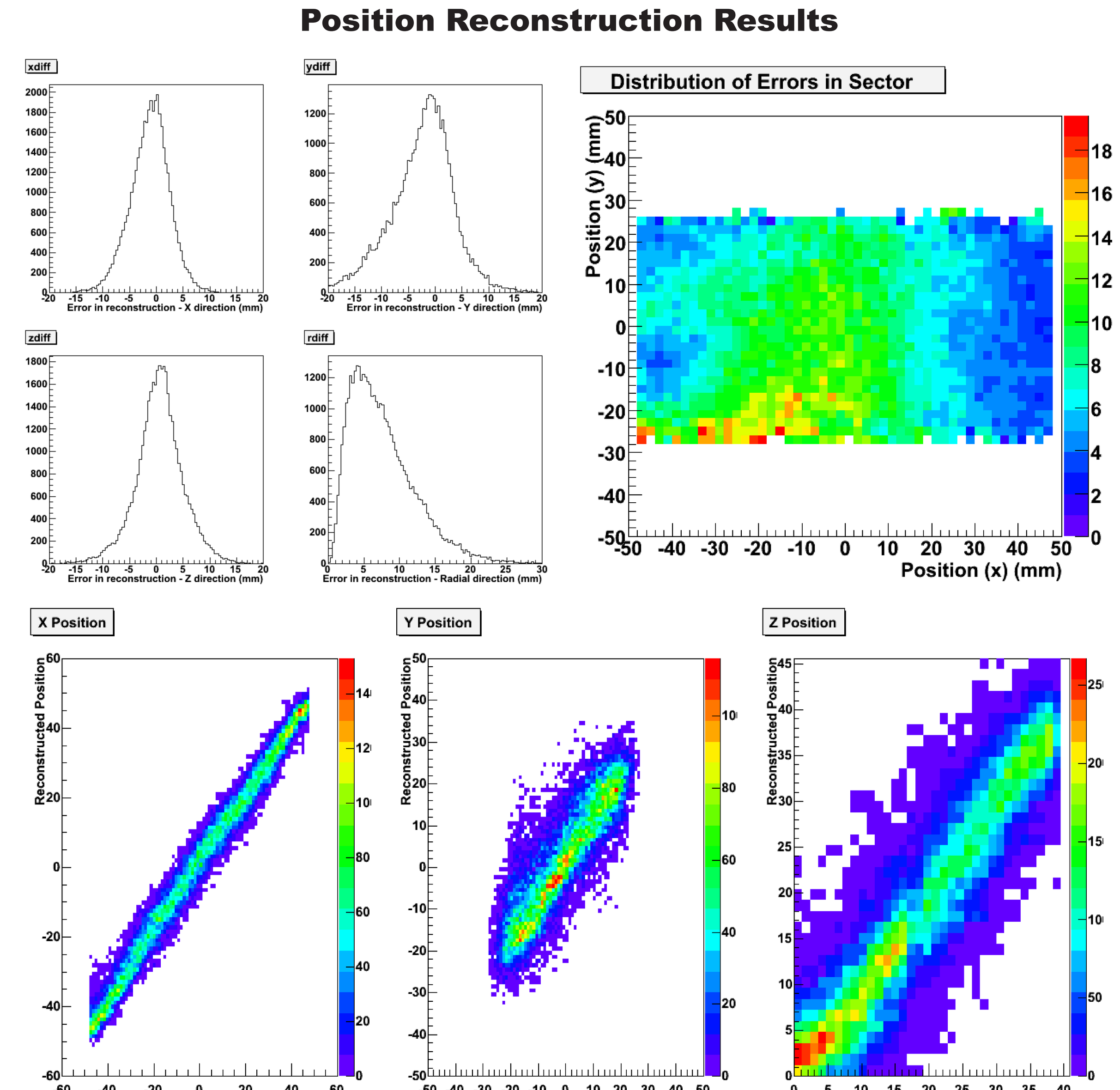

Figure 5: Reconstruction results for the case of no reflectivity within the sectors. Reconstruction error generally increases towards the center of the sector, away from the position of the APDs.

When electronics noise of 500 electrons is applied to the APD signal, the resolution is degraded to approximately 9.0 mm FWHM in 3 dimensions.

5. Results - Reflective Surfaces

Simulations were also performed using reflectivie survaces added to the innar walls of the sector similar to that which is achievable within the detector configuration. In this case, the 3-D spatial resolution was improved slightly to approximately 8.5 mm FWHM.

Position Reconstruction Results

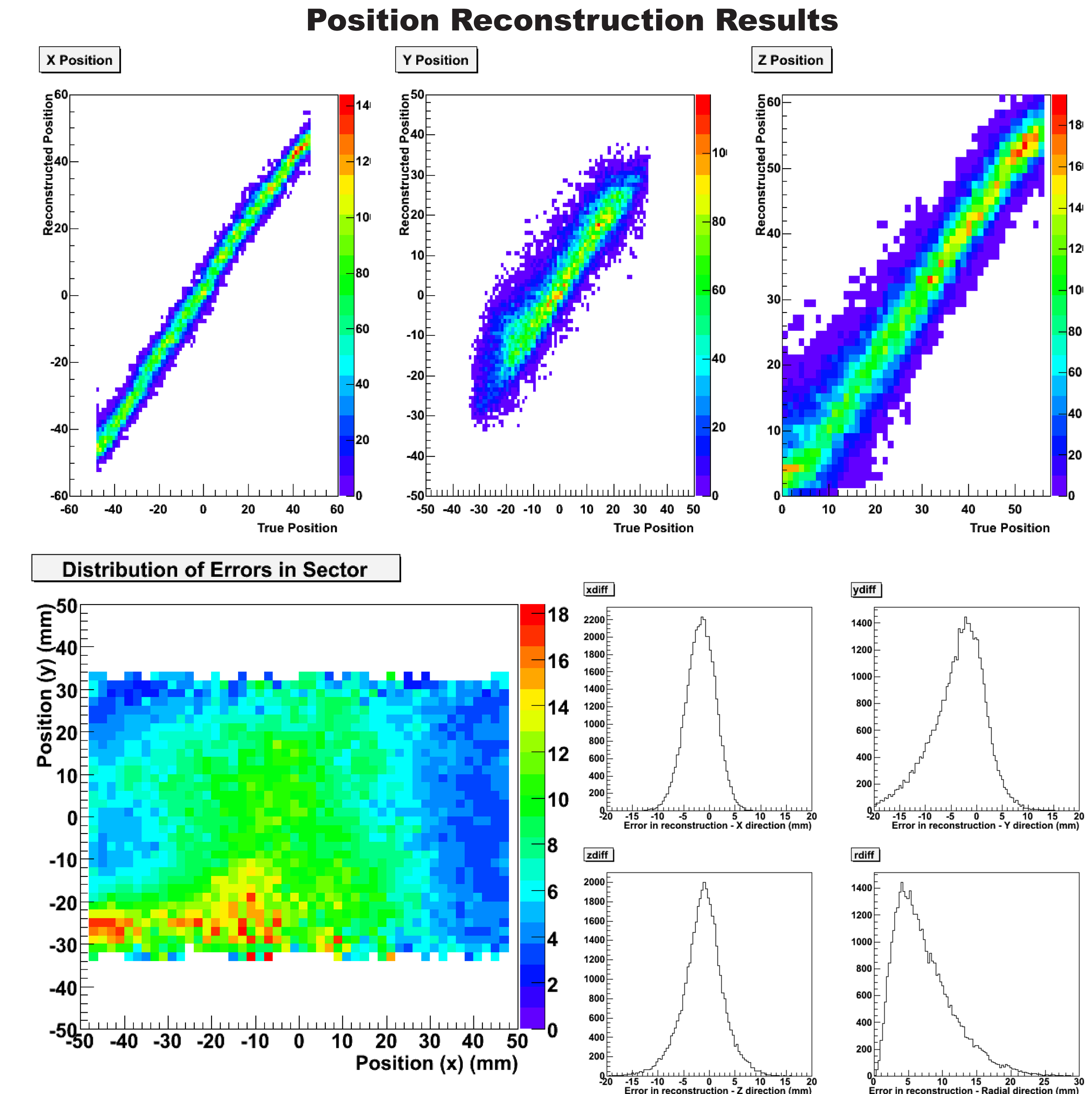

Figure 6: Reconstruction results from the case with reflective surfaces added to the sector configuration. The position reconstruction improved slightly over the zero-reflectivity case.

Further studies were performed in which the amount of electronics noise applied to the APDs was varied from 500 electrons to 200 electrons and compared to the case with zero electronics noise. In this case, the mean radial reconstruction error varied with both position and amount of electronics noise.

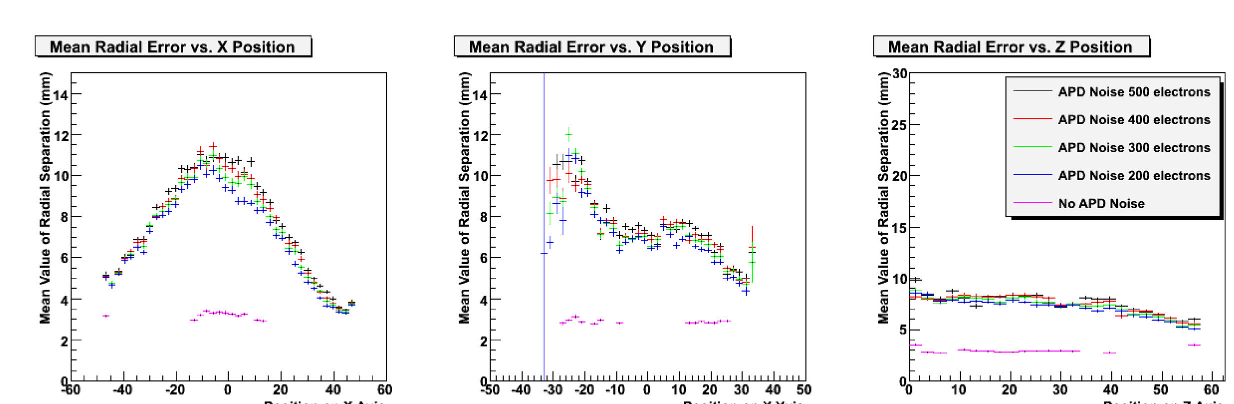

Figure 7: Simulation results win increased levels of electronics noise. Noise was varied from 200 to 500 electrons and compared to the case with zero electronics noise applied.

6. Conclusions

3-D reconstruction of positions of interactions are possible using Neural Network algorithms in a PET scanner employing LXeTPC detectors. Spatial resolutions of approximately 8.5 mm FWHM are achievable with various conditions of reflectivity on the inner surfaces of the detector. Further analysis of training methods and noise reduction techniques could improve this resolution further. Future studies include reconstruction of energy deposited, and examination of the energy resolution achievable with this method.

7. References

Amaudruz *et al*: *"Simultaneous reconstruction of scintillation light and ionization charge produced by 511 keV photons in liquid xenon: potential application to PET"*; Nuc. Instr. and Meth. in Phys. Res. A, **2009**

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