The Simulation and Optimisation of Position-Sensitive $LaBr_3$ Detectors for Compton Imaging

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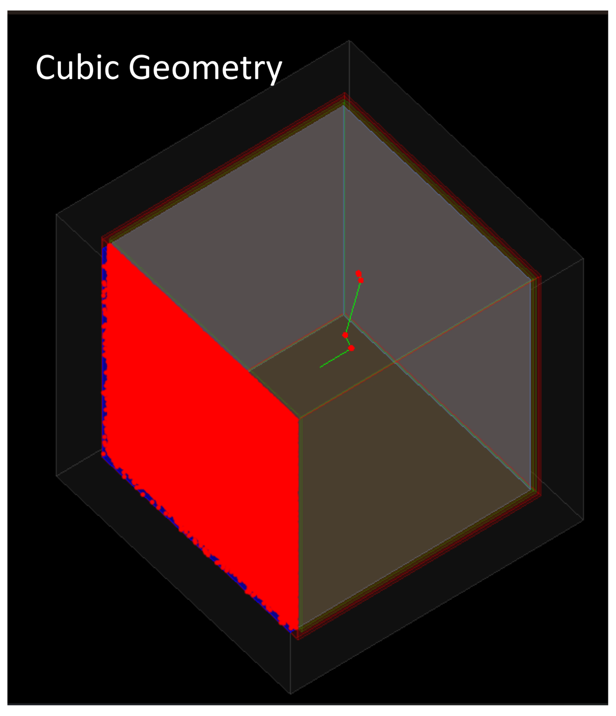
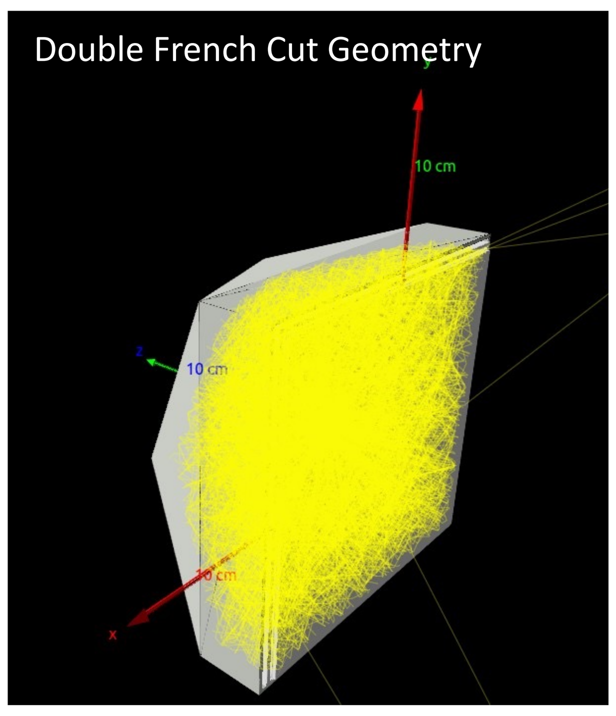
Introduction

Due to their electric collimation, Compton Cameras are more sensitive to detecting γ-rays and have improved range compared to traditional, collimation-based systems. Compton Cameras have a variety of uses in Nuclear Security, from applications in ports and at borders to identify and help confiscate illicit sources to proper nuclear safeguarding and quantification of nuclear waste.

Using a scintillator-based Compton camera is advantageous as they are cost effective, reliable, highly efficient, easily maintained, and can operate at room temperature. However their readout systems prove challenging in multi-tiered setups and they lack effective position resolution for multiple interaction events. This project aims to improve the position resolution of monolithic $LaBr_3$ by using novel crystal geometries combined with pulse shape analysis (PSA) for use in single-crystal Compton Imaging.

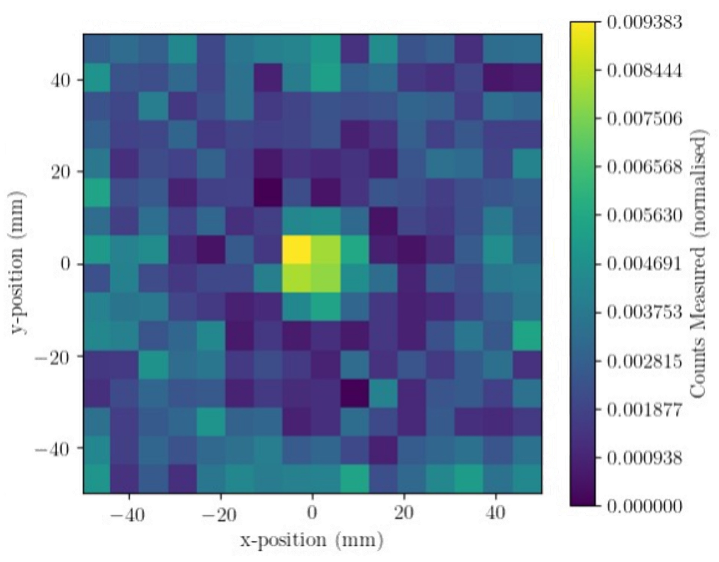
1. Detector Geometries

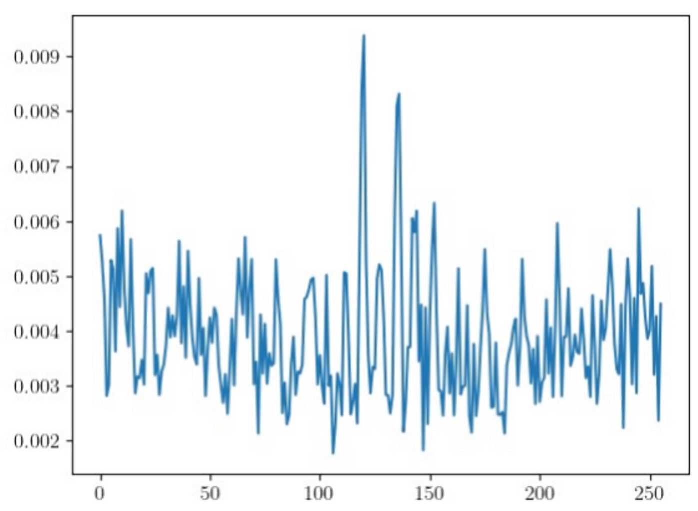




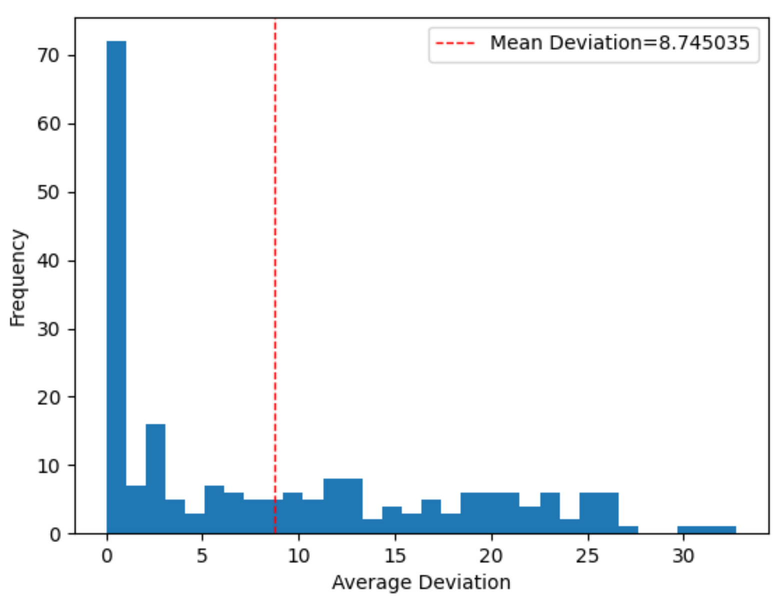
2. Position Sensitivity of Novel Detector

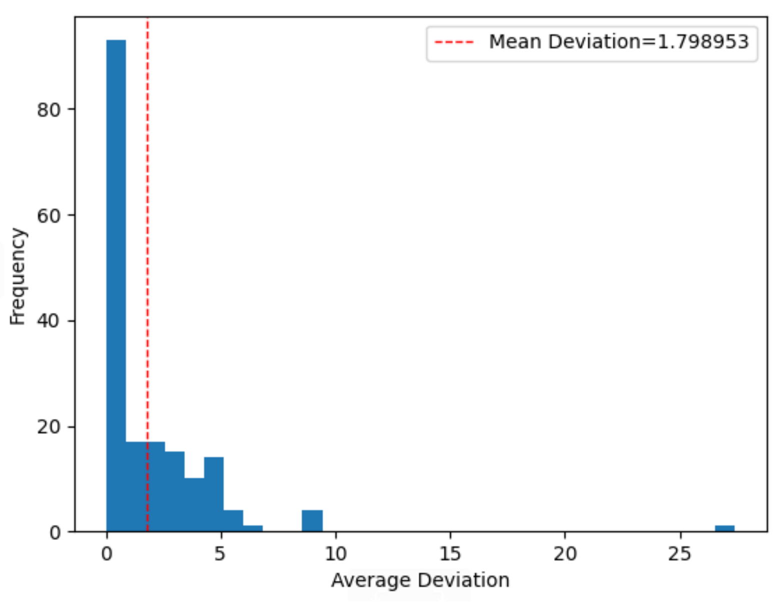
- Monte Carlo simulations were run for multiple positions in a geometry using GEANT4 to produce databases of signals.





- Realistic experimental signals were then generated and queried against the databases.
- In this comparison, the figure of merit was calculated, with the minimum Figure of Merit (FOM) considered as the location of the γ-ray interaction.
- This process was repeated 100 times and an average FOM and Euclidean deviation in mm was found for each position.

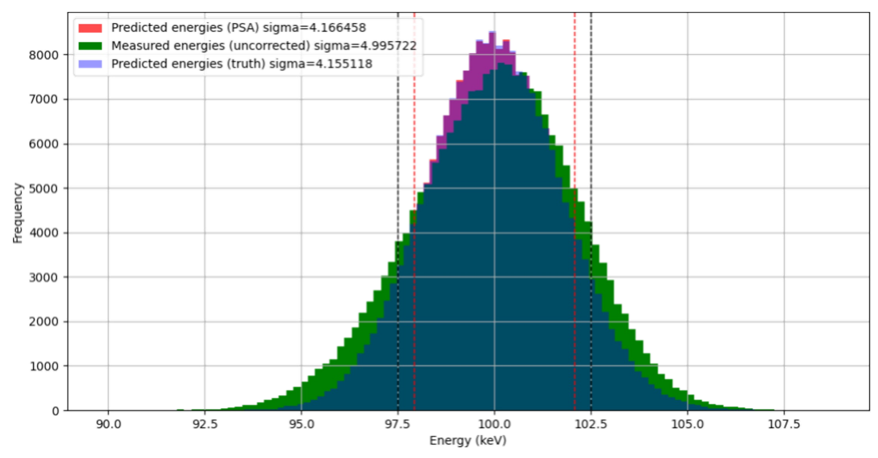


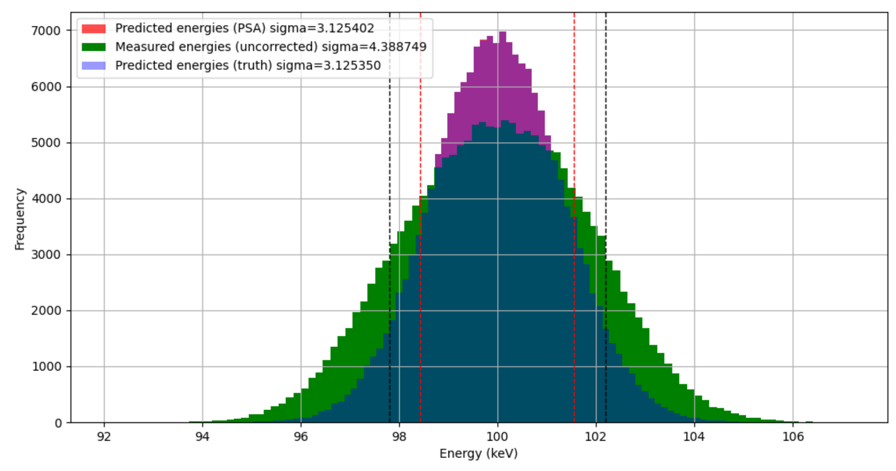


It was found that using a novel detector geometry increased the position sensitivity of the detector. This result can be seen in the deviation histograms for the cubic (left) and double French cut geometry (right) through the location of the mean. The novel geometry provides more information to the PSA from the additional reflections off the crystal faces.

3. Energy Resolution of Novel Detector

- In scintillators the collection efficiency varies as a function of position. Using GEANT4 the collection efficiency was quantified for each geometry and used as a corrective factor.
- Using PSA, the interaction position of simulated experimental signals was determined, and the correction applied to the measured energy to produce a PSA-predicted energy.
- This process was repeated 1000 times for each position and the mean measured and corrected energies were compared against a correction assuming perfect PSA recall.





Using a novel detector geometry (right) increases the accuracy of the PSA; as seen on the graphs, there is a closer overlap between the energies predicted by the PSA and the true energies for the novel design. Furthermore, the narrower PSA FWHM shows that the energy resolution is increased to a greater effect and improved when a novel detector is used.

4. Two Interaction PSA

Using a two-interaction PSA algorithm developed at Liverpool it was possible to correctly fit the combined contributions of two-interaction events without the use of windowing.

This process is made possible in the novel geometry by using the increased signal fidelity present in the signal database. This allows for Compton cones to be constructed from a single crystal system.