Basis Pulse Shape Analysis Using Planar HPGe Semiconductor Detectors

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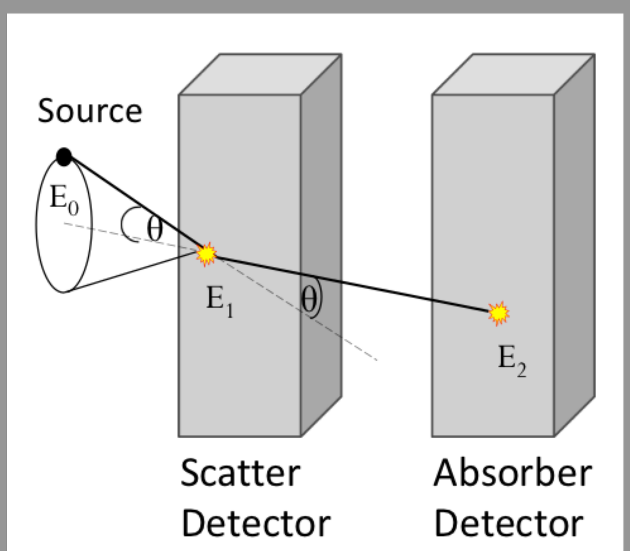
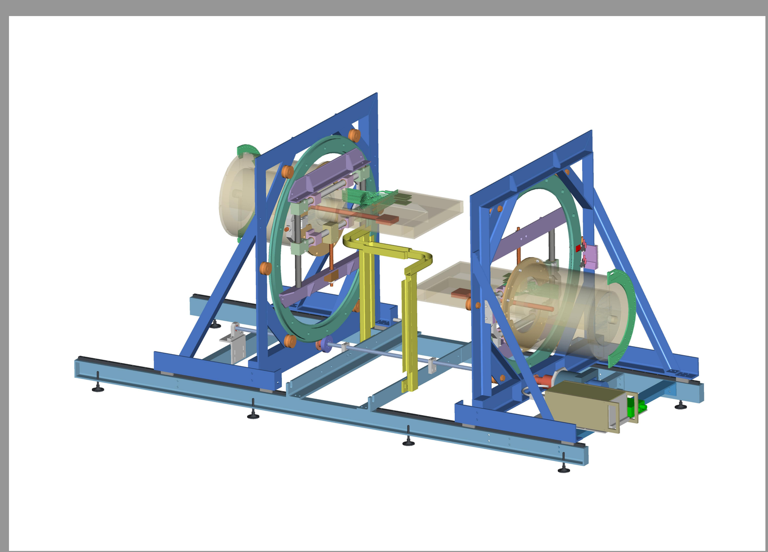
Abstract

We present an approach of applying Pulse Shape Analysis to preamplifier charge pulses from a planar High Purity Germanium (HPGe) γ-ray detector to improve interaction position resolution through depth. This leads to an improvement in the quality of images reconstructed by Compton camera systems that are comprised of such detectors. Algorithms that achieve this and recent experimental data is discussed.Digital ADCs allow charge pulses to be stored for each γ-ray interaction in the detector. By scanning the detector using a collimated source a database of reference pulses can be built corresponding to specific interaction sites. Experimental pulses can be compared to this database using a chi-squared minimisation method to extract position information beyond the raw granularity of the detector. This method was tested using a planar HPGe detector with an active volume of 60mm x 60mm x 20mm, electronically segmented to give raw position resolution of 5mm x 5mm x 20mm. Database pulses were recorded at 1mm intervals both across the face of the detector (x) and through depth (y) with FWHM values of ≤ 2.5mm for y positions at all given x positions. This was compared to datasets from a Compton camera experiment using the same detector and CAEN V1724 digital ADCs where ^{137}Cs and ^{22}Na measurements were taken in various positions and configurations. Experimental pulses were digitized and compared to the database to form a histogram of interaction depths. By comparing this to the expected exponential attenuation of γ-rays as predicted by theory this concept can be validated.

The Compton Camera System

The Compton camera gives position and energy information of radioactive sources by combining semiconductor detectors in configurations that harness the gamma ray interactions and the Compton scattering formula. Pertinent to this work is the use of two planar HPGe detectors as shown. In an ideal scenario, a radionuclide source emits a gamma ray of energy E0 which Compton scatters through an angle θ in the scatter detector depositing a fraction of its energy E1 and is absorbed in the absorber detector depositing its remaining energy E2 where E2 = E0 − E1 . Using these values and the Compton scattering formula the initial gamma ray energy and its scattering angle can be calculated, indicating the position of the source. The electron off which the photon scatters is not stationar however, therefore a cone of uncertainty is back projected from the scatter position on which the source lies. The source can be located at the point where cones intersect with an uncertainty arising from the energy and position resolution of the detector. The experiments were performed using the SmartPET system setup in Compton camera mode. It consists of two HPGe planar detectors of dimensions 60mm x 60mm x 20mm. They both have 12 AC and DC contacts arranged perpendicular to each other giving 144 electronically segmented voxels of 5mm x 5mm x 20mm.

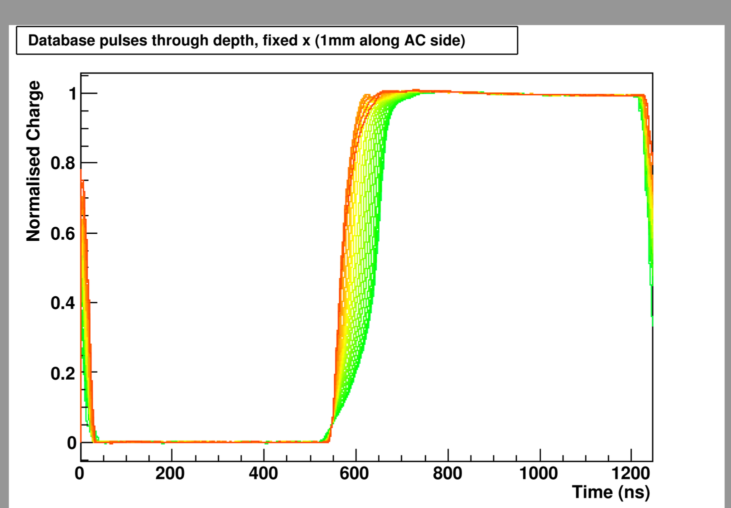


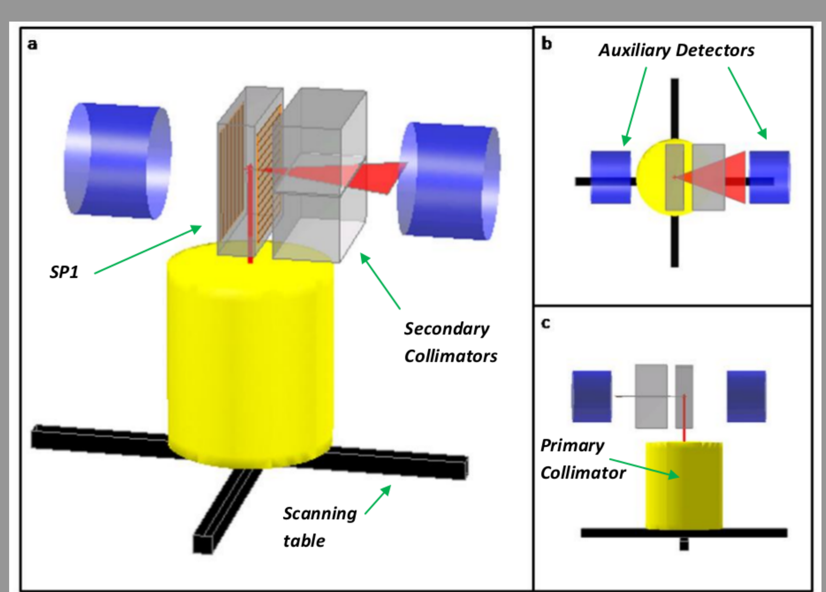


Pulse Shape Analysis

To obtain the best possible image quality from a Compton camera it is necessary to optimise its position and energy resolution. There are several ways of achieving this but a widely researched option is to study the signal generation from each interaction within the detector as a function of time. Generated pulse shapes are dependent on gamma-ray interaction depth and an understanding of the features of the pulses can be used to improve position resolution beyond the raw granularity of the system (as understood using the Shockley-Ramo theorem). A database of pulses of known interaction sites was compiled and by comparing experimental pulses to this database using a chi-square minimisation technique position resolution can be improved.

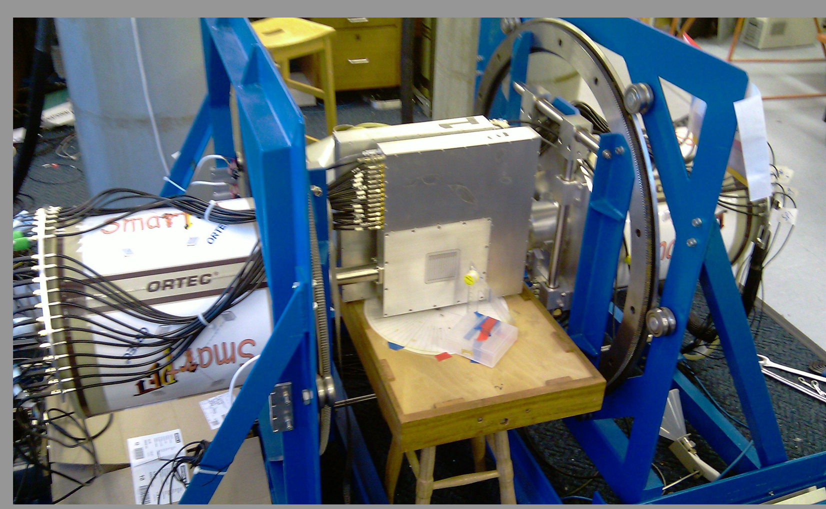
As part of his Thesis work, Dave Scraggs carried out a collimated coincidence scan on the SmartPET detector with a setup as as shown in the figure below. The scanning table houses a 1GBq ^{137}Cs collimated source to give a high number of gamma-rays incident on the detector. The beam emitted from the table was to be collimated to a given depth (z) and its position with respect to the face of the detector (x-y) controlled with the lead secondary collimator. Two HPGe coaxial germanium auxillary detectors were used to detect scattered gamma-rays to ensure true events were recorded as opposed to incident background radiation. As the auxillary detectors were placed at 90° and ^{137}Cs has one strong gamma emission at 662keV the Compton scattering formula can accurately predict the scattered gamma ray energy. Due to the rarity of 90° scatters of 662keV gamma rays stastics were only sufficient to record single site interaction pulses in 1mm increments through x and z.

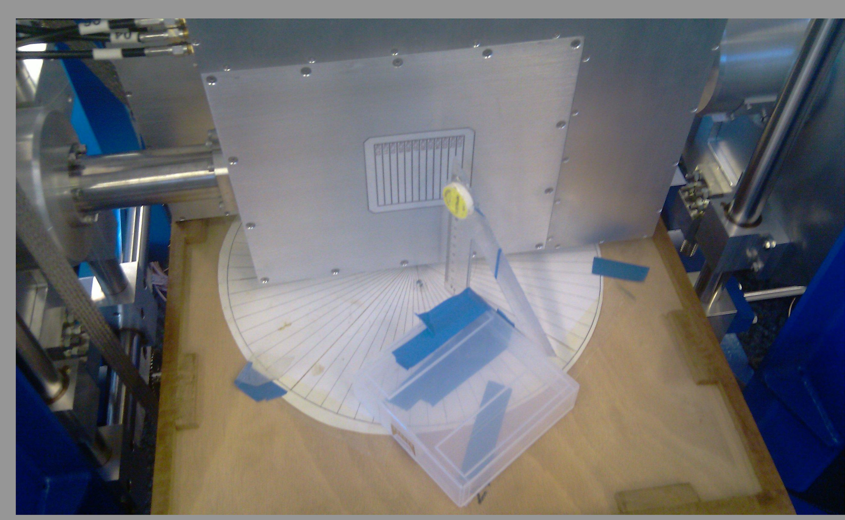




November 2010 Experiment

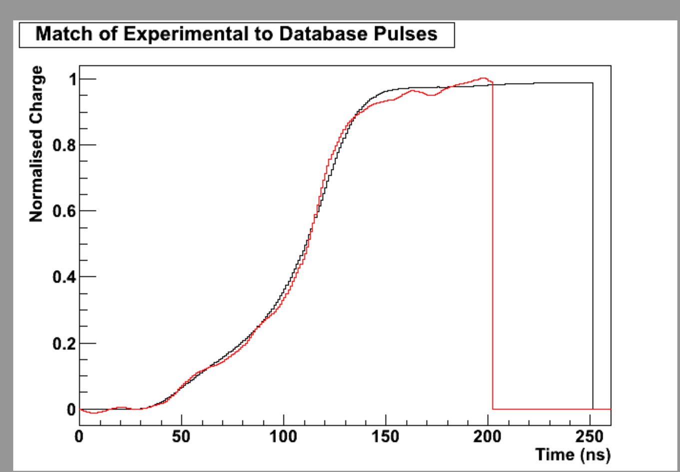
In November 2010 the SmartPET system setup incorporated CAEN V1724 digital Analogue-to-Digital Convertors in order to record the charge pulses of experimental data. A number of datasets ^{137}Cs point and ^{22}Na line sources were recorded in a number of positions and configurations. These datasets form the experimental basis of this research as well as work into parametric PSA and iterative image reconstruction tests.

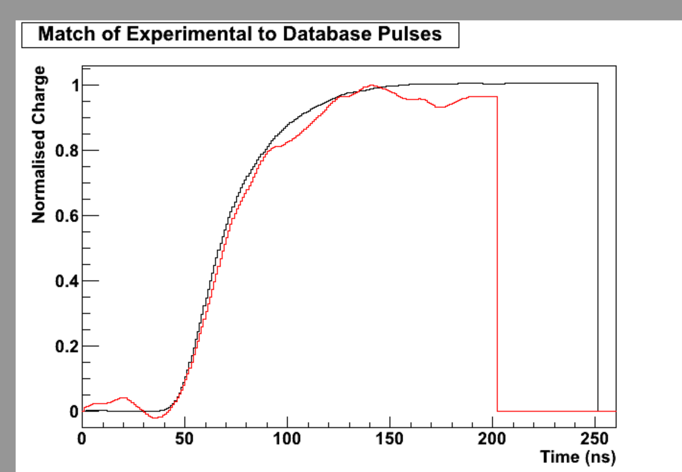




Analysis and Results

This research focused on the sort code algorithm that correctly matches experimental to database charge pulses. The code works by comparing experimental pulses with all database pulses in the voxel of interest by a chi-squared minimisation method. The closest basis pulse is the one that returns the smallest chi-squared correlation coefficient and its location is taken to be that of the experimental pulse.





Understanding the physics of the single site interactions is vital to ensure the algorithm is working corectly so position and image resolution is improved. The plot below shows the counts through depth for SmartPET 2. It shows at least a qualitatively expected trend; there is a build up a region in the first few mm due to the forward momentum of ejected electrons in gamma-ray interactions. As we measure charge carrier position as opposed to interaction position it is not possible to simply check this plot against expected attenuaton as first hoped. There are pulses that are mistakenly taken as single site interactons however, and these may be contributing to the large number of counts in the first bin. Work is ongoing to ensure these are correctly identified and vetoed. Current imaging results show an improvement in image resolution with PSA through depth, with a FWHM of 17mm in x and mm 20mm in y in the source depth plane. However the code is not yet optimised and it is believed further improvements in resolution will be yielded from a greater understanding of the matching function.