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Gammas

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Pulse Shape Analysis

Pulse shape analysis is a method of improving the performance of a detector by parameterising the preamplifier signals that are recorded using digital electronics. There are various techniques available and in this exercise we will consider parametric pulse shape analysis in a (60x60x20) mm HPGe detector, segmented into 12 x 12 orthogonal strips of 5mm pitch.

Image Charge Asymmetry

Position resolution in the lateral plane of a planar HPGe strip detector can be improved by analysing the asymmetry of image charges. Image charges are induced in neighbouring strips by the movement of charge carriers in the interaction strip. The signals have no net charge and are produced due to electrostatic coupling between moving charge carriers and the electrodes. The relative areas of the image charges present in the nearest neighbour strips can be used to identify the proximity of the interaction to the those strips, e.g. in Fig.1, the relative area of the image charge in AC04 is larger than in AC02 because the interaction occurs closer to AC04. Therefore, the ability to identify where the interaction has occurred within AC03 can be improved.

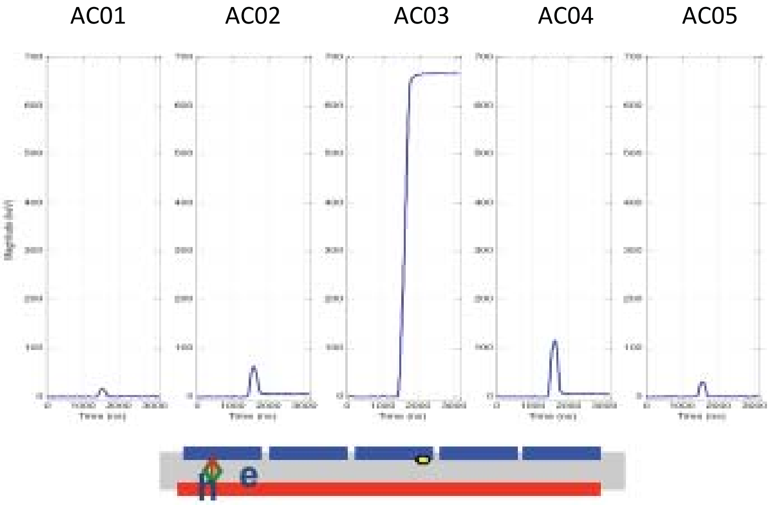


Fig1: Preamplifier signals recorded when a gamma-ray interacted in strip AC03 of a planar HPGe detector. The interaction is closer to AC04 than AC02, resulting in a larger image charge on AC04.

The image charge response must be calibrated for each strip in the detector (excluding the edge strips where this technique is not suitable). The calibration parameter is known as the image charge asymmetry. It can be calculated on an event-by-event basis by using the equation:

$$Asymmetry = \frac{Area_{left} - Area_{right}}{Area_{left} + Area_{right}}$$

Two major assumptions are made:

- The image charge asymmetry parameter is directly related to the position of interaction within a given strip. That is, a value of around zero results from an interaction close to the centre of the hit strip, while values of -1 and 1 indicate interactions have occurred towards strip boundaries.

- There is an equal probability of an interaction occurring anywhere in a strip.

Fig2 shows example image charge asymmetry distributions for 4 strips of a planar HPGe detector. As an example, each asymmetry distribution can be divided into five regions of equal area. The boundaries of these sections are then stored in a look up table which, along with the gate coefficients generated from the risetime correlation matrices, can be applied to further experimental data on an event-by-event basis to assign a sub-strip hit position for every event. By splitting up these distributions in this way, each substrip has a size of 1mm, which is consistent with the limit of spatial resolution expected to be achievable with HPGe detectors at this time.

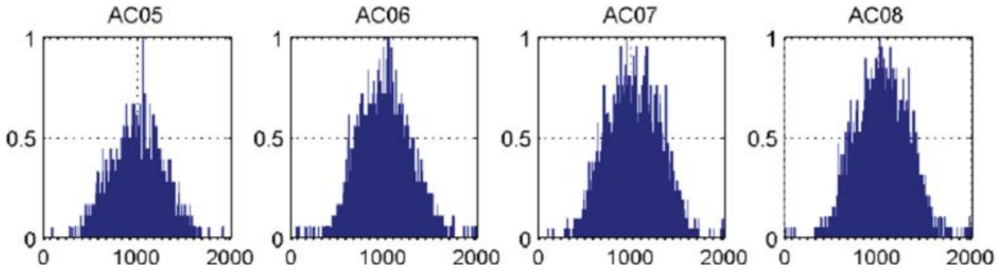


Fig2: Example asymmetry distributions for 4 strips of a planar HPGe detector

Risetime Correlation

To determine the interaction position between AC and DC coupled contacts (interaction depth in a planar detector), risetime correlation methods can be used. This technique relies on knowledge of how the charge collection time (risetime) varies as a function of gamma-ray interaction position. This method relies on a calibration for a particular detector. One such calibration is through the measurement of t30 and t90 of the preamplifier signals on an event-by-event basis at known interaction depths, where t30 and t90 are the time taken for the pulse to rise from 10% to 30% and 90% of its height, respectively. Plots of the distribution of t30 vs t90 for all events as a function of position can be produced, such as the example in Fig 3. In further measurements where the interaction position is unknown, the preamplifier signals are digitally recorded and analysed offline so that measuring the t30 and t90 and correlating them to the known response can facilitate identification of the interaction position in depth.

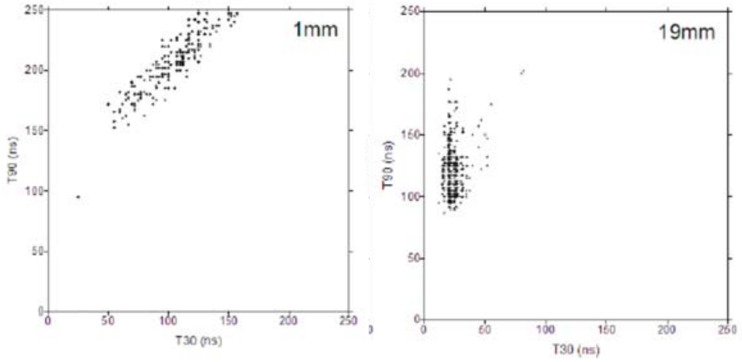
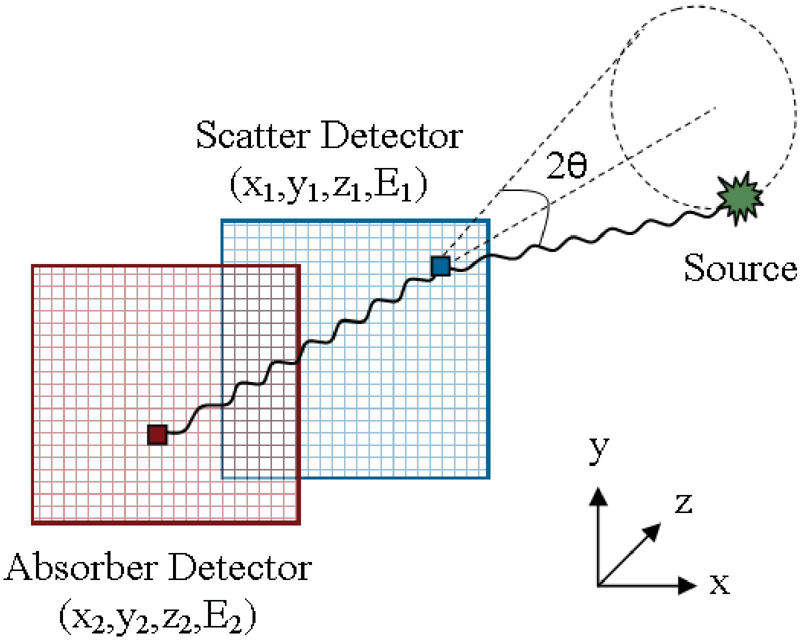


Fig3: Example t30 vs t90 plots for 2 interaction depths relative to the DC face in a planar HPGe detector

A brief introduction to Compton Imaging

For this exercise, the influence of pulse shape analysis on the performance of a Compton camera system will be investigated. Here, a brief introduction to Compton imaging is provided. Compton cameras are used to locate and image a source of gamma radiation. A Compton camera is typically composed of two energy and position sensitive detectors. The front detector is called the scatter detector and the back detector is called the absorber detector. In an ideal system, a gamma ray will Compton scatter from an electron in the scatter detector, depositing a fraction of its initial energy and then interact via Photoelectric absorption depositing its remaining energy in the absorber detector, as shown in Figure 1.



$$\cos\vartheta = 1 - m_e c^2 \left(\frac{1}{E_1} - \frac{1}{E_0} \right)$$

Fig1: A schematic diagram showing the cone produced for one incident gamma ray which transfers Energy E_1 to an electron via Compton scattering at (x_1,y_1,z_1) in the scatter detector and then deposits its remaining energy E_2 through photoelectric absorption at (x_2,y_2,z_2) in the absorber detector.

Compton camera data, (energy and position information from the two detectors) is acquired using digital electronics, which record the preamplifier signals. The data is then processed (cones built), using an image reconstruction algorithm. In the code, the scattering angle Θ of the gamma ray in the scatter detector is calculated using the Compton scattering formula, with knowledge of the energy depositions in the two detectors.

The calculated angle Θ is then used to form a cone with apex angle 2Θ. The axis of the cone is given by the vector difference between the two interaction positions. This process is carried out for every gamma ray, which interacts once in each detector, so that many cones are formed. The location of the radioactive source is then deemed to be located at the maximum intersection of the cone surfaces.

Compton Image Reconstruction Algorithm

Below is a brief user guide to the C++ Compton image reconstruction algorithm. The code will be used to generate Compton images from several experimental data sets.

Introduction
This code is run using the ROOT package to produce intensity versus position plots in (i) 1D and (ii) 2D (Compton images). The code works by calculating the size and position of the 2D conics that are produced when a cone is sliced at a given angle and z-distance. These conics are then projected onto a 2D imaging plane to produce the 2D image (as shown Fig.1). Information in 3D is generated by looping the calculations over several z (depth) slices.

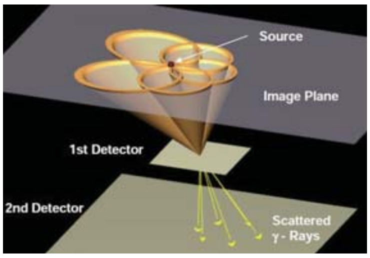


Fig1: A schematic diagram showing cones projected onto a 2D imaging plane

A 2D image slice of intensity versus position in the xy-plane is produced along with 1D intensity profiles, in the x- and y-axis of this slice through the point of maximum intensity. These 1D profiles are fitted using a custom function to determine the FWHM (position resolution) of the distribution. The fit assumes a Lorentzian peak on a quadratic background.

Running the code
The algorithm will be pre-compiled for you, so that you are provided with an executable. To run the pre-compiled executable, type the following command into a terminal

```
.x compton37.c
```

You will then be presented with a brief description of the code and asked to enter the format of the data you wish to image. If the wrong data format is entered, the imaging will not be successful!
The (1) Geant format is a simple ASCII text file which lists absolute positions and energies as z1, y1, x1, e1, z2, y2, x2 and e2 for each Compton event. Z = 0 is defined as the back face of the absorber detector. This should be used to generate images from data which has PSA applied. The data which has no PSA applied must be processed using (7) Smartpet + 5mm Ge format which reads the interaction strips and calculates co-ordinates from these. For all formats, the first thing you will be asked for is the name of the data file that is to be imaged. If the data file is not in the same directory as the program is being run from, the full path of the file must be entered. You will then be asked a series of questions. The following answers should be provided along with the values in the table:

- *Do you wish to produce single or multiple slices? [s/m]:* **optional**
- *Do you want to use BLD or MWD energies?:* **1**

- *Do you want to gate on the gamma-ray energy?:* **3**
- *How many gamma-rays do you wish to gate on? (1-10):* **1**
- *Please enter the lower and upper gamma-ray energies for gate 1 in keV:* **Choose a suitable gate**
- *Do you want to gate on the order of the scattering and absorbing interactions?:* **0**
- *Do you want to gate on the gamma-ray scattering angle? [y/n]:* **n**
- *Enter the number of peaks to fit in the X axis and Y axis (1 or 2):* **1**
- *Enter the compression factor (mm per bin):* **1**
- *Enter the number of points drawn per degree of the cone*: **10**
- *Enter the lower and upper X and Y gates for the cone count:* **350 and 450**
- *Enter the number of events to process* (0 for all events): **0**

Filename	**Format**	**Z slice**	**X range**	**Y range**
5mmFold1.txt	7	125	100	100
5mmPSA.txt	1	125	100	100
10mmFold1.txt	7	175	100	100
10mmPSA.txt	1	175	100	150
14mmFold1.txt	7	215	200	150
14mmPSA.txt	1	215	200	150

A series of images will then be produced showing the intensity as a function of position, as described in the following section.

T30 vs T90 Risetime Spectra

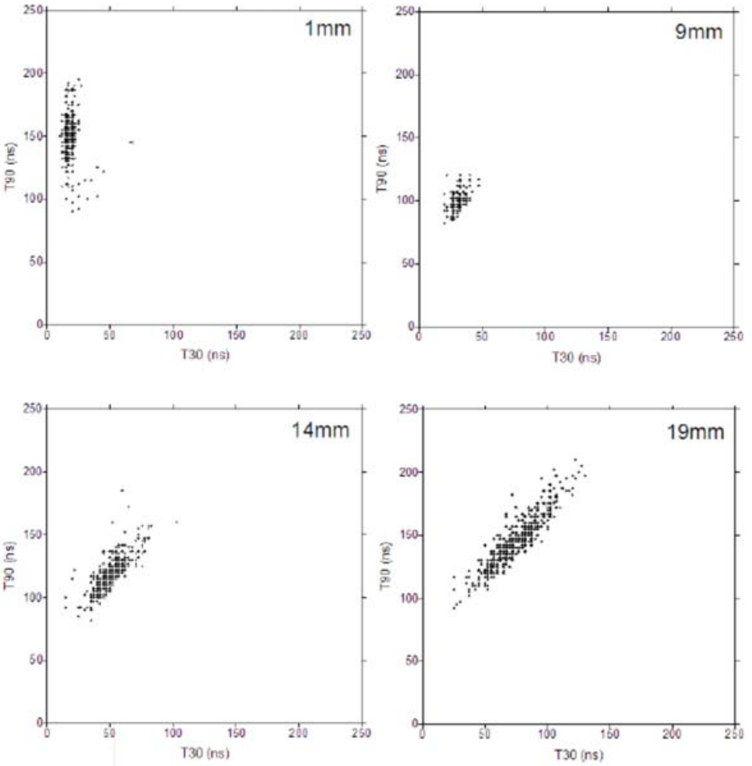


Fig1. T30vsT90 for an example DC strip at 4 different collimator depths, relative to the DC face of the detector

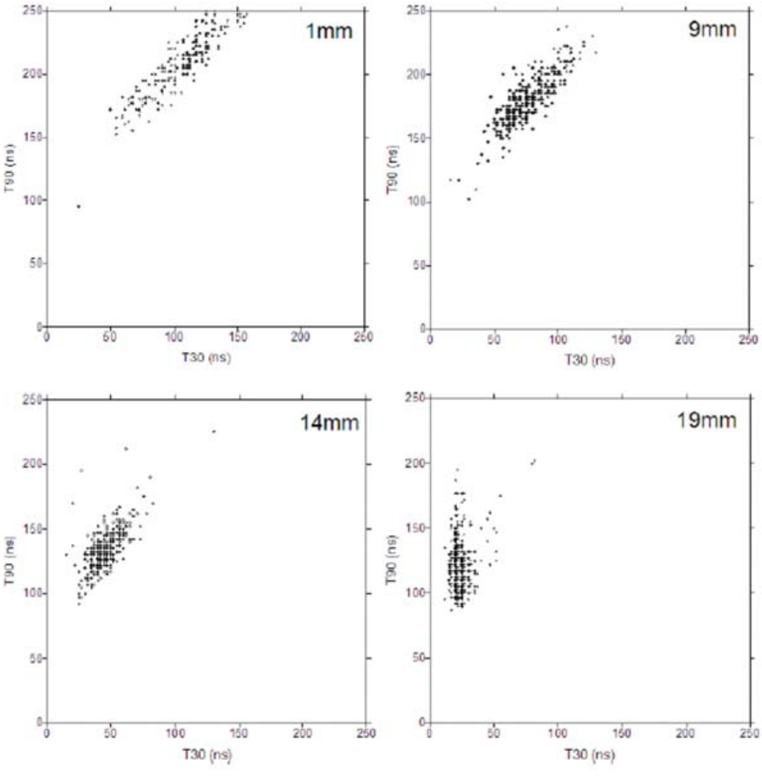


Fig.2 T30vsT90 for an example AC strip at 4 different collimator depths, relative to the DC face of the detector

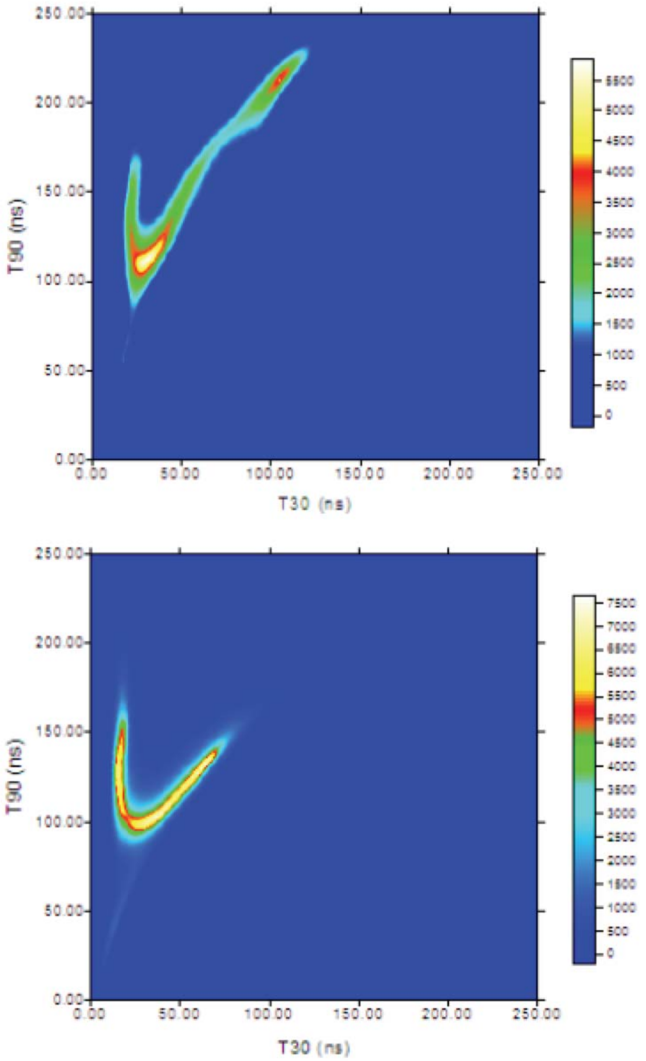


Fig.3 T30vsT90 for all interactions at all depths for an example AC strip (top) and DC strip (bottom)

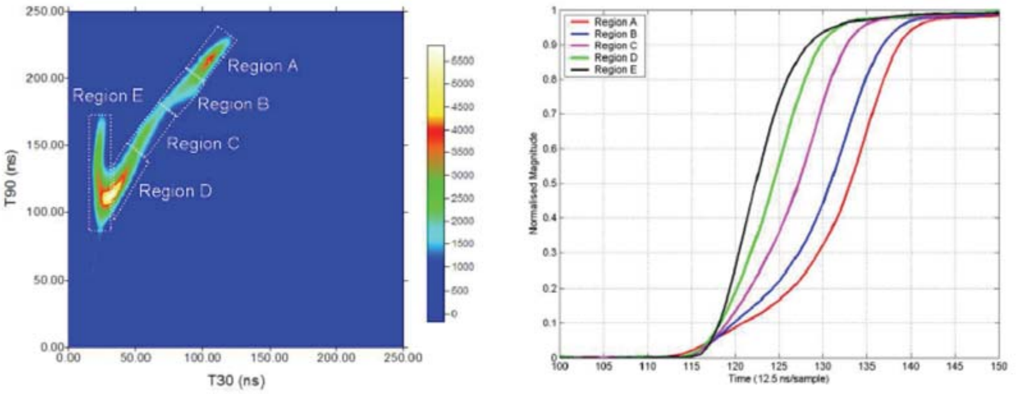


Fig.4 Left: T30vsT90 for for example AC strip, with 2D gates applied to select regions of depth. Right: Mean pulse shapes associated with the regions.