Improving Position Resolution in Pixelated CZT Detectors through Collimated Gamma-Ray Scanning for use in Molecular Breast Imaging applications

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12th International Conference on POSITION SENSITIVE DETECTORS

Hosted by UNIVERSITY OF BIRMINGHAM

Contents

Motivation

Breast cancer is the UK's most common form of cancer

- Currently used x-ray mammography and ultrasound screening methods have reduced diagnostic performance for patients with mammographically dense breast tissue

Alternative screening method: Molecular Breast Imaging (MBI)

- Radioactive tracer ^{99m}Tc in conjunction with a gamma-camera -> Image malignant breast tissue
- Investigate and develop a CZT-based Gamma-camera for MBI applications

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Gamma-camera spatial resolution dependent on accurate measurement of **Energy** and **Position** of Interaction

- Develop and apply Pulse Shape Analysis (PSA) methods to provide improved (sub-voxel) position resolution

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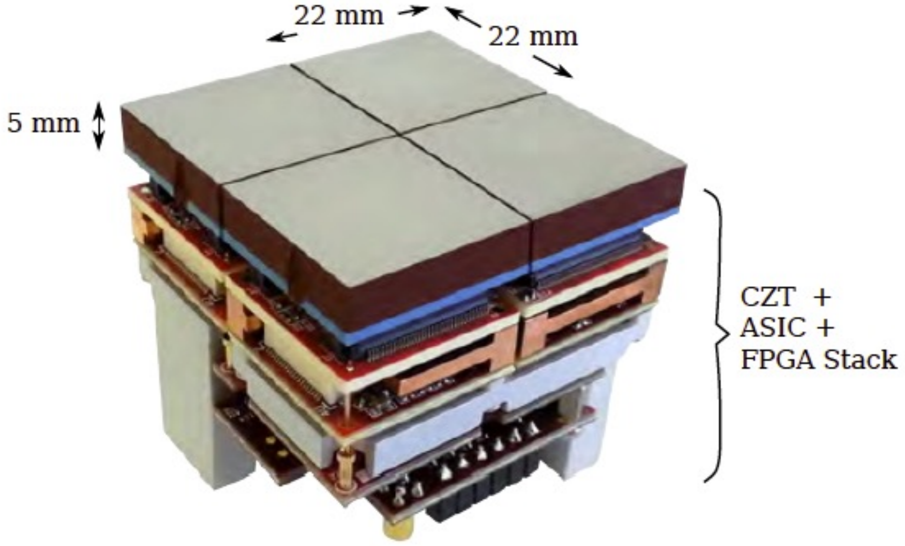
-> Collimator designed to make best use of achievable position resolution

Liverpool Detector System

Kromek DMatrix gamma ray imager

Crystals**: 22 x 22 x 5 mm^3**, pixelated into:

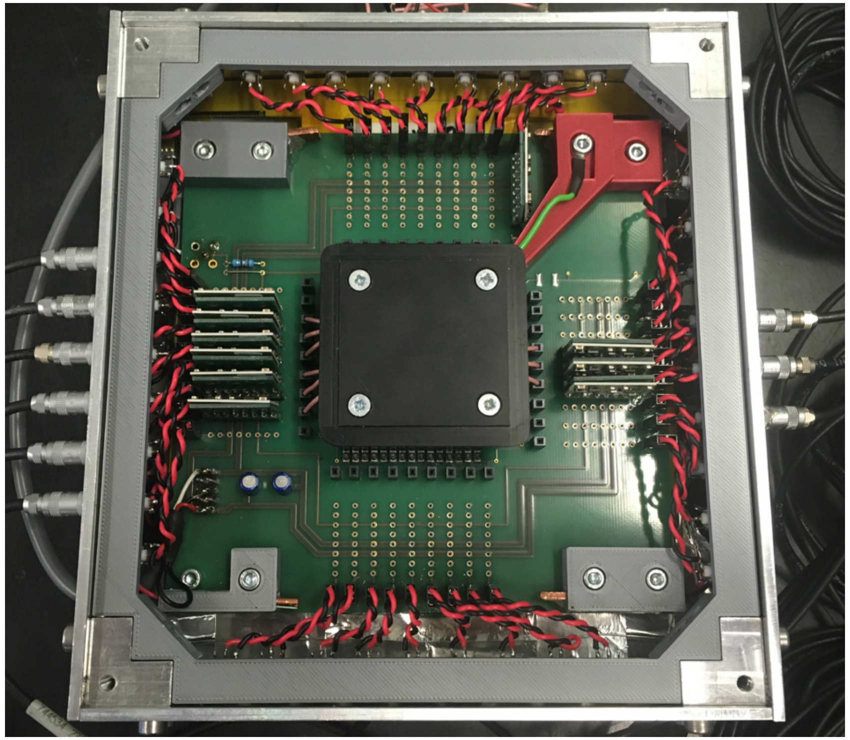
- 121 anode pixels
- 1 planar cathode



Previously characterised: L.H. McAreavey *et al* 2017 *JINST* **12** P03001

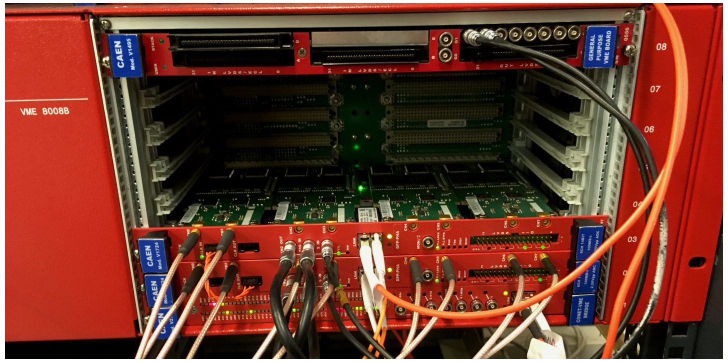
Pixelisation: 2 x 2 x 5 mm^3 voxelisation

ASICs provide **Energy** and **Timing**



Read-out system designed and built

- Separate crystal from ASIC + FPGA Stack
- Read 3x3 pixel cluster + cathode out via preamplifiers
- Digitise and save signal trace to disc

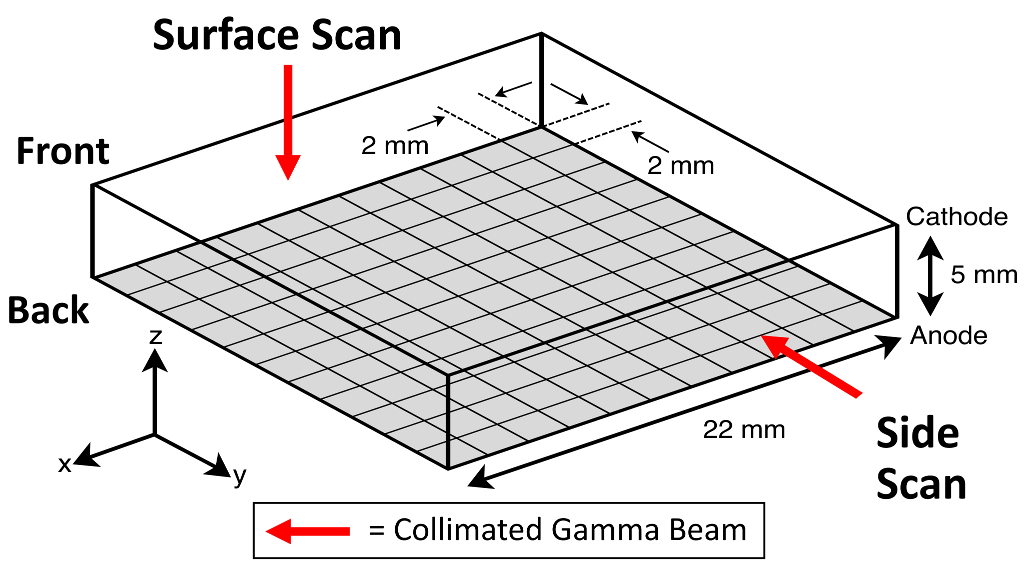


Digitisation

- 8 channel CAEN V1724 Modules
- 100 MHz sampling
- 5 µs signal length

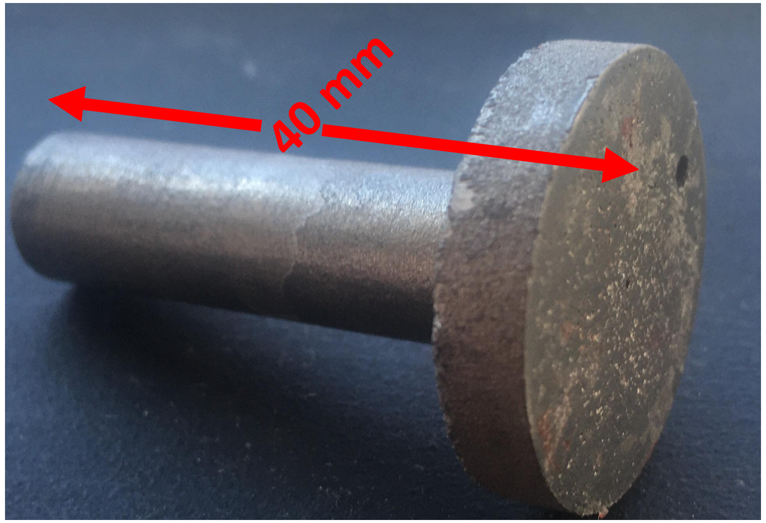
Collimated Scanning

Scan type	Primary axis scanned	Useful signals	Information Collected
Side Scan	Z	Charge collection signals	Charge collection time
Surface Scan	X and Y	Transient image signals	Magnitude of ‘left’ and ‘right’ image charges



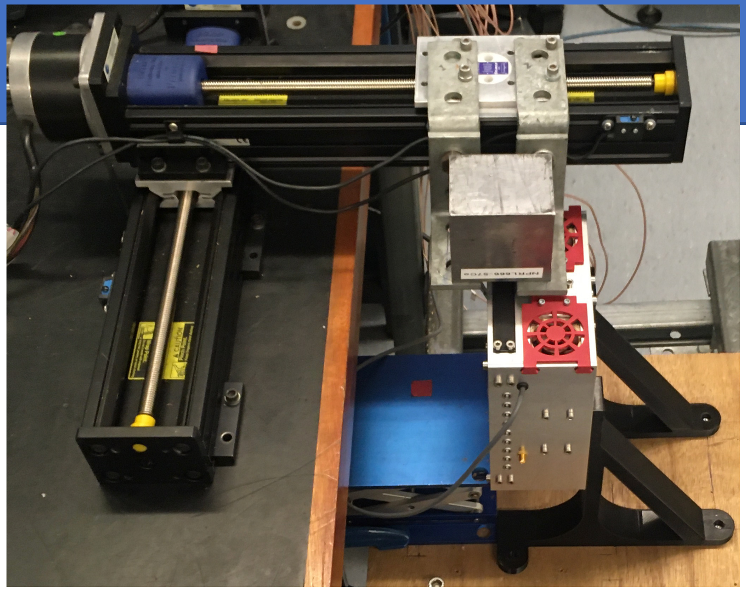
Charge collection times varies as function of depth of interaction (in 5 mm Z-depth)

Image charges (in pixels neighbouring one collecting charge) vary in magnitude – larger when interaction is closer across 2 mm pixel width



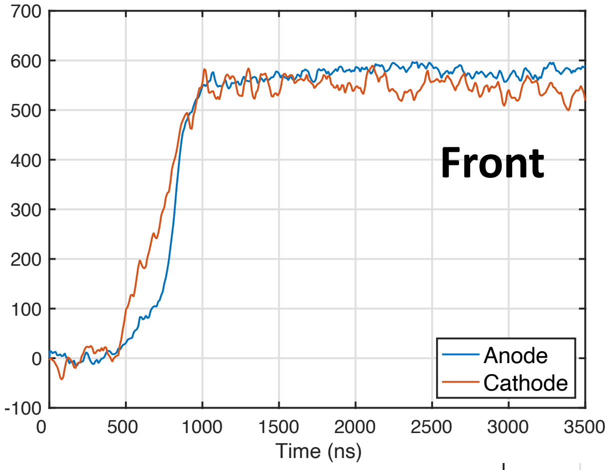
- Tungsten collimator – 0.5 mm internal diameter, 40 mm length
- ~0.3 GBq ^{57}Co source
- Velmex stepper arms
- 0.2 mm step, 120 second (side scan) and 90 second (surface scan) dwell time

^{57}Co Side Scan – Signal Formation

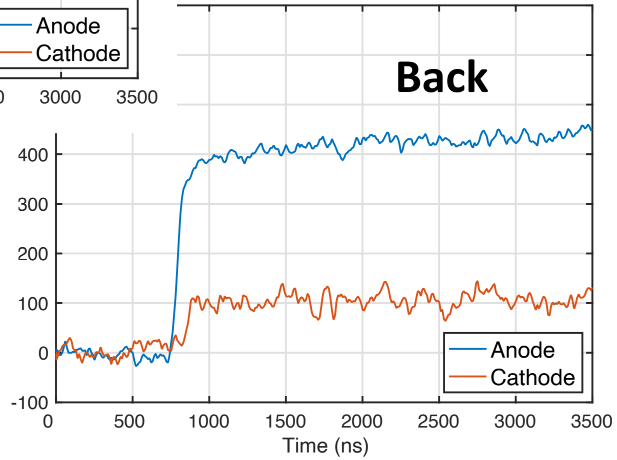


Average signals formed through depth - *122.1 keV and 136.5 keV energy depositions in single pixels used – depth correction applied to collected charge*

- Average signal for each pixel at each 0.2 mm z-step
- Scattered and subsequently absorbed gammas excluded - *Rejection based on comparison to the mean signal*
- Signal length not long enough to observe complete charge collection



- Charge collected varies as function of interaction depth



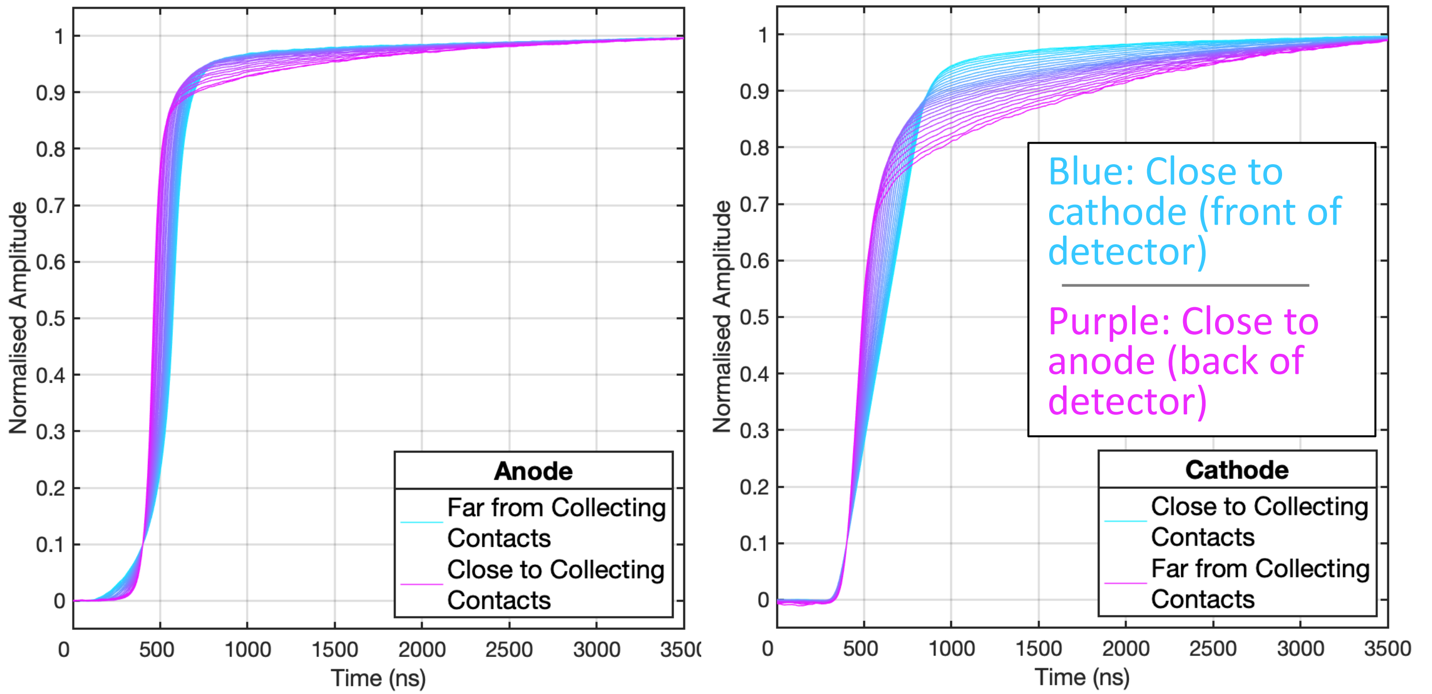
Noise at detector front:

- Anode ≈ 5%
- Cathode ≈ 10%

Noise at detector back:

- Anode ≈ 7%
- Cathode ≈ 50%

Normalised Signals



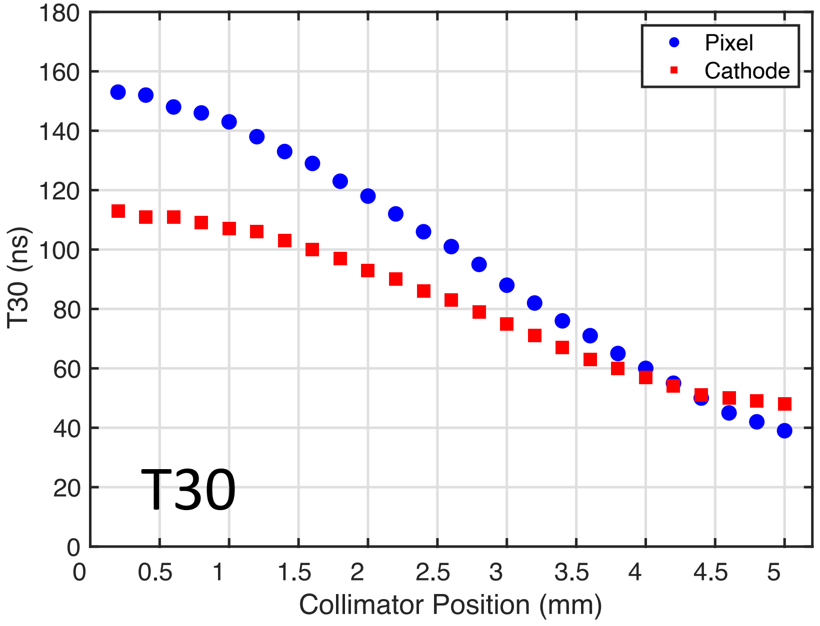
^{57}Co Side Scan – Rise Time Response

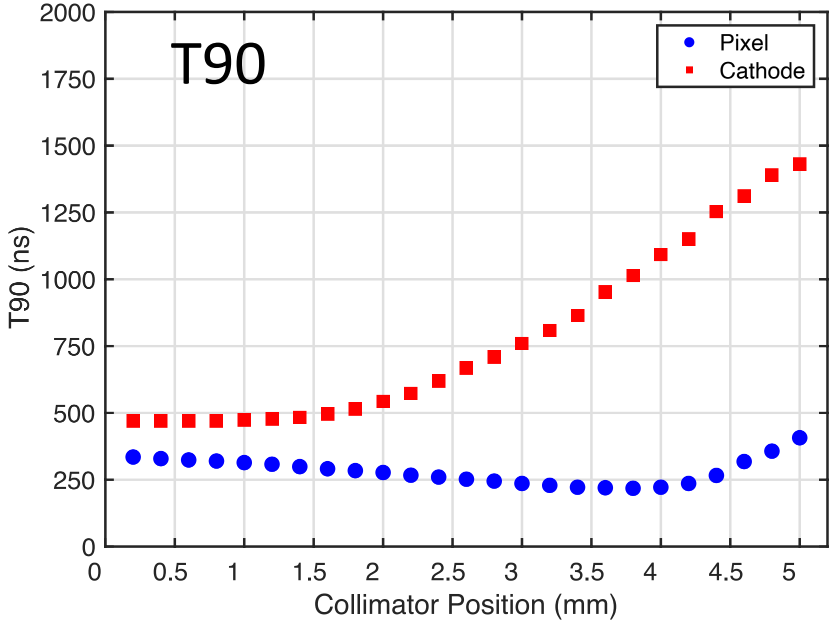
Parameterise average signal into simple values

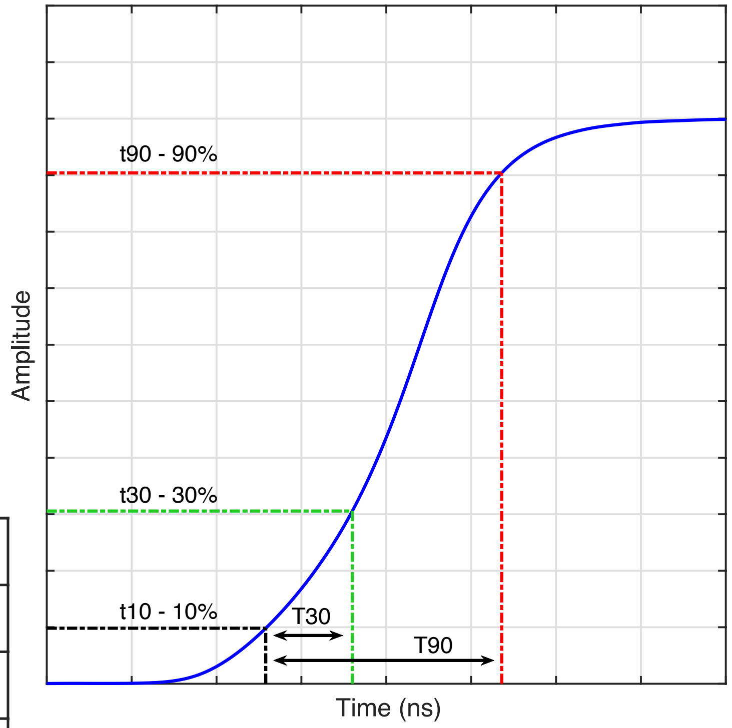
- *T30 = time between 10% and 30% of total charge collection*
- *T50 = time between 10% and 50% of total charge collection*
- *T90 = time between 10% and 90% of total charge collection*

Characterised rise time response produced through 5 mm Z-depth of crystal

- T30: Mostly linear through depth (T50 very similar)
- T90: Strong cathode response at detector back, weak at front







Collimator Position = 0 mm -> Cathode (Front)
Collimator Position = 5 mm -> Anode (Back)

Average signal -> little/no noise contribution

^{57}Co Side Scan – Position Resolution

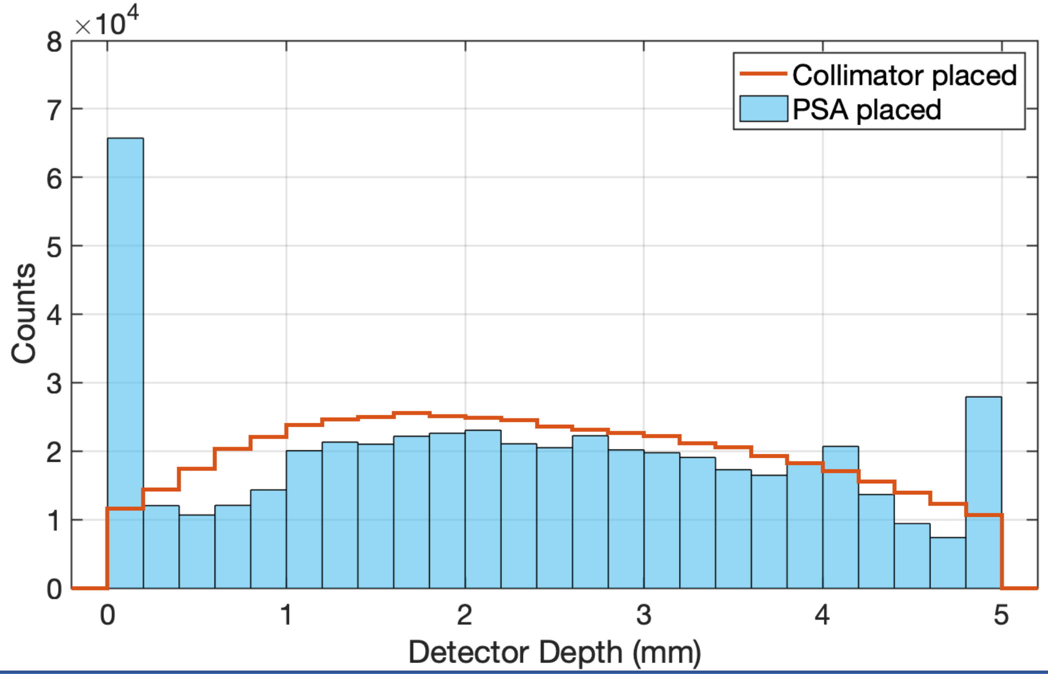
Improve position resolution in Z-depth

- Experimental signal T30, T50, T90 measured
- Difference between these and characterised values minimised

-> Estimation of Z-depth of interaction (DoI)

Simple GEANT-4 simulation
-> Collimated beam spot size
FWHM = 1.22 mm

Reanalyse side-scan data -> Apply Z-PSA -> Estimate DoI profile

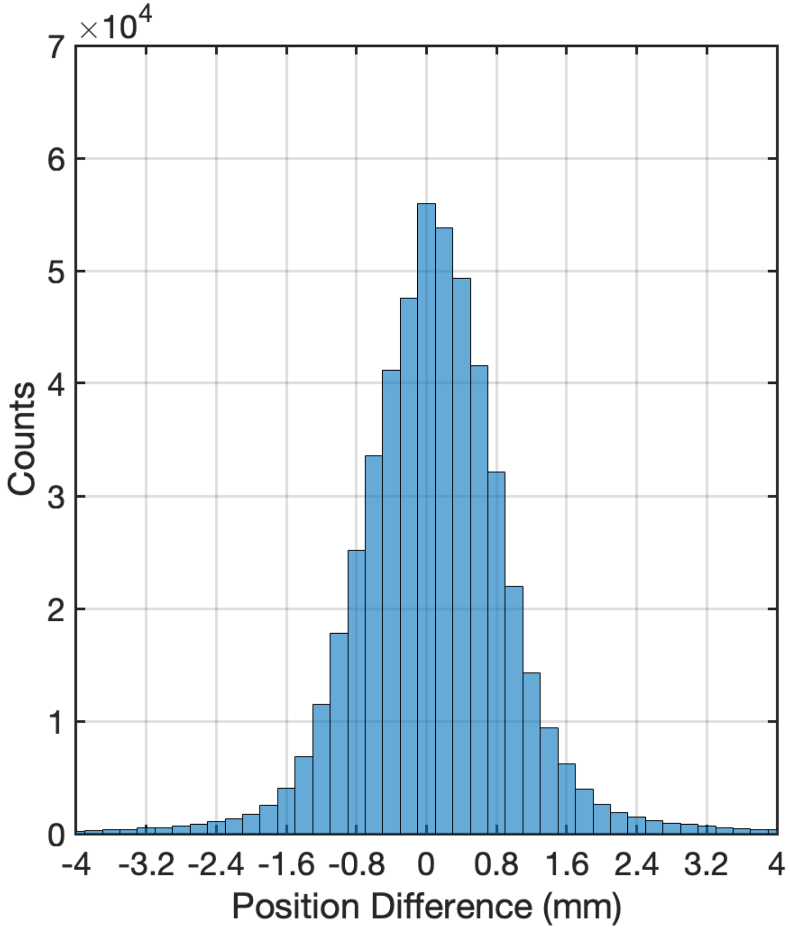


<- Compare to profile based on collimator position

Calculate Position Resolution

Method applied:

- Difference between collimator depth and depth found by Z-PSA
- Histogrammed difference from all events
- FWHM of applied fit taken as position resolution -> **1.75 mm**

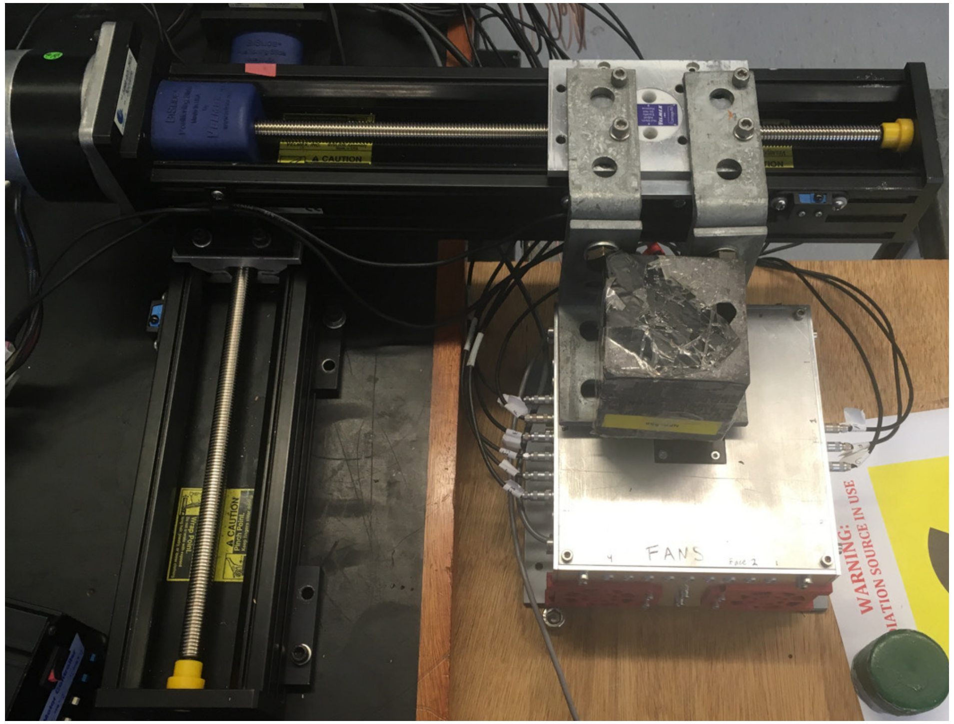


^{57}Co Surface Scan – Image Charge Response

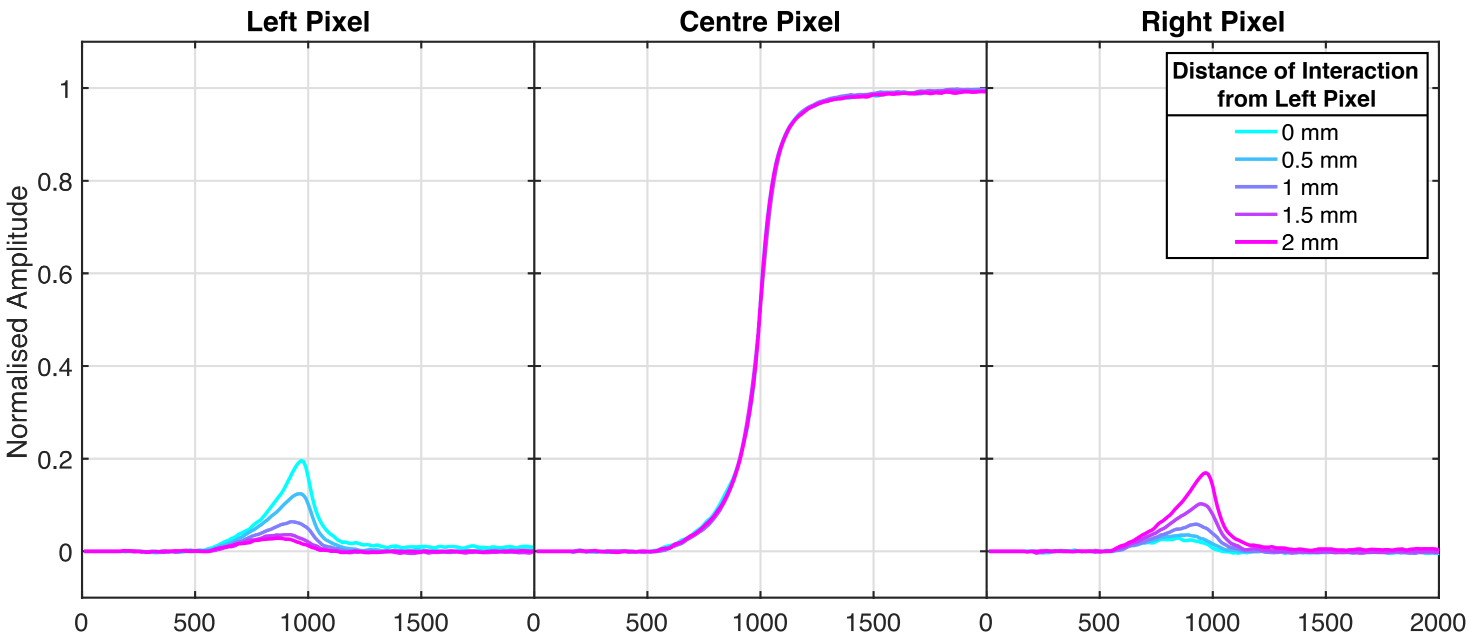
Average signals formed as a function of X-Y position - *122.1 keV and 136.5 keV energy depositions in single pixels used – depth correction applied to collected charge*

- Average signal for each pixel at each 0.2 mm z-step
- Scattered and subsequently absorbed gammas excluded - *Rejection based on comparison to the mean signal*

Simple GEANT-4 simulation
-> Collimated beam spot size
FWHM = 0.54 mm



Transient image charge signals in pixels neighbouring central pixel -> observed variation in magnitude



^{57}Co Surface Scan – Asymmetry Parameterisation

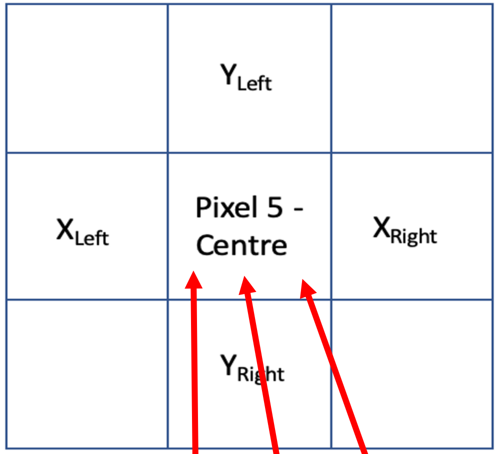
Asymmetry Parameterisation

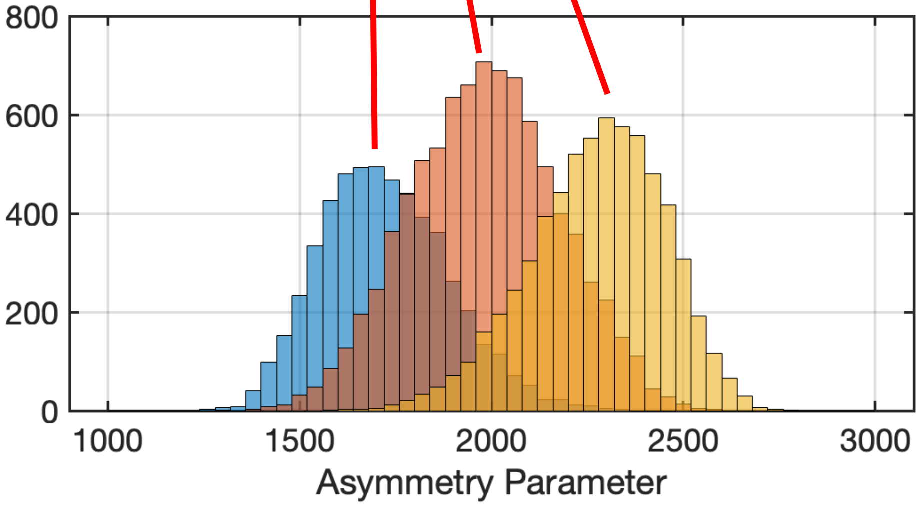
- Calculated separately in X and Y
- Asymmetry between neighbouring image charges
- Examples at three collimator positions across pixel

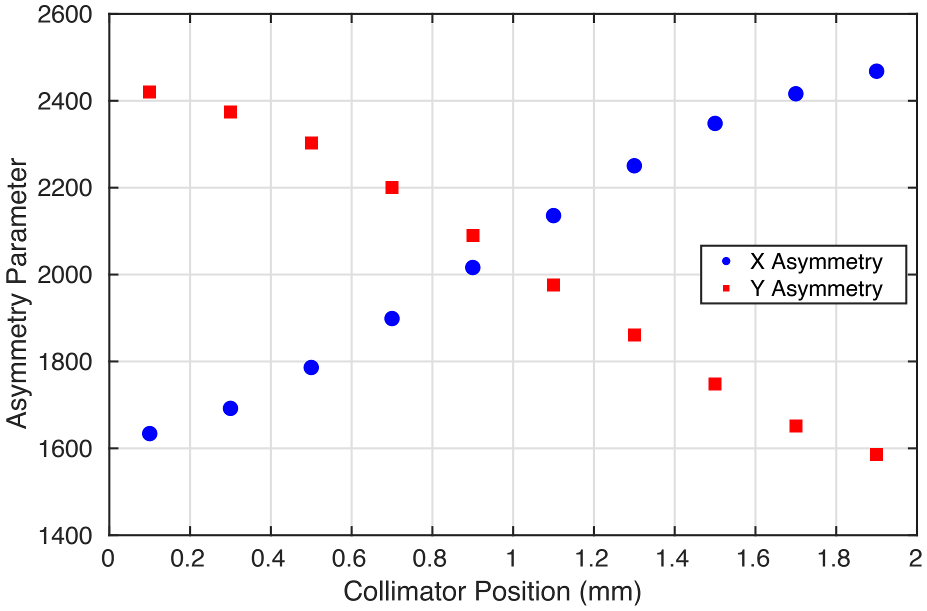
$$X_{Asymm} = \frac{1000\times(X_{Right}-X_{Left})}{X_{Right}+X_{Left}} + 2000$$

$$Y_{Asymm} = \frac{1000\times(Y_{Right}-Y_{Left})}{Y_{Right}+Y_{Left}} + 2000$$

$\{X_{Left}, X_{Right}, Y_{Left}, Y_{Right}\}$ = image charge areas







Parameterise asymmetry in X and Y as a function of position

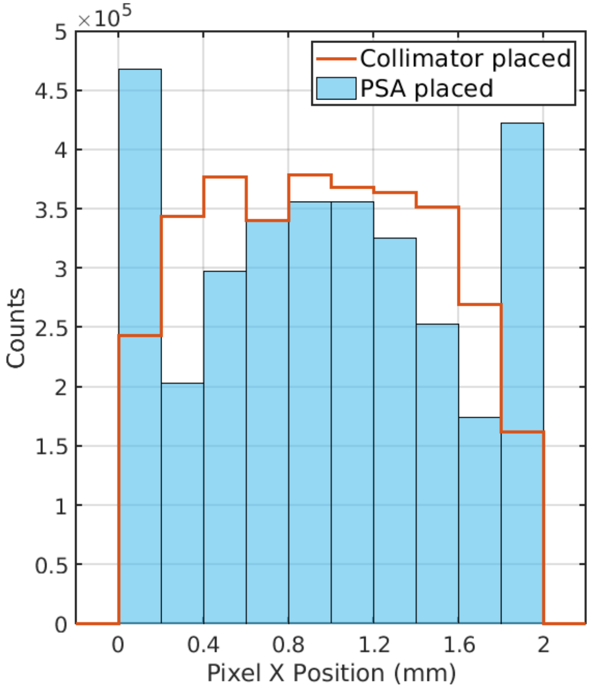
- Large variation across pixel
- Mostly linear response

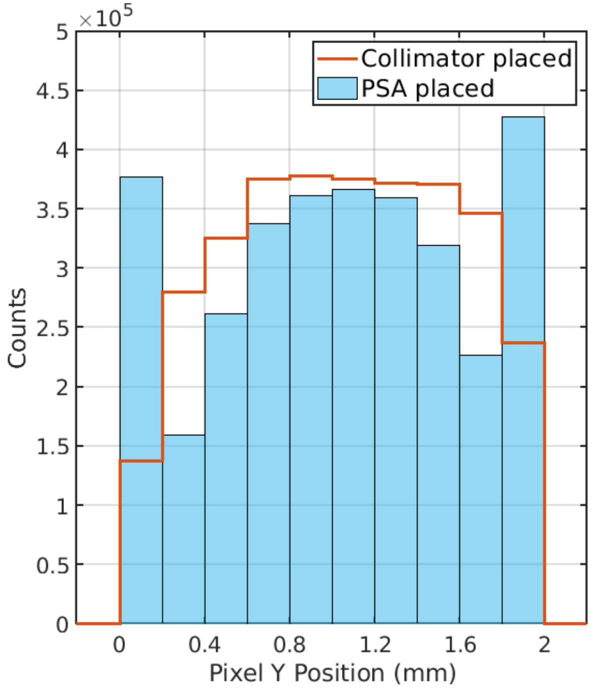
^{57}Co Surface Scan – Position Resolution

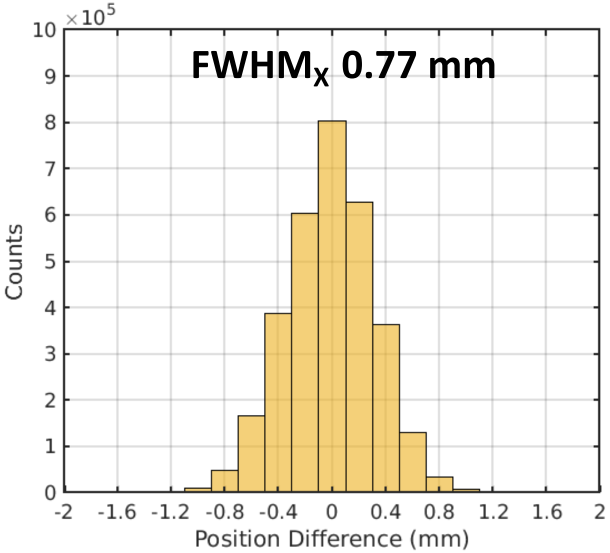
Improve position resolution in X-Y

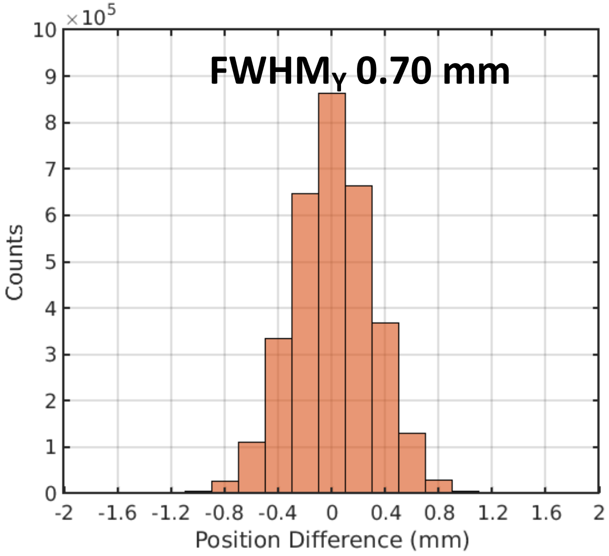
- Experimental X and Y asymmetry parameter calculated
- X and Y position of interaction estimated based on asymmetry map

Reanalyse surface-scan data -> Estimate Position with XY-PSA -> Compare to profile based on collimator position ->









Calculate Position Resolution

Method applied:

- Difference between collimator X-Y and X-Y found by XY-PSA
- Histogrammed difference from all events
- FWHM of applied fit taken as position resolution

$FWHM_{X,Y}$ = (0.77,0.70) mm

Conclusion and Future work

Signal response of a **22 x 22 x 5 mm^3** CZT detector has been characterised through collimated scanning

- Average signals formed as a function of XY lateral position and Z-depth
- Parameterisation maps (Asymmetry and Rise Time) formed
- Pulse shape analysis methods applied to improve the position resolution

Gamma rays placed in centre of **2 x 2 x 5 mm^3** voxels, improved to **0.77 x 0.70 x 1.75 mm^3**

Noise is limiting factor in this work -> Building a new read-out system

- Noise reducing features (improved shielding)
- Smaller container -> reduced collimated beam spot size
- Larger HV limit -> bias and scan thicker CZT crystals (10 mm currently awaiting scanning)

Investigate position resolution as a function of gamma energy

- Higher energy ^{137}Cs source available
- Lower energy ^{241}Am scans performed

Thanks to Collaborators

University of Liverpool – Laura Harkness-Brennan, Dan Judson, Hannah Brown, Dave Wells, Chris Everett and Kieran Green

Kromek – Alex Cherlin and Ian Baistow

Questions?