Application of Segmented Semiconductor Detectors for Compton Imaging

Adam Caffrey – University of Liverpool

UNIVERSITY OF LIVERPOOL

GRI+

Presentation Structure:

- Overview of GRI+
- Parametric PSA
- Parametric PSA Results
- Database PSA
- Database PSA Validation and Results

Overview Of GRI+

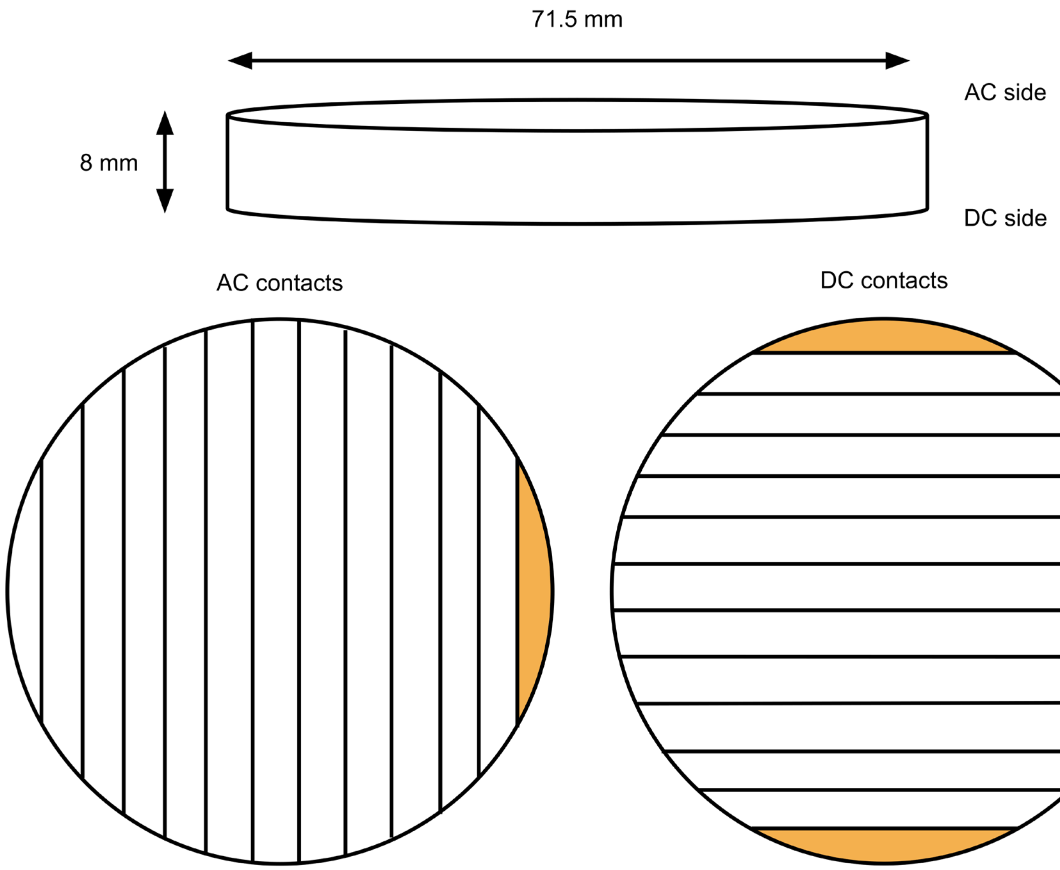
GRI+ - **G**amma-**R**ay **I**mager

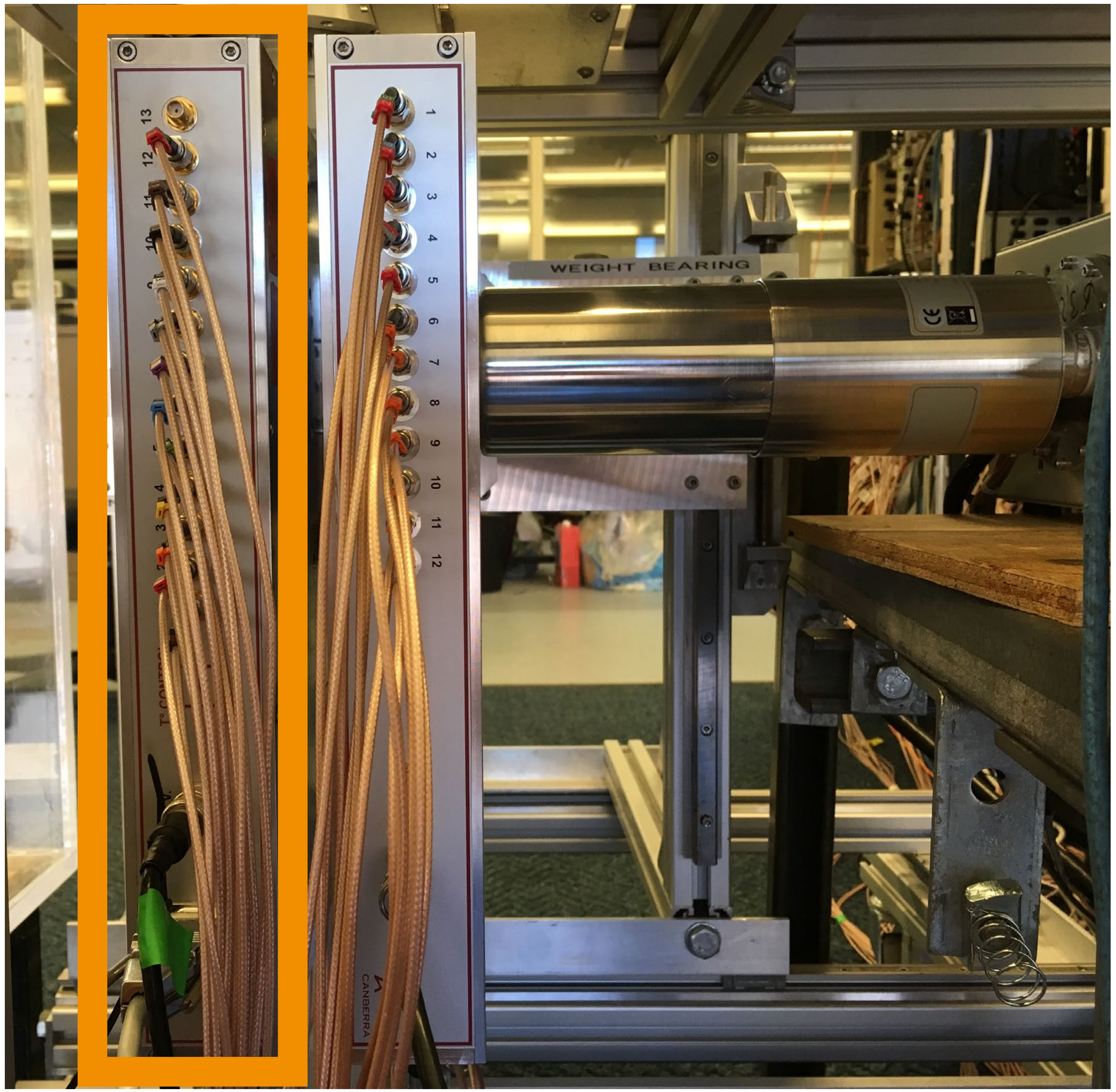
GRI+ is a mobile Compton camera consisting of three semiconductor detectors in a three configuration:

1. Si(Li) DSSD planar detector
2. Ge DSSD planar detector
3. Coaxial HPGe detector

Si(Li) planar detector:

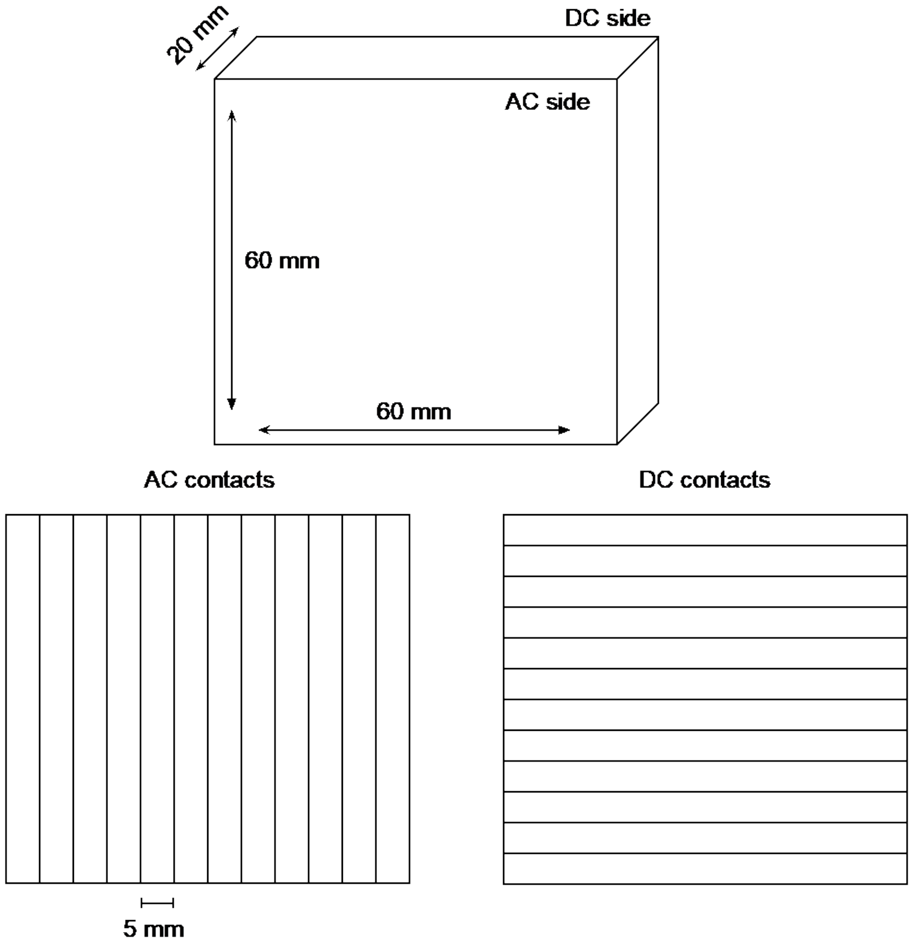
- 13 AC and 13 DC strips
- 5.5 mm strip pitch
- 8 mm thick – 71.5 mm diameter

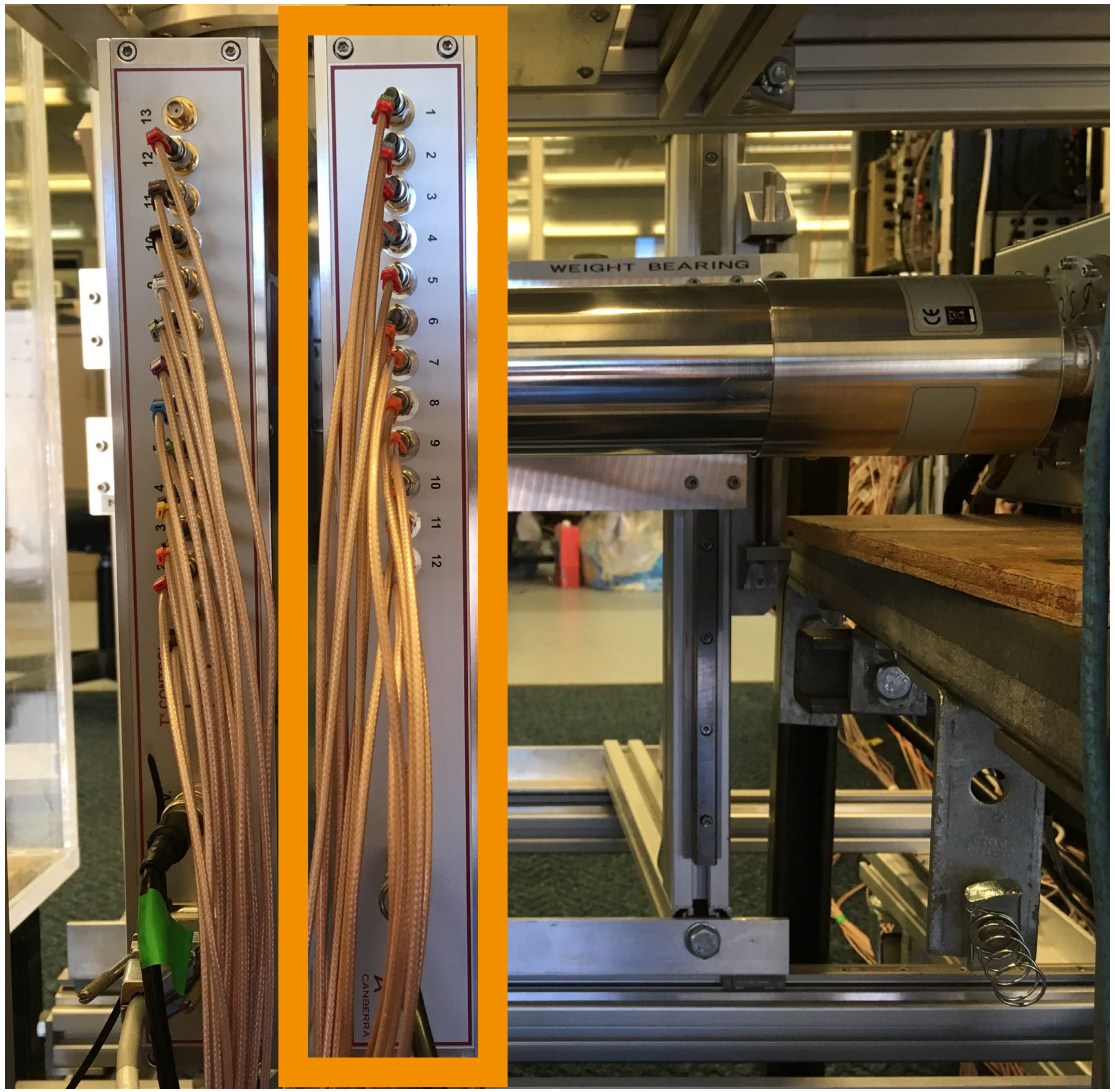




Ge planar detector:

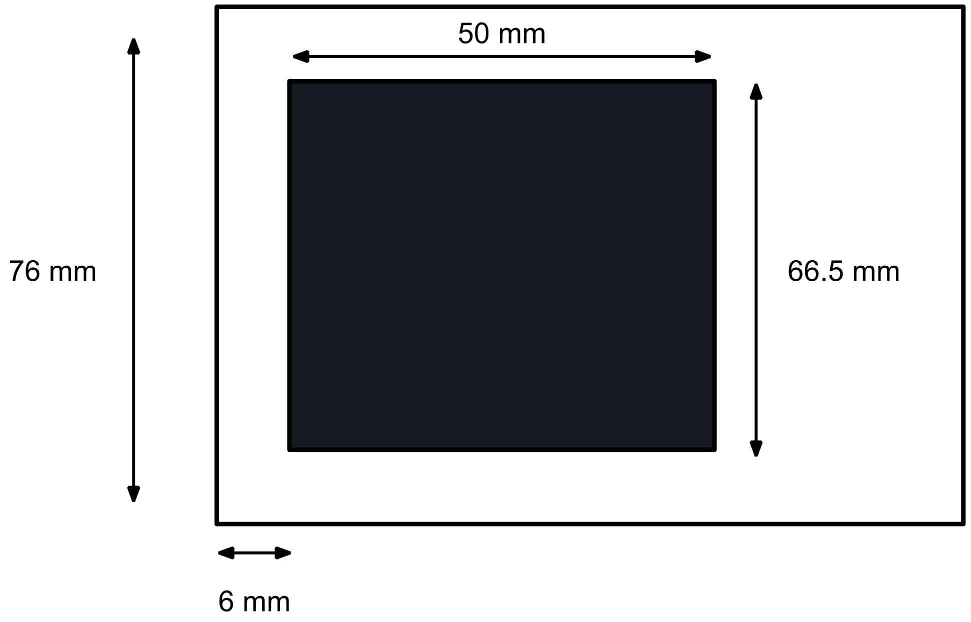
- 12 AC and 12 DC strips
- 5 mm strip pitch
- 60 x 60 x 20 mm^3

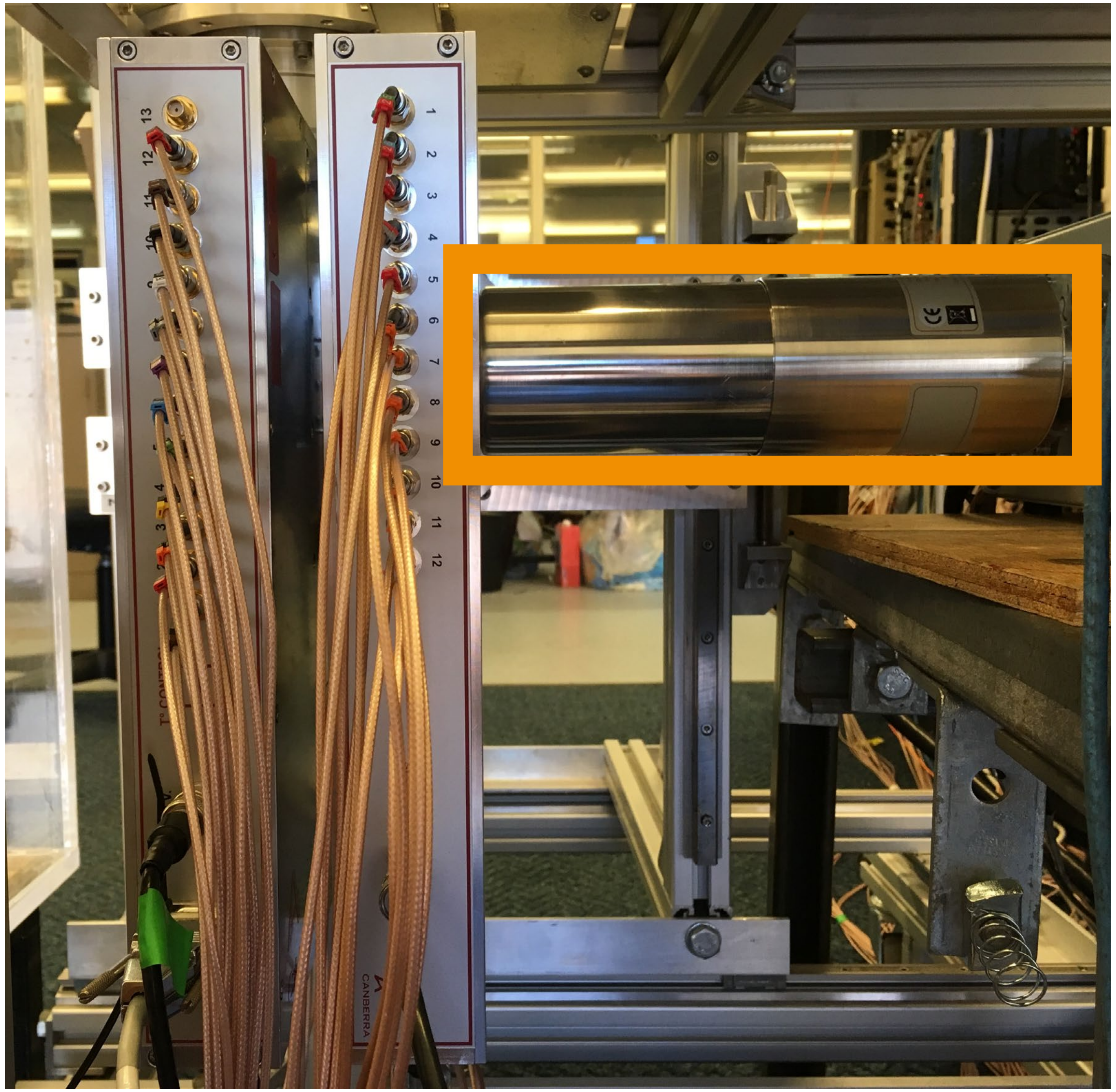


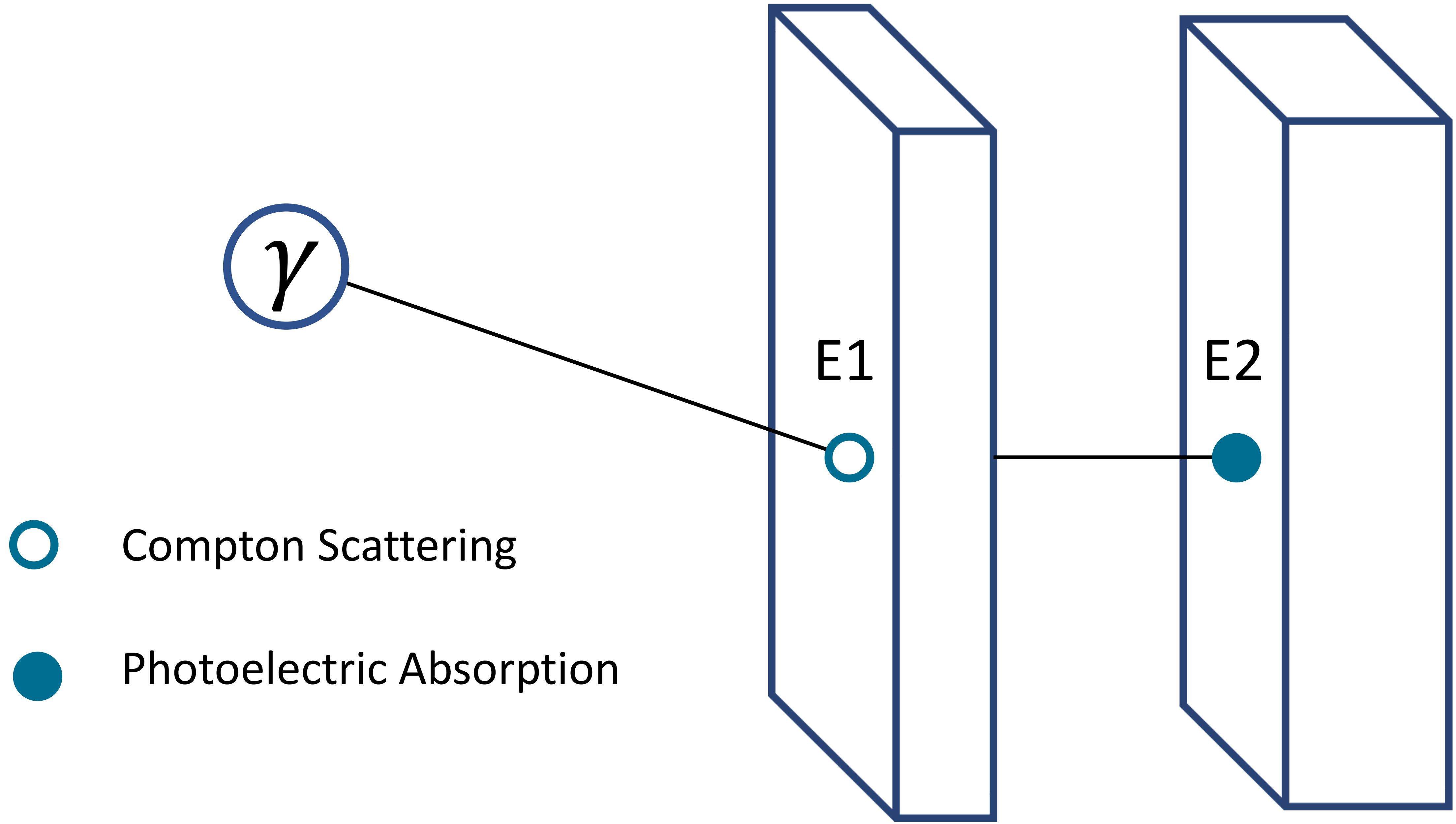


HPGe coaxial detector:

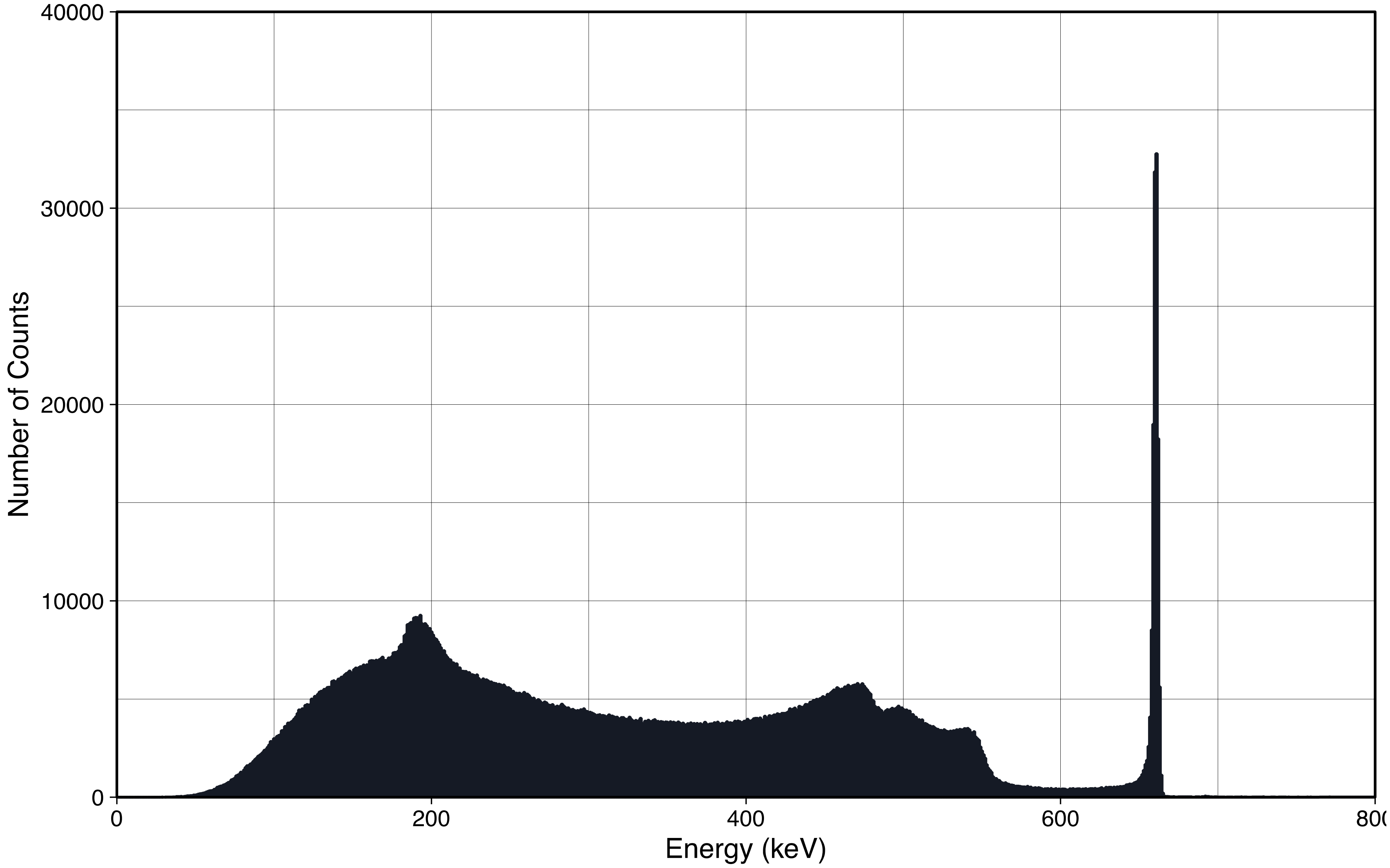
- Model GC4018
- Relative efficiency > 40 %
- 50 mm thick – 66.5 mm diameter

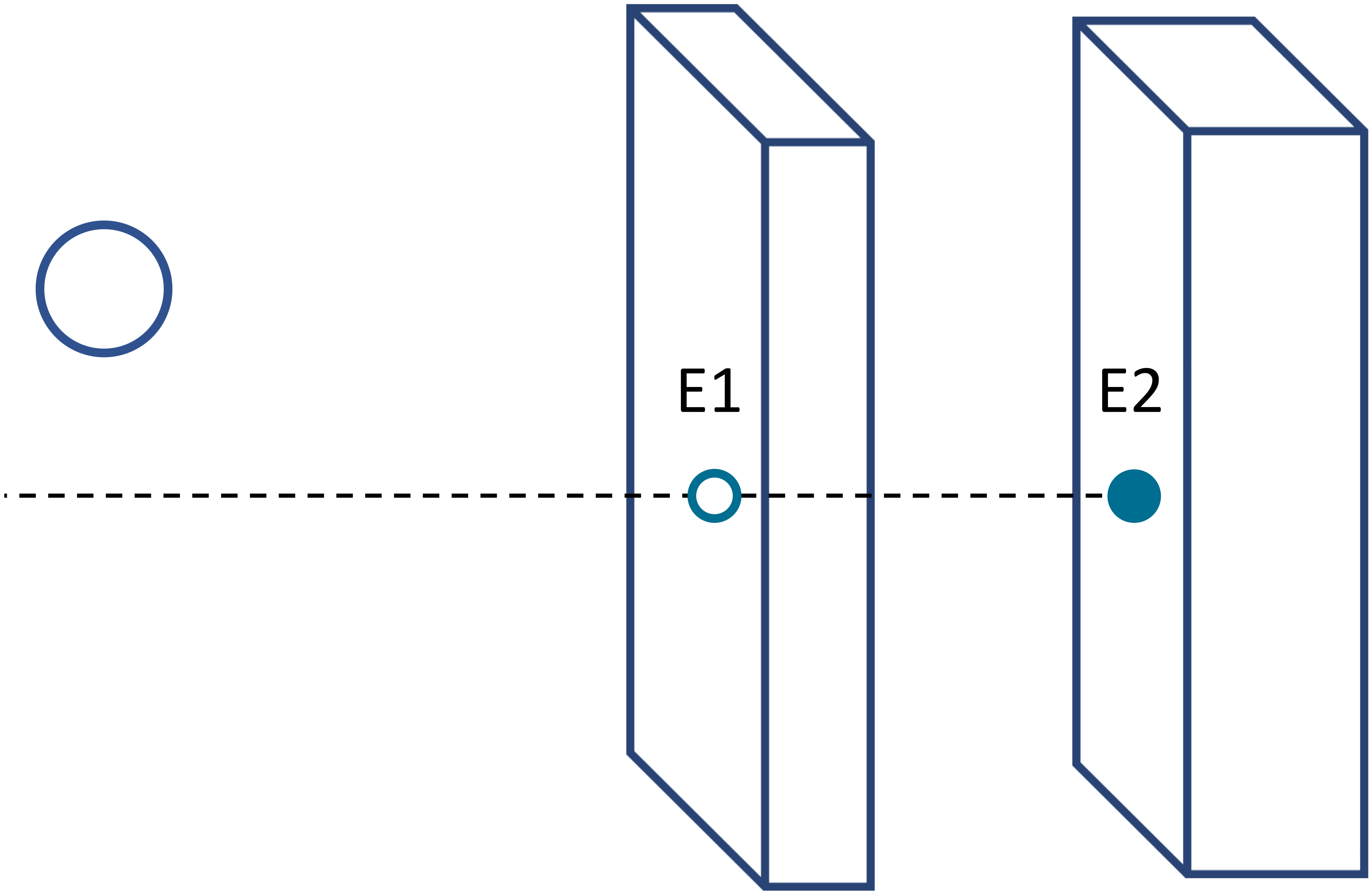




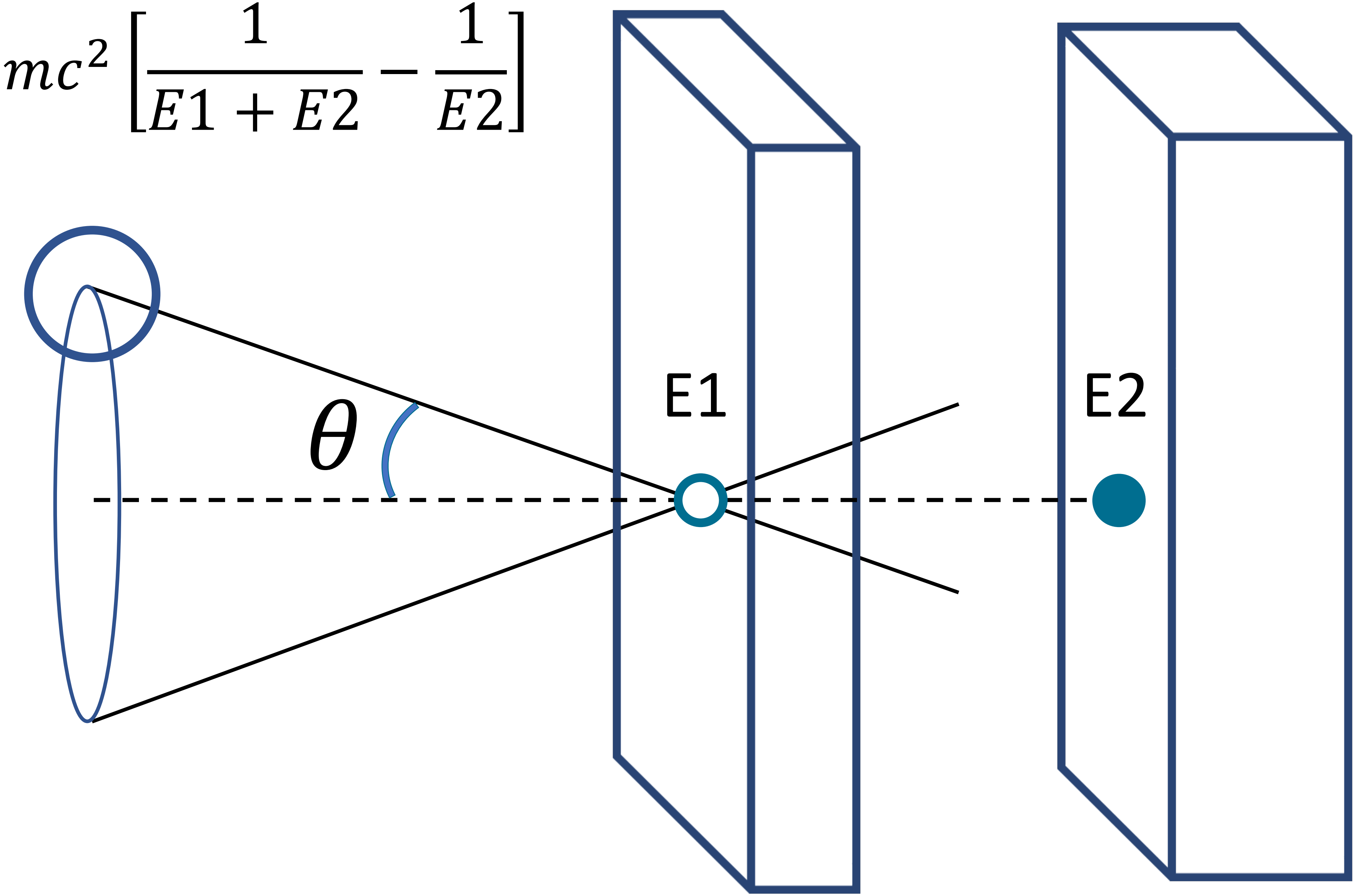


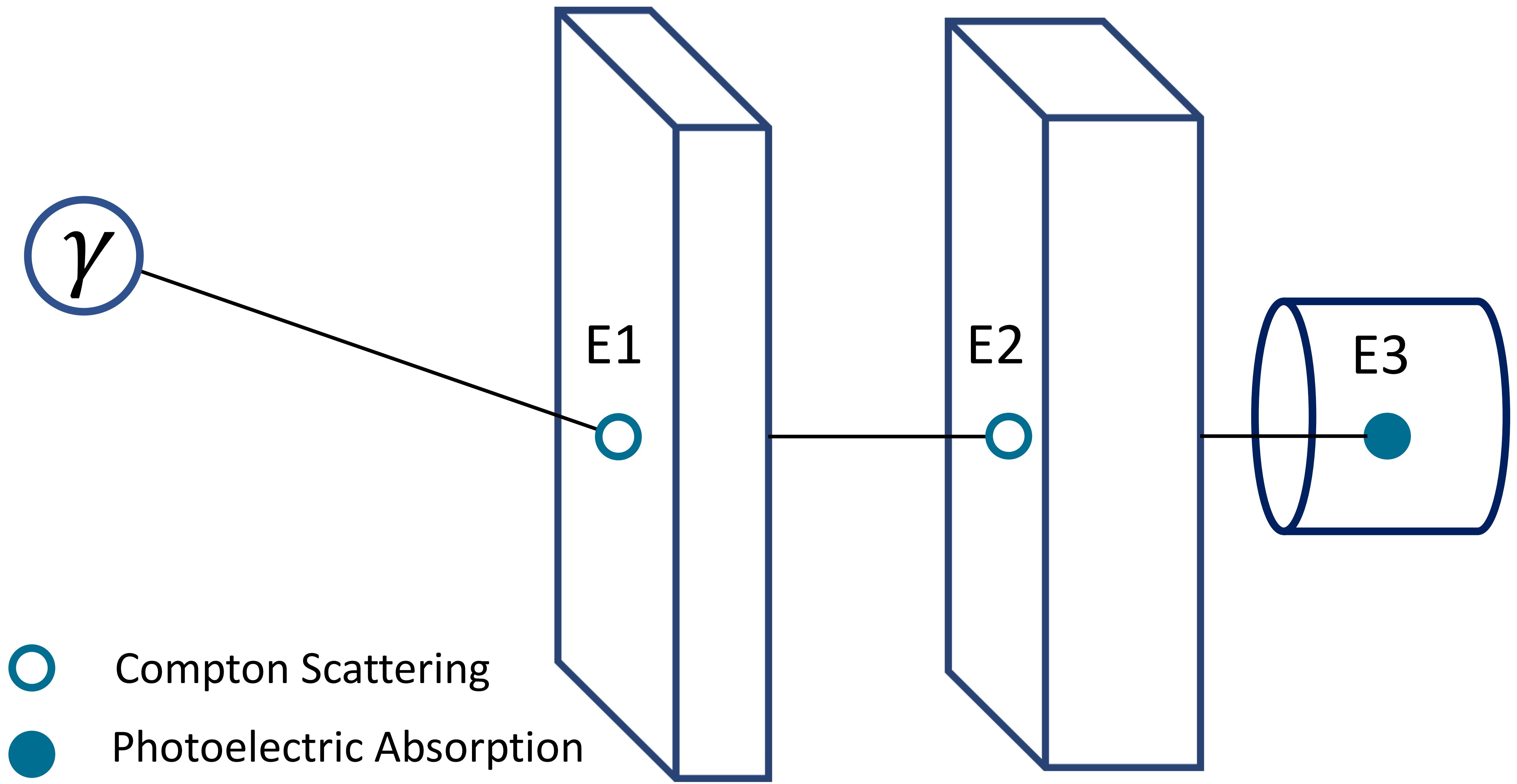
γ
E1
E2
Compton Scattering
Photoelectric Absorption


40000
30000
20000
10000
0
Number of Counts
0
200
400
600
800
Energy (keV)

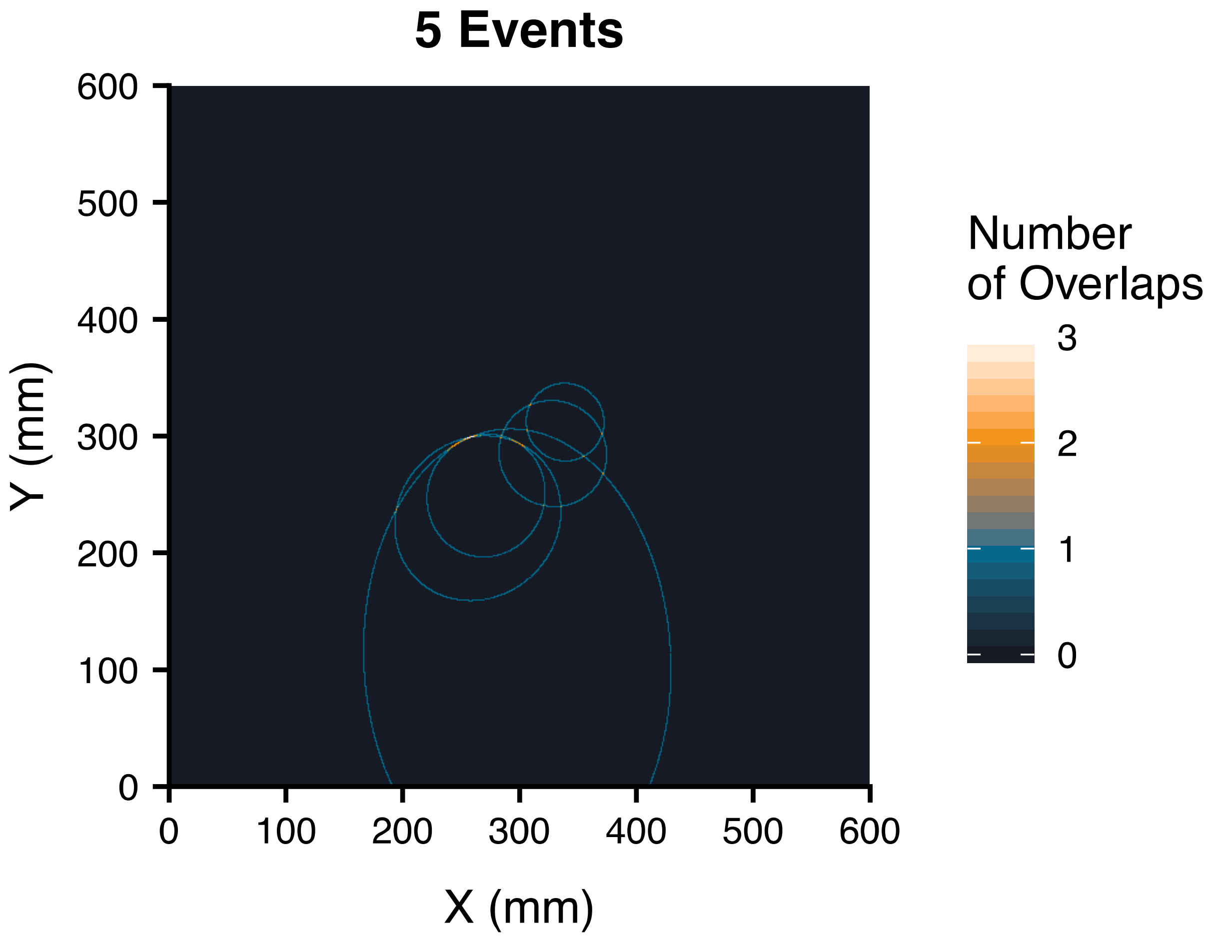

E1
E2

$$\theta = 1 + mc^2\left[\frac{1}{E1 + E2} - \frac{1}{E2}\right]$$




γ
E1
E2
E3
Compton Scattering
Photoelectric Absorption

Overlapping cones determine the location of a source



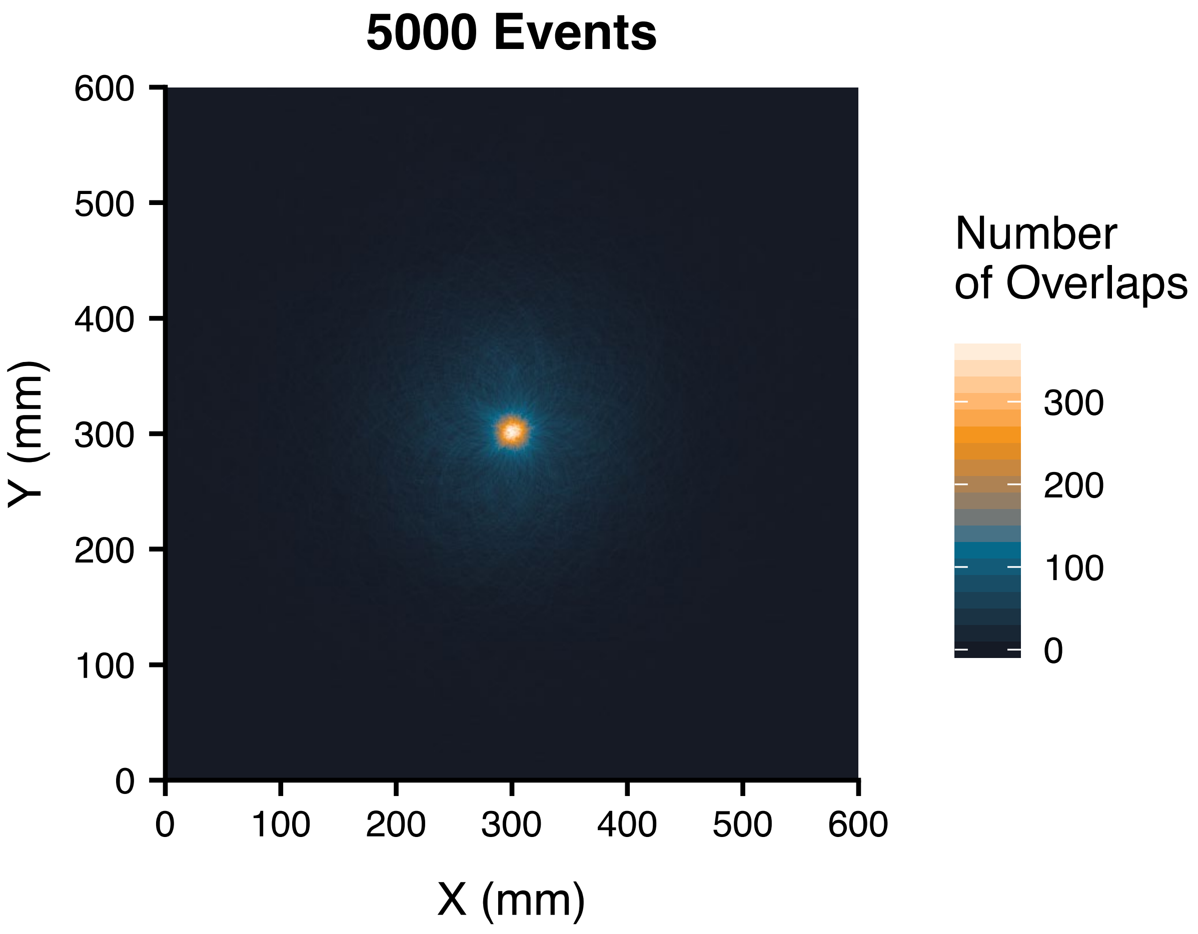
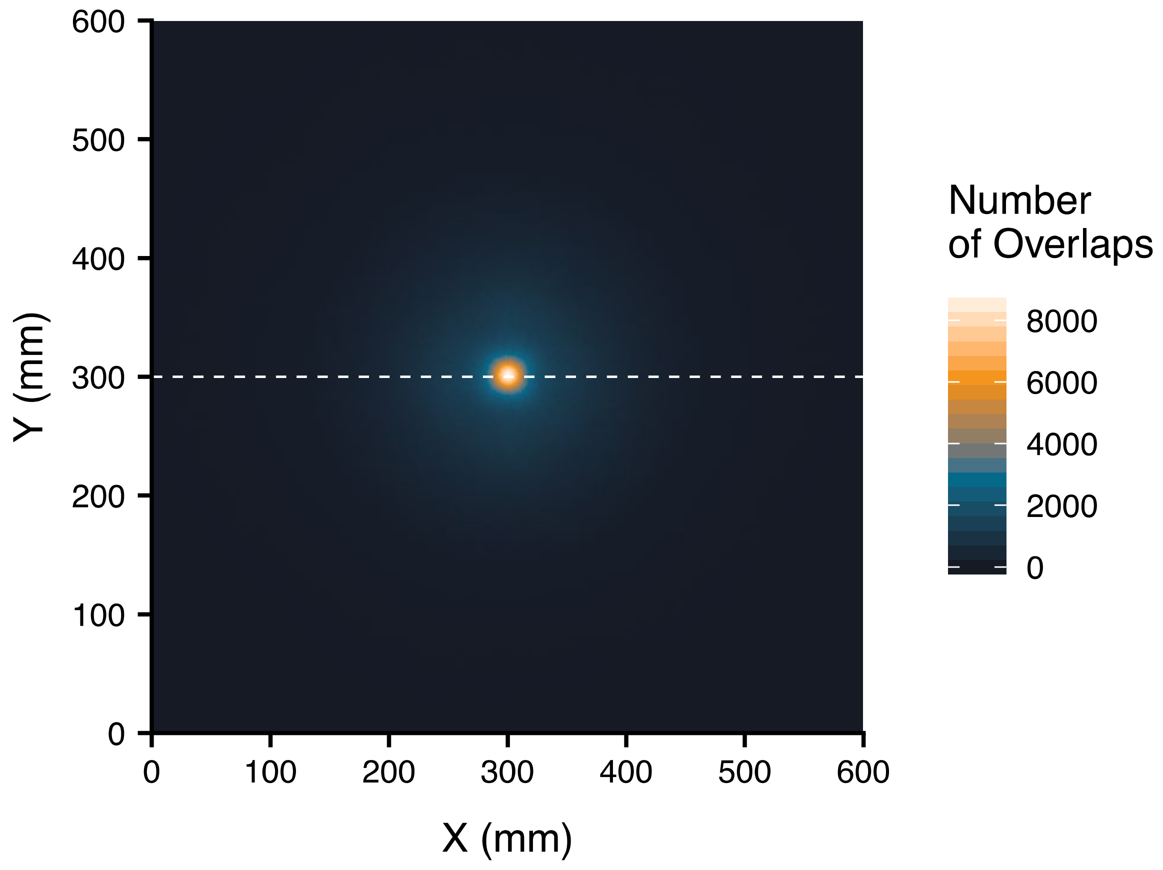
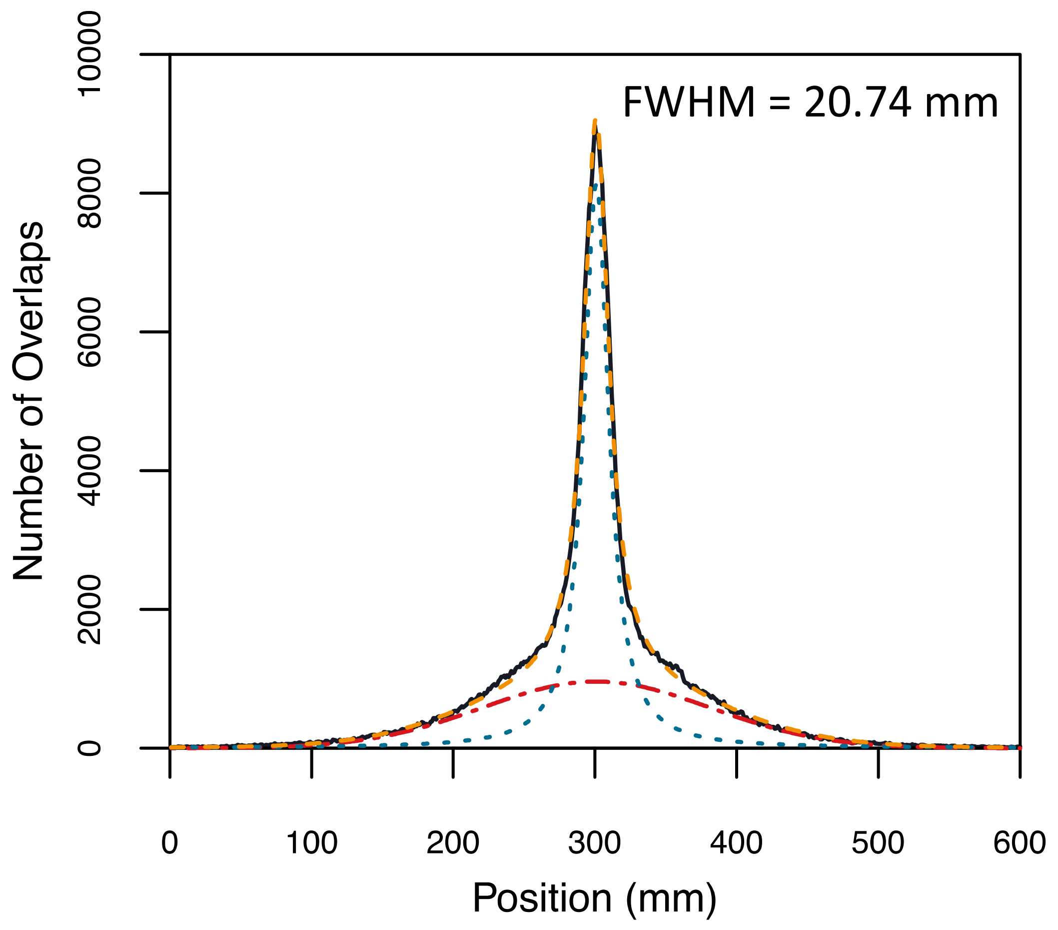
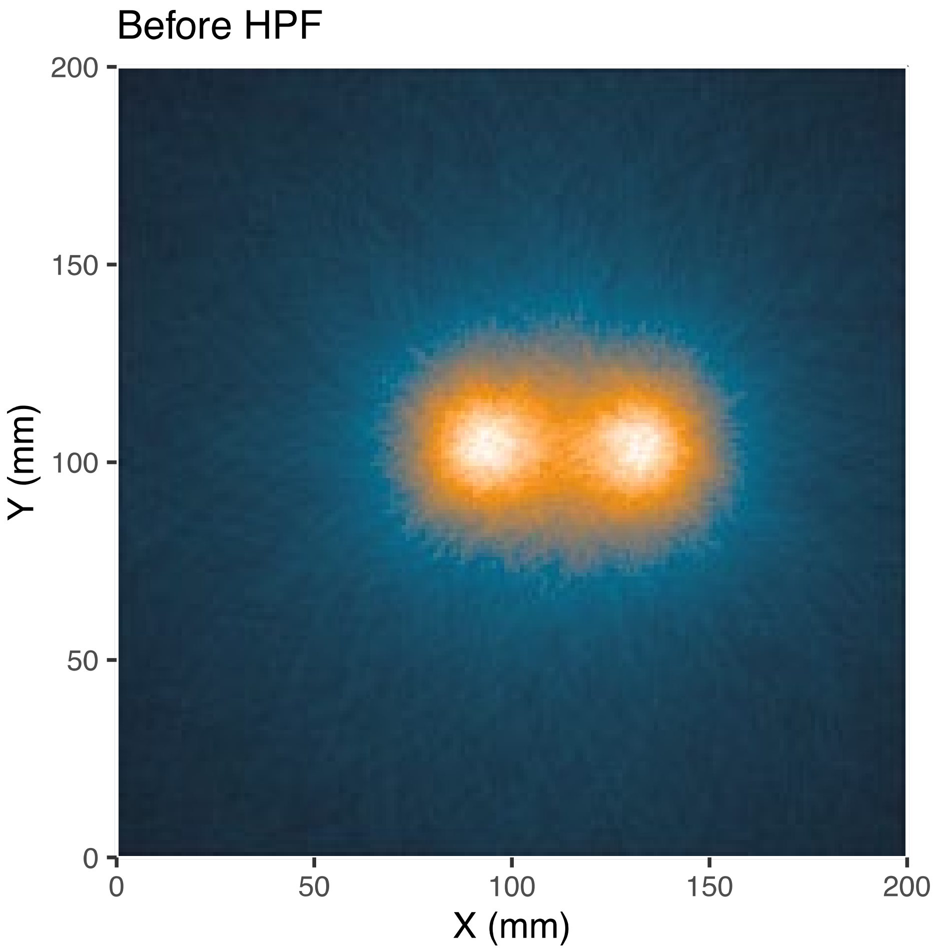


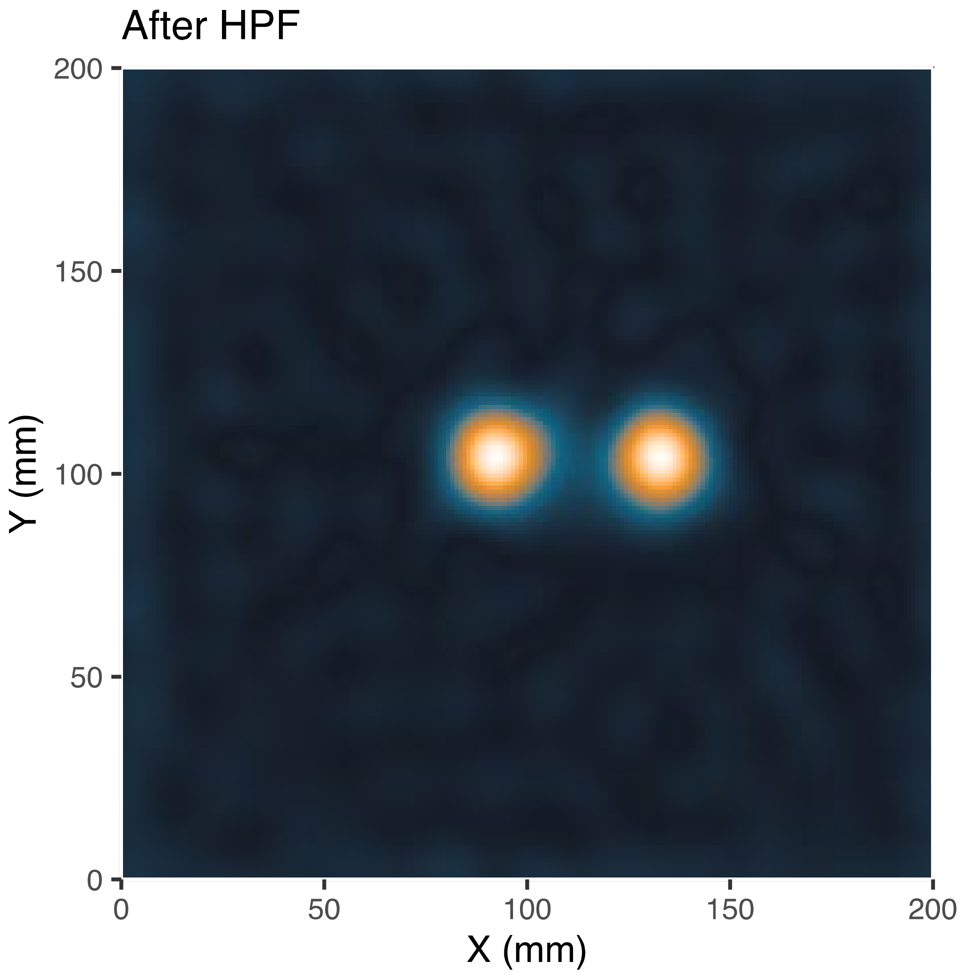
Image resolution is calculated as the FWHM of the Lorentzian peak from a point source





A high-pass filter (HPF) can be applied to the slices to improve the image resolution

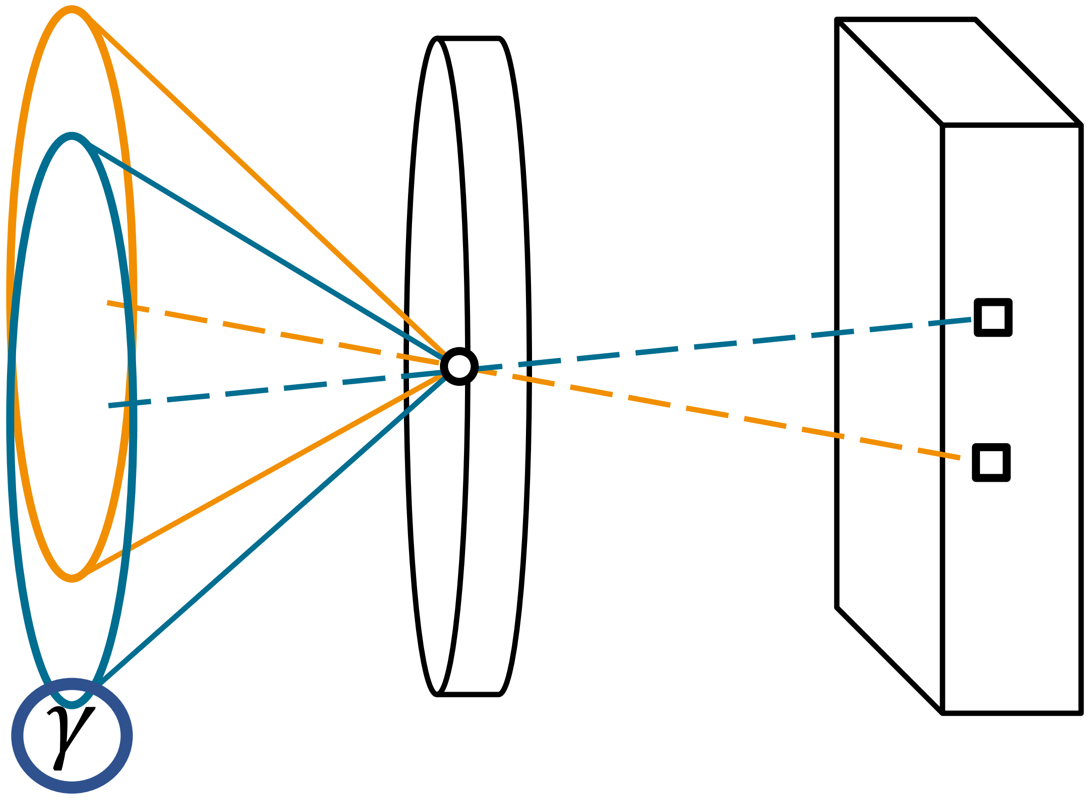


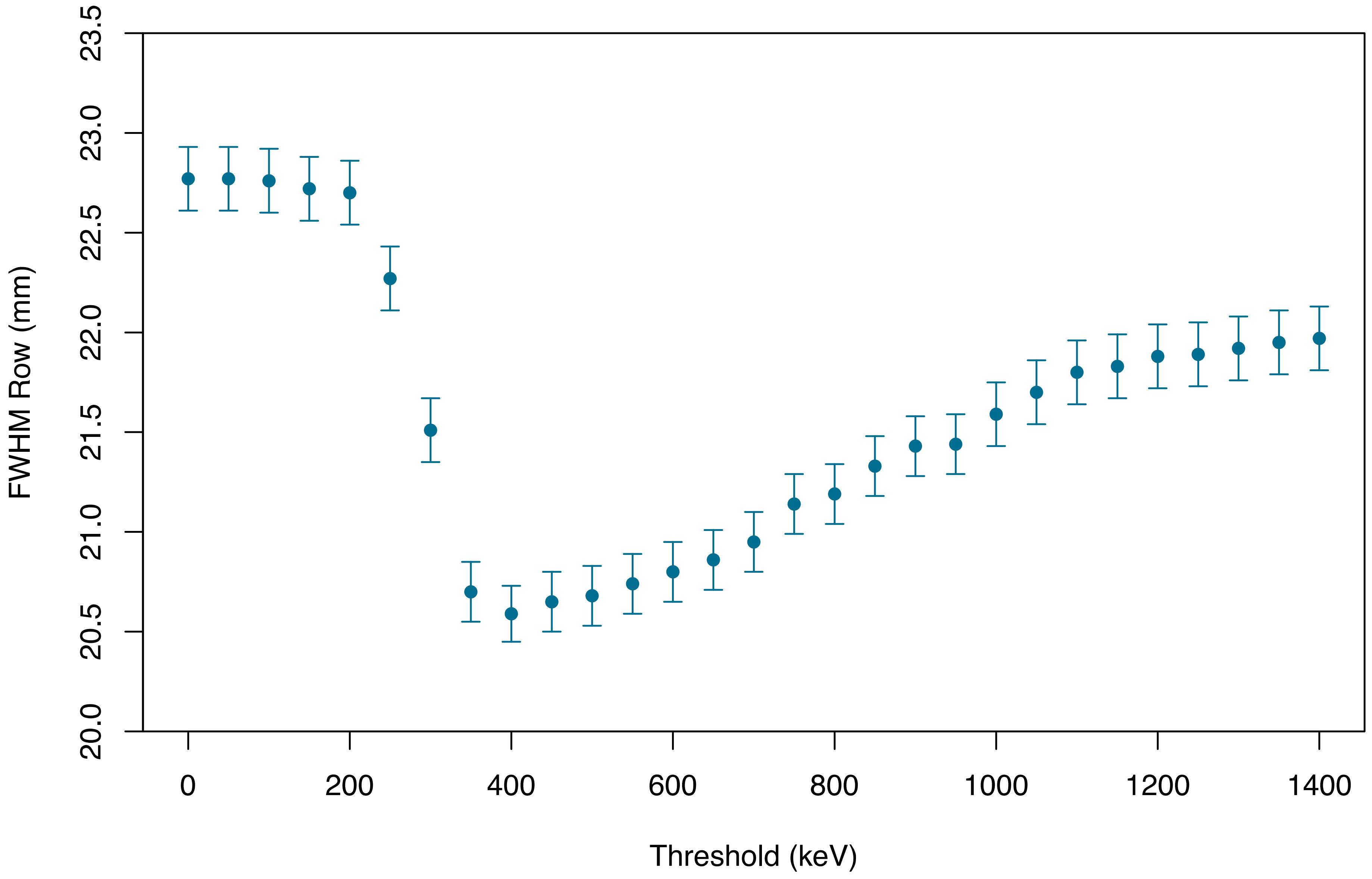


Fold-2 Event Usage

- To use events which interact twice in the absorber detector the order of events must be determined.

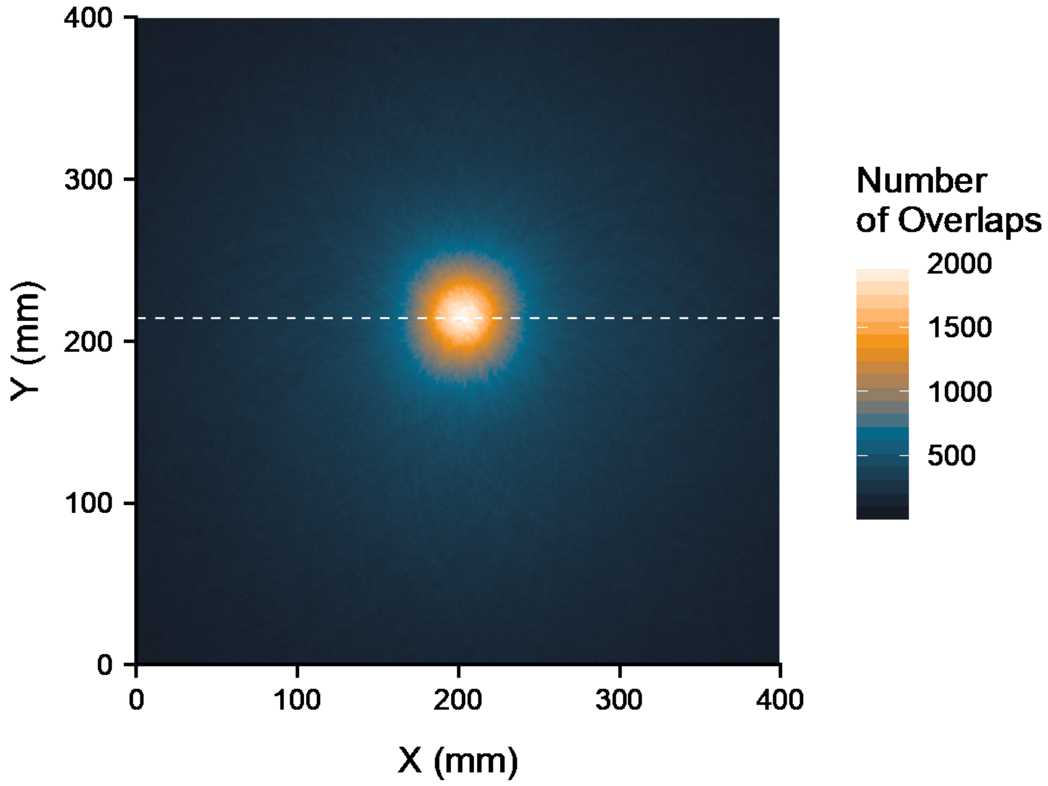
- The first event is used to create the cone axis.

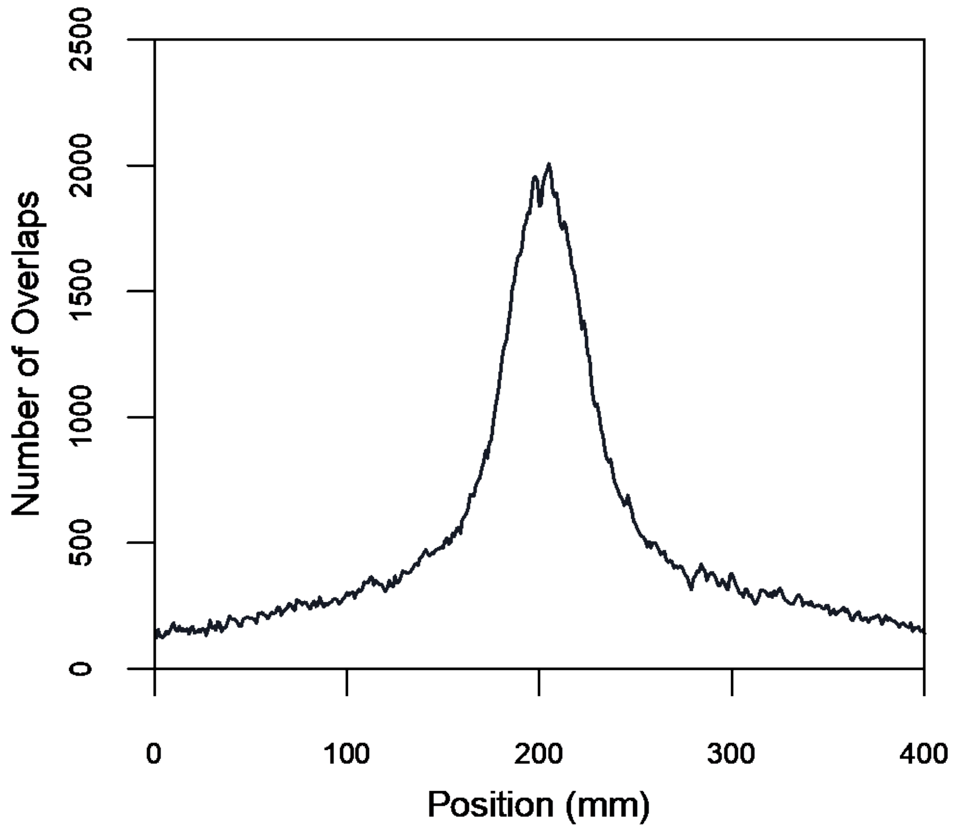




FWHM Row (mm)
20.0
20.5
21.0
21.5
22.0
22.5
23.0
23.5
0
200
400
600
800
1000
1200
1400
Threshold (keV)

- Cs-137 point source 20 cm from the detector

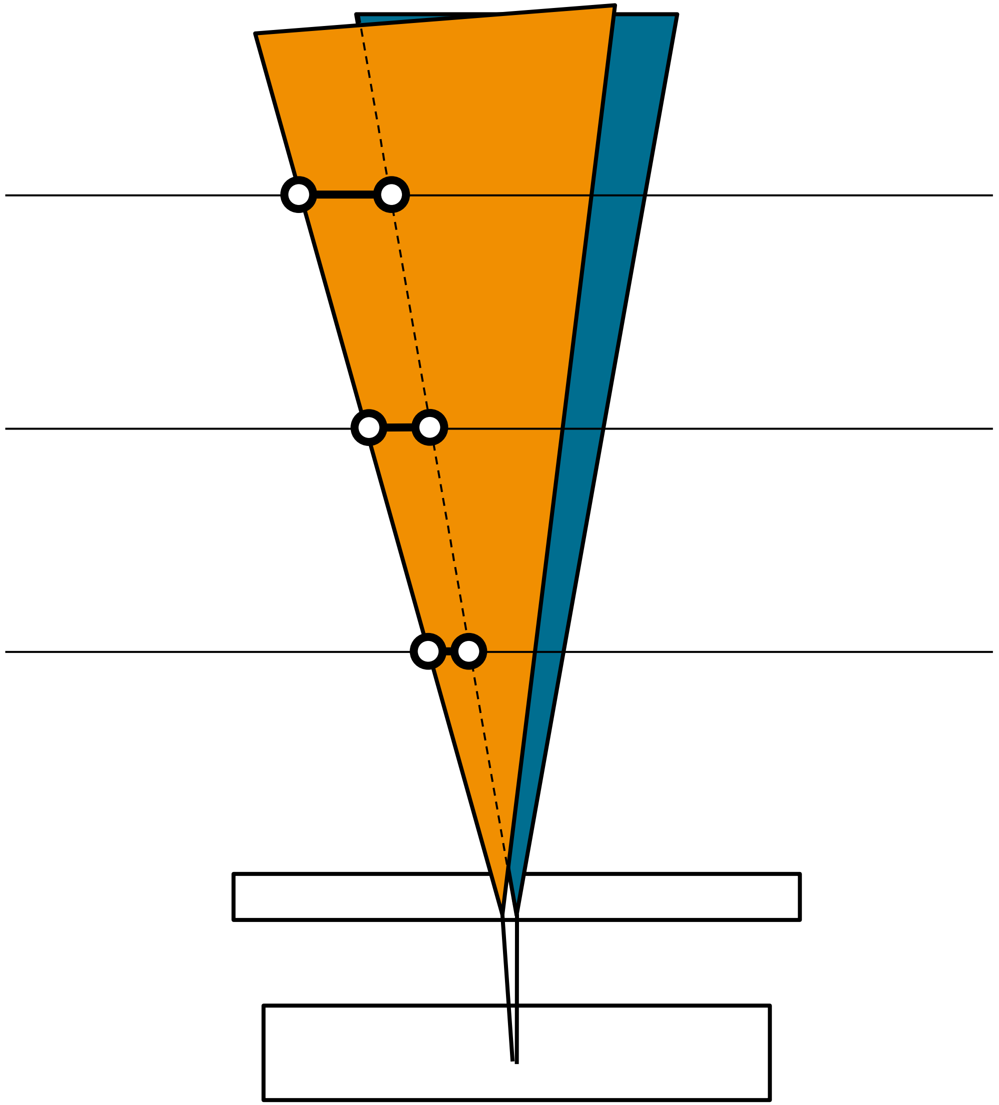




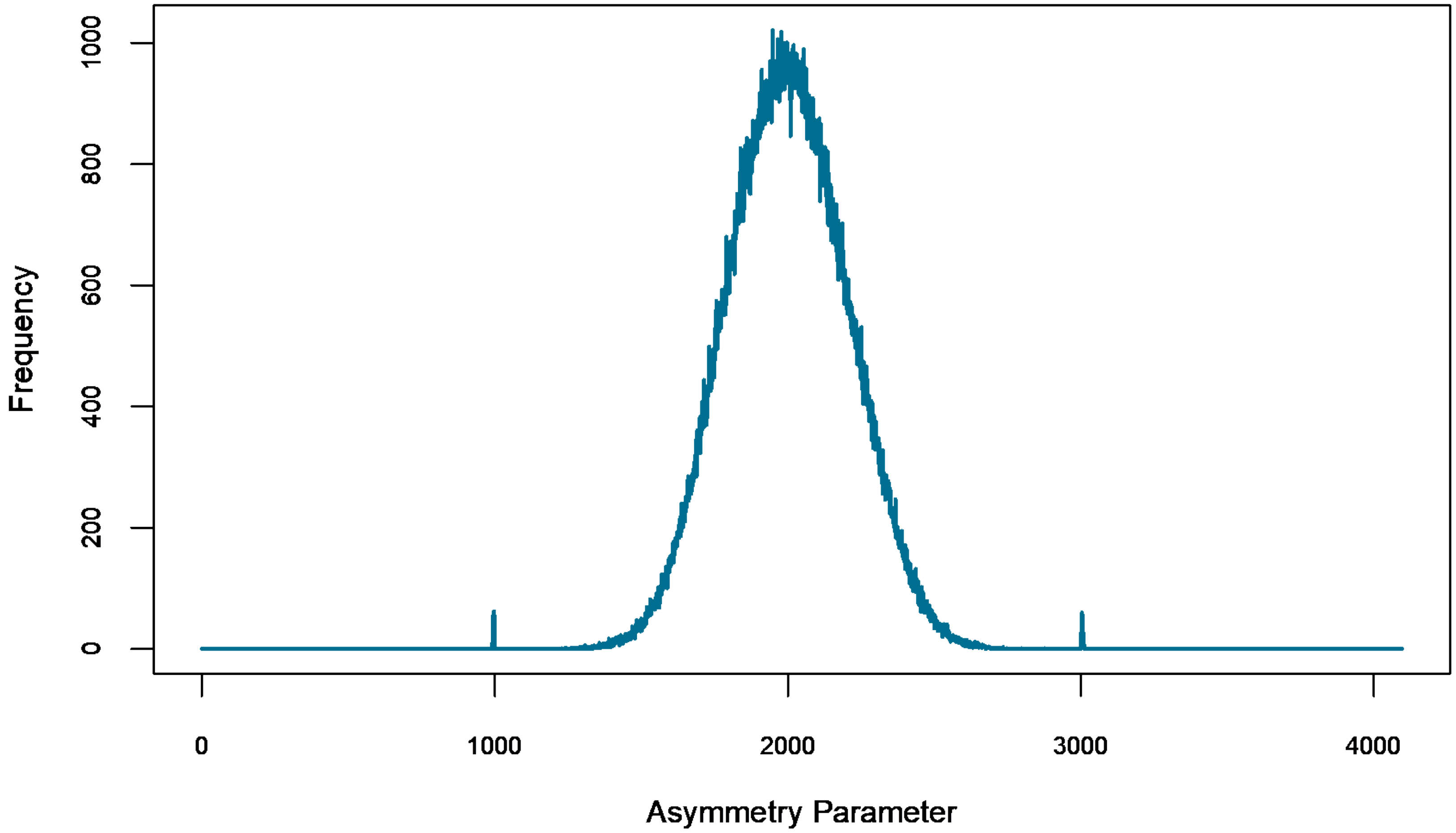
Parametric
Pulse Shape Analysis

Parametric **P**ulse **S**hape **A**nalysis (**PSA**)

- Interactions are localized to the segmentation produced from overlapping orthogonal strips.
- Events are assumed to interact at the center of voxels.
- This leads to errors in the positioning of the cone's asymmetry axis!
- Need to increase the segmented detector's position resolution



The asymmetry parameter distribution is split into 5 equal parts for each of the contacts. Comparison of asymmetry values with the distribution determine the location of an event

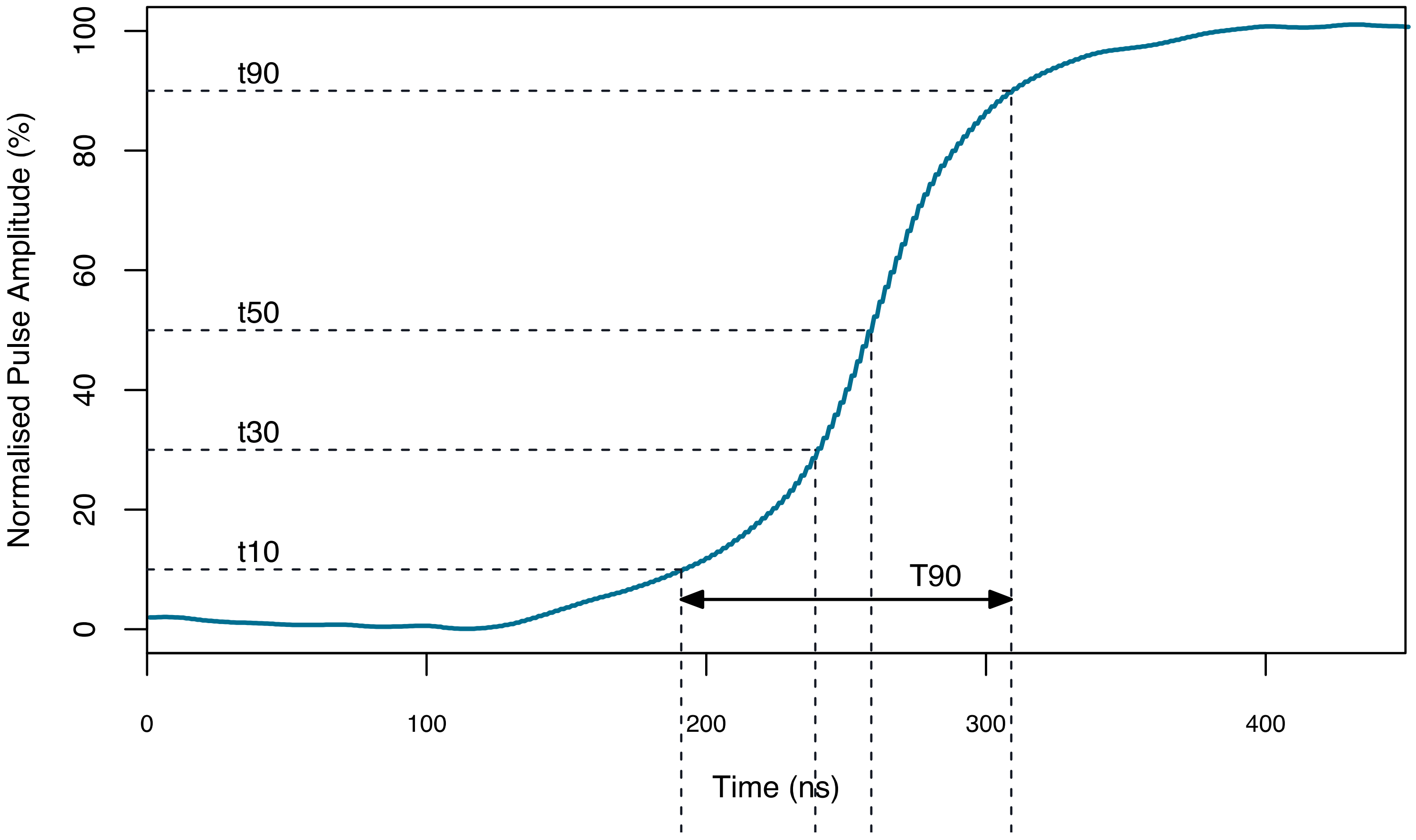


Z PSA

- Risetime is the time required for a signal's amplitude to reach a percentage of its maximum height. Usually given relative to another risetime.

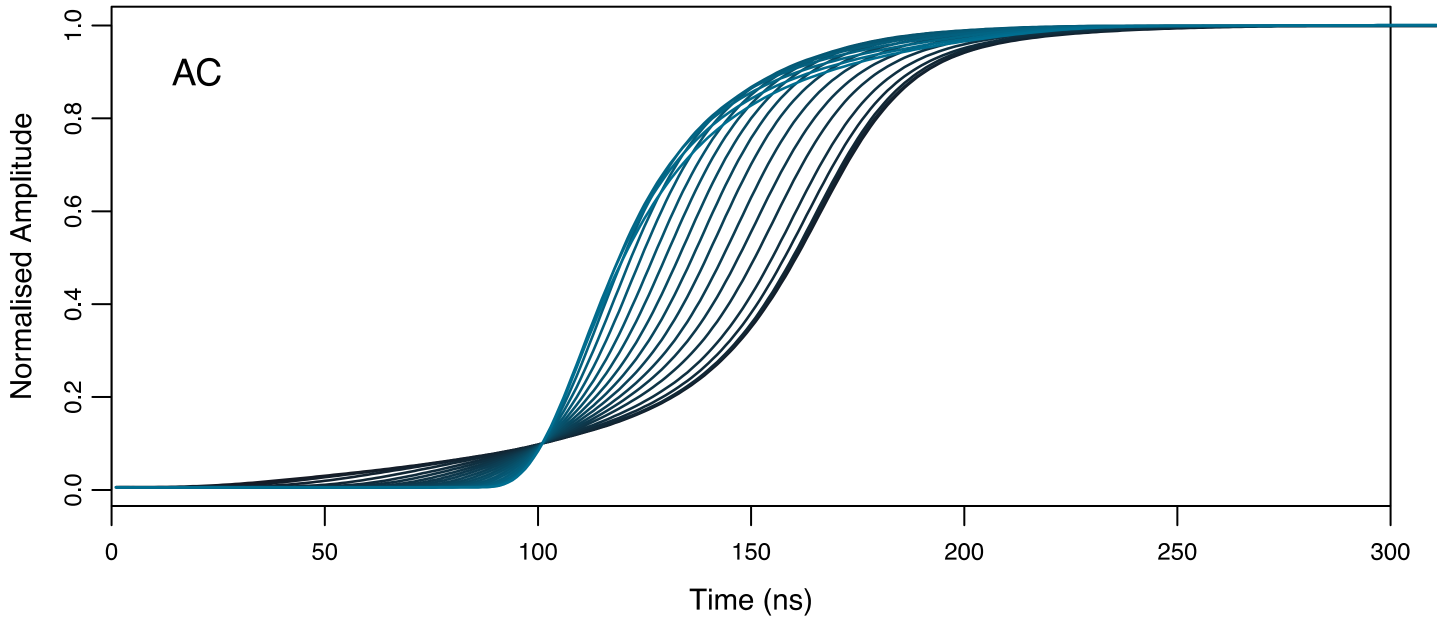
- Z-PSA was only implemented for the absorber detector, a detector scan was required. We have a side scan of it using a collimated Cs-137 source.

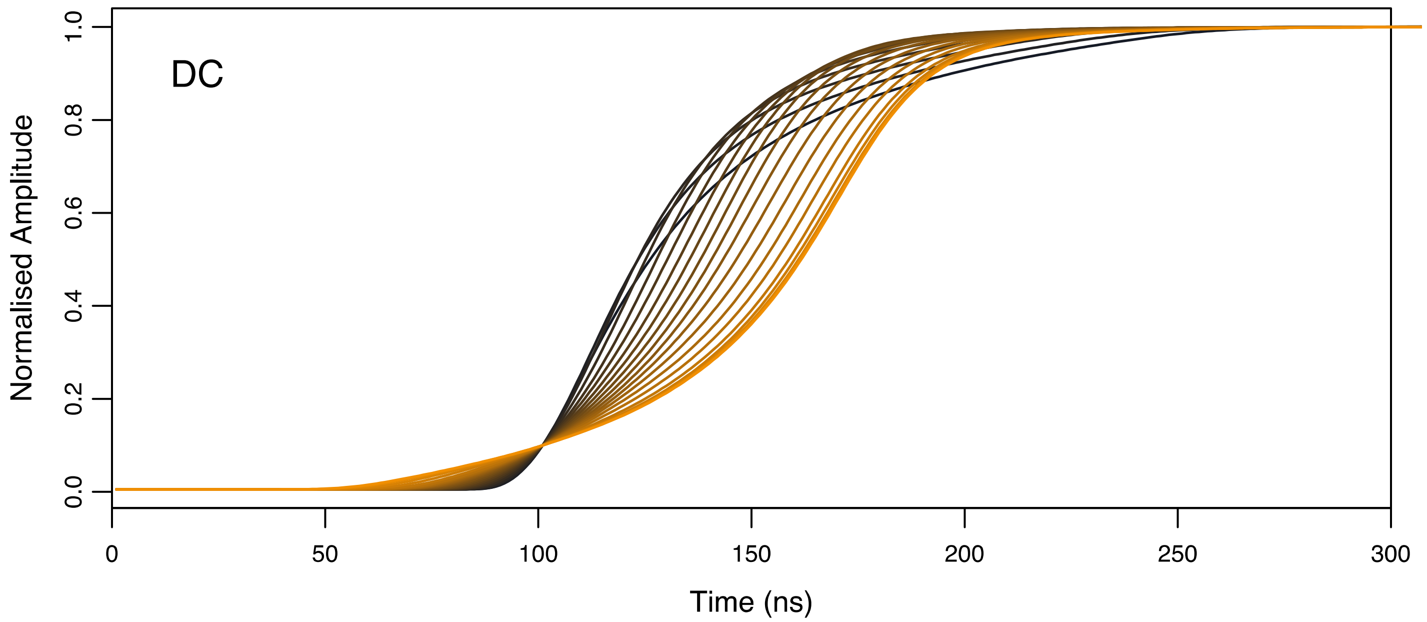
T90 = t90 – t10



- The time taken for signals to reach 30, 50 and 90 percent of their max amplitude was compared to the average risetimes from interactions in known detector locations.

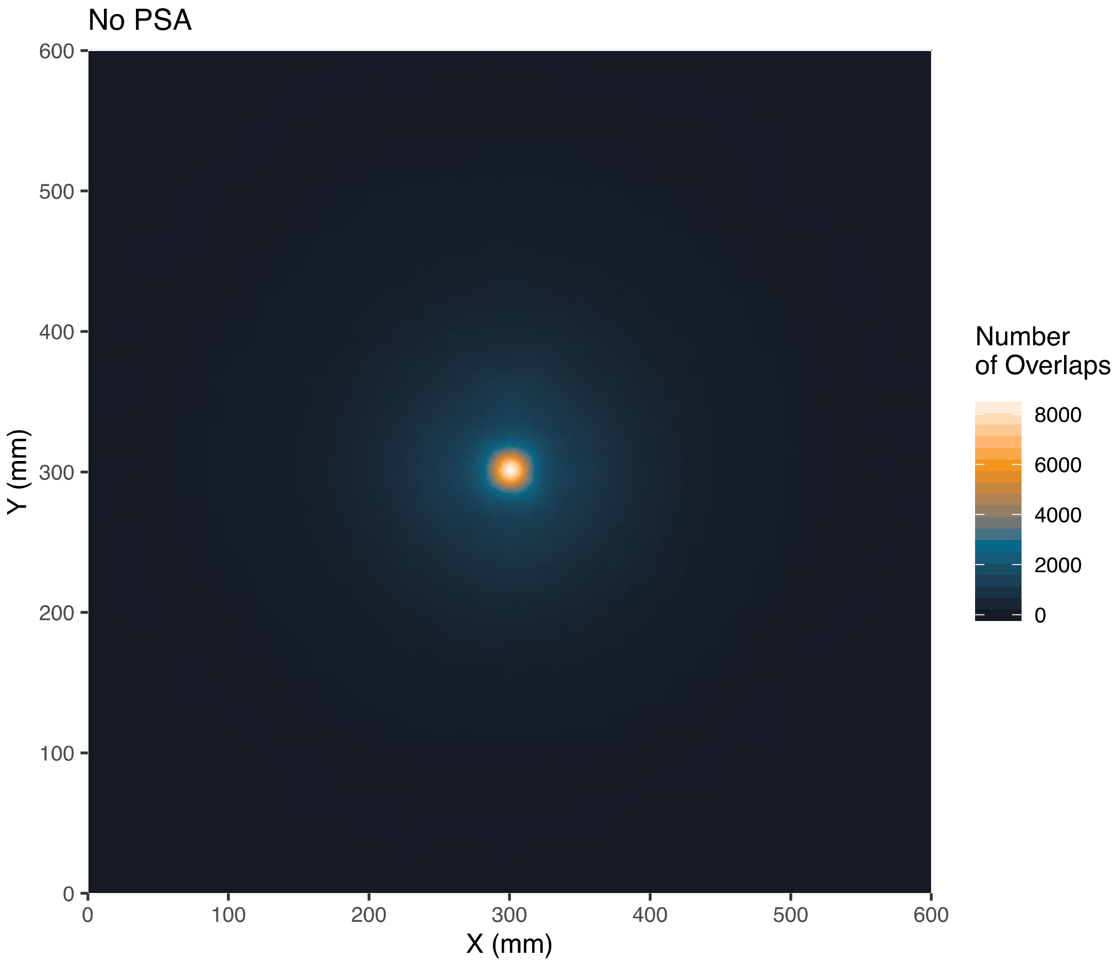
- Absorber interactions were localized to the millimeter depth best matching the risetimes.

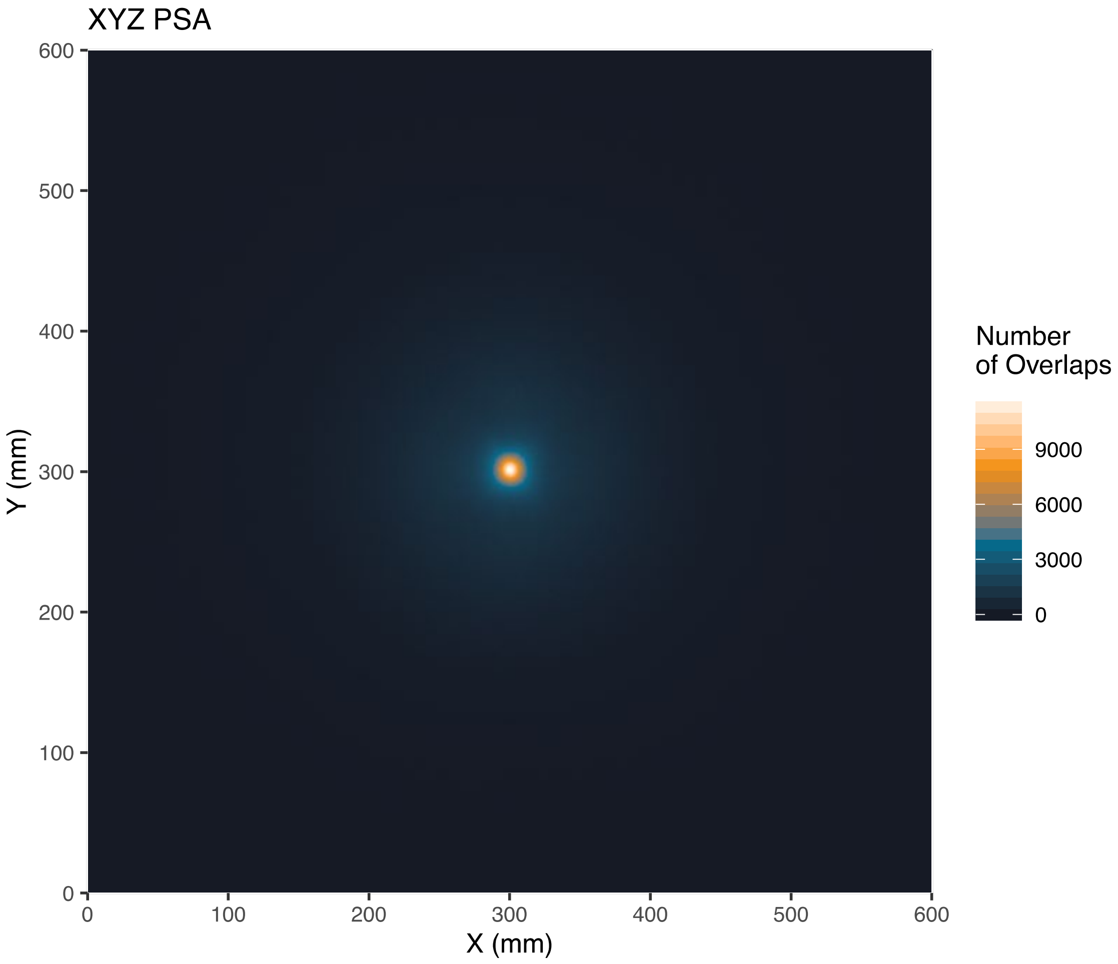


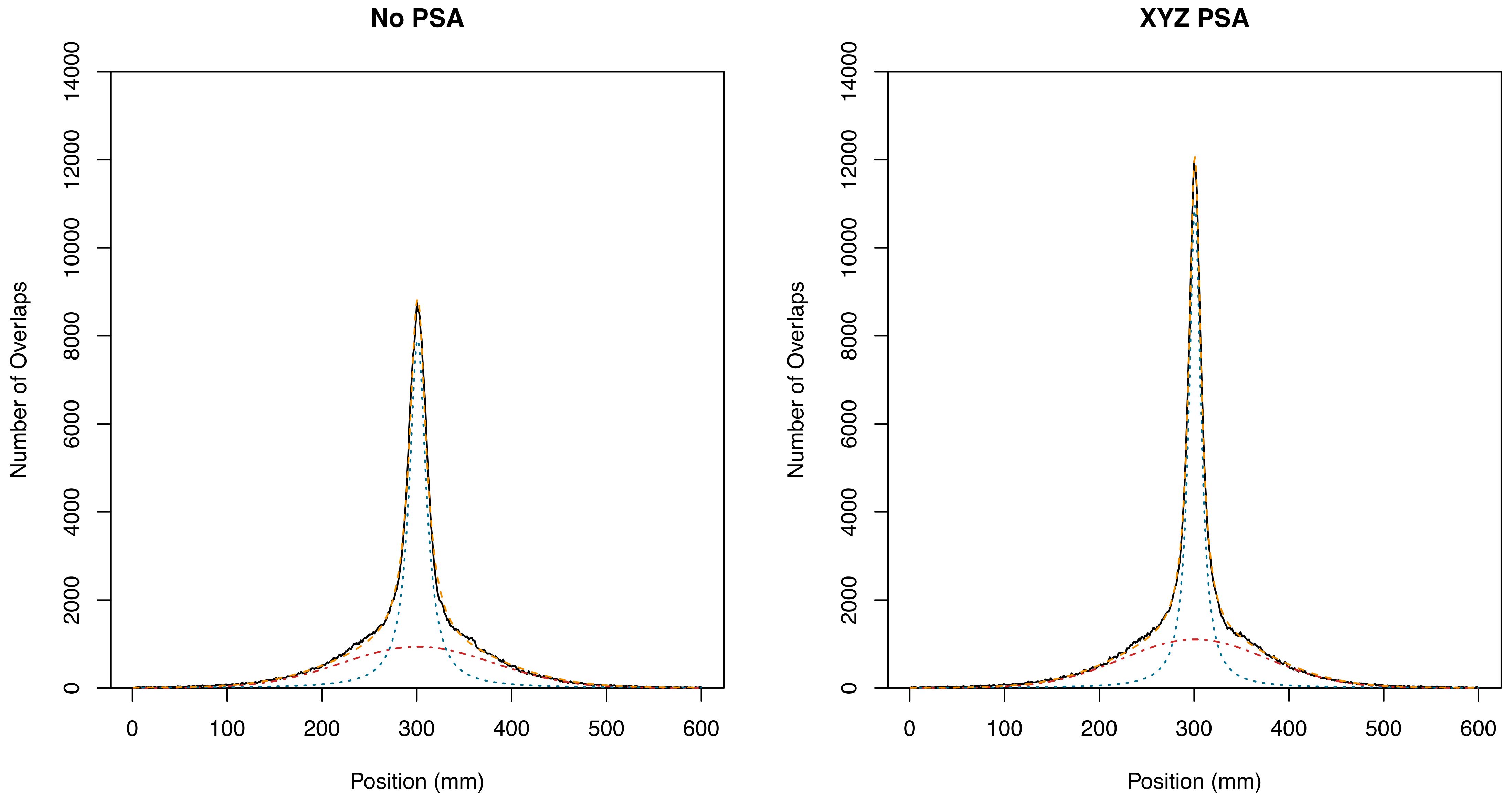


Parametric
PSA Performance

Cs-137 point source 10 cm from the detector.

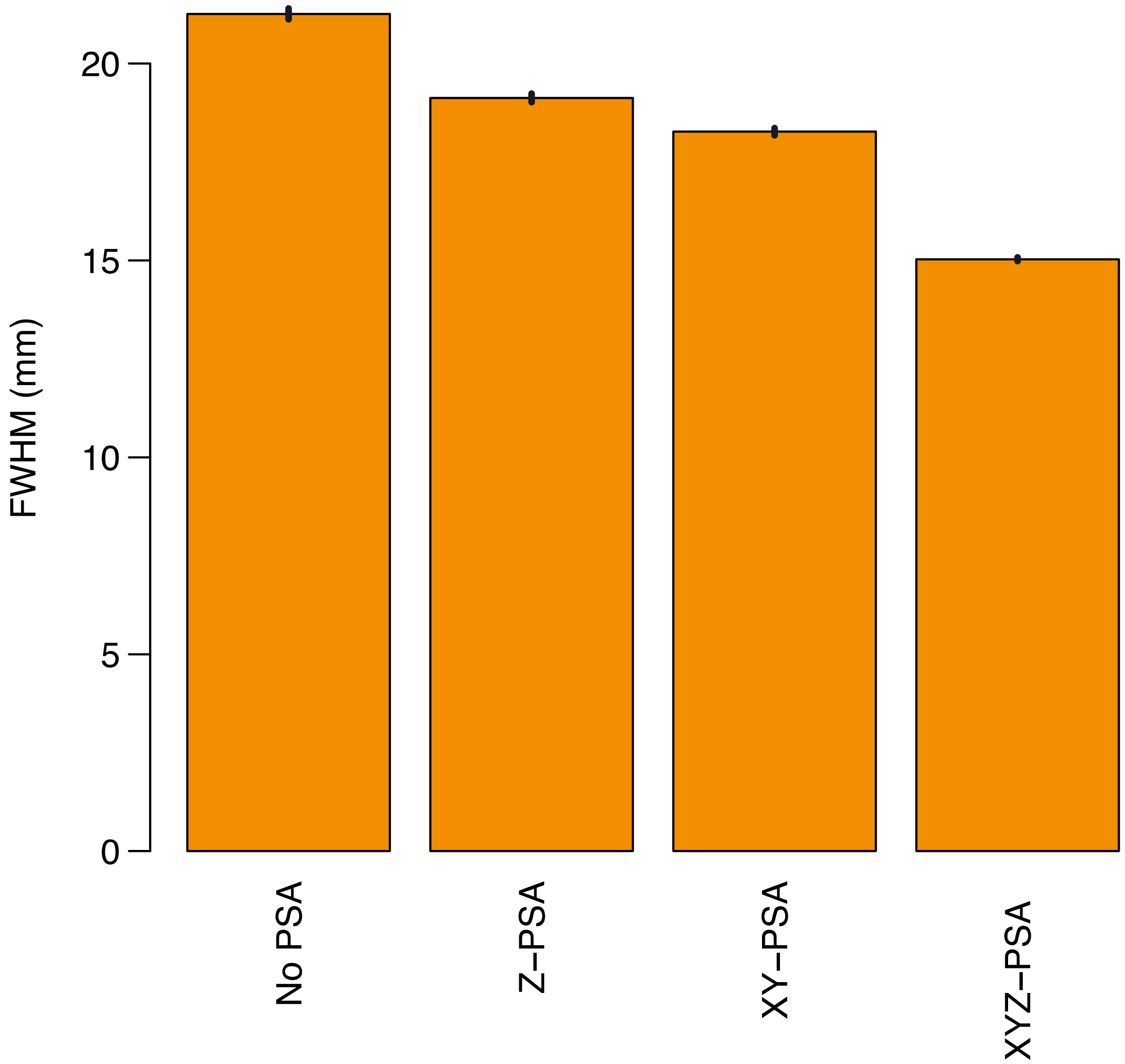





No PSA
XYZ PSA
Number of Overlaps
Position (mm)
0
2000
4000
6000
8000
10000
12000
14000
0
100
200
300
400
500
600

- Image resolution for a Cs-137 point source 10 cm from the detector improved from 21.26 mm to 15.03 mm.

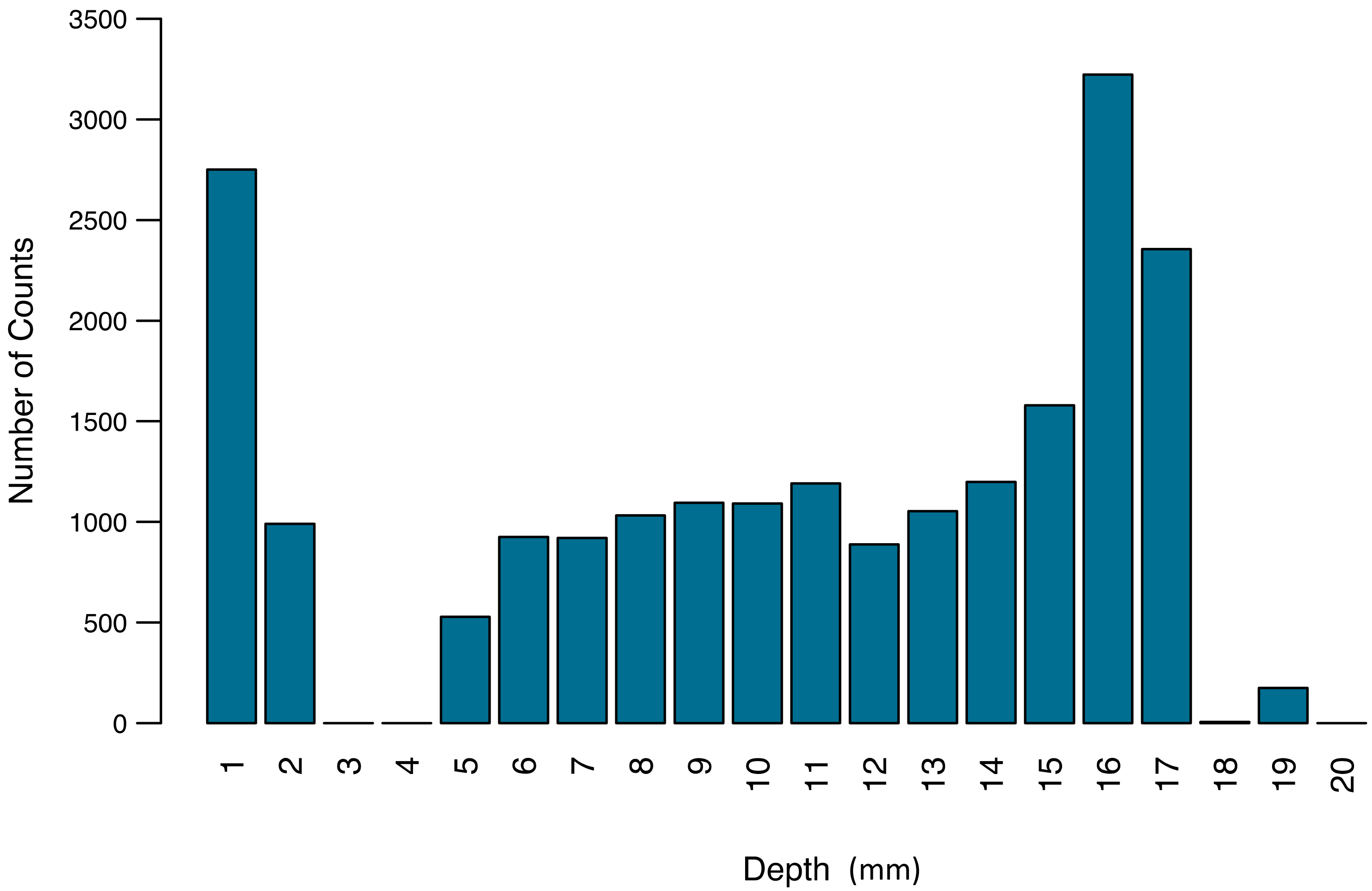
- **30 % increase in image resolution!**



- **This is not perfect!**

- The distribution of interaction depths shows non-uniform sensitivity throughout the bulk of the detector.

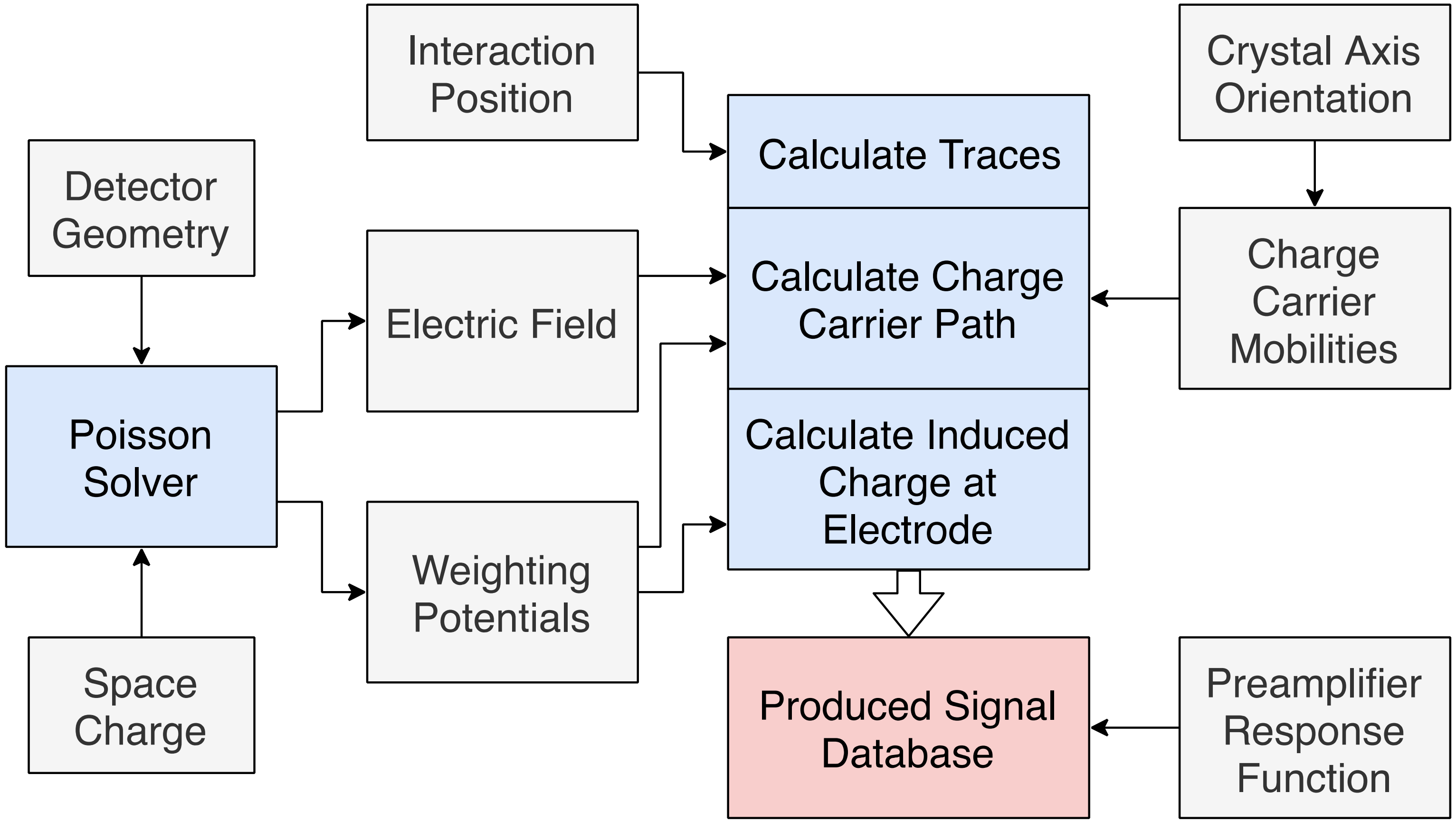
- There is not as much variation in risetimes at the edge of the crystal.



Database PSA

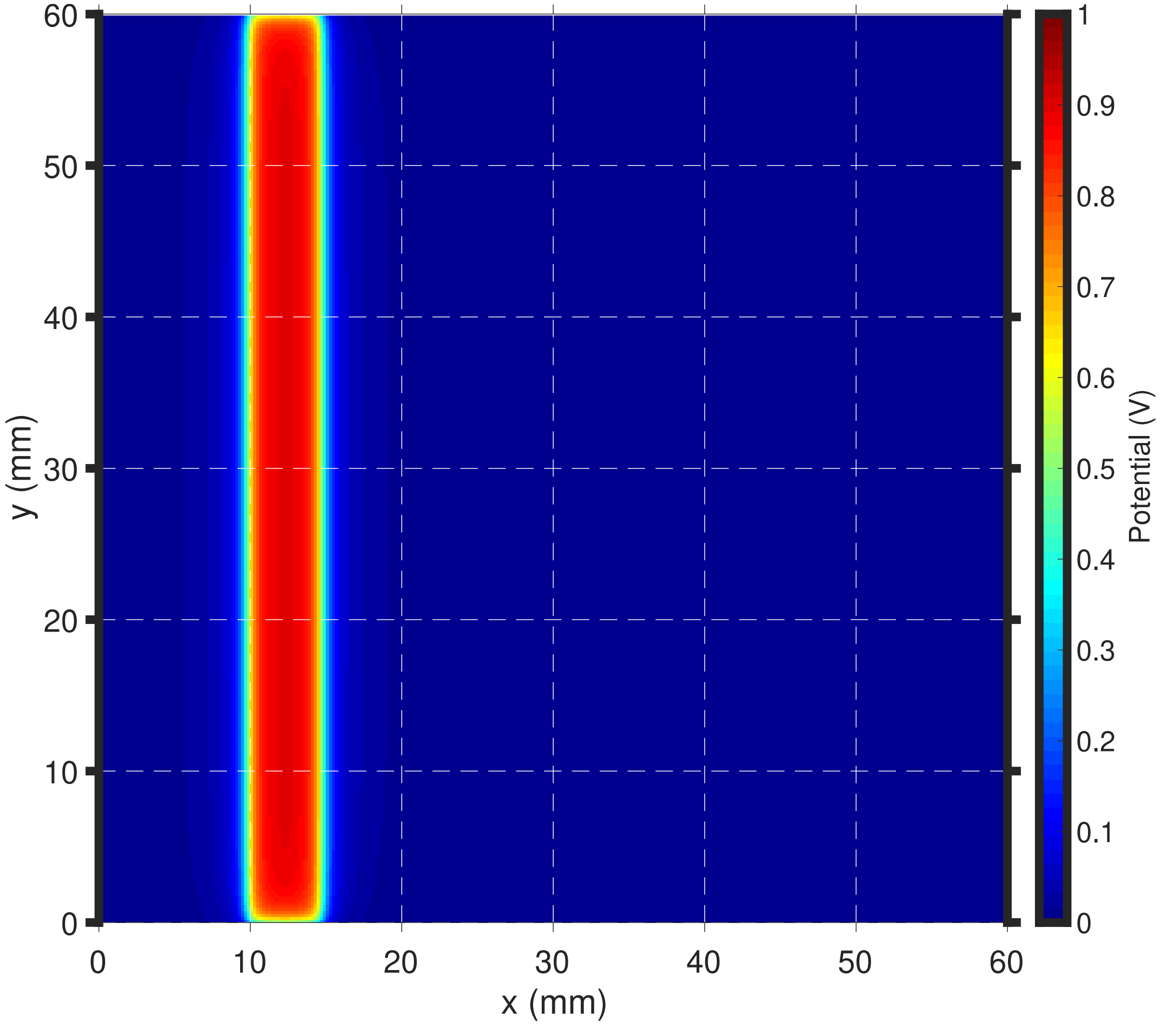
AGATA Detector Library (ADL) Database Creation

- Pulses needed from 60 x 60 x 20 positions through the crystal (72,000), 1 mm cubed grid
- Input electron and hole mobilities, bias voltage, relative permittivity and impurity concentrations on each face.
- Solved for a 0.2 mm cubic grid

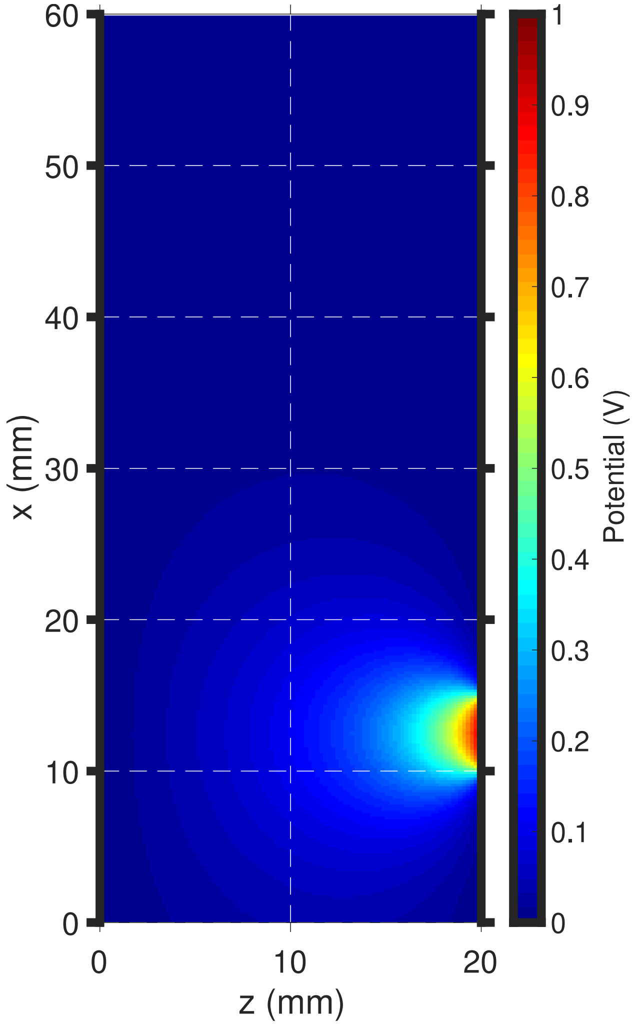


Weighting Potential

- Calculate Electric and weighting potentials
- Weighting for one strip contact shown
- Calculated weighting potential is pretty much uniform along a contact



X-Y slice at 2 mm from DC side



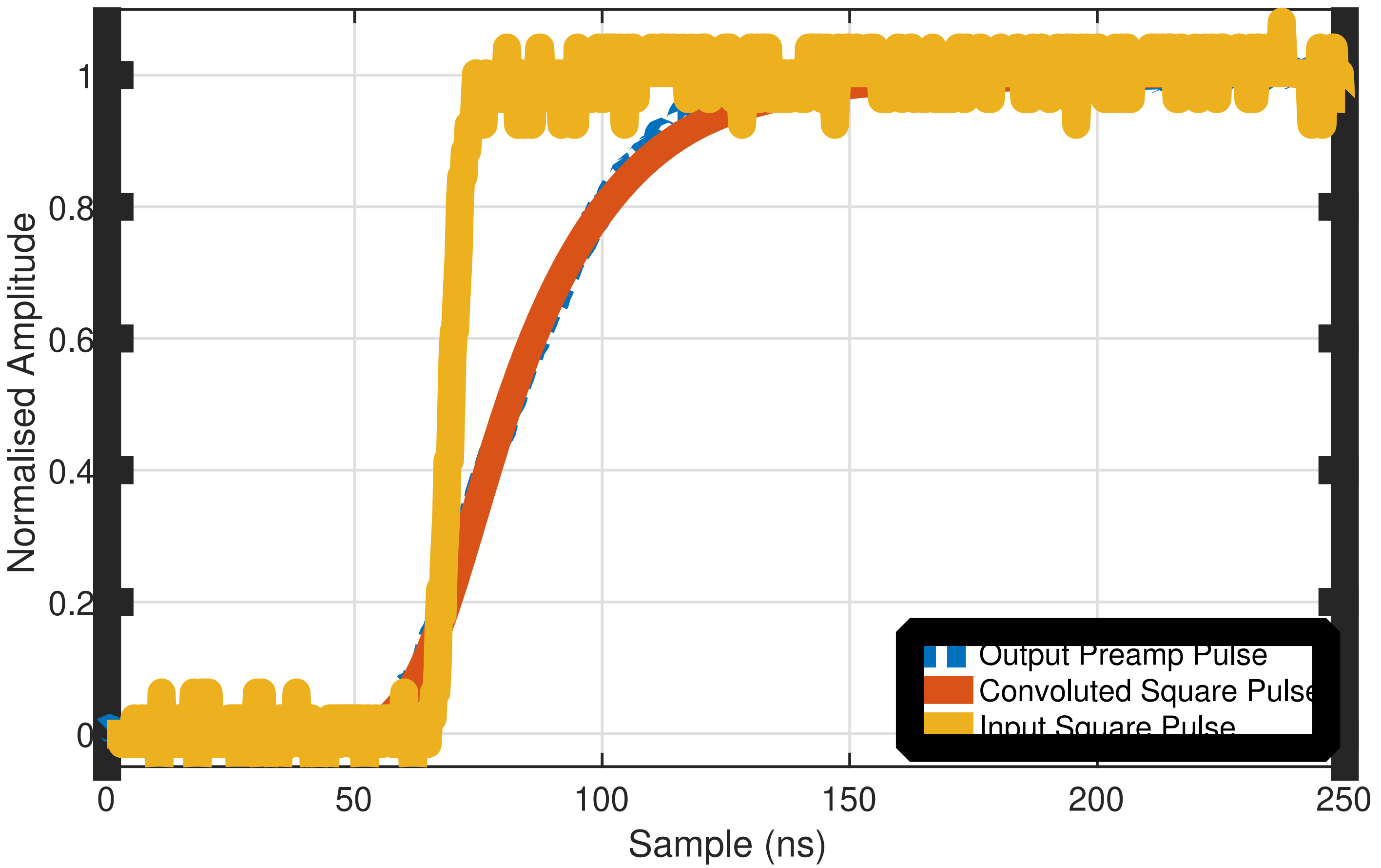
Z Slice through detector

Simulating Preamplifier Effects

- Square pulse input into PSC823C preamplifier test input

- Optimization of preamplifier response function constants to simulate effect of preamplifier electronics.

$$R(t) = g\,\frac{1}{1-c}\left(\frac{1}{1+\frac{1-c}{c}e^{-bt}}\right)e^{\frac{-t}{t_d}}$$

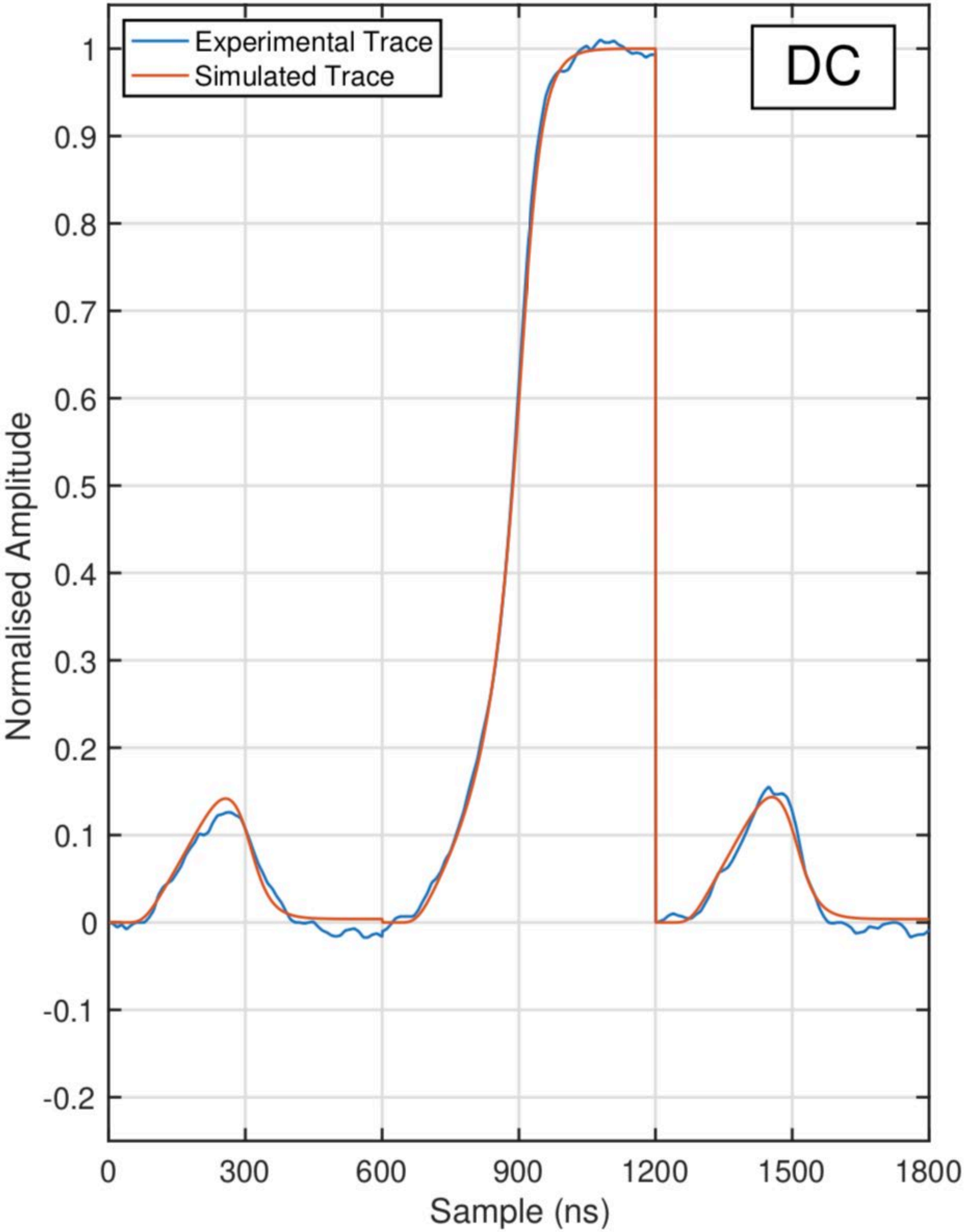


g = gain, b and c optimised. R(t) is the signal response function

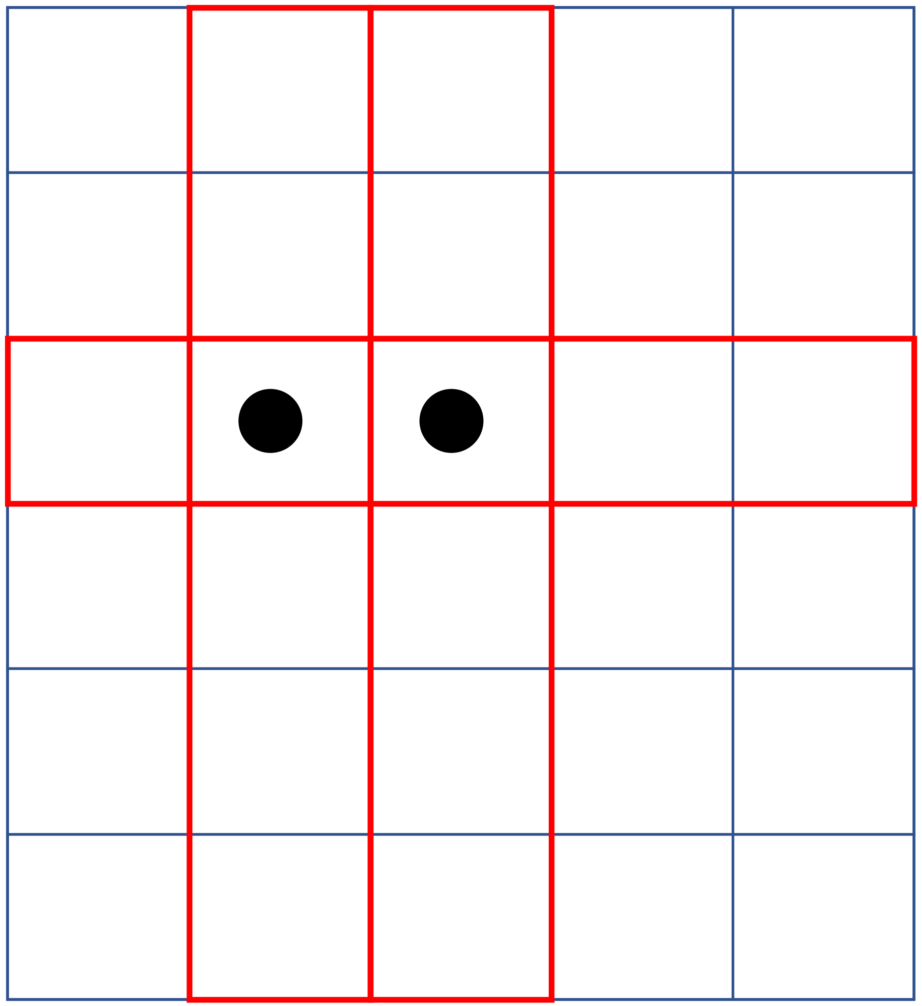
Grid Search Algorithm

Fold-1 Events

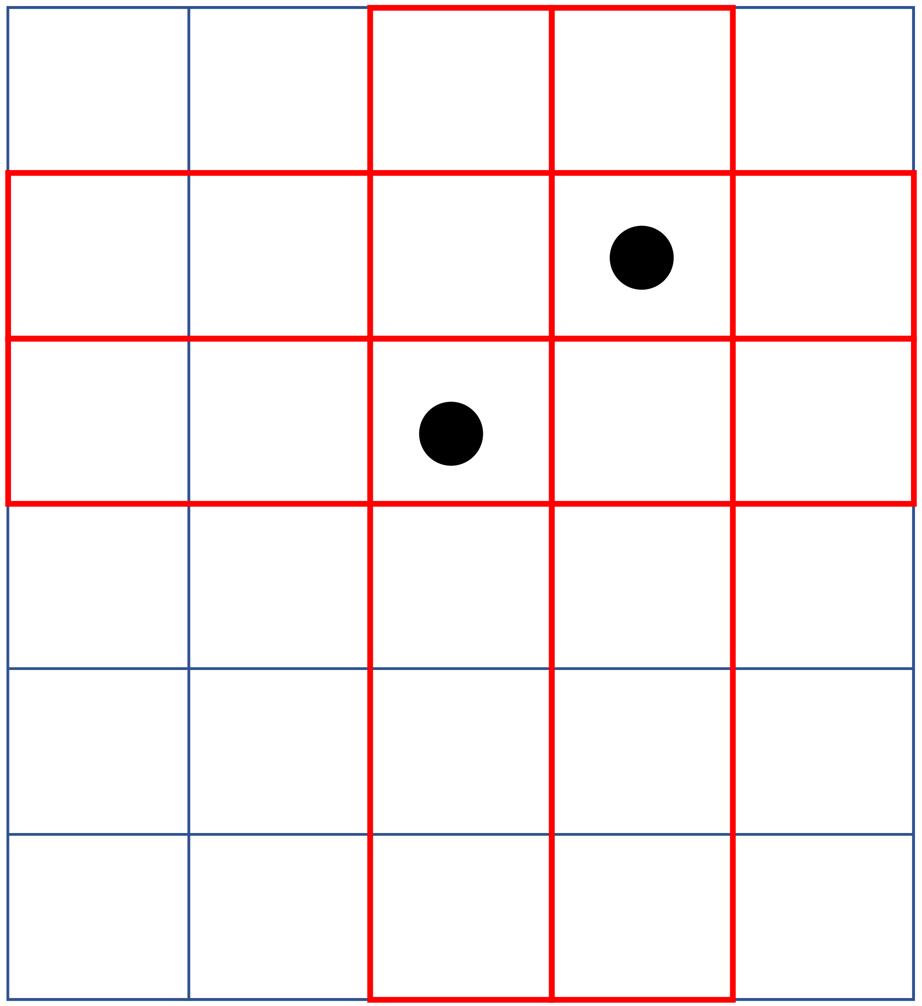
- Normalise and t30 time align all real/transient signals
- Concatenate into a super-trace
- Compare to the simulated super-traces in the 5 x 5 x 20 mm^3 grid using chi-squared method
- Only 500 comparisons, brute force method!



Fold 2,1



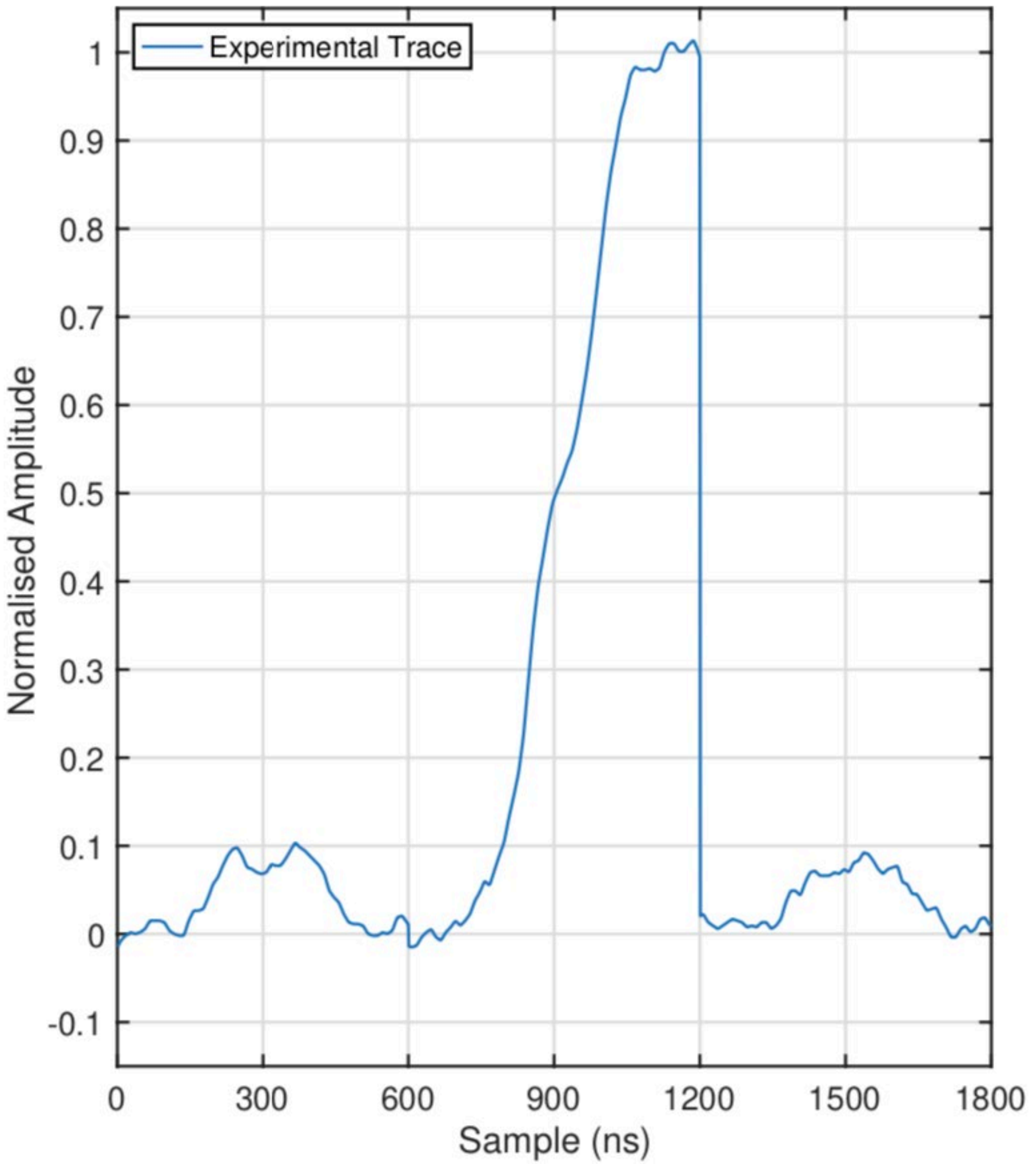
Fold 2-2



Fold-2 Events

A more difficult case!

- Convolution of signals
- Time alignment of database pulses, which interaction occurred first?
- 250,000 signal combinations to compare. Brute force approach unfeasible. Adaptive grid search!



Example of a fold-2,1 event

Step 1 – normalise, time align on t30 and concatenate experimental traces

Step 2 – Obtain rough time alignment estimate by shifting second pulse in time at set positions

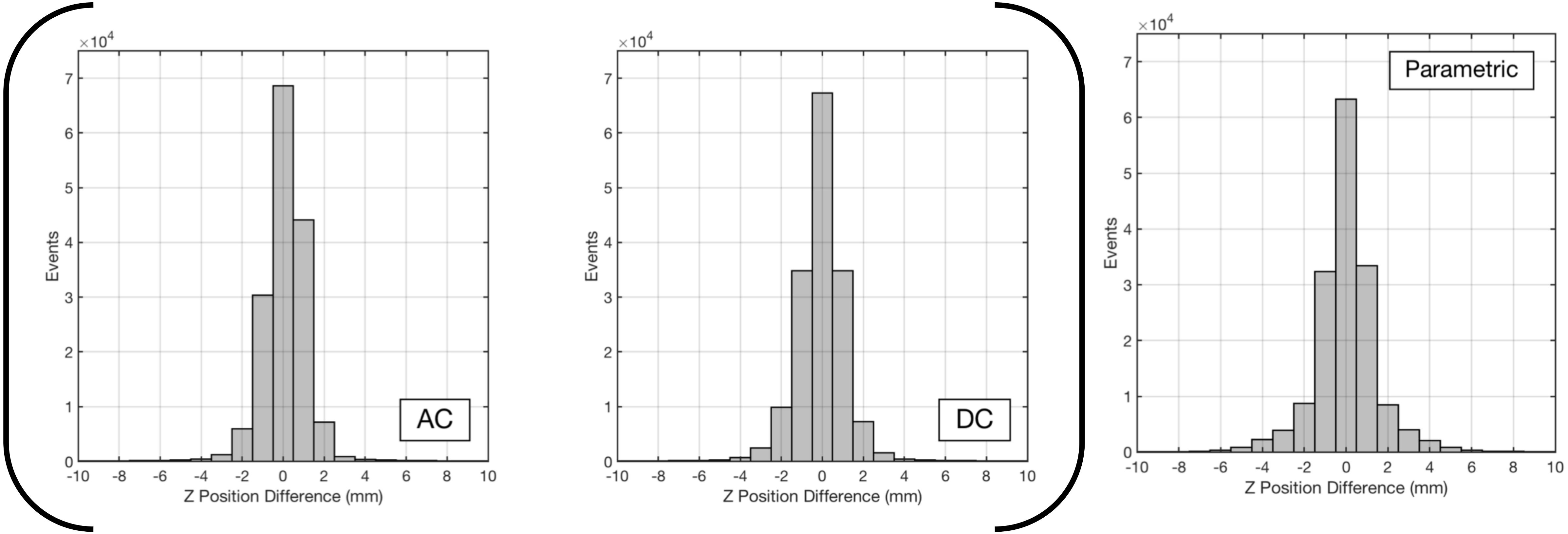
Step 3 – Finely shift both pulses to obtain better estimate

Step 4 – Compare shifted pulses at set locations to determine Z interaction locations

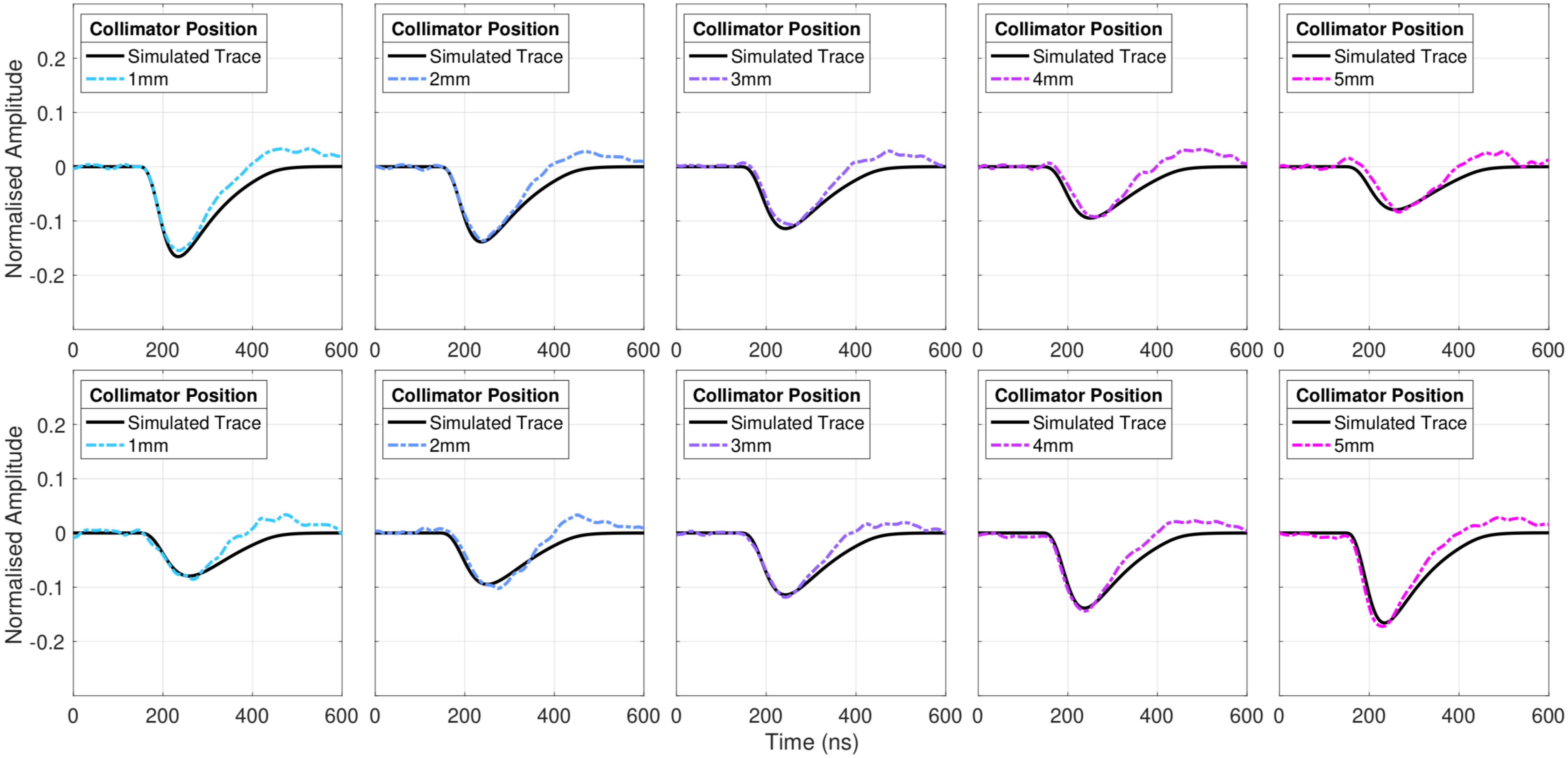
Step 5 – At each Z, compare within the 5 by 5 mm^2 grid for X and Y

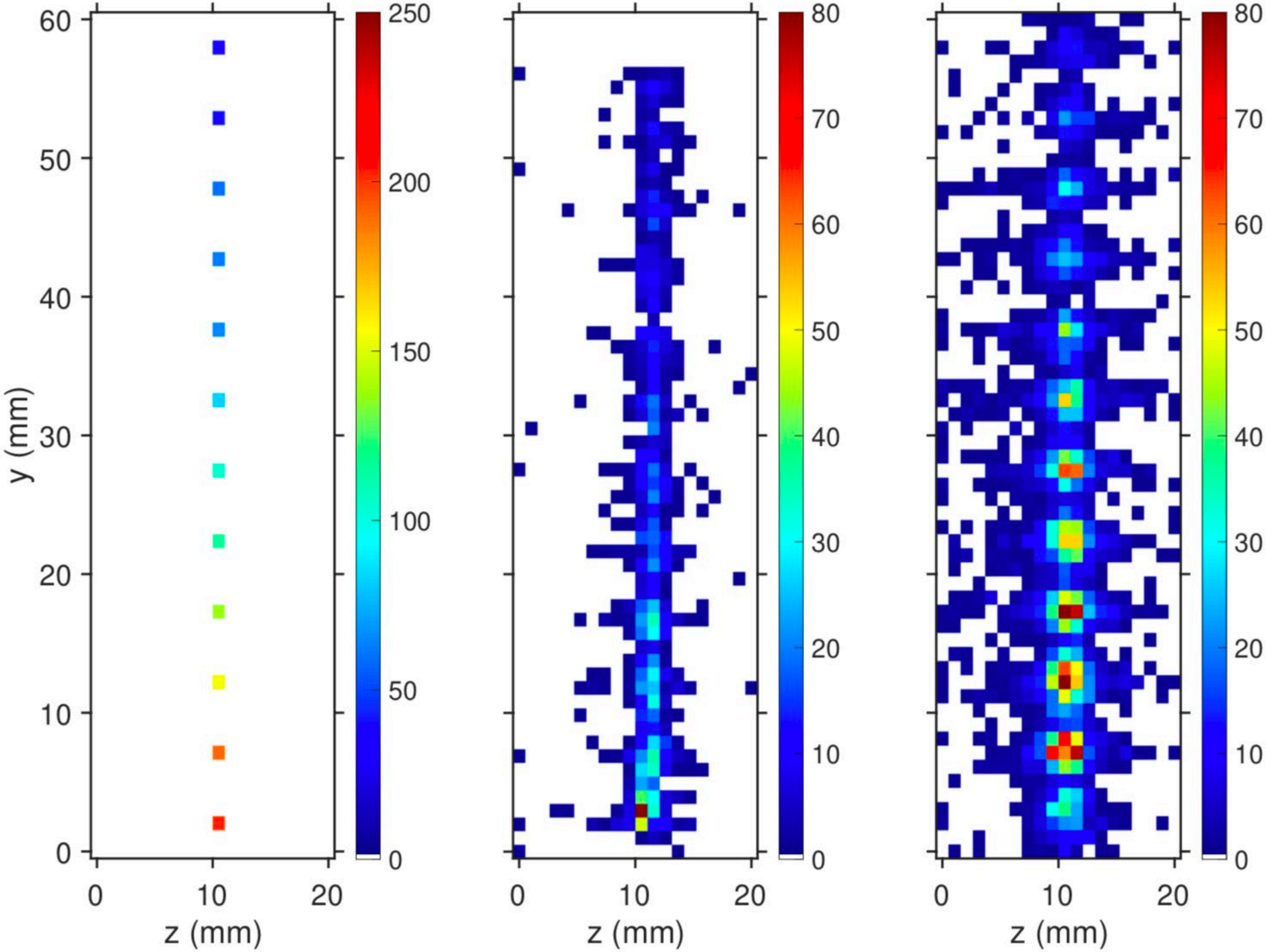
Database Validation

Database **Parametric**



Face	0mm	1mm	2mm	≤2mm
Database AC	42%	46%	8%	97%
Database DC	42%	43%	11%	95%
Parametric z-PSA	38%	40%	10%	89%


Collimator Position
Simulated Trace
1mm
2mm
3mm
4mm
5mm
Normalised Amplitude
0.2
0.1
0
-0.1
-0.2
0
200
400
600
Time (ns)



y (mm)
z (mm)
z (mm)
z (mm)
0
10
20
30
40
50
60
0
10
20
0
50
100
150
200
250
0
10
20
30
40
50
60
70
80

Conclusion

- Successfully implemented Database and Parametric PSA algorithms to better define Compton cones -> Better image resolution

- Accurately determined the order of gamma-ray interactions in the absorber detector to use fold-2 events

- Some work is still ongoing for database PSA

Thanks for listening!

Caffrey. A, Rintoul. E, Boston. A, Boston. H, Judson. D,
Harkness-Brennan. L, Creswell. J, Nolan. P, Alshamiri. H,
Kantalan. S, Platt. J, Woodroof. T, Unsworth. C, Holliway. F

E.Rintoul@Liverpool.ac.uk – Ellis’ email for more database PSA info if needed