Neutron damage studies of A009 & A601

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Current status of A601

- Still undamaged.
- All initial measurements bar coincidence and surface scans have been completed, which will be performed on the new scanning table.
- The new table is undergoing final paperwork for bringing in and installing the ^{137}Cs source - this is the last step.
- Progress has been delayed by issues with shorted segment wires in the endcap, an unexpected thermal cycle destroying the cold and warm electronics, and an orientation specific contact between the endcap and the encapsulation.
- Despite this, the detector is working well still.

The characterisation suite

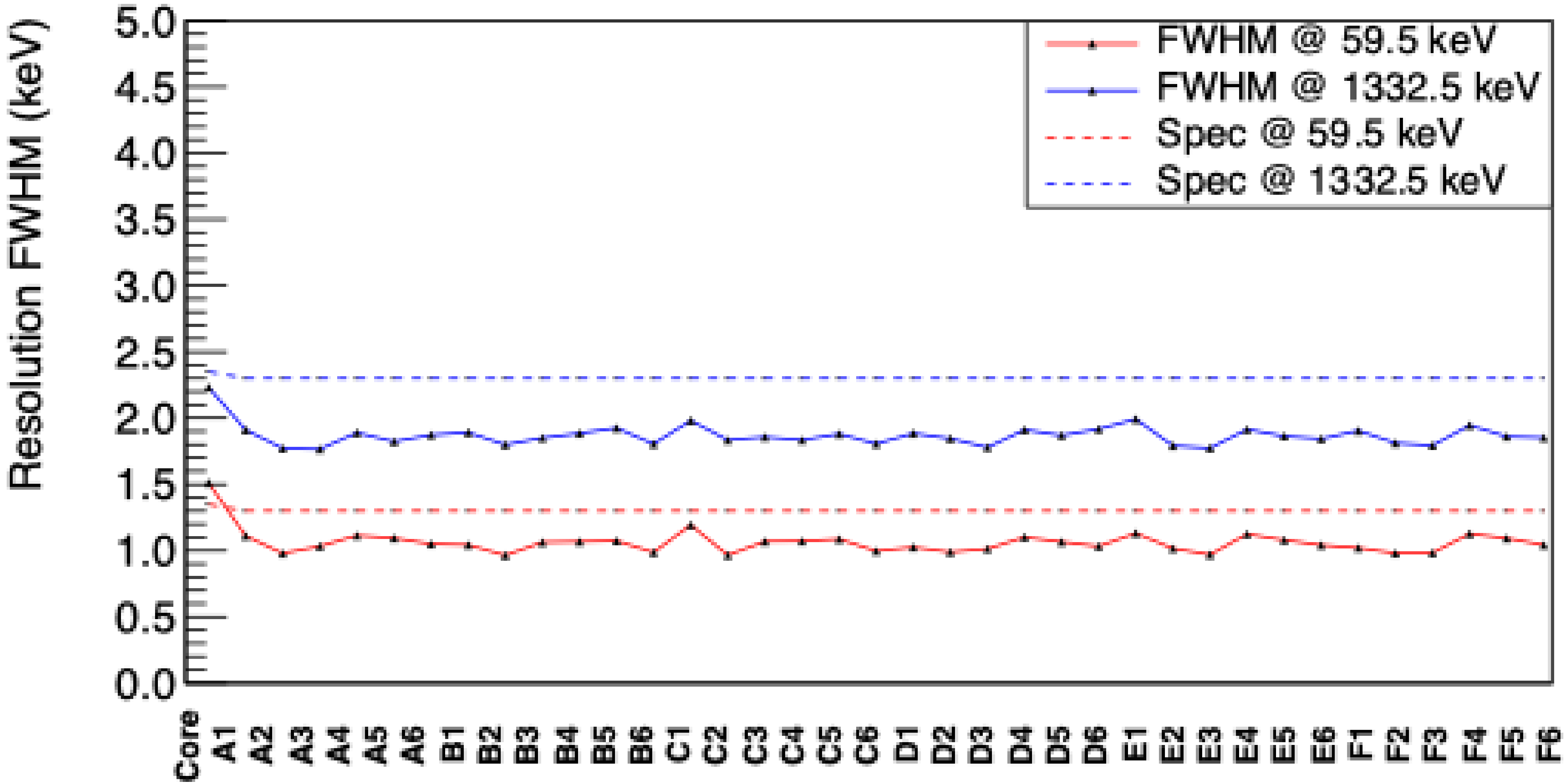
Analog measurements:

- Energy resolution measurements at 60, 662, 1173 & 1332 keV. ✓
- Relative efficiency measurements. ✓
- Relative efficiency measurements as a function of angle in ring 5 – source at side of detector. ✓
- Absolute efficiency measurements with ^{241}Am and ^{152}Eu. ✓

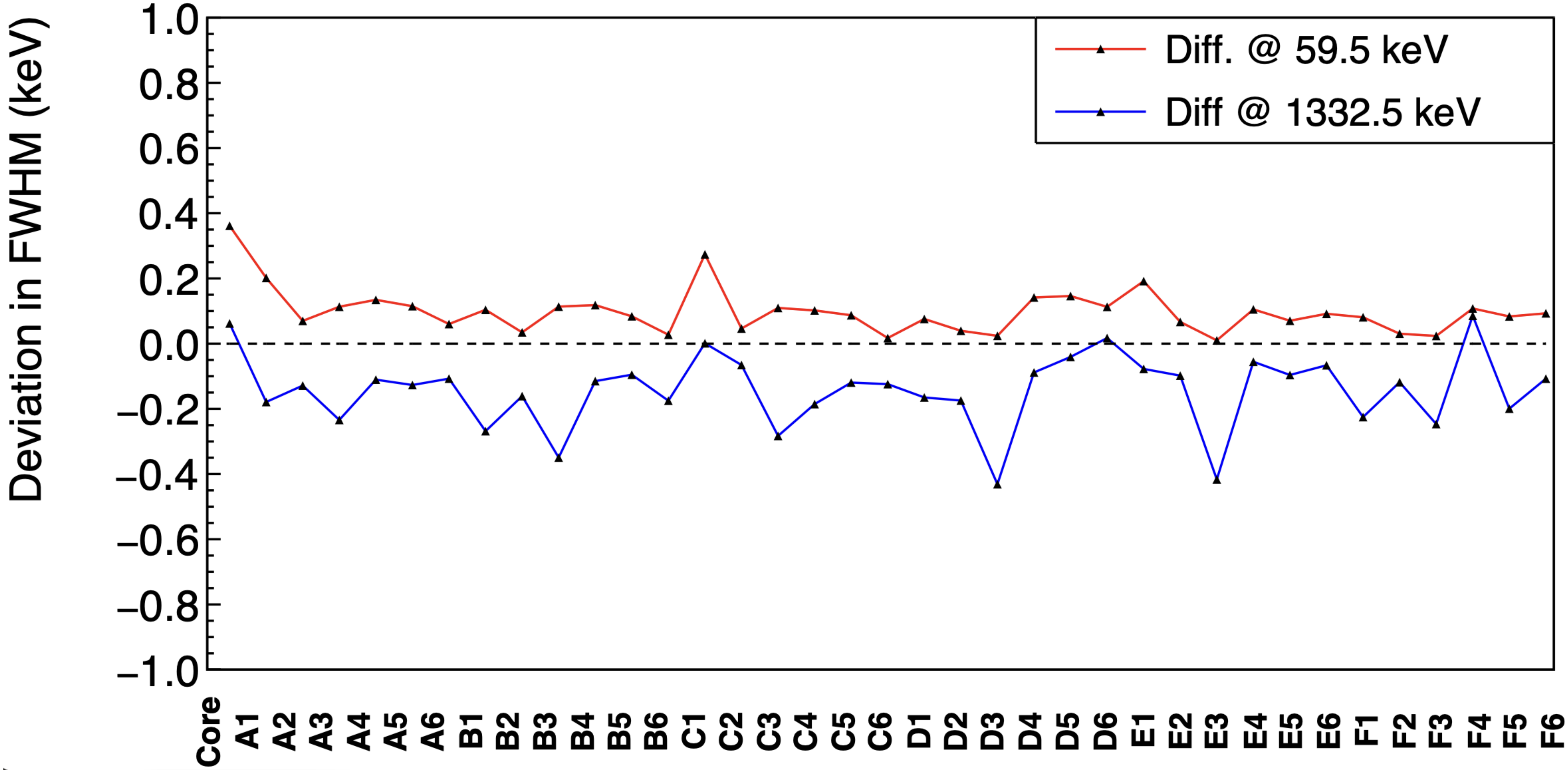
Digital Measurements:

- *High statistics front scan, at both 5 kV, and depletion + 100 V (~ 2.35kV).* ✓
- *Side scan in two positions: C-side down and F-side down.* ✓
- ^{60}Co flood dataset. ✓
- ^{241}Am/ ^{57}Co dataset – flood or scan.
- Coincidence measurements in rings of similar ICD, and lines through the volume.

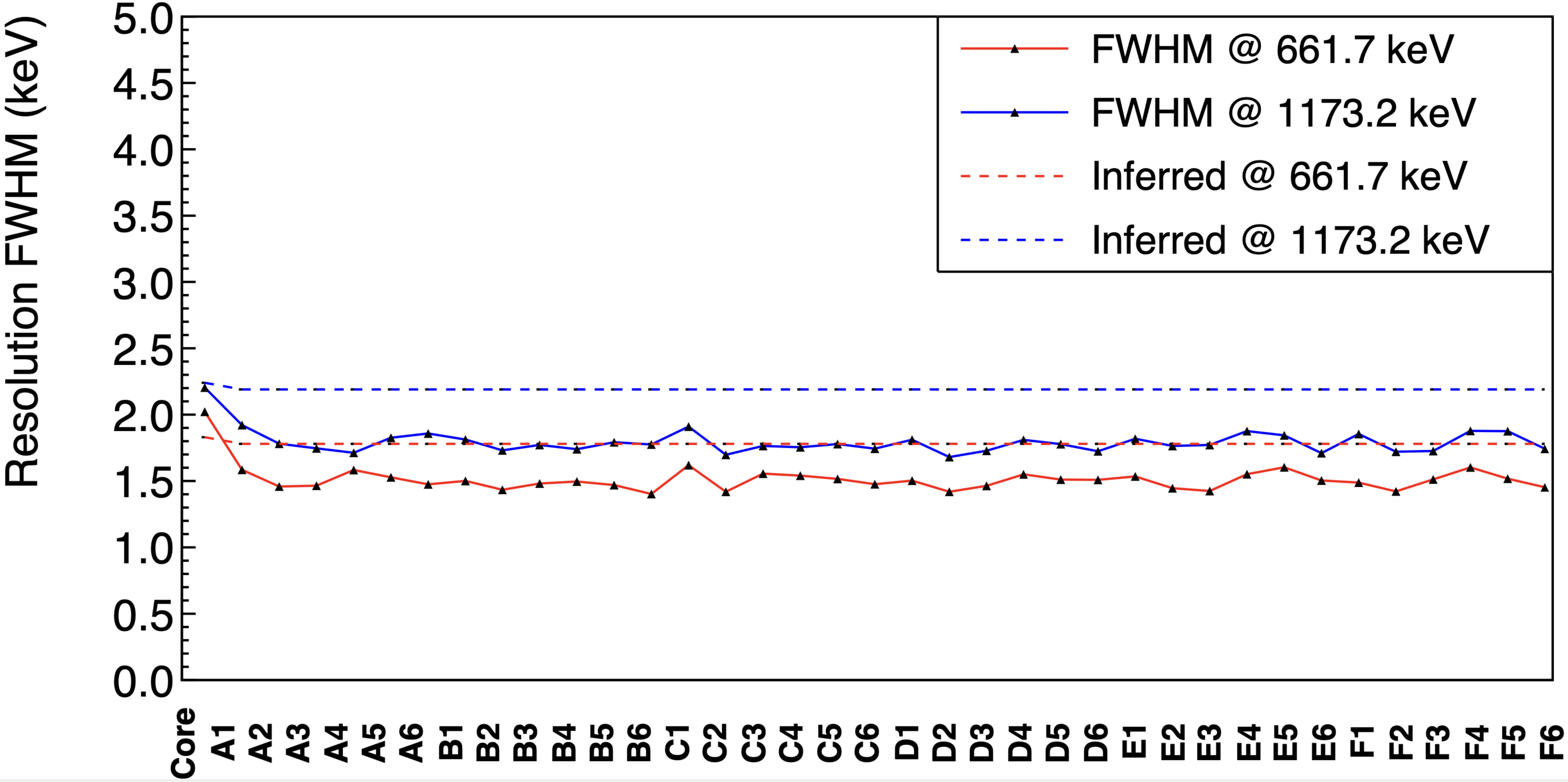
Analogue detector resolution results



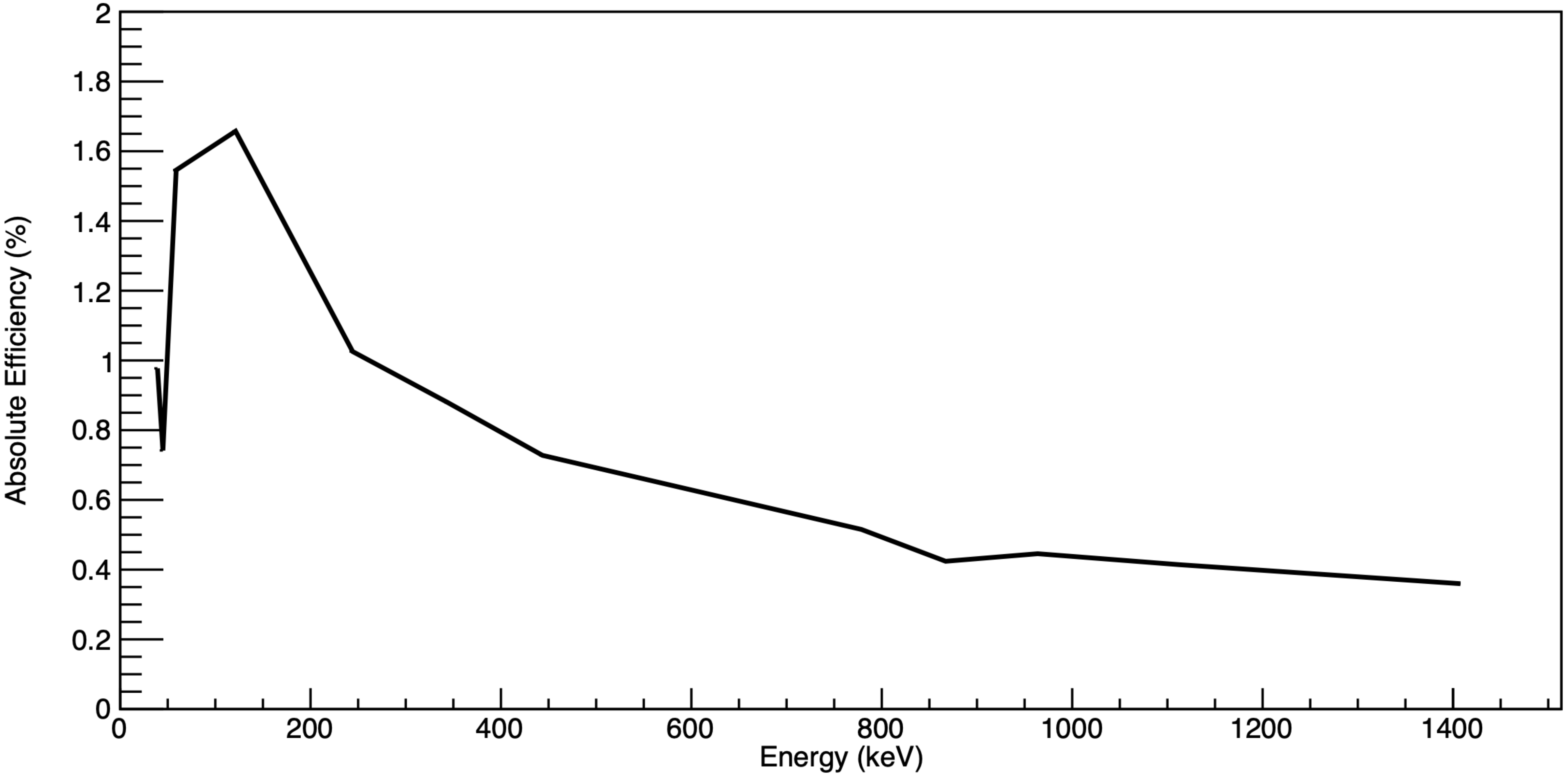
Liverpool FWHM – Mirion FWHM values



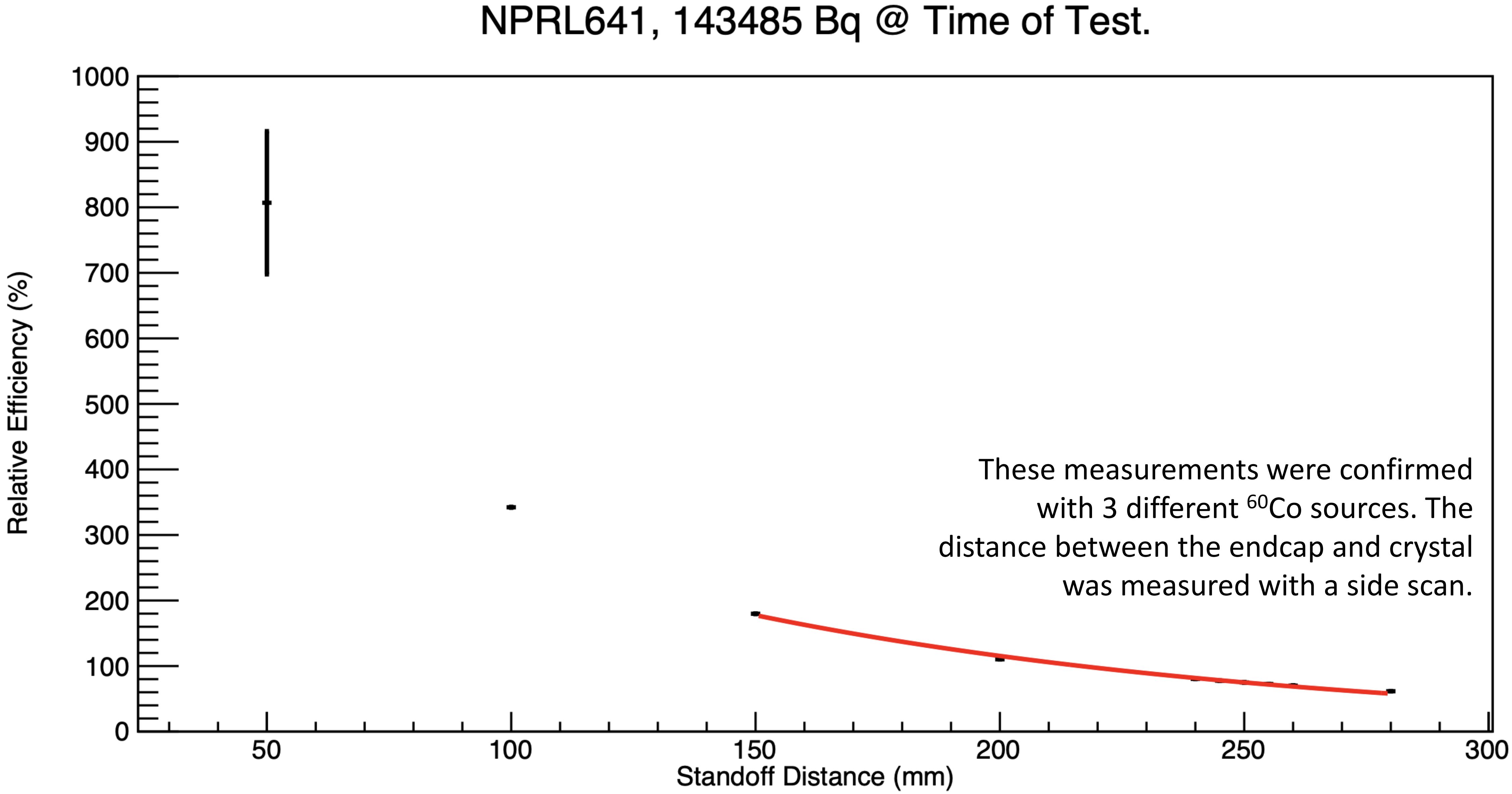
More analogue detector resolution results



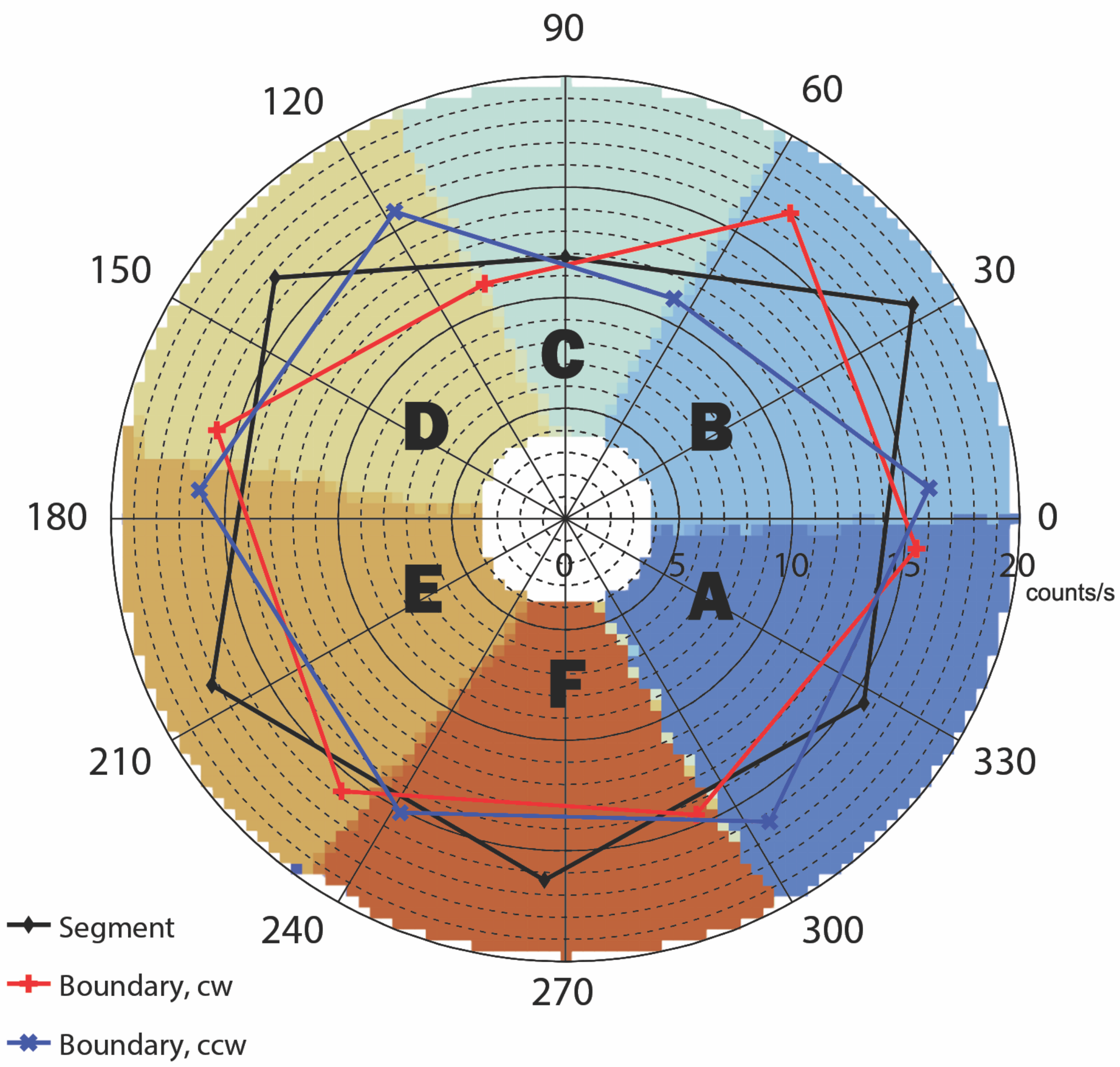
Absolute efficiency measurements, ^{152}Eu & ^{241}Am



Relative efficiency measurements, ^{60}Co, 1332 keV gamma



These measurements were confirmed with 3 different ^{60}Co sources. The distance between the endcap and crystal was measured with a side scan.

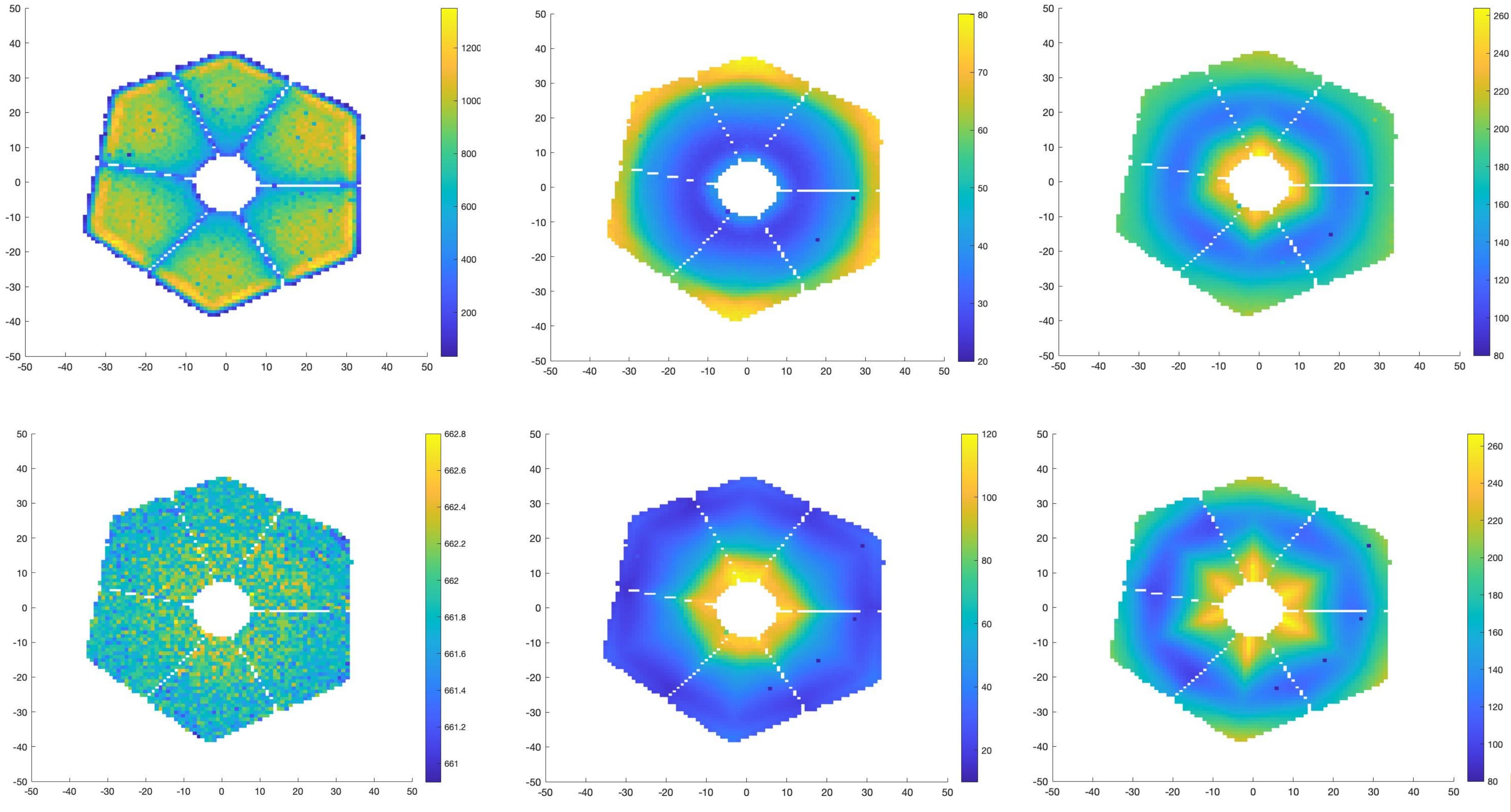


Count rate of 1332 keV events as a function of angle in ring 5.

Source positioned facing the side of the detector at a stand off of about 15cm.

Measurement of efficiency with respect to the crystal lattice.

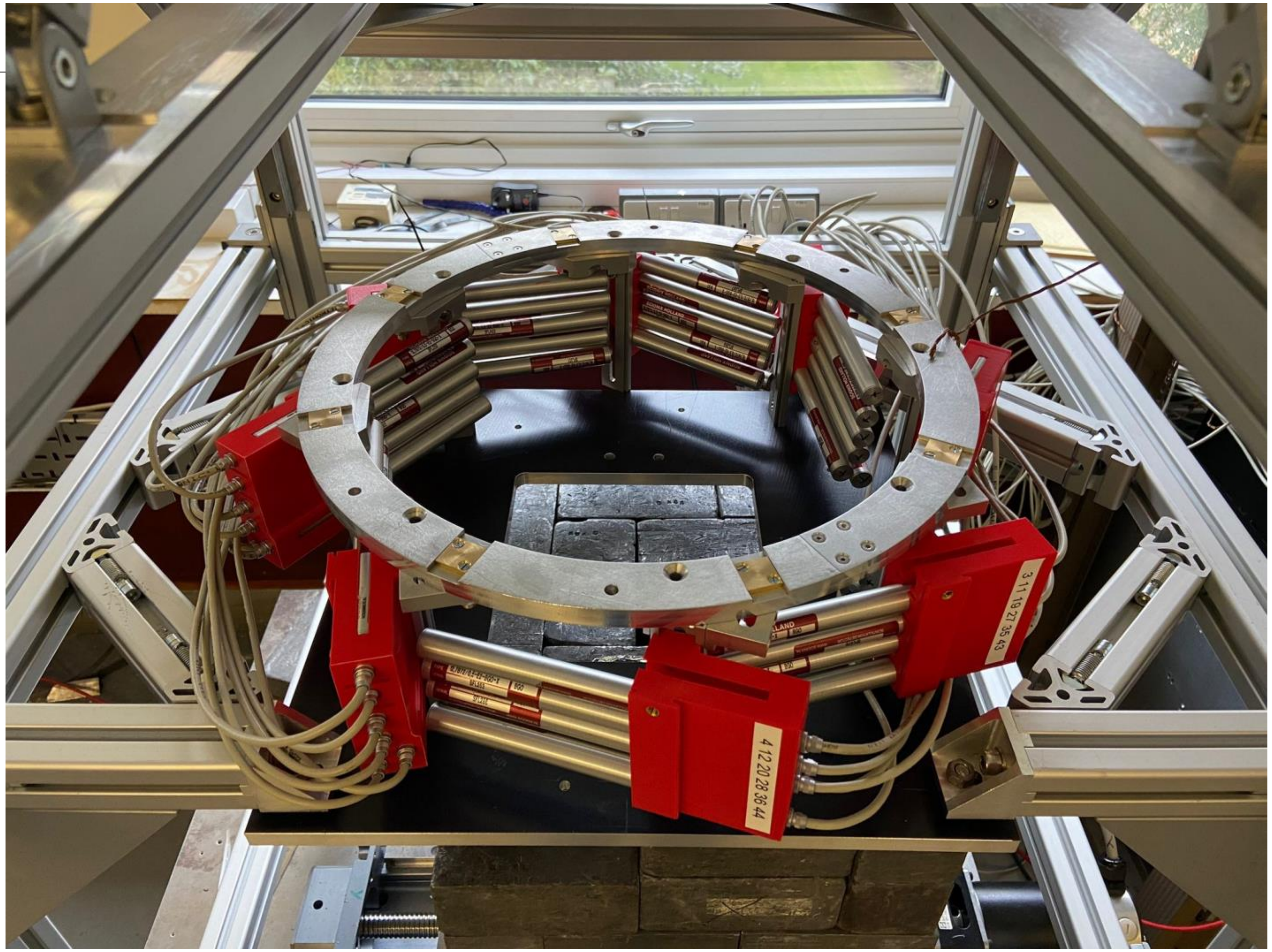
Future measurements will use the same source and be normalized to these results.



50 40 30 20 10 0 -10 -20 -30 -40 -50
-50 -40 -30 -20 -10 0 10 20 30 40 50
1200 1000 800 600 400 200
80 70 60 50 40 30 20
260 240 220 200 180 160 140 120 100 80
662.8 662.6 662.4 662.2 662 661.8 661.6 661.4 661.2 661
120 100 80 60 40 20
260 240 220 200 180 160 140 120 100 80

Condition of new Liverpool scanning table

Everything but the source.



The A601 neutron damage plans

The neutron facility

We currently plan to use the new HF-ADNeF neutron accelerator facility at the University of Birmingham.

They use 2.6 MeV protons at > 30 mA beam current, impinging a ^{7}Li target to produce neutrons.

For A601 at a nominal distance, this gives:

$1x10^{13}$ n/s x 12hr x 3600secs = $4.3x10^{17}$ neutrons in total hitting the detector, for $4.3 \times 10^{17}/(\pi \times 0.5 \times 7cm^2)$ ~ 1 x 16 n/cm^2 per day

We need maybe ~100 seconds worth of run time to achieve the levels of damage necessary. Though this will increase by an order of 10 each time.

Photo from https://www.birmingham.ac.uk/research/activity/nuclear/about-us/facilities/high-flux-neutron-facility
Simulation & Calculations from Jack Bishop @ University of Birmingham

The current plan

1. Fully characterise at Liverpool.
2. Drive detector to Birmingham **– while still cold.**
3. Perform analogue energy resolution measurements with ^{241}Am, ^{137}Cs and ^{60}Co.
4. Irradiate to an integrated flux of 2, 5, and 8 x 10^{x} n/cm^{2} , repeating the analogue measurements between each. *Should the detector be under bias for this?*
5. Return to Liverpool for full characterisation suite.
6. Steps 2 – 5 are repeated (at least) three times, for x = 7, 8, 9… **keeping the detector cold throughout.**
7. Temperature cycle the detector when all irradiations have been performed, then characterise again.
8. Possibility of mounting A601 in a CP5-plus cooler cryostat, allowing for trapping measurements as a function of temperature.
9. Anneal, and characterise again.

Datasets

- An analogue measurement set upon arrival, and after each of the three irradiations within one visit. These will be analysed on-site to quantify damage as it occurs – as well as ensuring the detector has survived transport.

- A full characterisation suite at Liverpool after each visit, taken once an integrated flux of 8×10^{x} n/cm^2 is obtained. These will be used to show the evolution of neutron damage through the detector over the data taking period.

- Another full characterisation after a thermal cycle when the neutron damage is complete – determine whether we see annealing or trap migration because of this.

- Possible temperature studies in a CP5-Plus cryostat - might be a step too far for the PhD, depends on if the annealed dataset is important for the thesis, and the availability of a compatible unit.

Improvements to the analysis

A larger lookup table has been generated using the A601 front scan data.

Finer binning of interaction-contact distance is possible via collection of larger datasets, made quicker hopefully by the new scanning table.

Pulse-by-pulse energy correction, rather than point-by-point. Energy spectra are recreated only from pulses that pass a χ^2 fit to the average pulse for a given scan position.

Lost energy calculated and re-added on a pulse-by-pulse basis, with each pulse being located using the lookup table.

This analysis has been tested on the neutron damaged A009 dataset.

Looking to go on to use of either the PSA basis, or the experimental basis generated at Strasbourg to get better z-depth resolution.

What this new analysis has shown so far

Cutting pulses that don't fall within a tight χ^2 value of the average signal response for a specific scan point removes those that have clear indications of multiple interactions.

By recreating the 662 keV energy spectra from the accepted pulses, the overall segment resolution is found to improve on average by 10% when compared to the original analysis, for both the original and energy-corrected datasets.

Improvement is <u>not</u> seen in the annealed dataset however, where the non-gated pulse energy spectra FWHM values do not differ from the pulse gated spectra value – it is symptomatic of the trapping.

Performing the energy correction on the gated energy spectra brings the FWHM to within 2% of the annealed results – while the original analysis was 10% higher.

What the new analysis implies

- A complete neutron damage correction method needs to know every single interaction point and the amount of energy deposited.
- The current methods are able to correct the mean energy measured using the averaged multi-hit position, but they cannot reduce the range of the energies measured. They can remove the low energy tailing, but cannot completely restore energy resolution.
- This method of pulse gating is also not feasible for use – it costs 40% of the dataset.
- I plan to test this theory further, by attempting to predict and correct for the intra-segment scattering using a random number method – not a solution to the problem, by any means.
- This should also imply that addback spectra show improved resolution after the correction has been applied – more interactions are being accounted for.

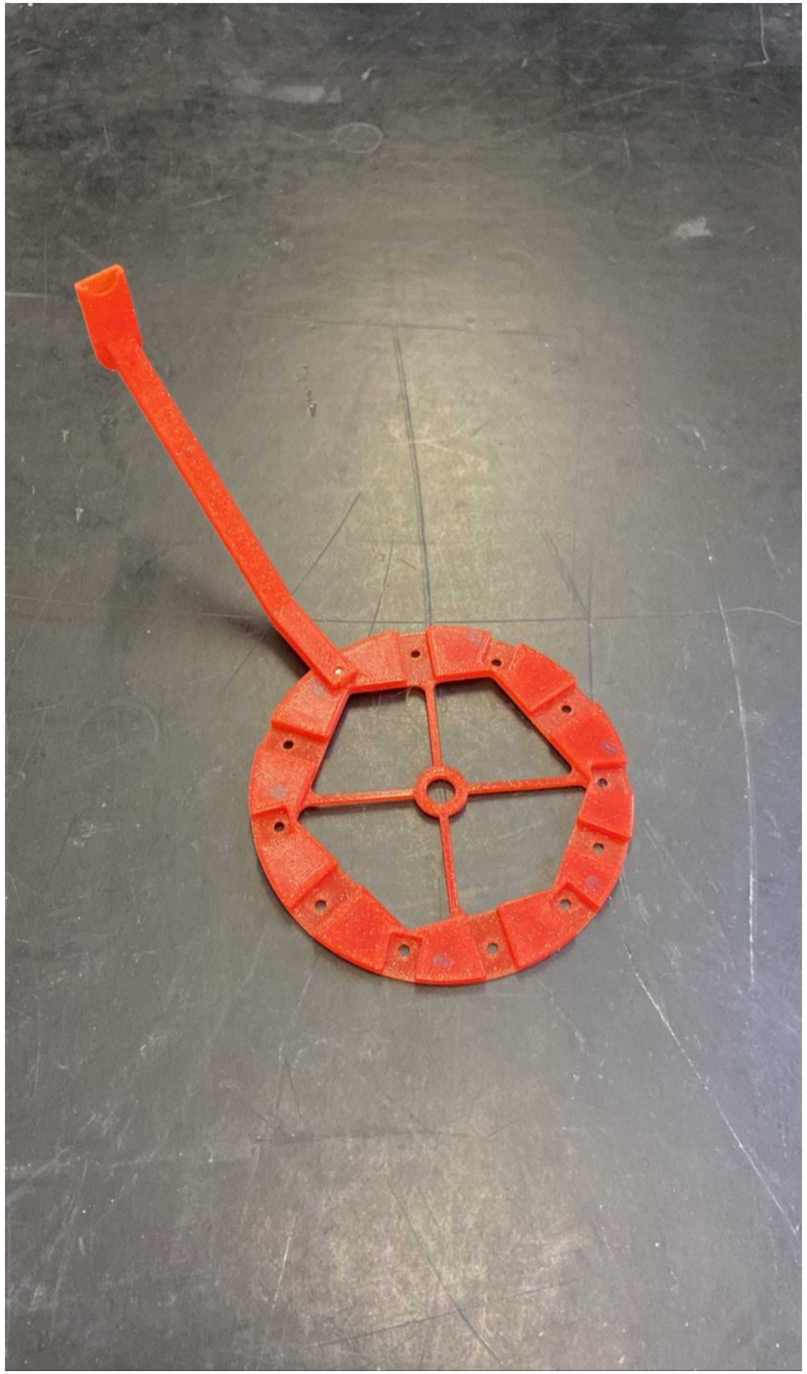
In the analysis pipeline

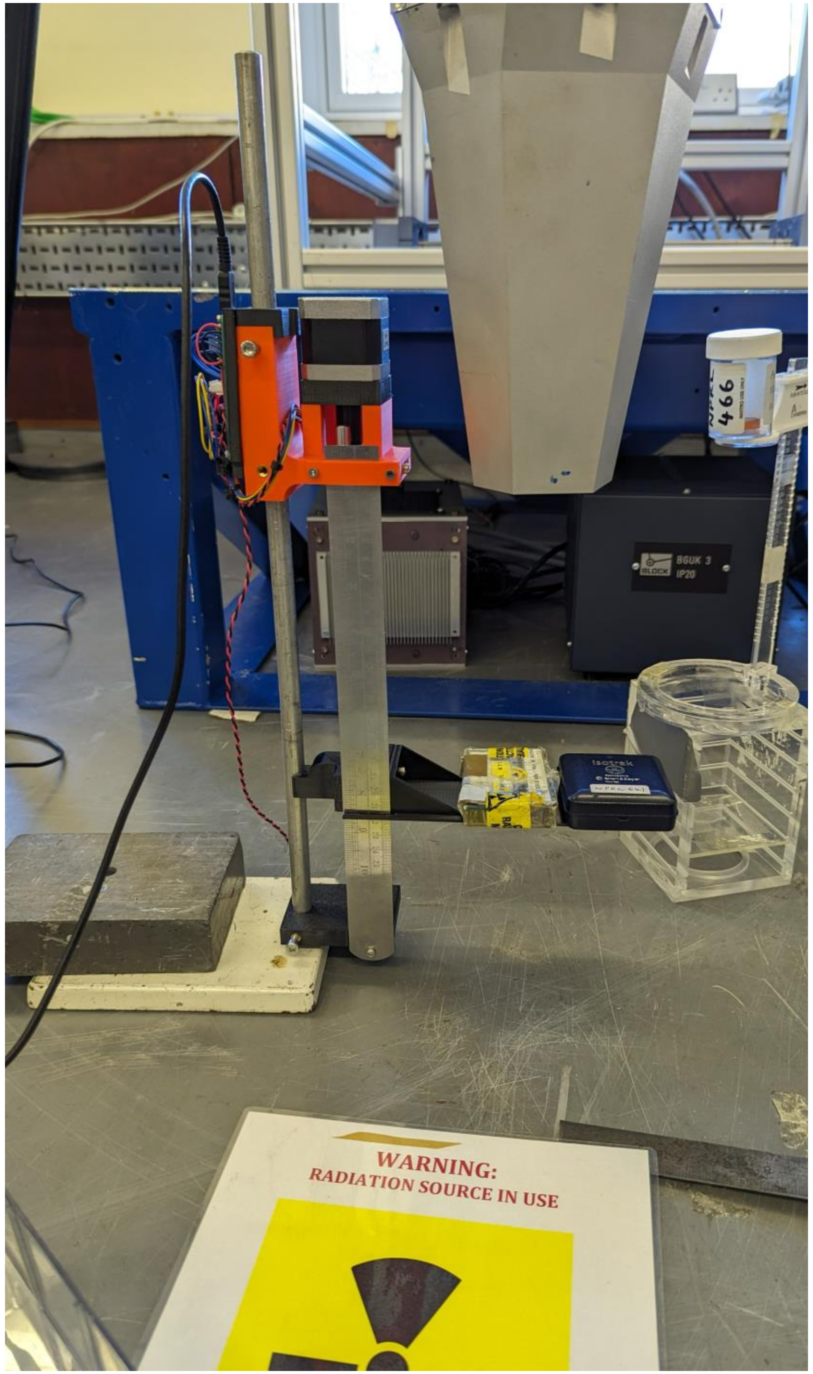
Analysis is currently underway of a ^{60}Co flood measurement taken by Rosa at the end of March while the array was heavily neutron damaged.

The traces from this dataset will be used to ascertain the energy loss as a function of interaction-contact distance – and hopefully to develop a tool that allows quantification of array neutron damage state in-situ.

My correction will be applied, and compared to the theoretical correction. My assumption is that an all-event correction will return similar results – but rejecting pulses with the indications of multiple same-segment interactions will show improvement.

Thank you for listening.

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