Spectral performance, characterisation and simulation of 5 mm thick CZT detectors hybridised to a Timepix ASIC

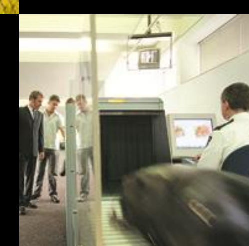
kromek™
detect image identify

diamond
www.diamond.ac.uk

Alexander Cherlin
Dima Maneuski
Neil Moffat
Val O'Shea
Ian Radley
Heribert Wilhelm
Kenneth Wraight

University of Glasgow
VIA VERITAS VITA

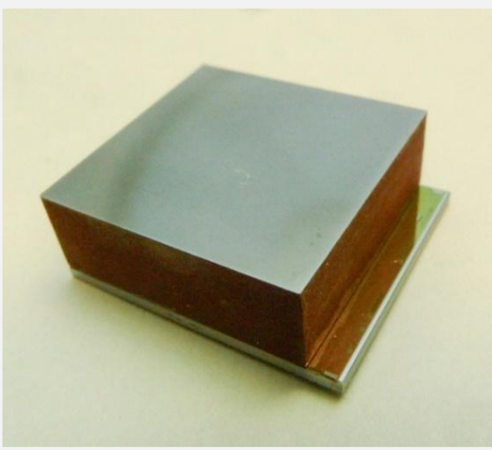
4 July 2017

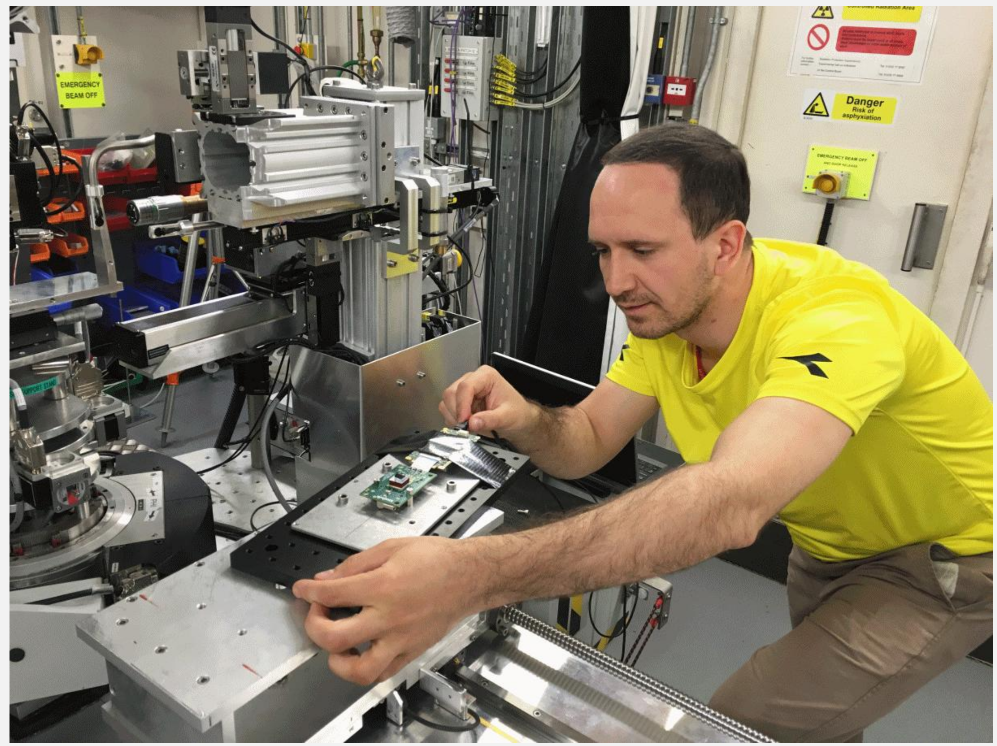


19th International Workshop on Radiation Imaging Detectors, Krakow, Poland.

Outline

- Motivation
- Simulation of 5 mm thick CZT detectors with Timepix ASIC
- Experimental program and comparison between simulation and measurement results:
  - ❑ Isotope measurements: ^{241}Am and ^{137}Cs
  - ❑ Measurements at I15, Diamond Light Source, with a collimated beam





Motivation for the current work

- Enable understanding of the CZT material properties at the fine scale of hundreds of microns. This is of utmost importance for developing CZT detectors capable of delivering high spatial resolution combined with good energy resolution.
- The leveraging factors affecting detector performance on the spatial scale of ~100-200 µm are rather different than with bigger pixels (~1 mm):
    - Escape range of Cd and Te fluorescence becomes important
    - Small pixel effect is extremely strong
    - Strong charge sharing is always present
- Detector simulations are a very useful tool for:
    - Understanding detector performance
    - Interpreting experimental data
- Therefore, our experimental program is combined with a very intensive simulation development

Modelling and simulation / Simulation flow description

COMSOL Multiphysics:

- Calculate charge induction efficiency (CIE)
- Create X-Y-Z lookup table

GATE (GEANT4):

- Generate physics interactions with very low photon and electron process energy thresholds
- This enables tracking fluorescence and electron ionisation

- Take each charge deposition point from GEANT4 data
- Add Fano noise
- Find the appropriate CIE value in the lookup table, basing on the location of the charge deposition point
- Use the CIE to calculate the induced charge in all pixels in range
- Emulate Timepix noise and signal measurement in ToT mode in each pixel
- Perform clustering

Modelling and simulation / Charge Induced Efficiency

Charge Induction Efficiency is calculated using the well known method of adjoint continuity equations described by T.H. Prettyman in his 1999 paper:

- The continuity equation:

$$\frac{\partial n}{\partial t} = \vec{\nabla}(n \cdot \mu_n \cdot \vec{\nabla}\varphi) + \vec{\nabla}(D_n \cdot \vec{\nabla} n) - R_n + G_n$$

where R_n in G_n are recombination and generation terms correspondingly

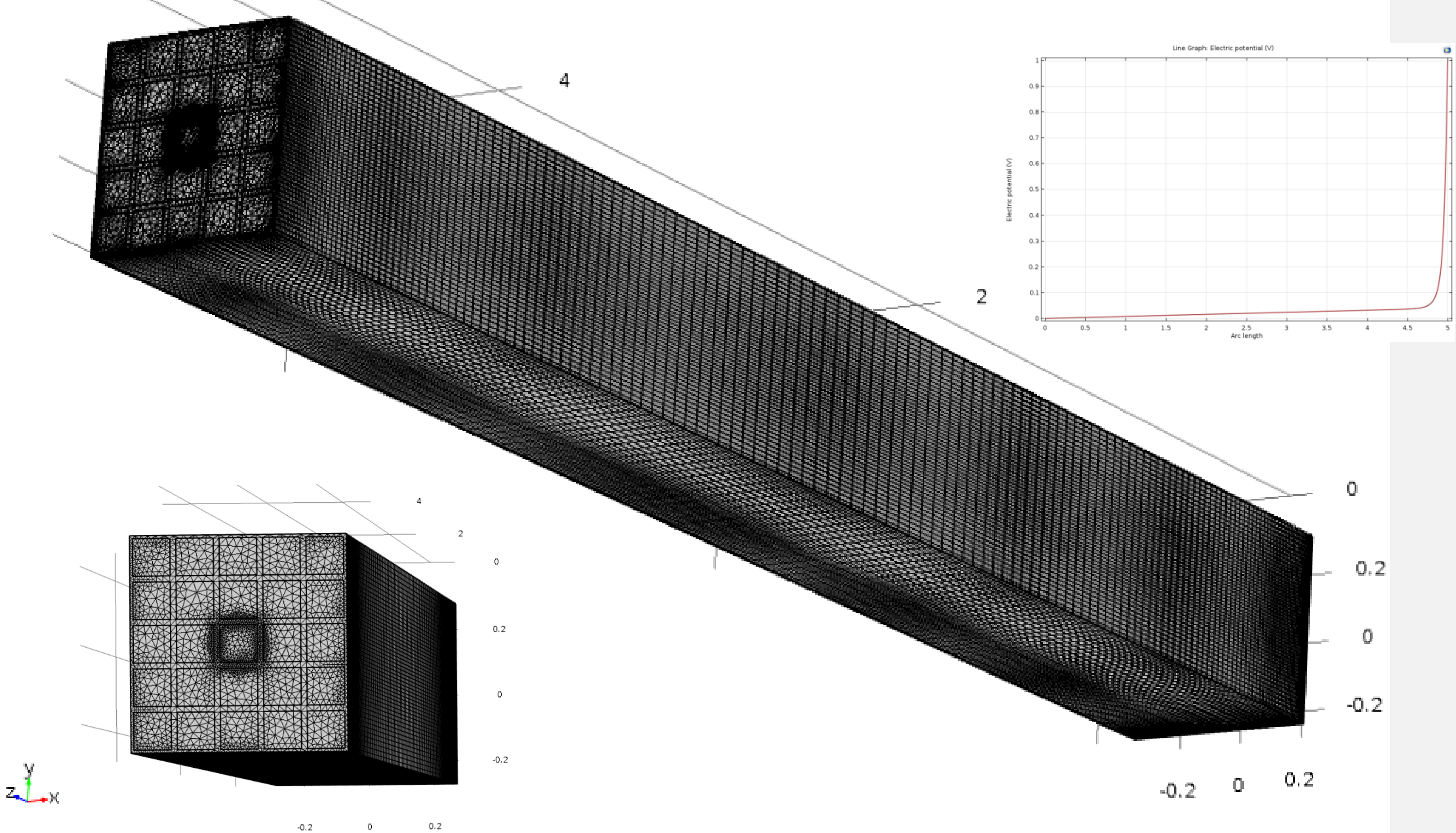
- The adjoint continuity equation describes the corresponding CIE:

$$\frac{\partial n^+}{\partial t} = \underbrace{\vec{\nabla}(n^+ \cdot \mu_n \cdot \vec{\nabla}\varphi)}_{\text{Drift}} + \underbrace{\vec{\nabla}(D_n \cdot \vec{\nabla} n^+)}_{\text{Diffusion}} - \underbrace{\frac{n^+}{\tau_n}}_{\text{Trapping}} + \underbrace{\mu_n \cdot \vec{\nabla}\varphi \cdot \vec{\nabla}\psi_w}_{\text{Generation}}$$

  - ✓ The recombination term is represented by the trapping/detrapping since the recombination in CZT is dominated by the trap assisted Shockley-Read-Hall process (charge carrier density is very low)
  - ✓ The generation term is represented by the interaction between the weighting potential and the drift field

Modelling and simulation / 110 µm pixel

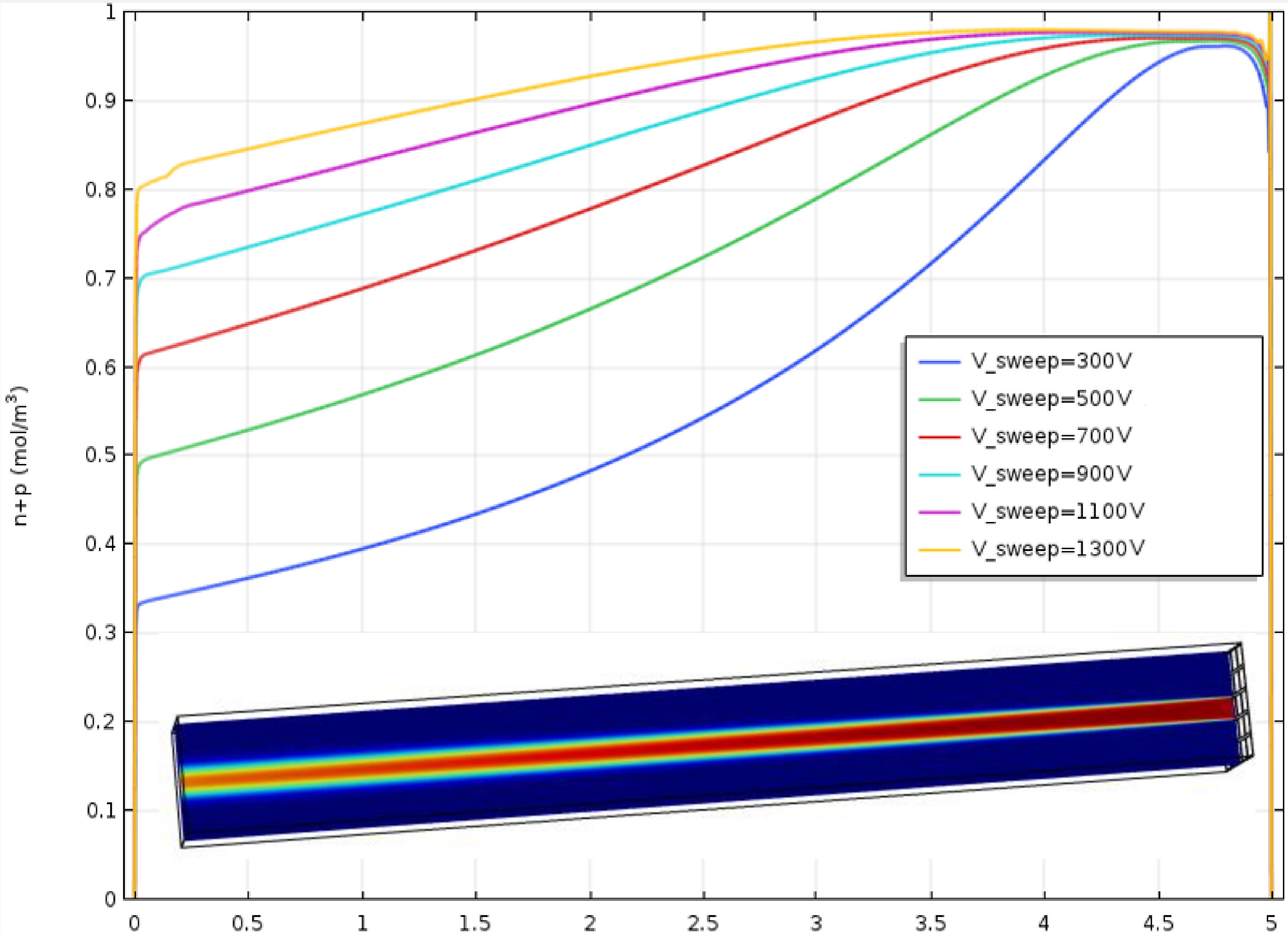
Takes ~ 1 day to render the full COMSOL model



Modelling and simulation / Charge Induction Efficiency (CIE) calculation

Below pixel centre

Cathode side
Z = 0 mm

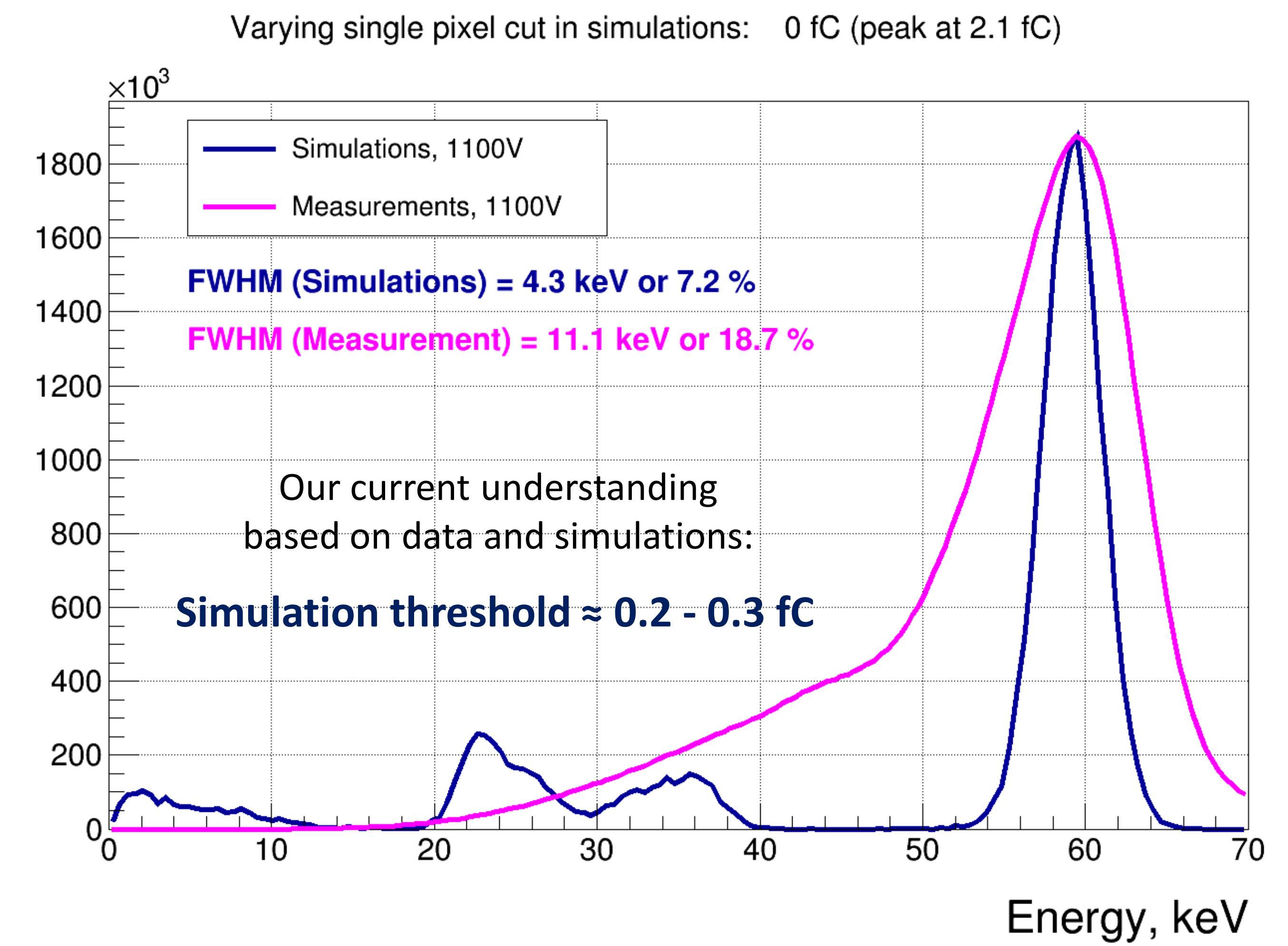


Distance from cathode, mm

Pixelated anode side
Z = 5 mm

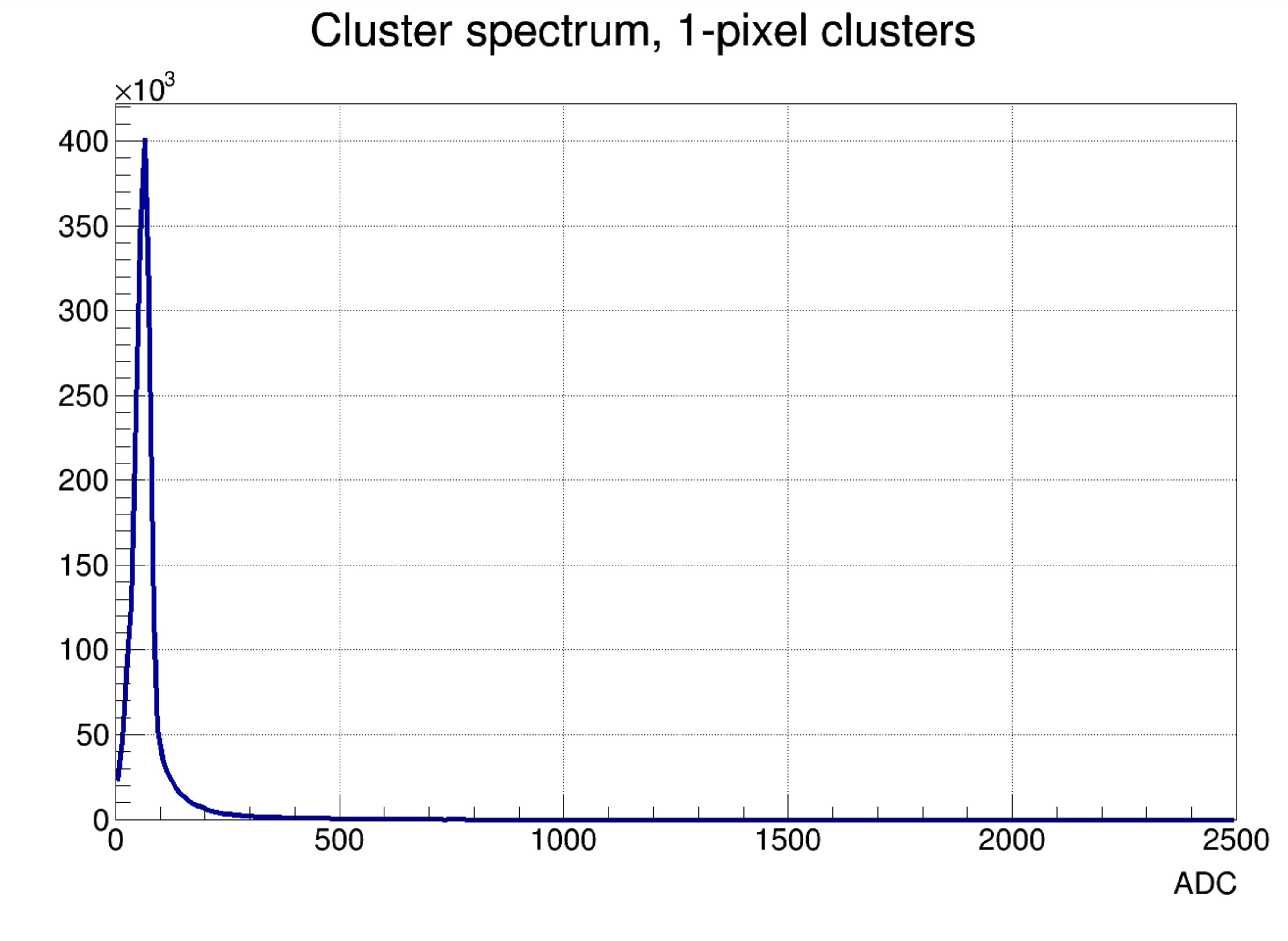
Gamma measurements / ^{241}Am 59.5 keV spectrum – simulation vs measurement

- Noise sources included in simulations:
  1. ASIC (preamp) noise
  2. ToT noise
  3. ASIC channel gain (ASIC + detector) non-uniformity
  4. Threshold non-uniformity
- Noise sources not included in simulations:
  1. Detector related noise
  2. Bulk material non-uniformities such as defects and Te inclusions
- ToT measurement in simulations is emulated with single pixel cut on induced charge in the pixel
- **ToT threshold in all measurements: ~10-15 keV**
- The correlation between the thresholds in measurement and simulations is still under investigation



Gamma measurements / ^{137}Cs 662 keV spectra by cluster size - measurement

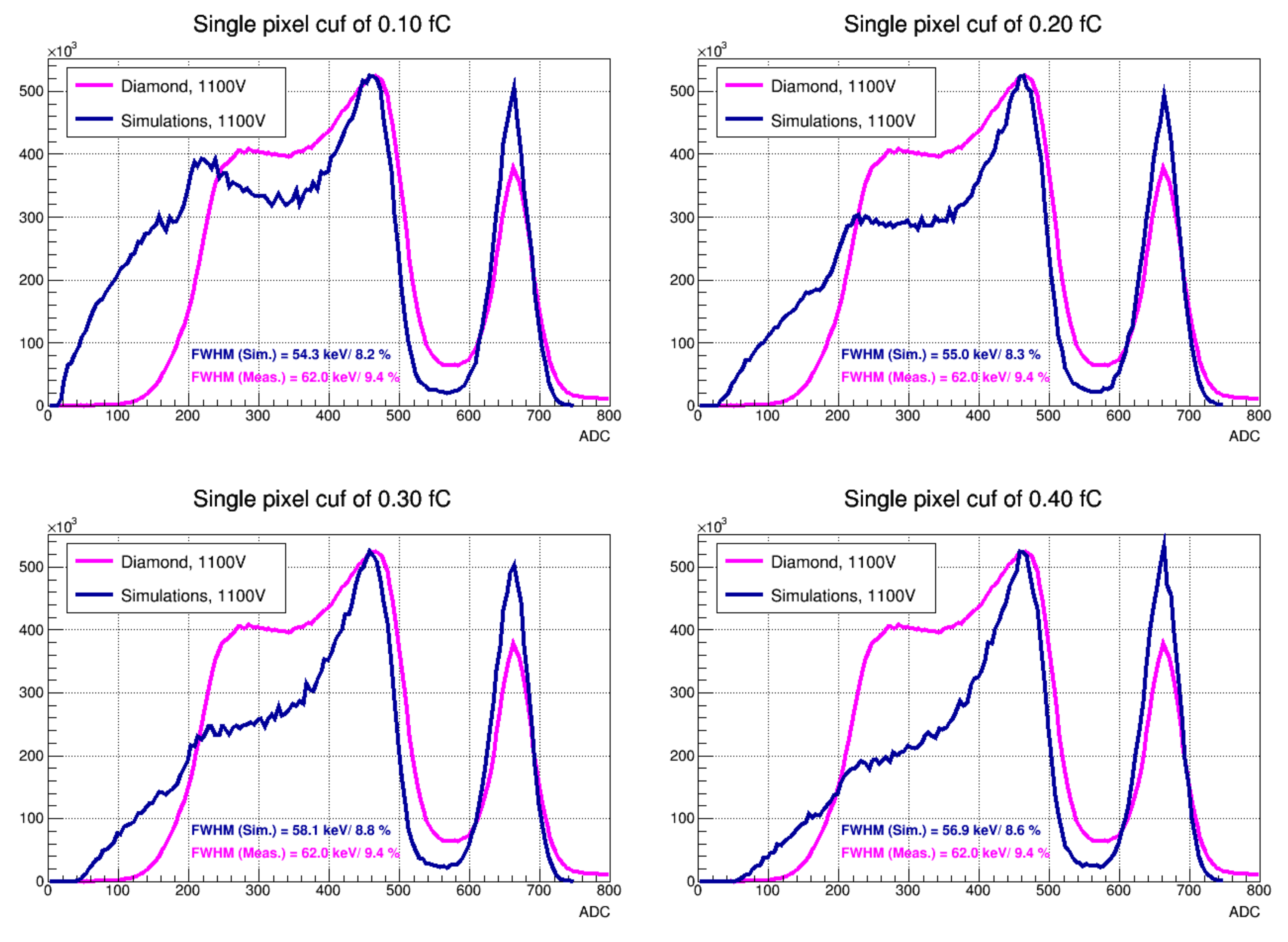
- ^{137}Cs 662 keV spectra are comprised of large clusters, ~ 5 to 15 pixels
- Spectral shapes depend strongly on cluster size
- This provides additional tool for spectral analysis
- For summing the spectra of different cluster sizes, they are re-scaled so that the known energy peak is in the same ADC channel
- After that, the energy calibration could be performed



Gamma measurements / ^{137}Cs 662 keV spectrum – simulation vs measurement

- ^{137}Cs 662 keV photoelectric peak is higher is simulations due to better energy resolution

- The Compton edge position is in a good agreement between simulations and measurement

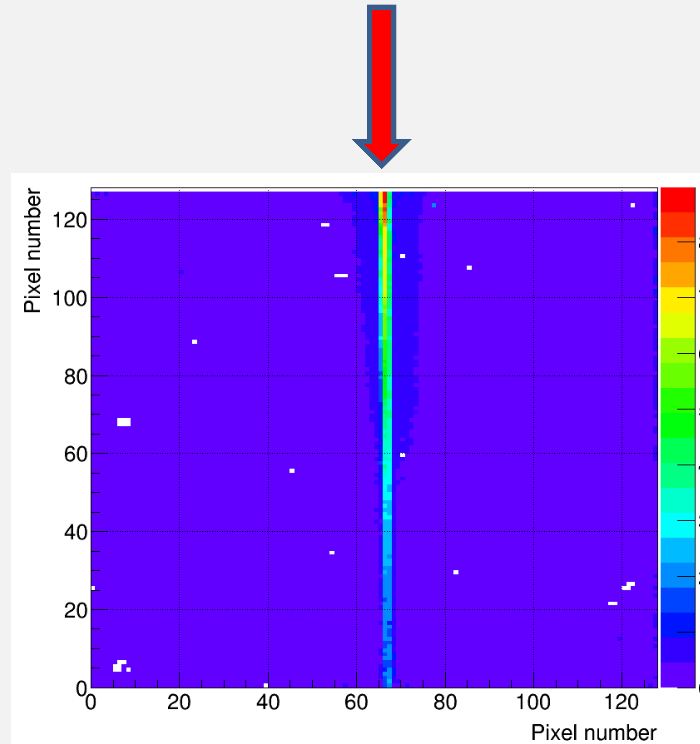


kromek

Diamond Light Source measurements

- Measurements at Diamond Light Source in May 2017 with collimated beam of up to 79 keV photons ~50 μm in diameter:
    1. Illuminating a few single pixels from cathode side with various HV biases and beam energies
    2. Line scan across ~4 pixels with 10 μm step, various HV biases and beam energies
    3. Illuminating the detector from the side with 79 keV beam, HV = 500V, 800V, 1100V and nine 0.5 mm steps through the detector thickness (~0 mm – 4.0 mm)
- The analysis is still ongoing, only the side illumination data has been fully analysed
- Heavy Aluminium filtering to allow ToT measurement
- Resulted in strong attenuation of 79 keV photons and strengthening of allowed beam harmonics (3^{rd}, 4^{th} …)
- In side illumination all 79 keV photon are filtered out by the first few pixels
- Only 3^{rd} harmonic (237 keV) is clearly seen in the spectrum

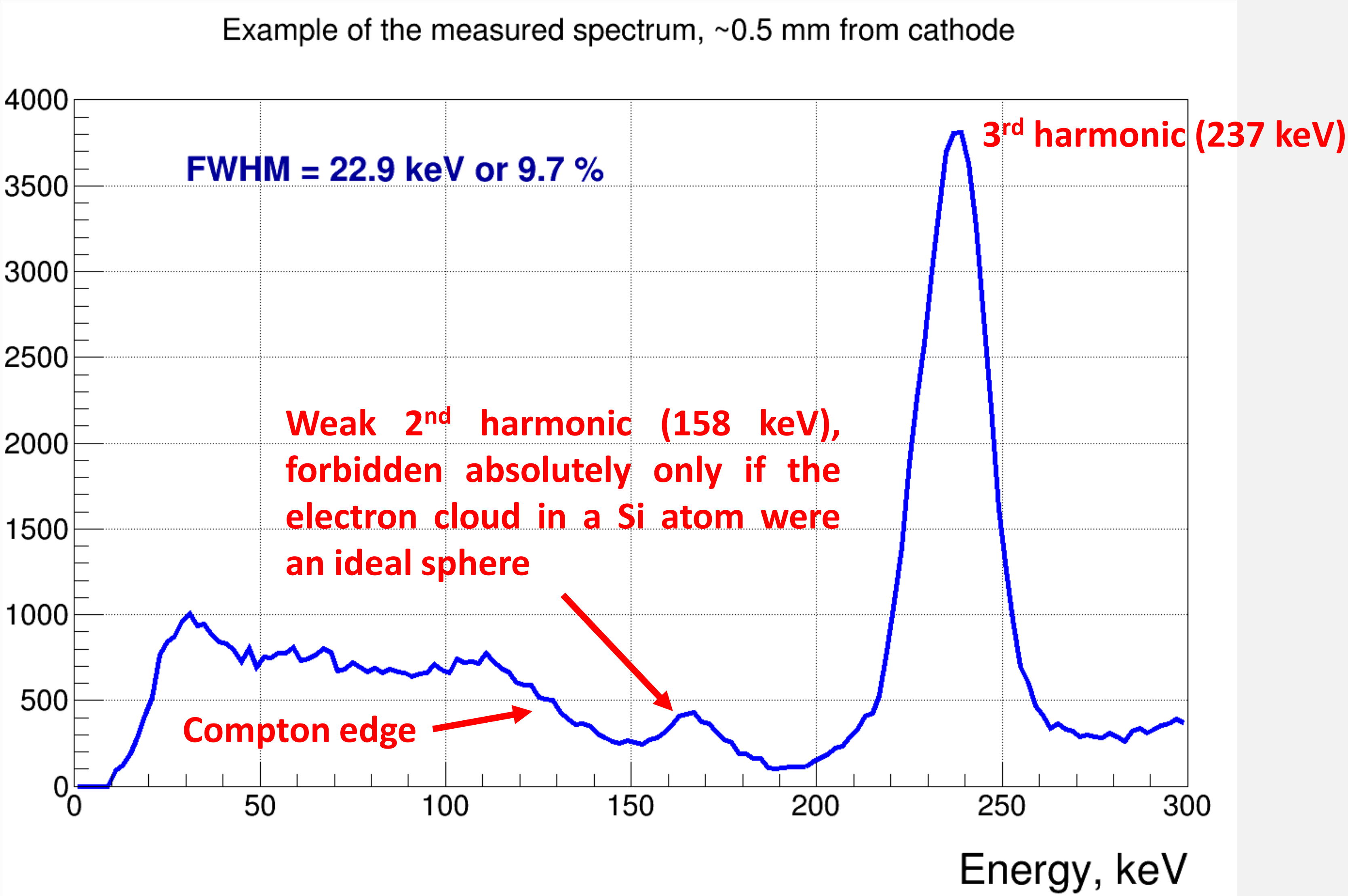
Incoming beam



In my analysis I plot the integrated spectrum of the illuminated column

kromek

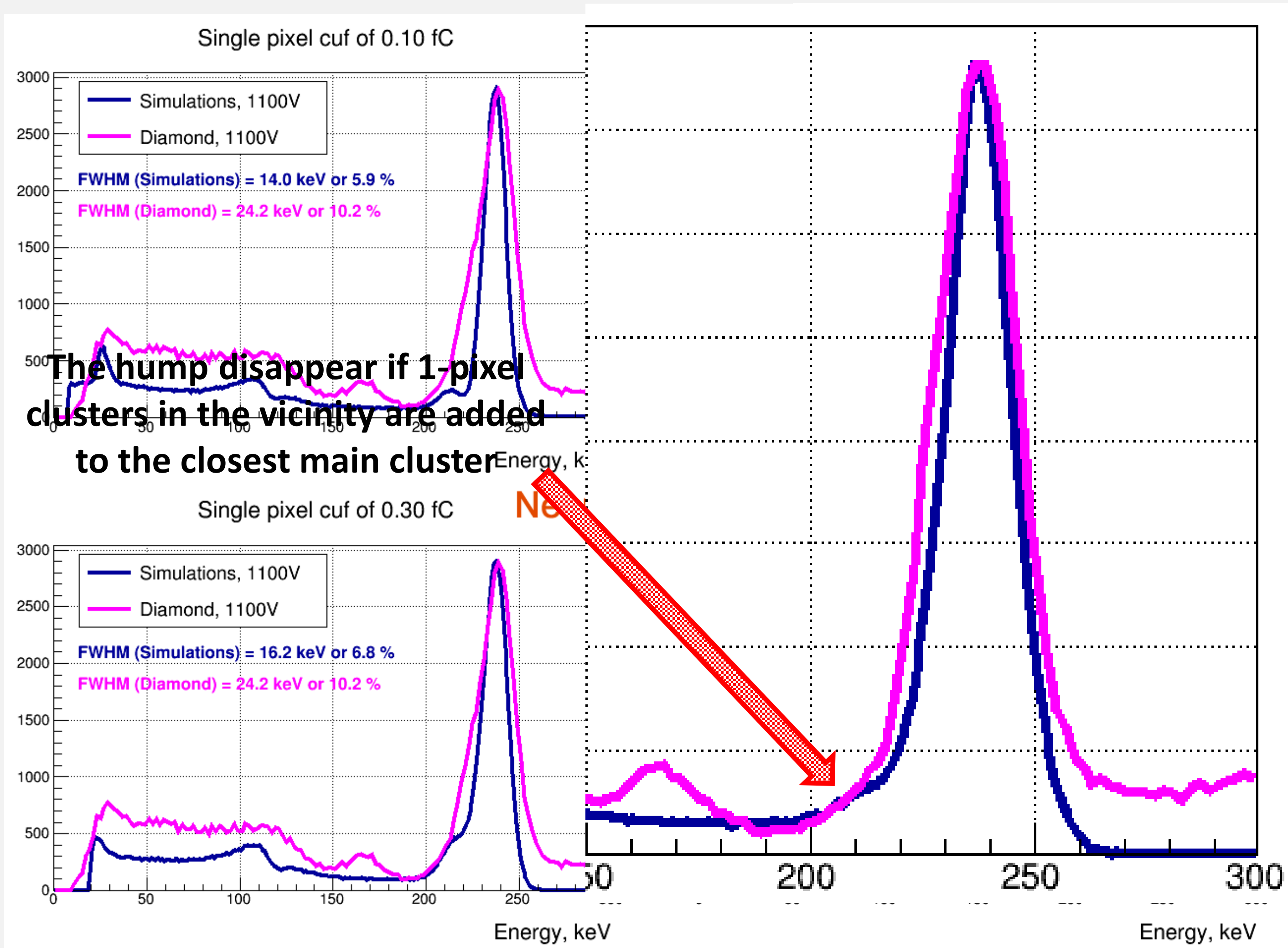
Diamond measurements / Side illumination – measured spectrum example



Diamond measurements / Side illumination, 237 keV (3rd harmonic of 79 keV beam)

- Good agreement between simulations and measurements
- The energy resolution of simulated spectra deteriorates considerably when moving towards anode
- The energy resolution doesn't change much with the single pixel cut in simulations
- A possible explanation:
  - ➢ Closer to anode the resulting clusters are smaller and the fraction of charge per pixel is bigger
  - ➢ Therefore, in simulations the clusters are less sensitive to single pixel cut
- Also – bigger clusters result in better energy resolution

Spectrum variation across detector thickness, 1100 V

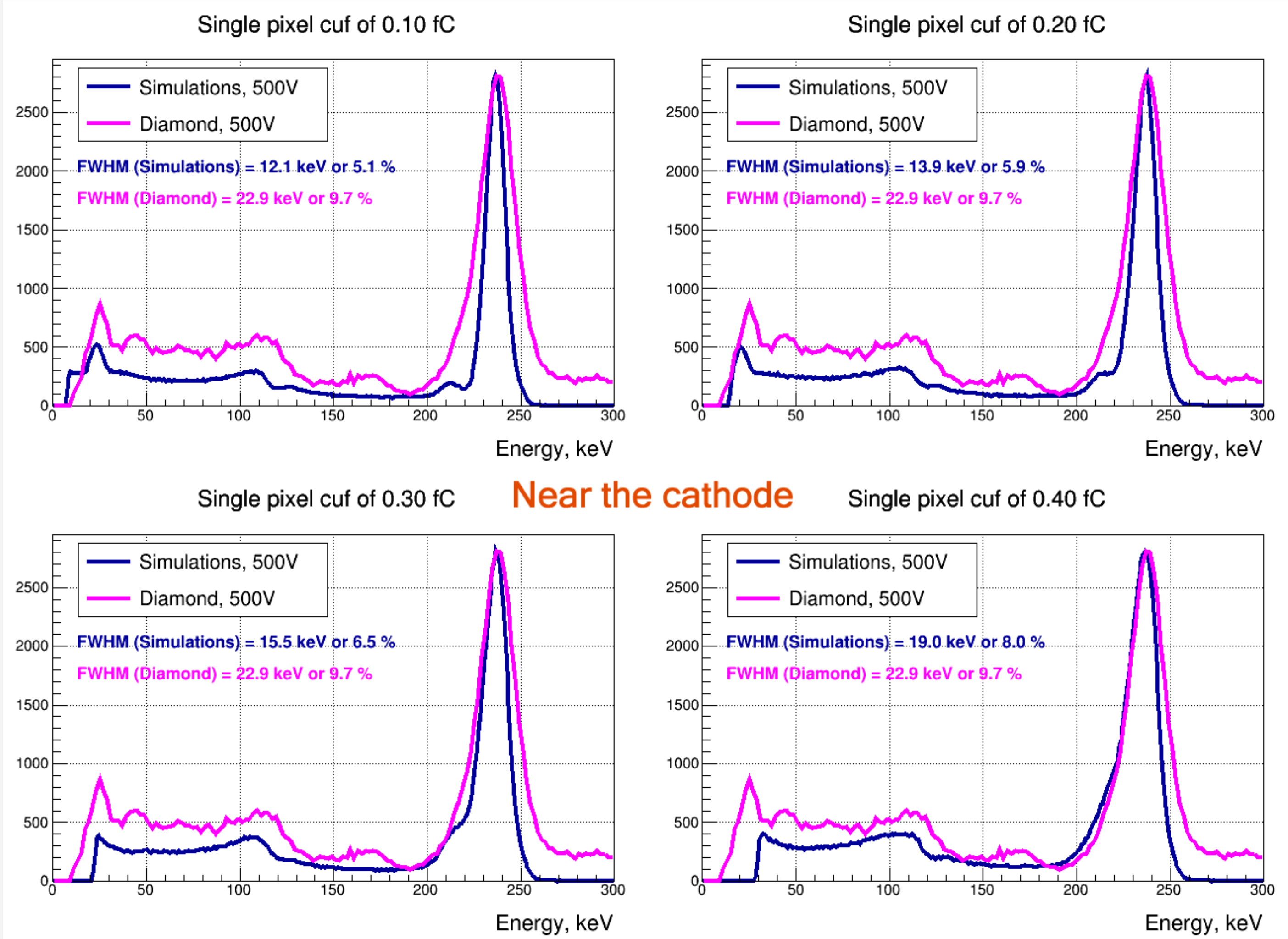


kromek

Diamond measurements / Side illumination, 237 keV (3rd harmonic of 79 keV beam)

- At lower HV bias, the resulting pixel clusters are bigger due to longer drift time
- The simulated spectra are more sensitive to the single pixel cut, but their energy resolution still deteriorates while moving towards the anode.

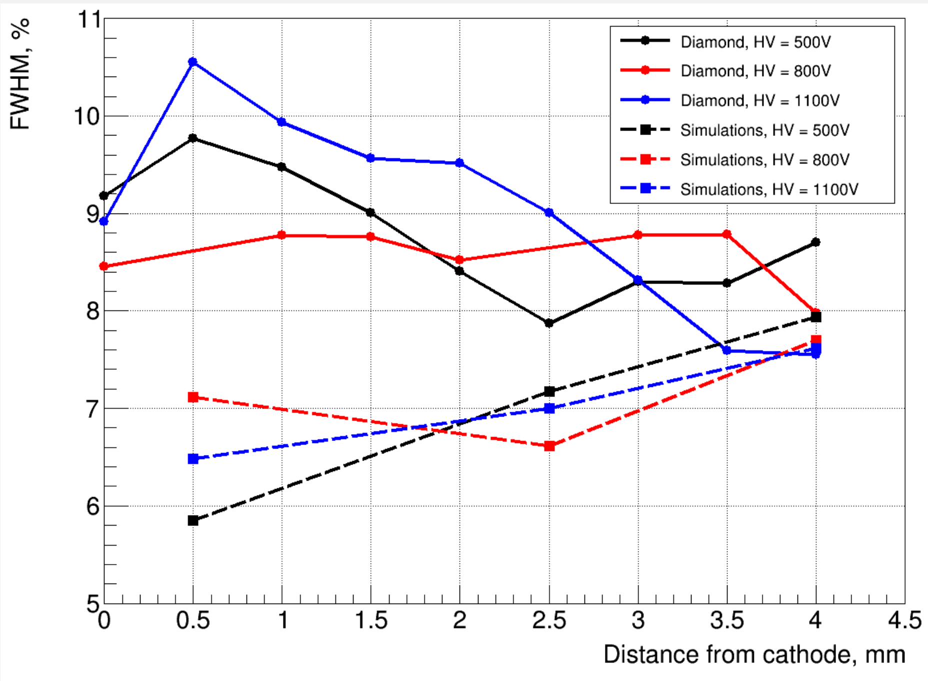
Spectrum variation across detector thickness, 500 V

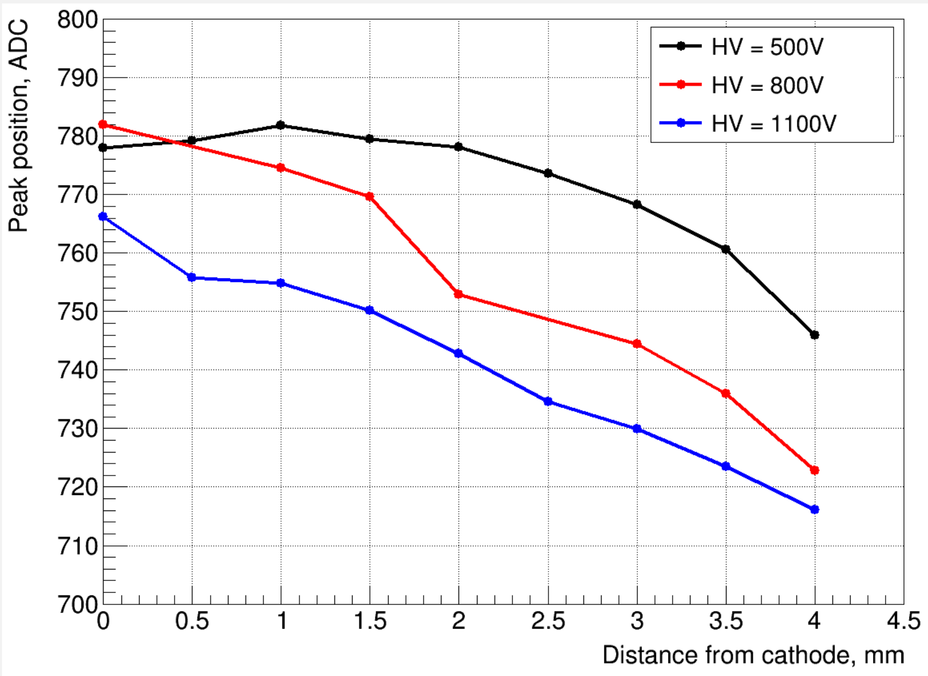


Diamond measurements / Side illumination, 237 keV (3rd harmonic of 79 keV beam)

- Simulated and measured spectra have different trend as one goes across detector thickness
- The work on understanding that is ongoing
- Current understanding is that in measured spectra the variation is driven by the detector properties, while in simulated spectra by cluster reconstruction and simulation parameters

Simulation data with single pixel cut of 0.2 fC





Summary

- The first results on simulating 5 mm thick CZT detectors on Timepix ASIC and their comparison to the measurements are reported
- There is good agreement between the measurement and simulations, but more work is still ongoing:
  1. To improve implementation of Timepix ASIC functionality in the model
  2. To resolve the difference between the cluster size in simulations and measurements
  3. To add detector material related noise sources into the model
- The current level of producing and understanding of CZT detectors in a wide thickness range hybridised to ASICs from the Medipix and Timepix family allows using this technology in a variety of applications demanding a combination of good imaging performance, high position resolution and reasonably good energy resolution
- Kromek is engaged in a number of activities in developing this technology
- We are working on manufacturing and characterising 5 mm thick CZT detectors on Timepix3 ASIC in collaboration with Glasgow University. These detectors are going to allow us 3D position resolution which is expected to improve the spectral performance by allowing to sum up contributions from Compton scattering and fluorescence events belonging to the same incident photon.

Thank you

Kromek Group Headquarters
NETPark
Thomas Wright Way
Sedgefield
County Durham
TS21 3FD UK

T: +44 (0) 1740 626060
F: +44 (0) 1740 626061

E: sales@kromek.com
W: www.kromek.com

Kromek USA

eV Products Inc
near Pittsburgh, Pennsylvania USA

NOVA R&D Inc
near Los Angeles, California, USA

Kromek UK Operations

Neutron R&D Centre
Huddersfield UK