Diagnostics at pulsed radiation sources using a hyperspectral, high framerate HEXITEC camera system

Frederic Van Assche
M. C. Veale, D. Pooley, B. Cline

Ghent University
Centre for X-Ray Tomography
UKRI Science and Technology Facilities Council

23rd iWoRiD International Workshop on Radiation Imaging Detectors

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Introduction & background

Team

Science and Technology Facilities Council

GHENT UNIVERSITY

Matt Veale

Principal Detector Scientist
HEXITEC

Dan Pooley

Principal Detector Scientist
PImMS

Ben Cline

Graduate Detector Scientist

Frederic Van Assche

Readout & Acquisition

Neutron detection with gadolinium

- Naturally occurring element
- …with **highest interaction probability** for thermal neutrons
- Neutron capture gives prompt photon and electrons

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Excellent neutron converter

Neutron detection with gadolinium

GP2 neutron camera

- PImMS-2 based system
- CMOS imager for ToF-MS
- Extensively used @ ISIS
- 4 μm Gd layer deposited as converter

Parameter	Value
Pixel size	70 × 70 μm
Pixel number	324 × 324 = 104976
Active area	22.7 mm × 22.7 mm
Bit depth (time bins available)	12 bit (maximum 4095)
Smallest temporal bin width	12.5 ns
Registers per pixel	4

Selected parameters of the PImMS sensor, relevant to ERNR.

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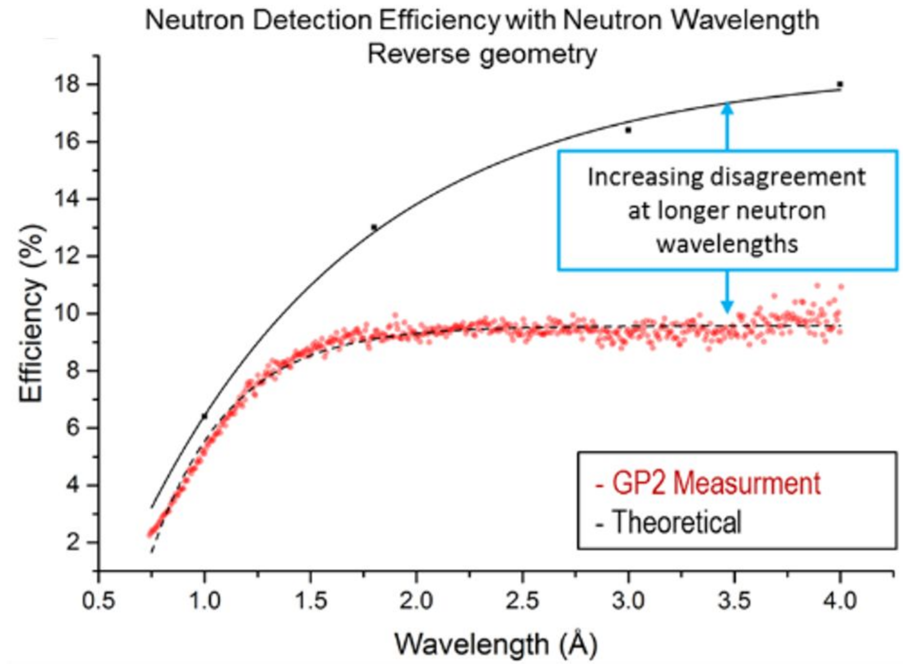
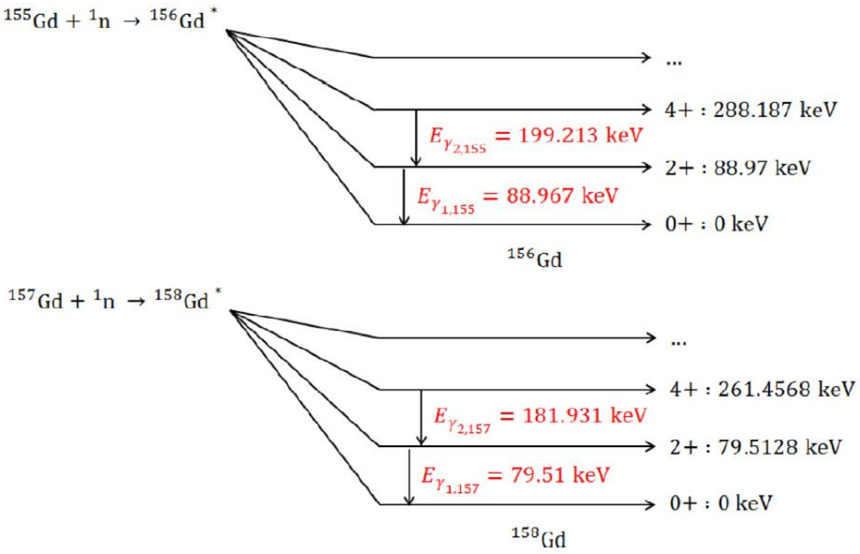


Significant efficiency mismatch

The efficiency problem



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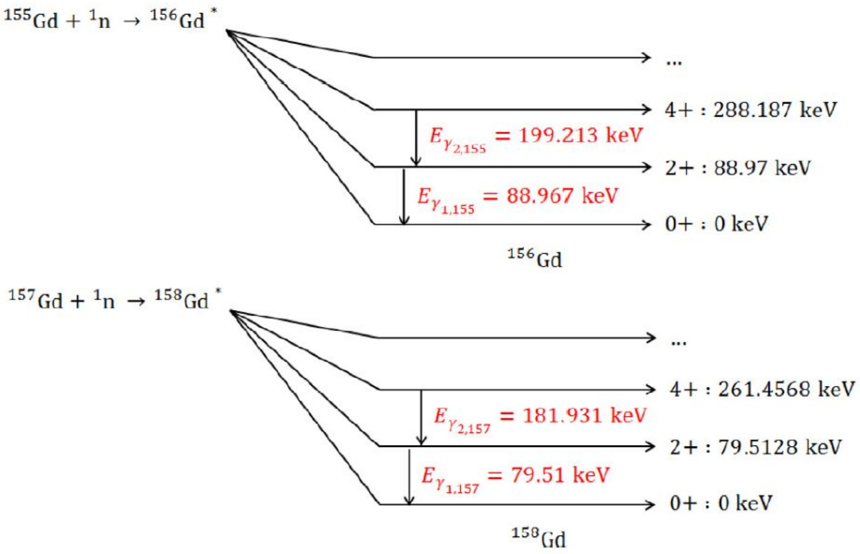

Prominent internal conversion electrons, X rays and Auger electrons after Gd(n, γ) capture.

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- Theoretical efficiency depends on simulated emissions
- Simulations in turn depend on decades old measurements
- Few more recent measurements, we were confident we could do better

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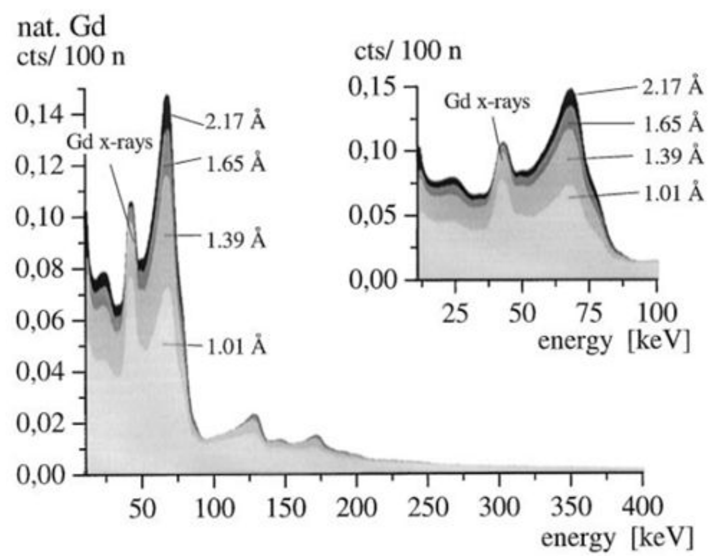

G. Bruckner et al., *NIM A* **1999**, 424

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The efficiency problem

Are the simulations wrong?

Is it a technical issue?

The efficiency problem

Are the simulations wrong?

Is it a technical issue?

Better measurements needed!

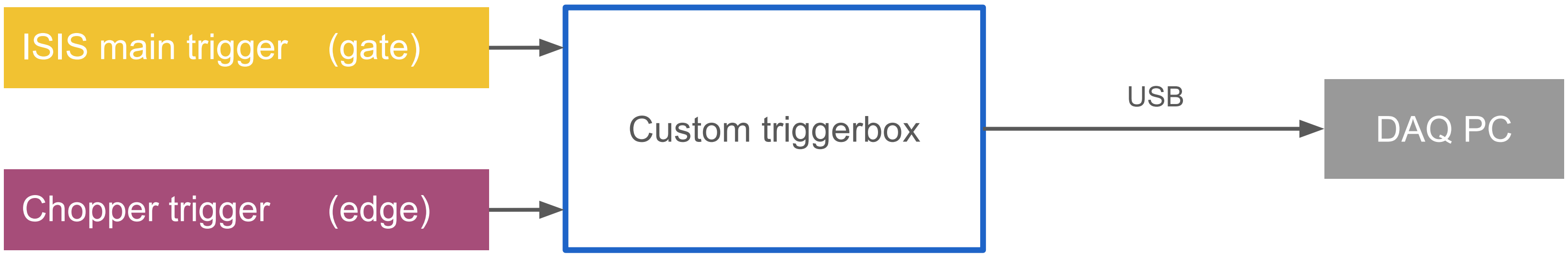
Technical implementation

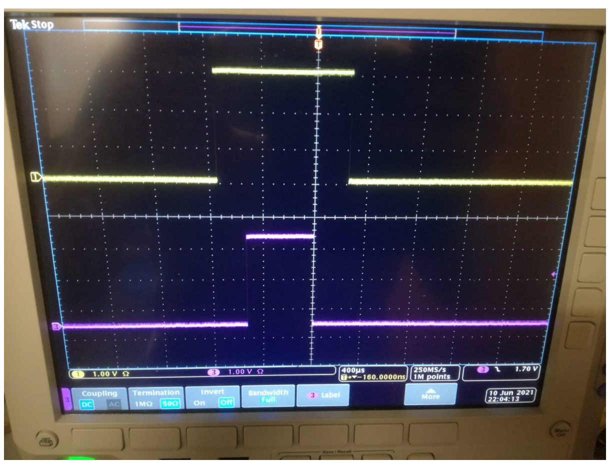
The ISIS neutron source

- Pulsed neutron source:
  - 50 Hz pulses from spallation target
  - Two target stations (TS1 & TS2)
  - Every 5th pulse goes to TS2

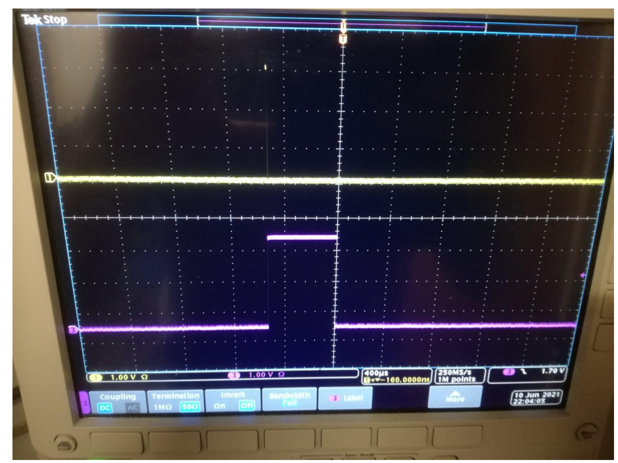
- Experiment performed at LoQ instrument @ TS1
- Chopper blocks every other pulse, shows long tail of cold neutrons

Triggering setup





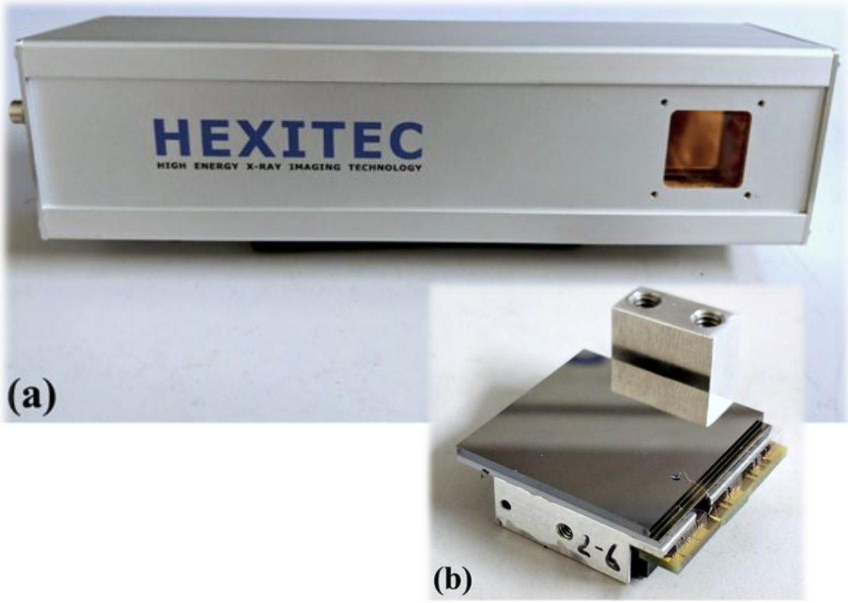
TS2 pulse = ignore



TS1 pulse = capture

The HEXITEC detector

- 80 x 80 pixels of 250 μm pitch
- Fully spectroscopic
- 9.6 kHz framerate
- FWHM energy res. of 500 eV with p-type Si
- CdTe, CZT, GaAs:Cr, p-type Si sensors



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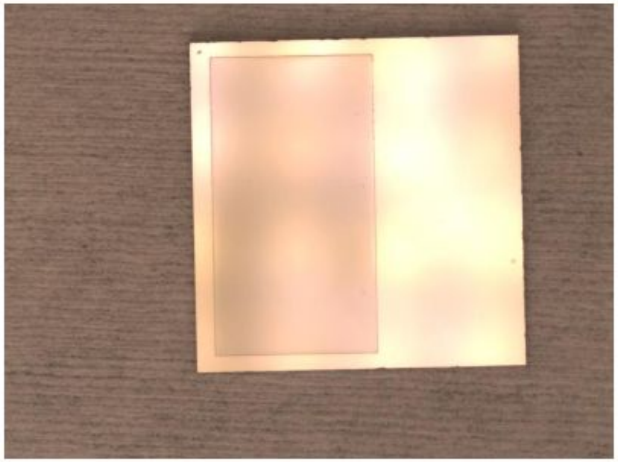
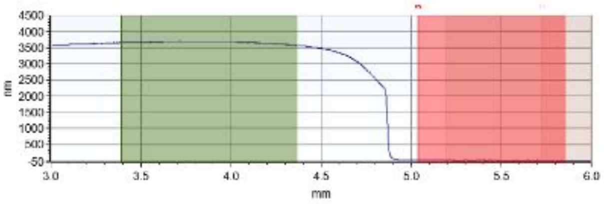
HEXITEC for neutron diagnostics

- GaAs:Cr and p-type Si sensors
- Directly deposited Gd of various thickness
- Read-out at 8.5 kHz (storage limited)
- Placed directly in beam
- Minimal neutron absorber to optimise flux

Lot: AG-466 #34, Sample: 4
Gd thickness: 4 µm





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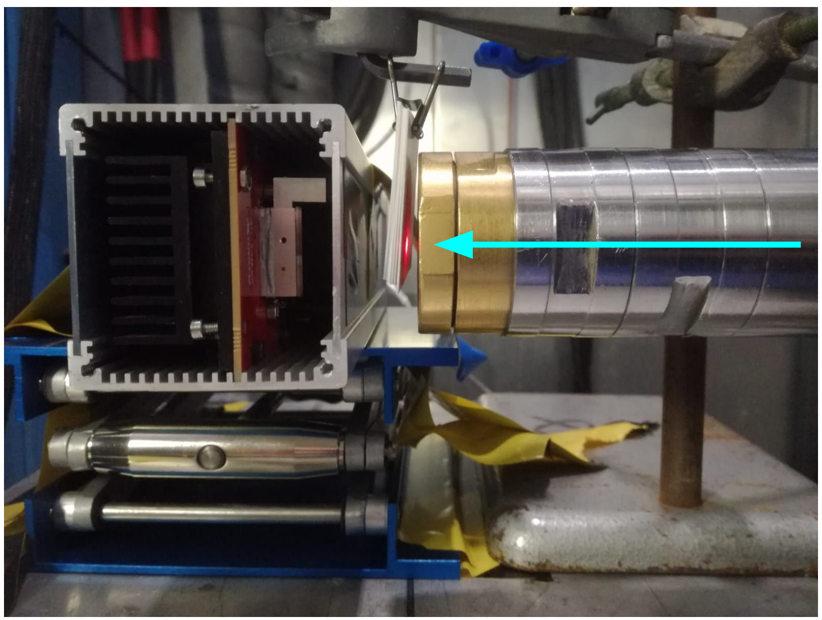

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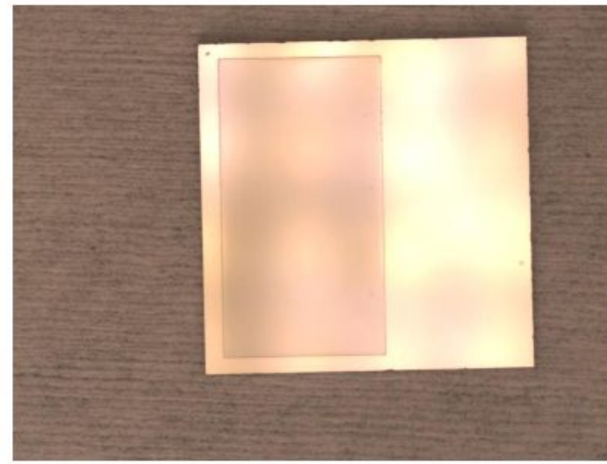
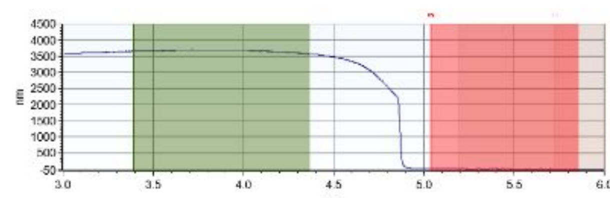
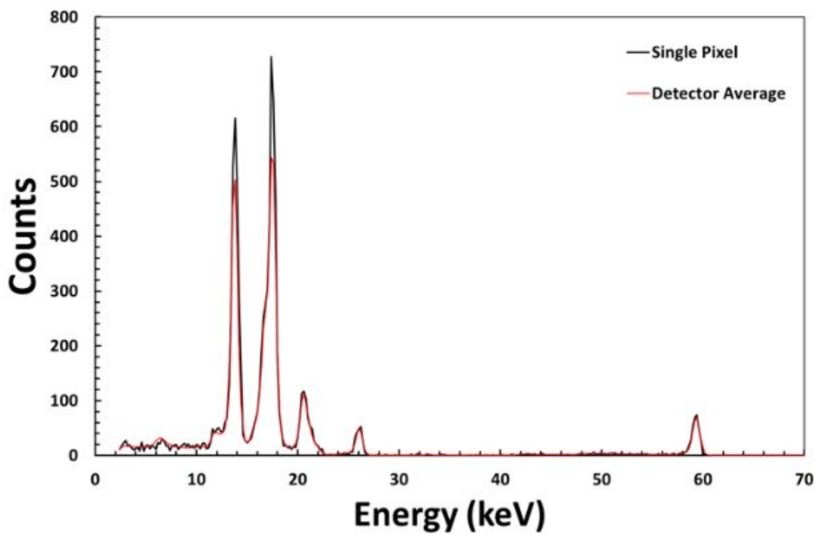
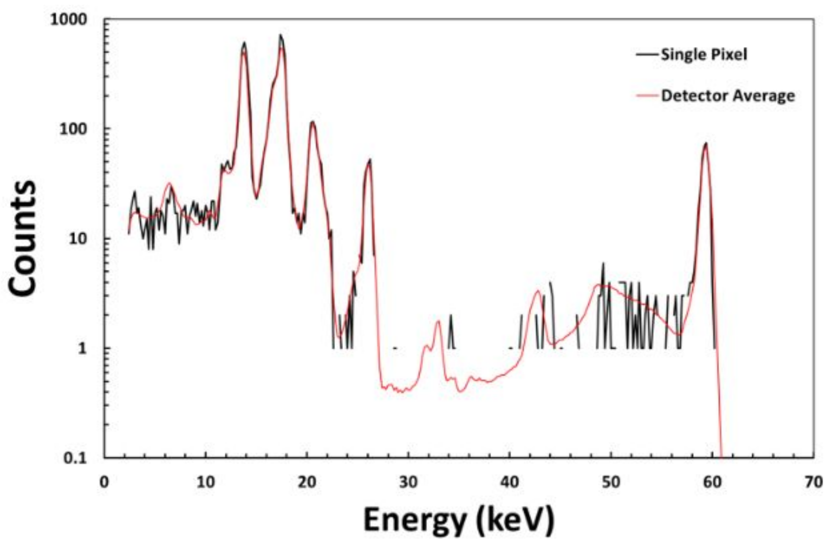




Sensor calibration

Si sensor ^{241}Am spectra





Synchronisation

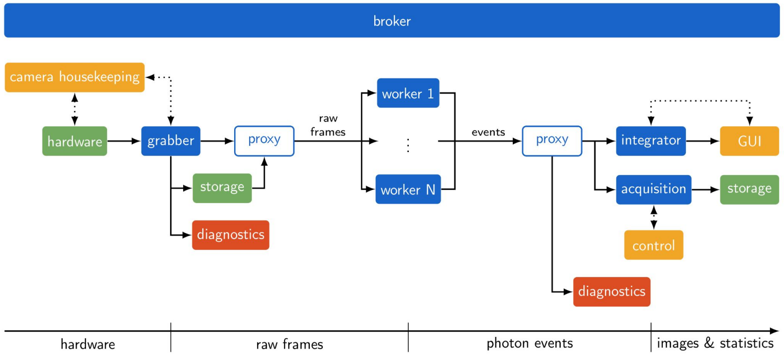
- HEXITEC readout is GigE Vision based:
  - Supports **Precision Time Protocol** (PTP)
  - Camera synced to master clock of DAQ PC
  - Frames timestamped in hardware to sub-μs accuracy

- Custom triggerbox events retrieved over low-latency USB protocol, timestamped in software on DAQ PC

- Synchronisation verified using pulsed visible light:
  - Trigger event arrives before relevant HEXITEC frame
  - Constant delay, jitter less than one frame

DAQ software

- Based on SpeXIDAQ framework:
    - Written at UGent specifically for hyperspectral X-ray camera readout
    - Unaware of pulsed sources in default config
    - Highly modular, network based components
- Single workstation machine



F. Van Assche et al., *Sensors* **2021**, *21*, 563

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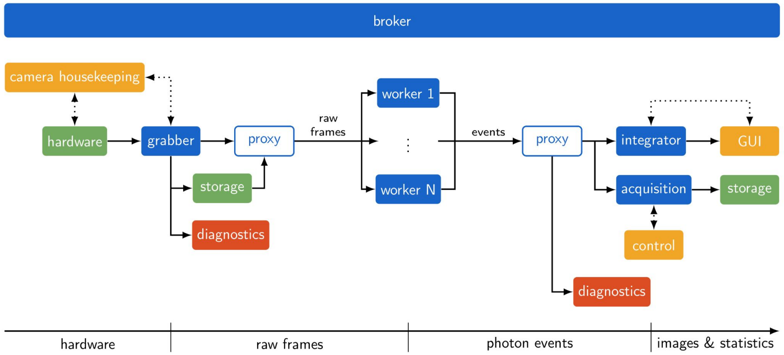

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F. Van Assche et al., *Sensors* **2021**, *21*, 563

Developed custom pulsed mode processing

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Pulsed mode processing

Principles

1. Individual pulses don't matter
2. Data integrity is essential – don't expect second chances

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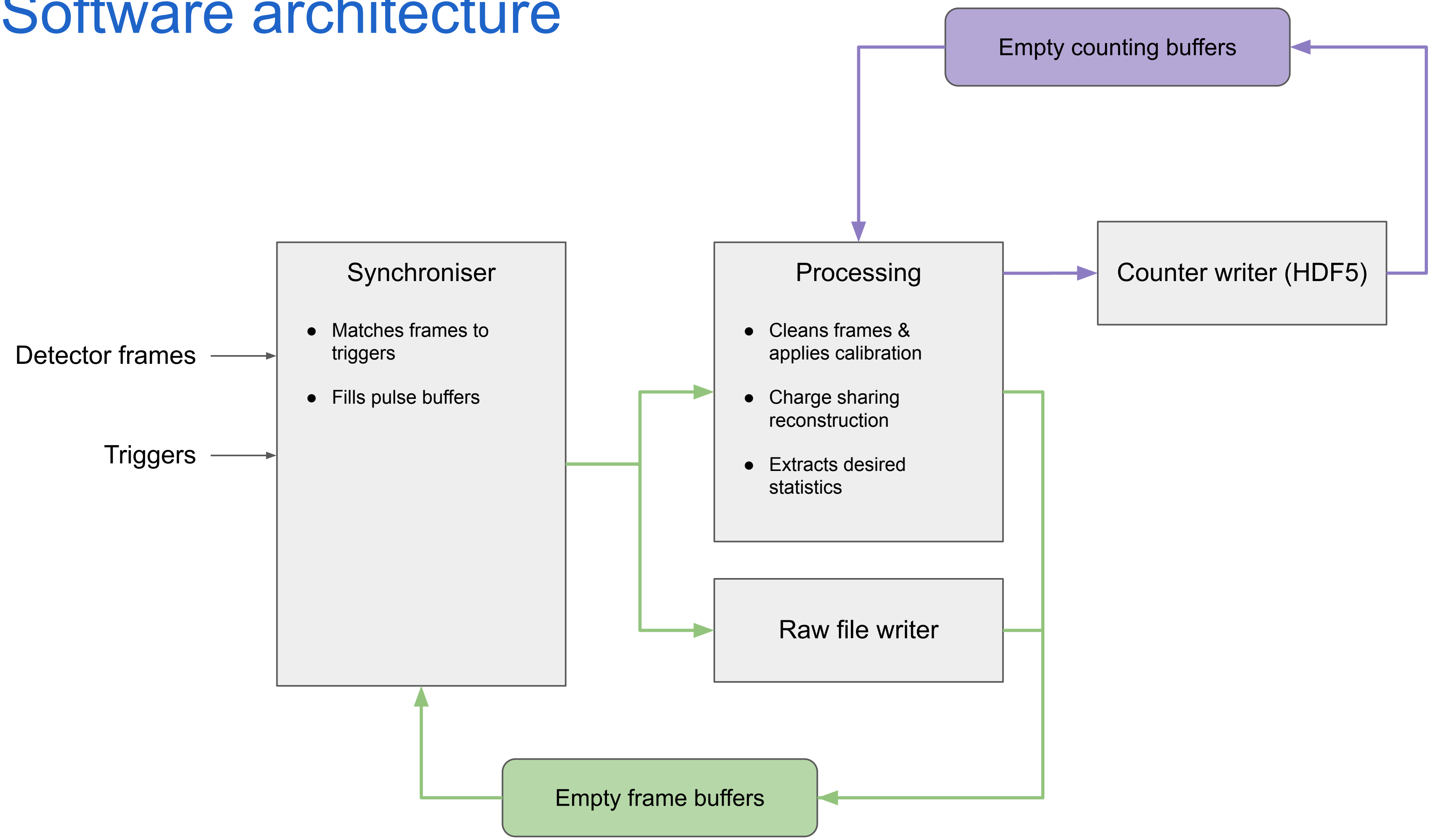
Translation to implementation

- Drop pulse if incomplete or corrupted
- Summing together (processed) pulses is acceptable
- Store processed frames for live monitoring
- Store raw detector output for offline analysis
- Frequently open new files for storage

Software architecture



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Processed data

Ideally (*X*, *Y*, *E*, *t*, *n*) “hypercubes” with hit counts

- *X* and *Y*: 80 x 80 detector pixels
- *E*: 2000 bins between 0 and 160 keV
- *t*: 320 bins of ~ 0.12 ms each (8.5 kHz and 25 Hz pulses)
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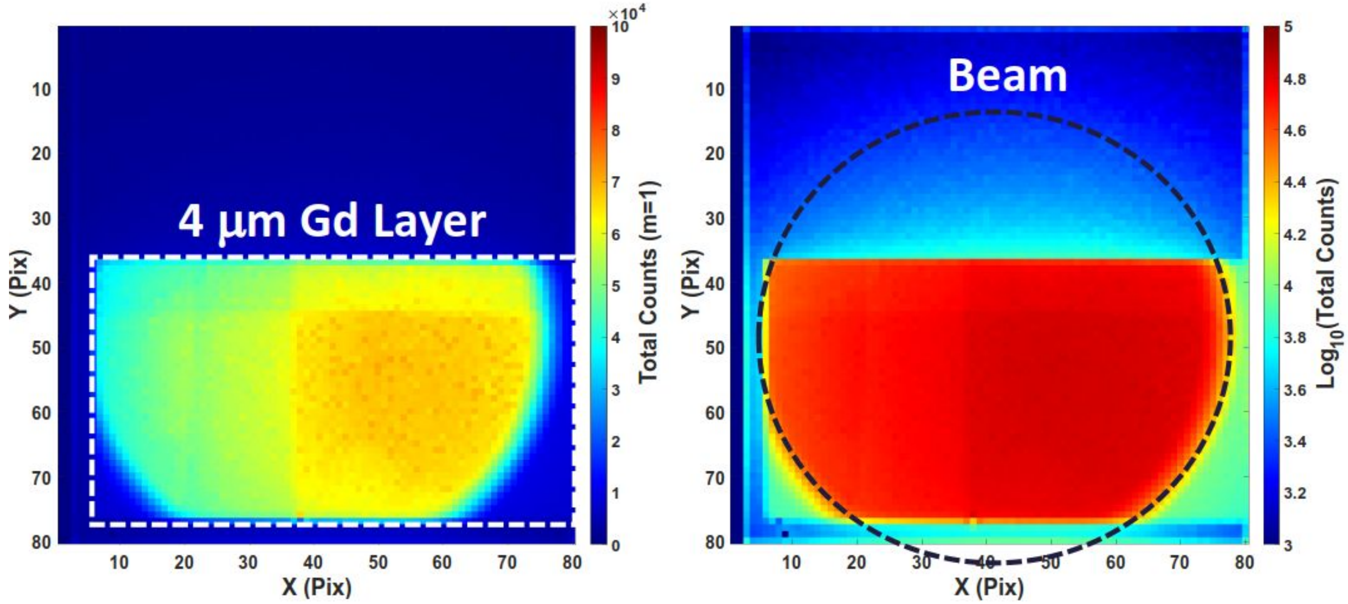
Too expensive: with 16 bit counters 50 Gb required per buffer!

Don't forget: raw frames streaming to disk @ almost 1 Gbps too

Processed data

Solution: reduce processed output to three maps of lower dimensions:

- (E, t, n) of combined events **in beam, inside Gd layer**
- (E, t, n) of combined events in beam, **outside** Gd layer
- (E, t, n) of combined events **outside beam**



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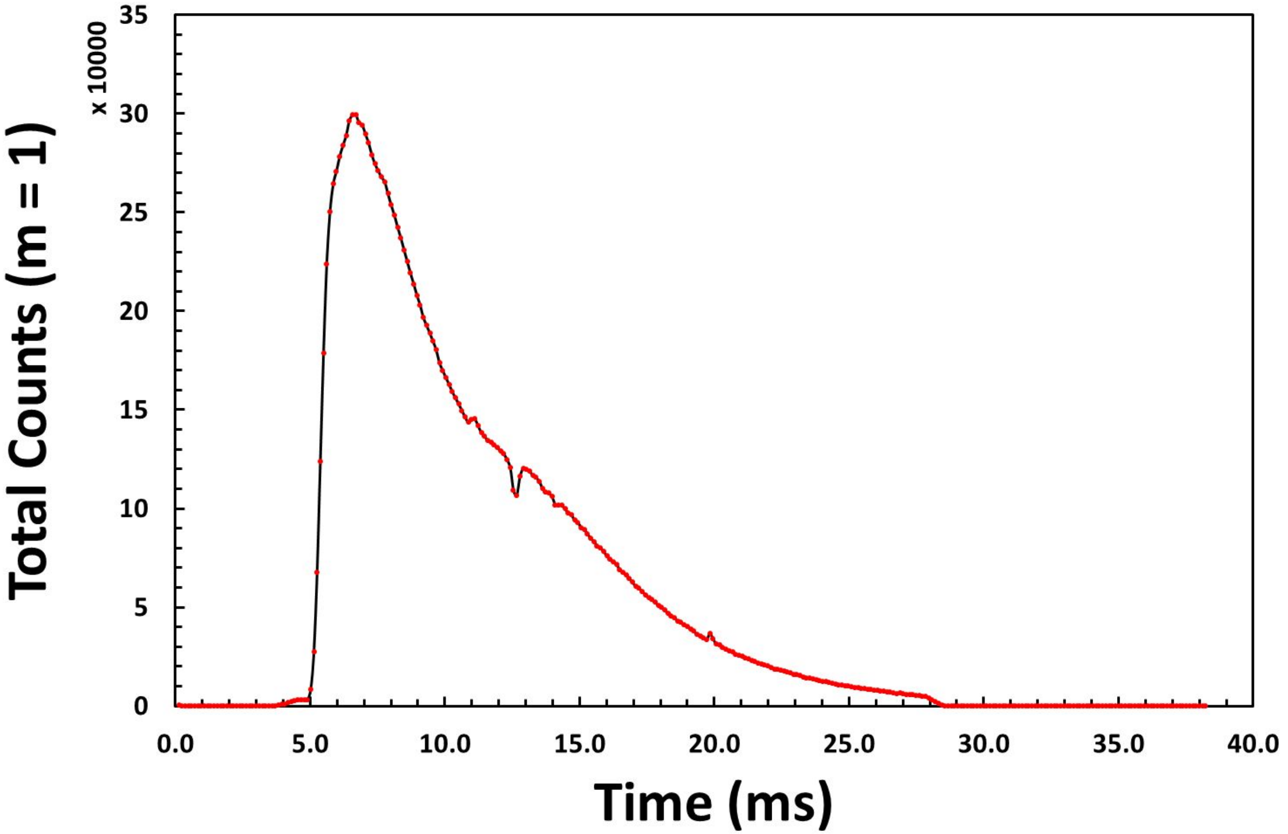
Tentative results

Excellent alignment of ToF



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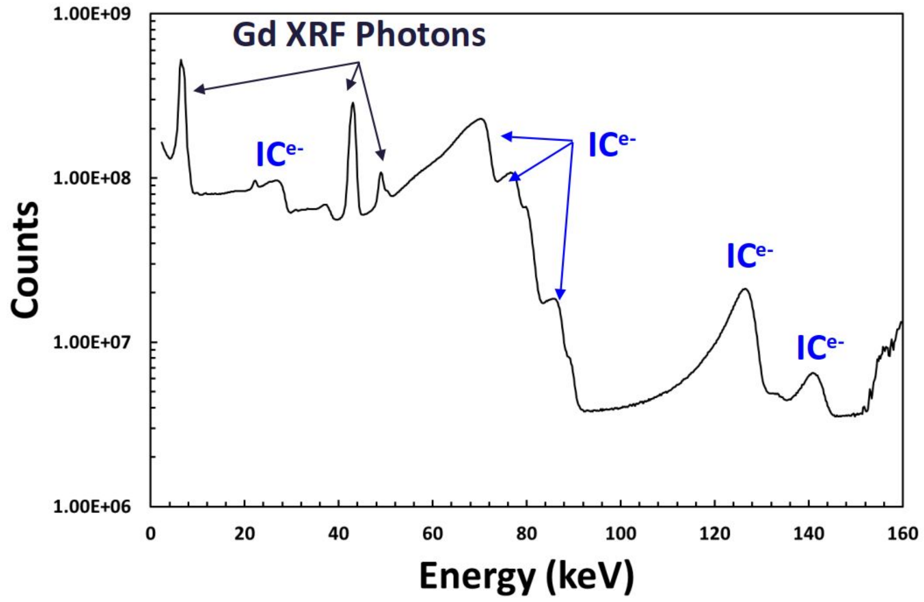
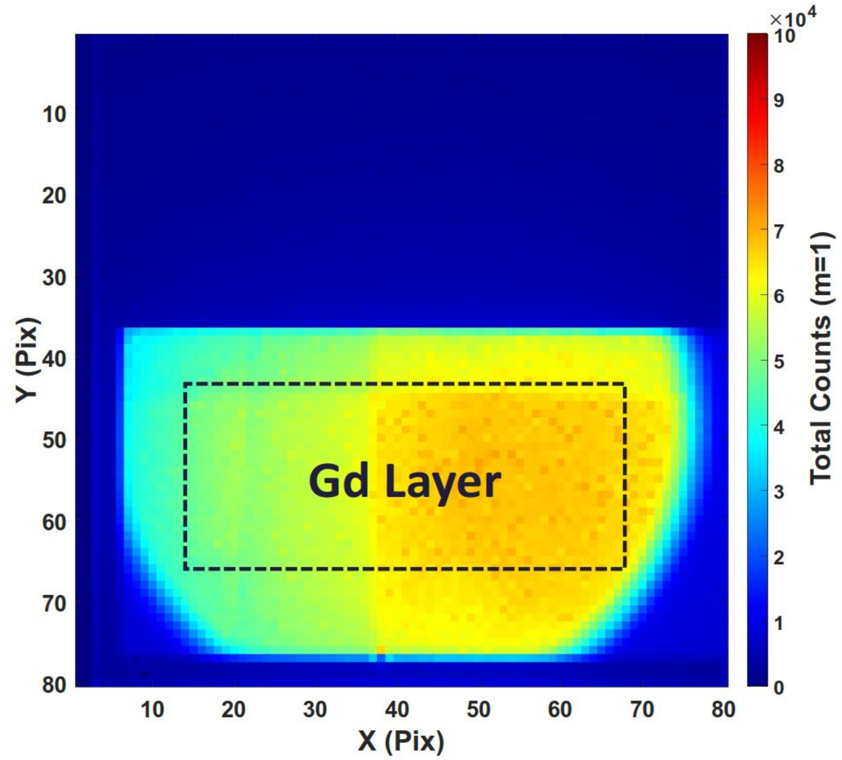
Spectrum for 4 µm Gd layer





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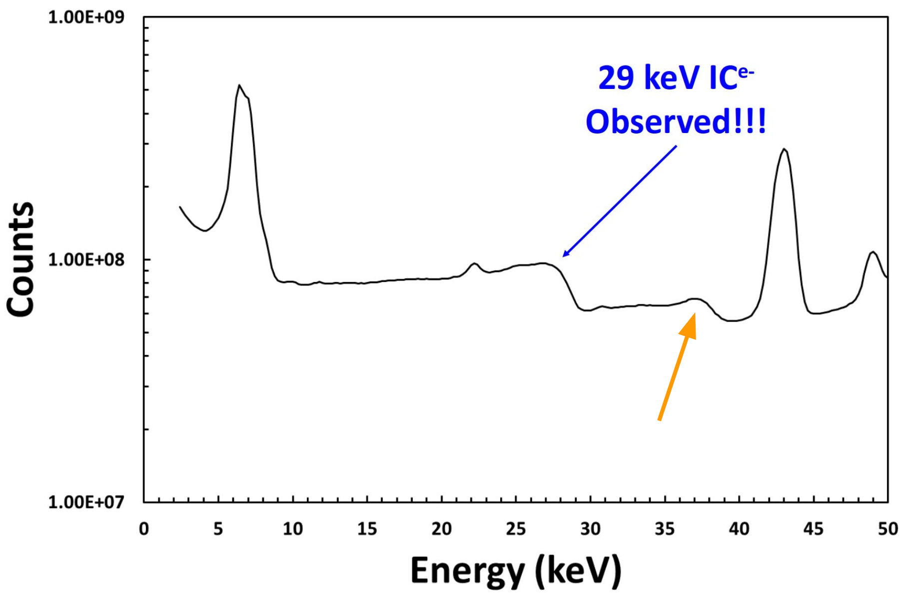
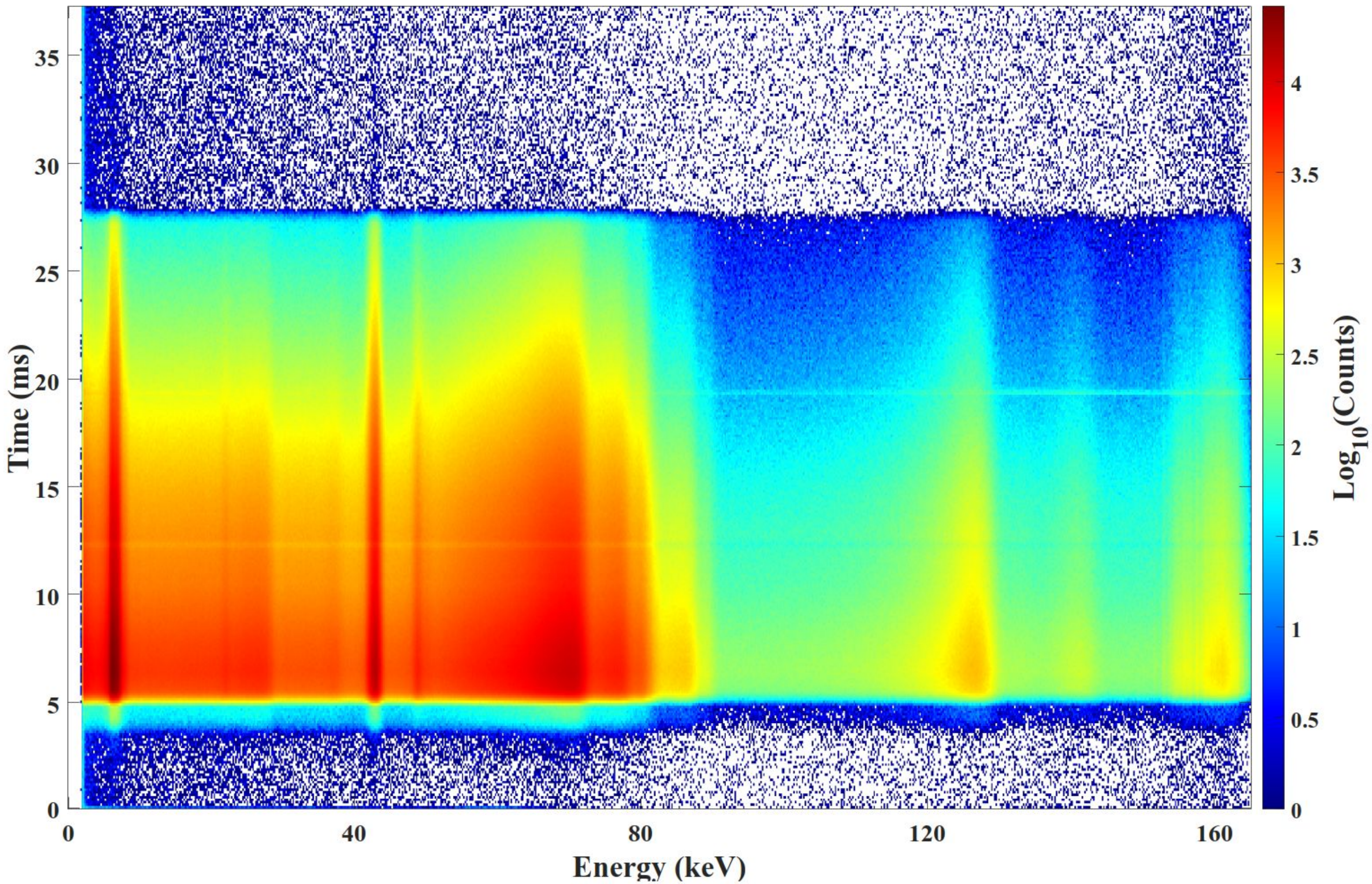


Temporal spectroscopy



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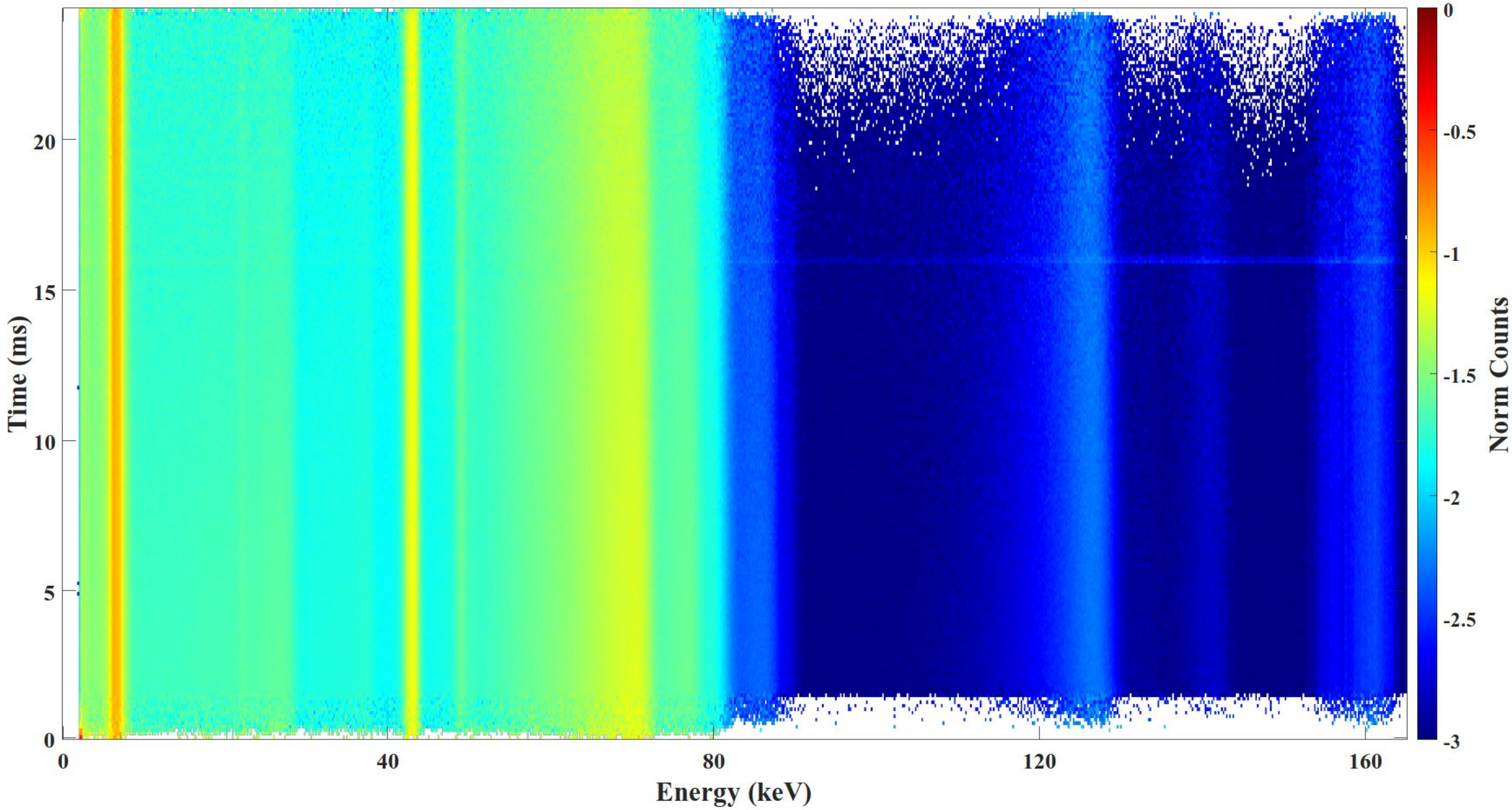
Normalised to XRF lines



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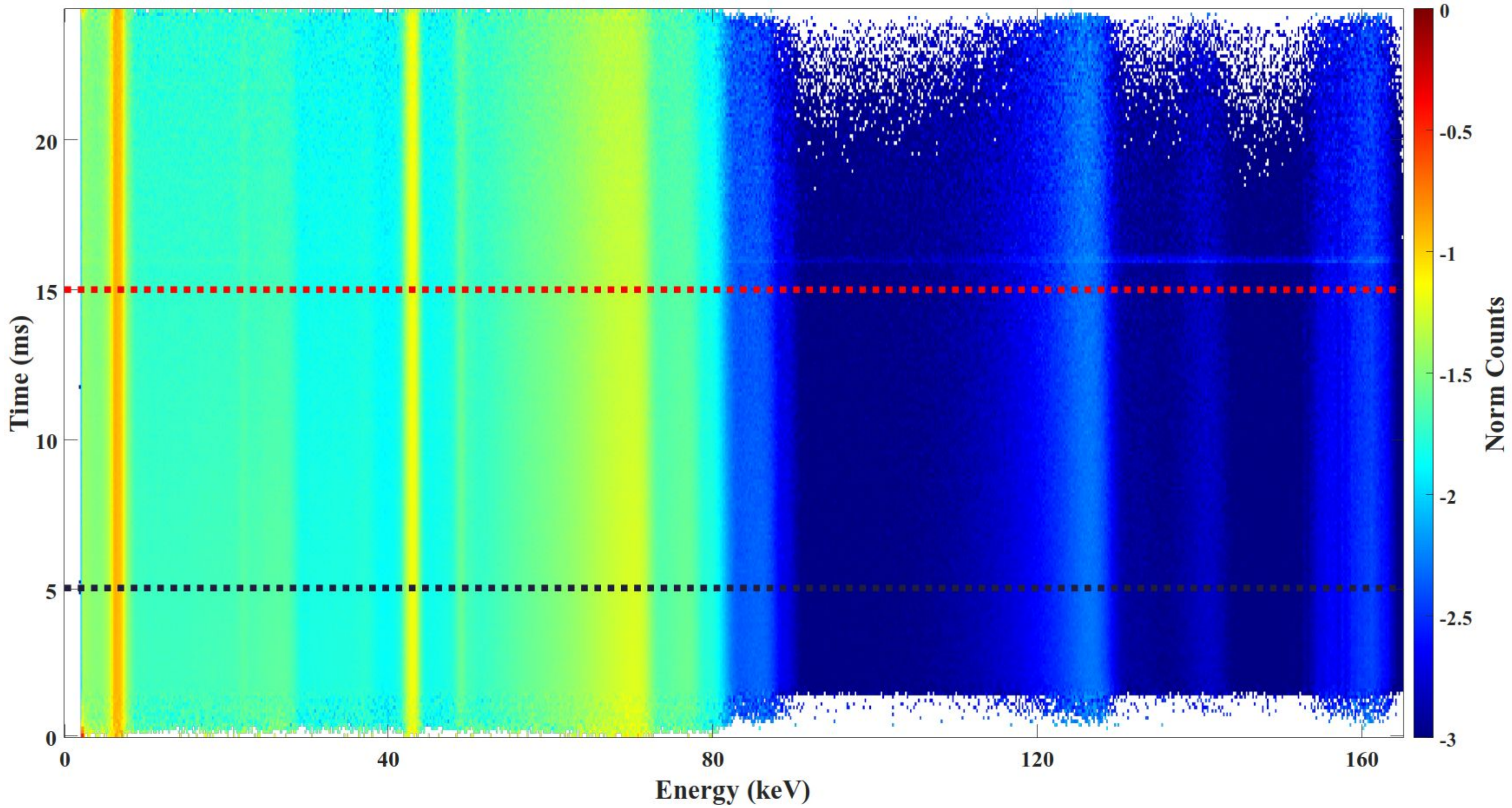

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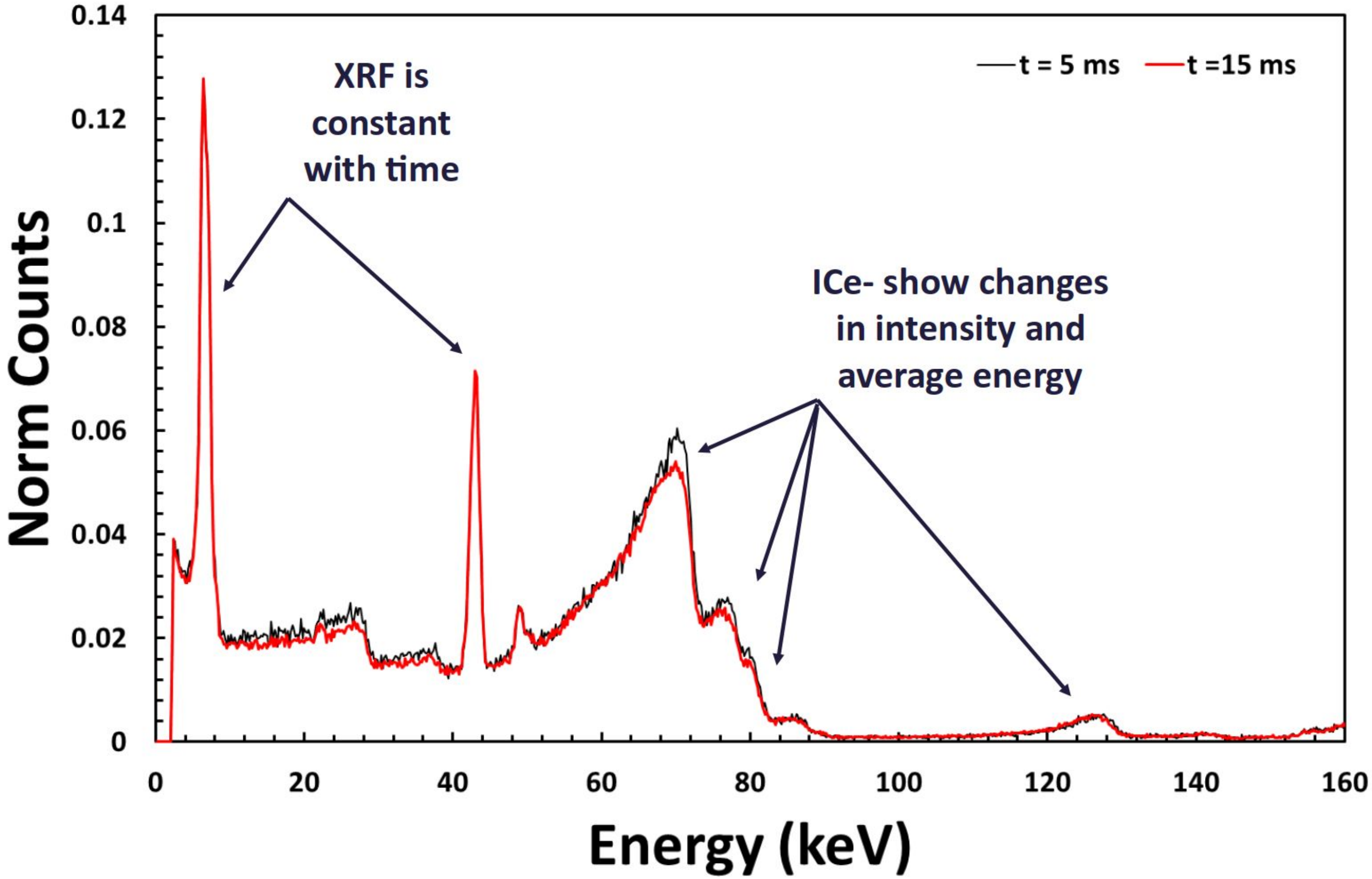
Behaviour of IC electrons



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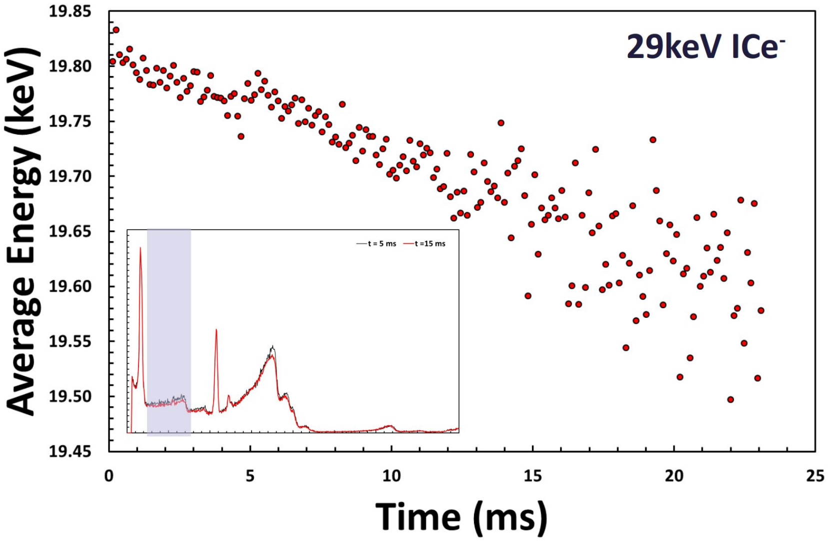

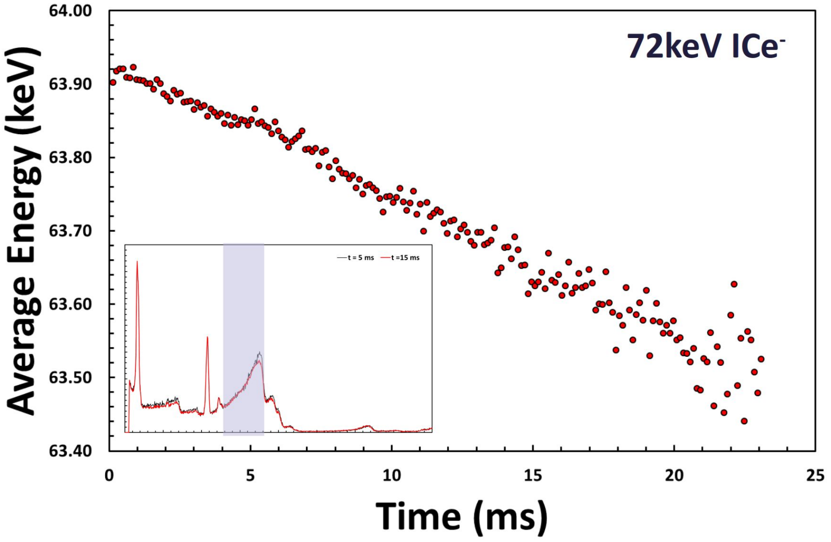

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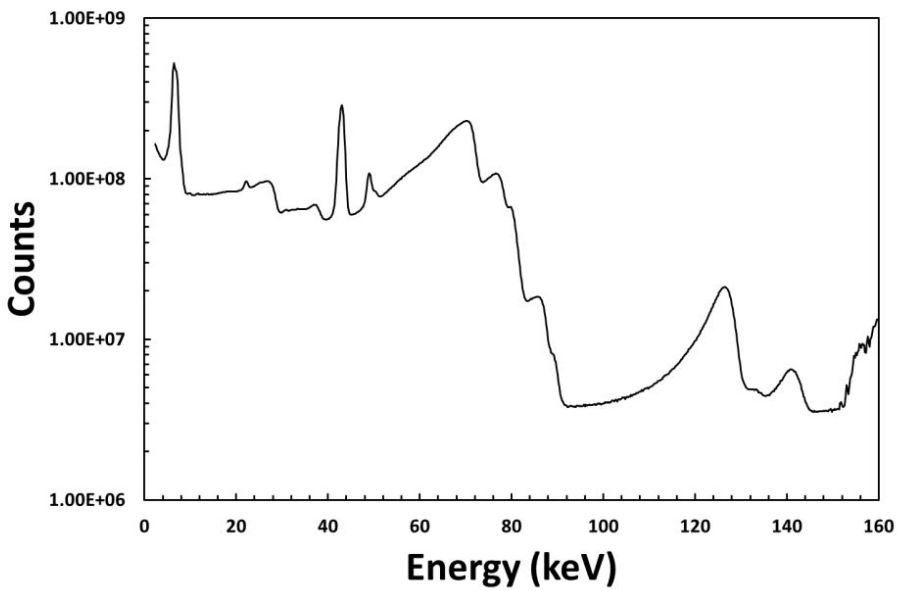
Even better spectrum with 100 nm Gd

4 µm Gd layer



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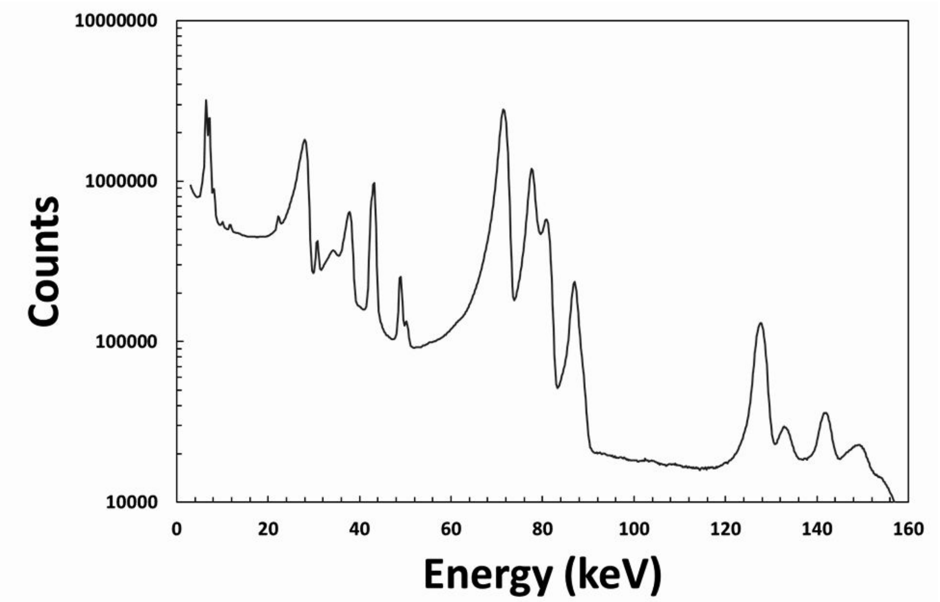

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Next steps

1. Finish analysis and publish results
2. Check how fits with simulations:
    - Branching ratio tweaks?
    - Better input data?
3. Resource for detector design: Gd thickness optimisation guidance
4. HEXITEC MHz: 100-fold better timing resolution!
    - Talk by Joseph Nobes on Tuesday 12:30
    - Poster by Ben Cline (Monday) & poster by Matt Veale (Wednesday)
5. Include measurements in standards databases?

Thank you!

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Matthieu N. Boone

Sander Vanheule

Matthew C. Veale

Daniel E. Pooley

Ben Cline

Stephen M. King (LoQ Instrument Scientist)

International Workshop on Radiation Imaging Detectors 23rd iWoRiD

Frederic Van Assche
frederic.vanassche@ugent.be

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Trigger structure