

Development and Optimisation of a Two-Stage SiPM-Based Compton Camera

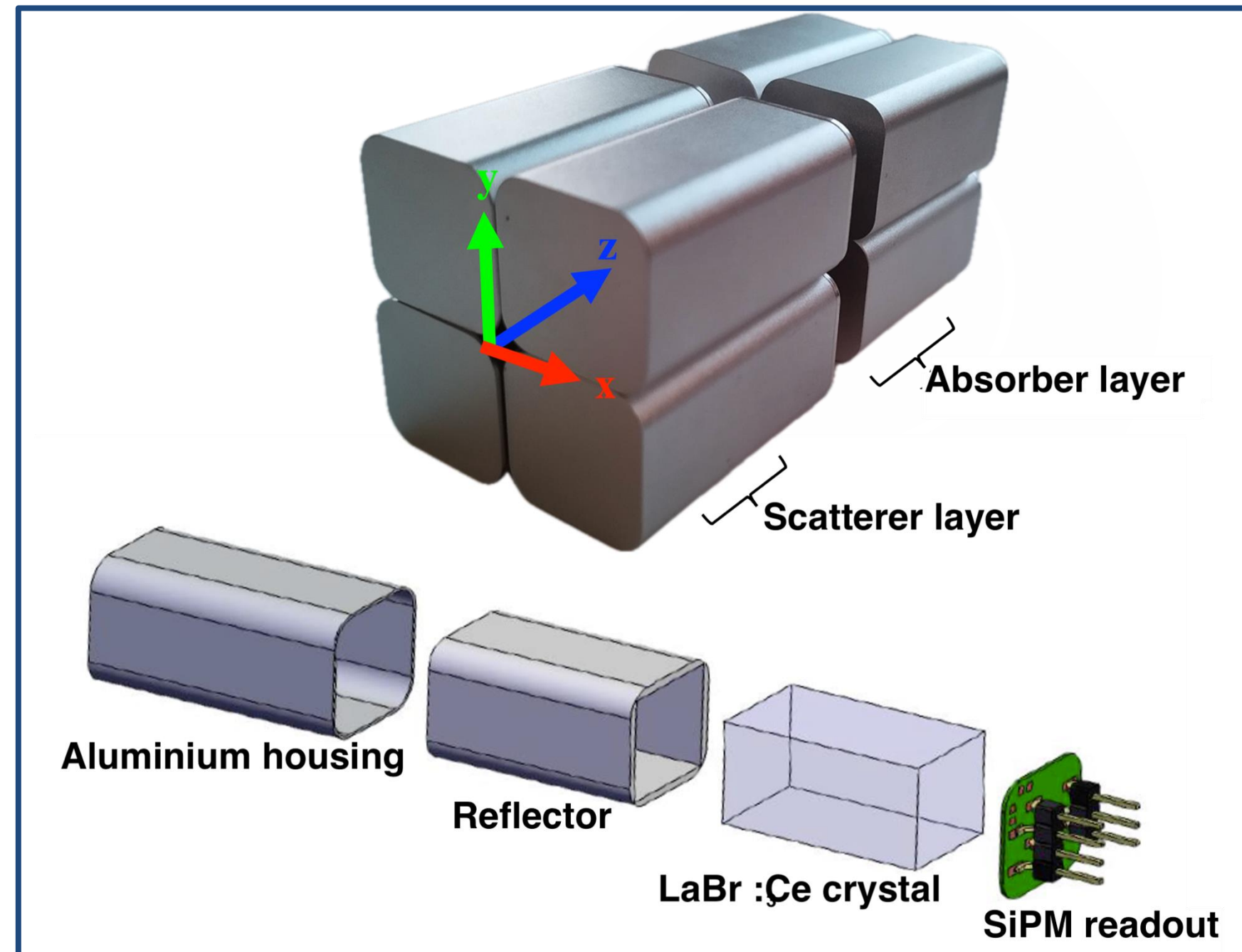
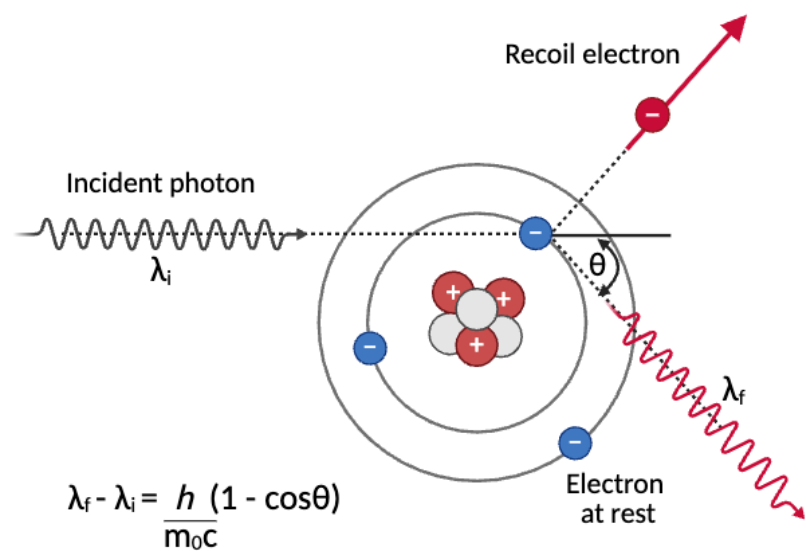
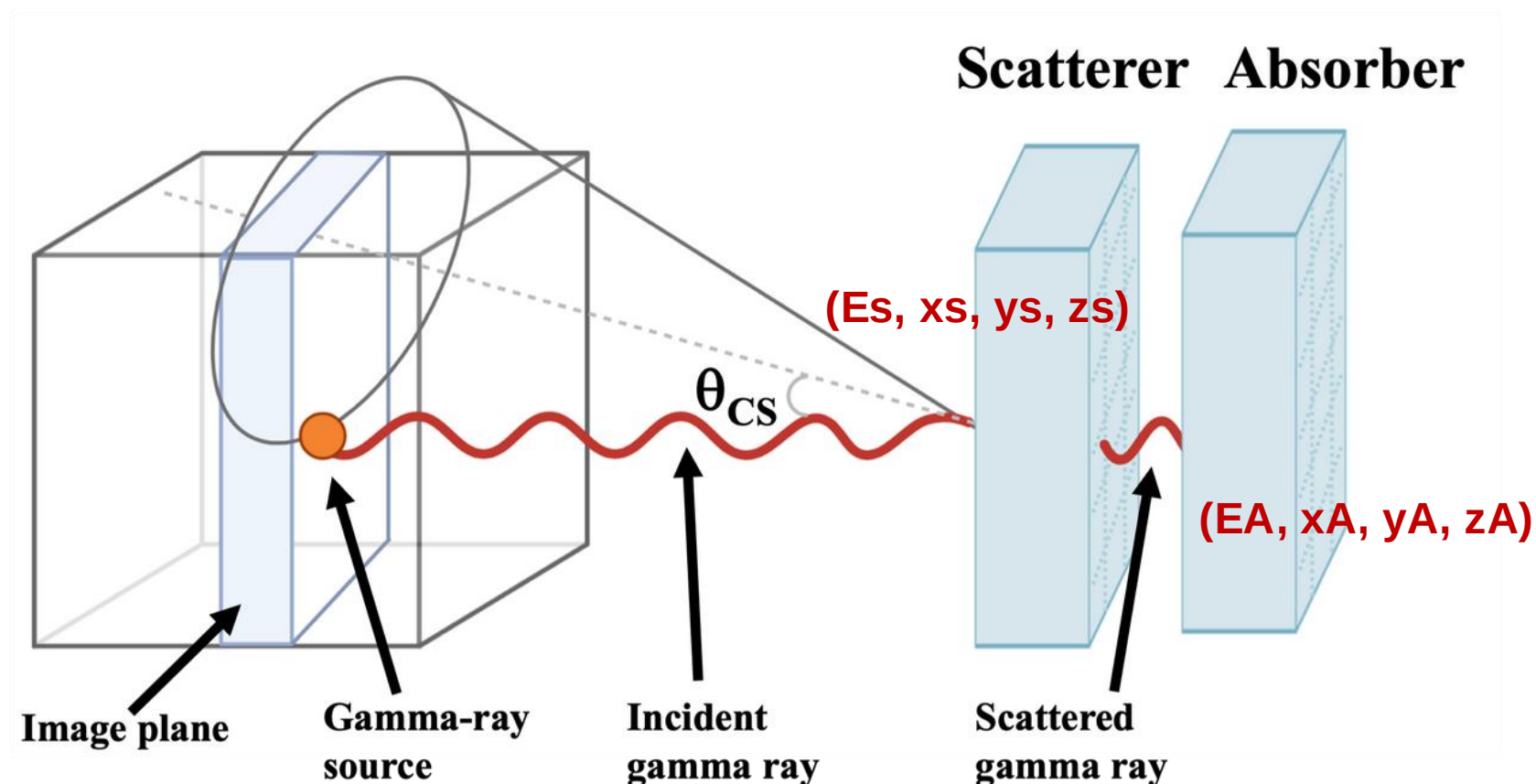
Shanyn Hart, Postdoctoral Researcher at iThemba LABS

ANSTT 2026

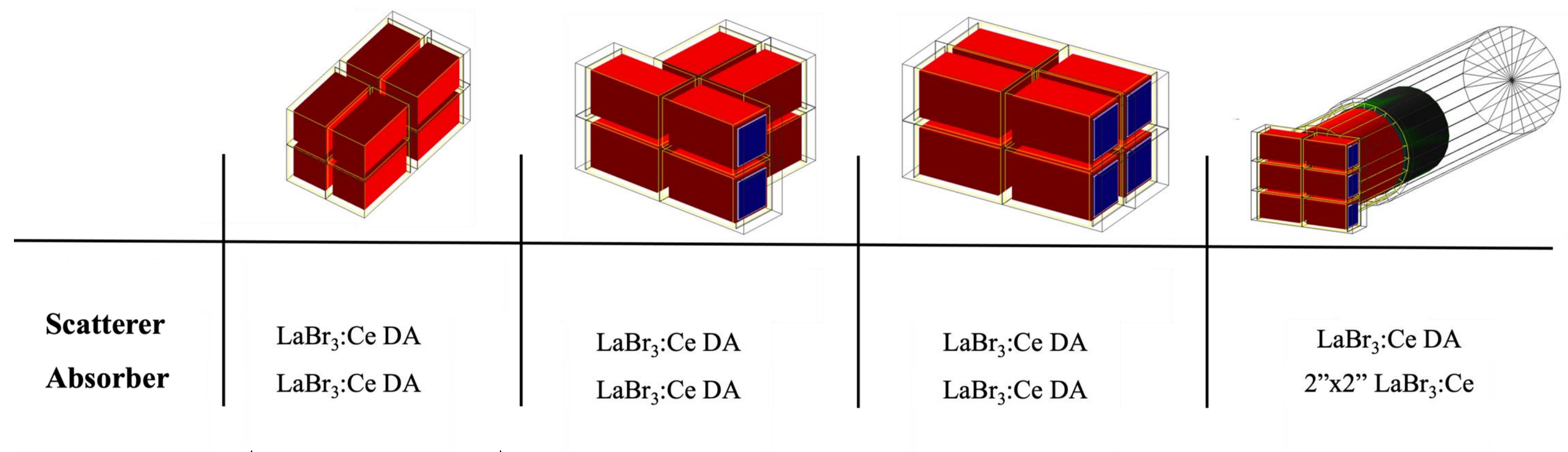
Compton Camera Principle

Scatterer and Absorber Layers:

MacroPixel LB-14x25c-SiPM-T LaBr₃:Ce detector assemblies in 4 × 1 arrays.



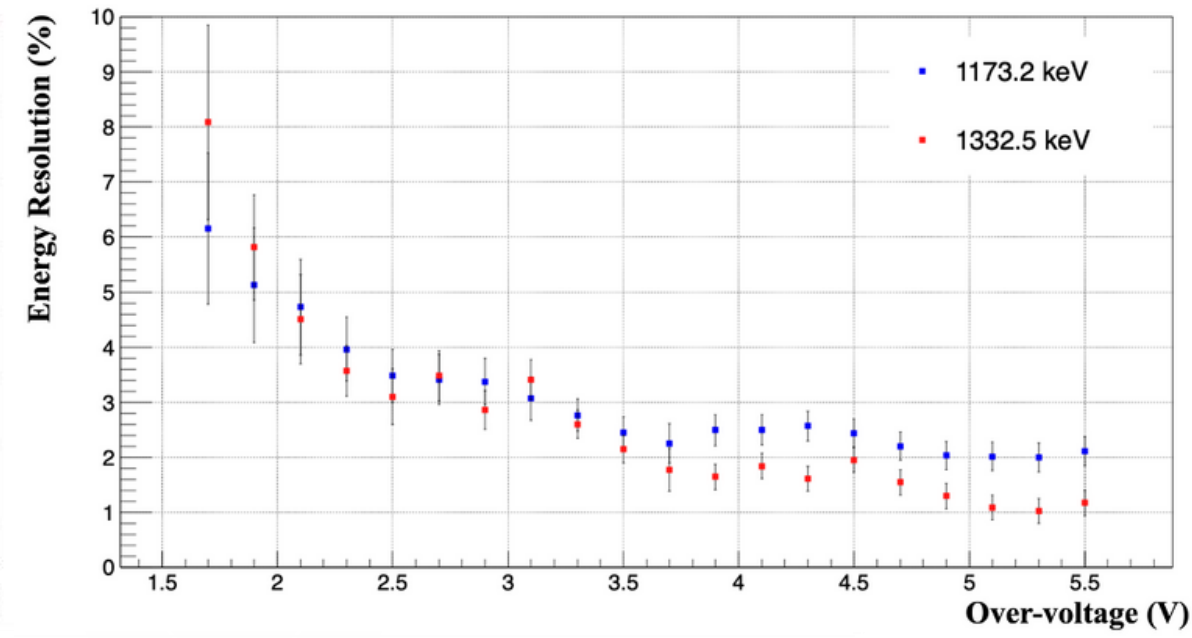
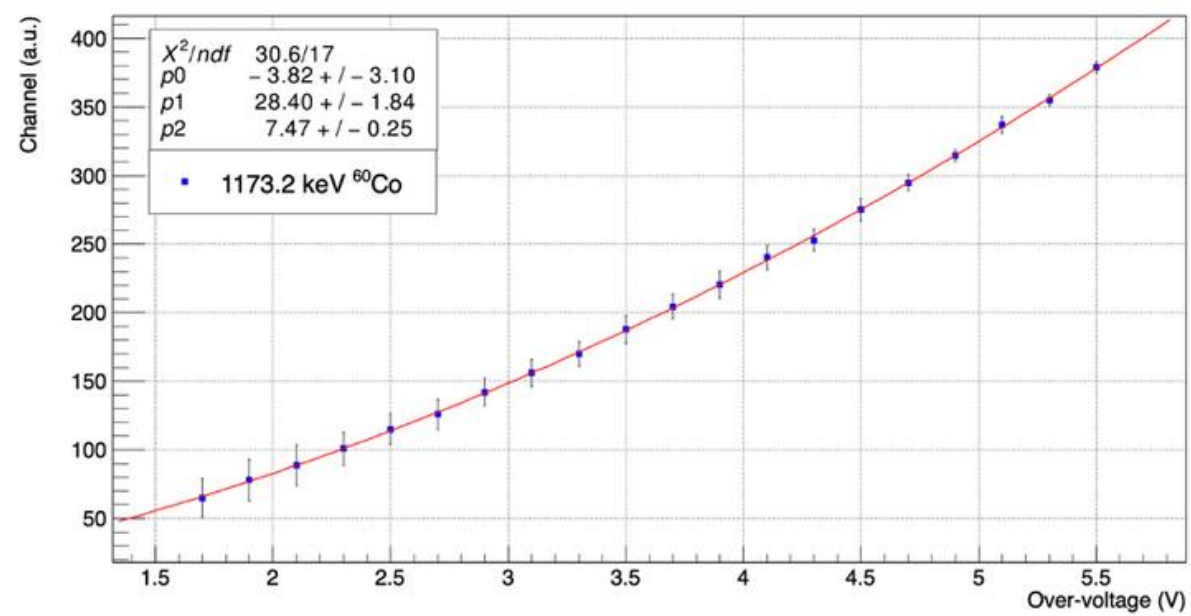
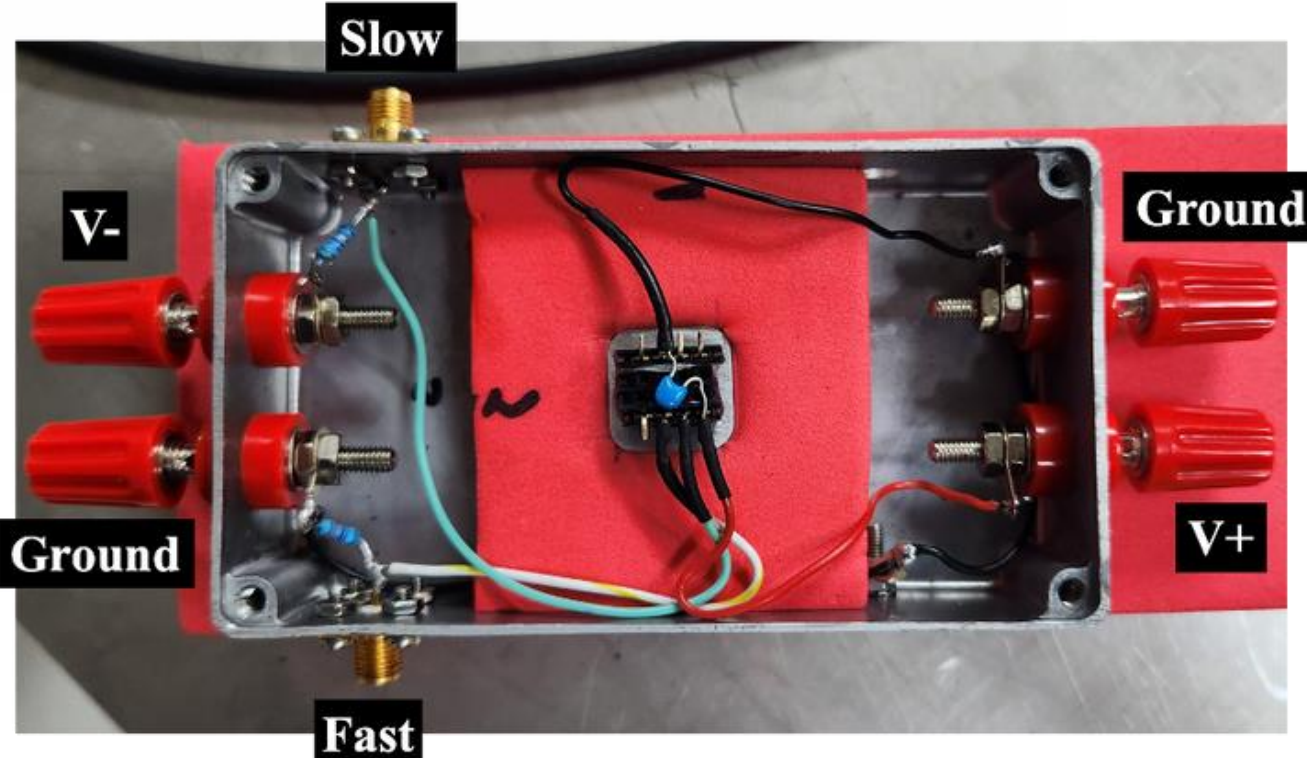
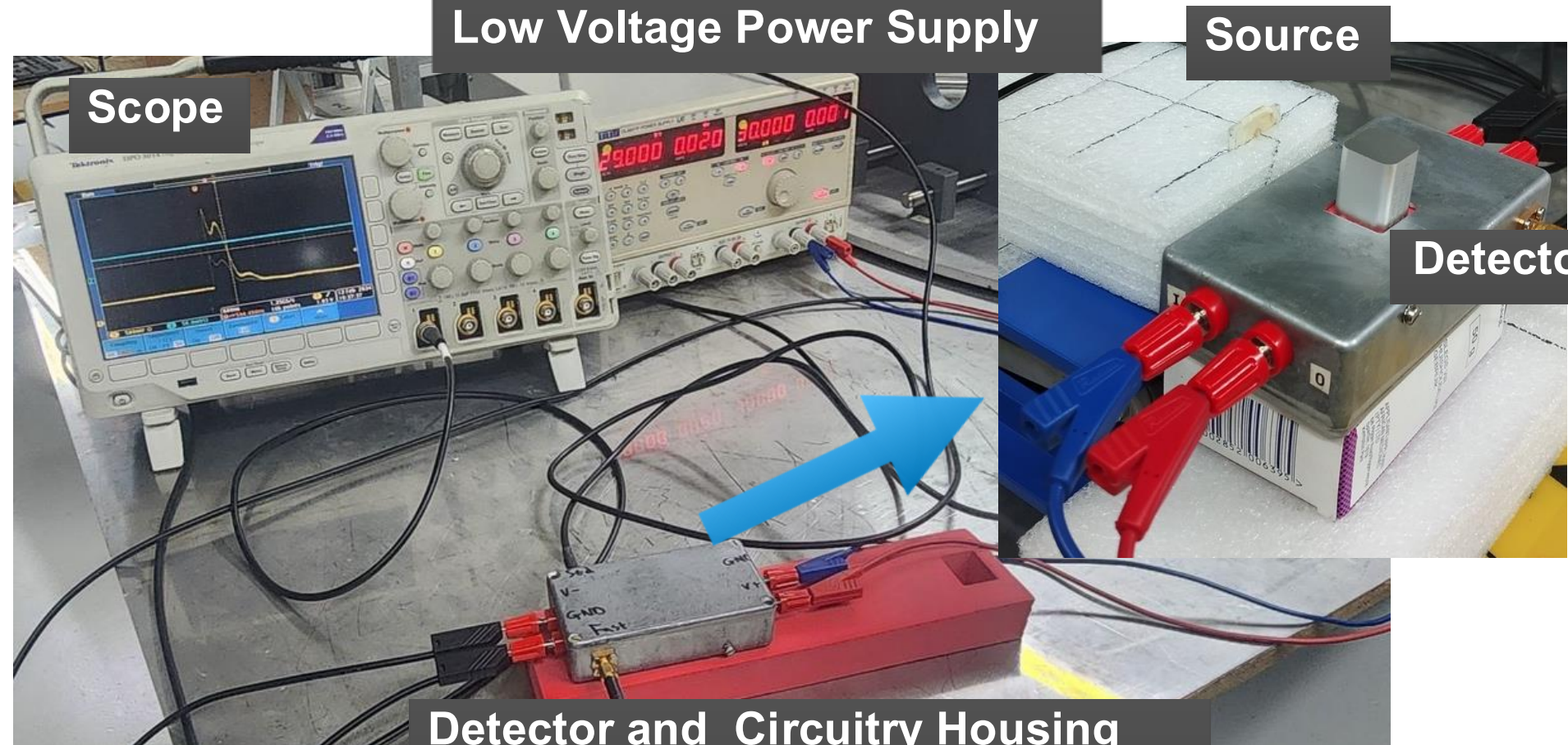
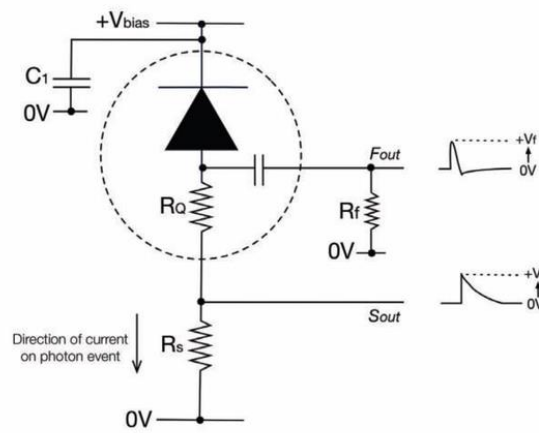
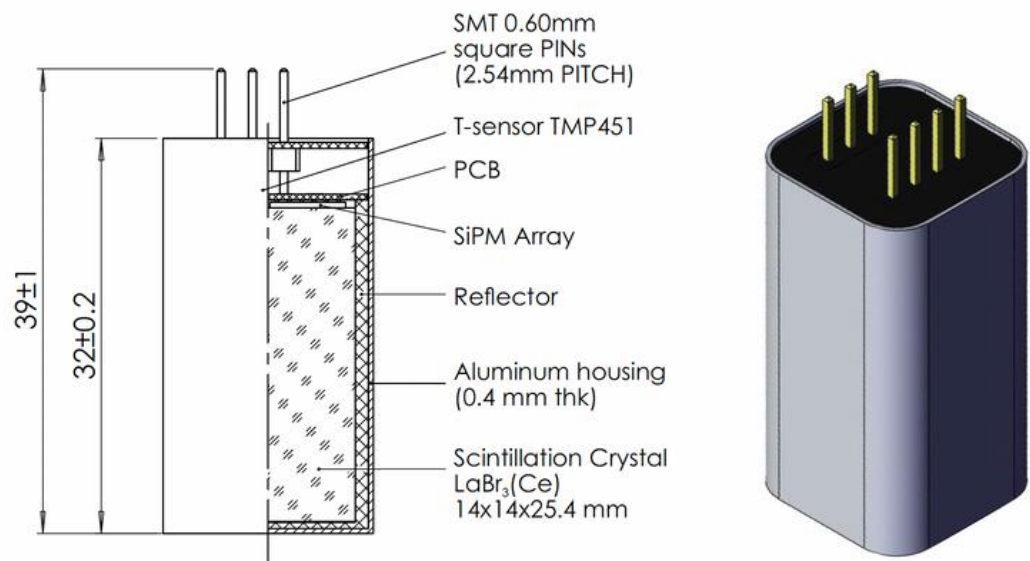
Compton Camera Geometries Investigated



I will discuss this design.

CC Detector Characterisation

Compton Camera of $\text{LaBr}_3:\text{Ce}$ detectors ($14 \times 14 \times 25.4 \text{ mm}^3$) coupled to a **2x2 MicroFJ-60035-TSV SiPM** array and **TMP451** temperature sensor packed in an aluminium canister. Manufactured by **CapeScint** (MA,USA).



Operational voltage chosen to be 30 V (5.3 V overvoltage)

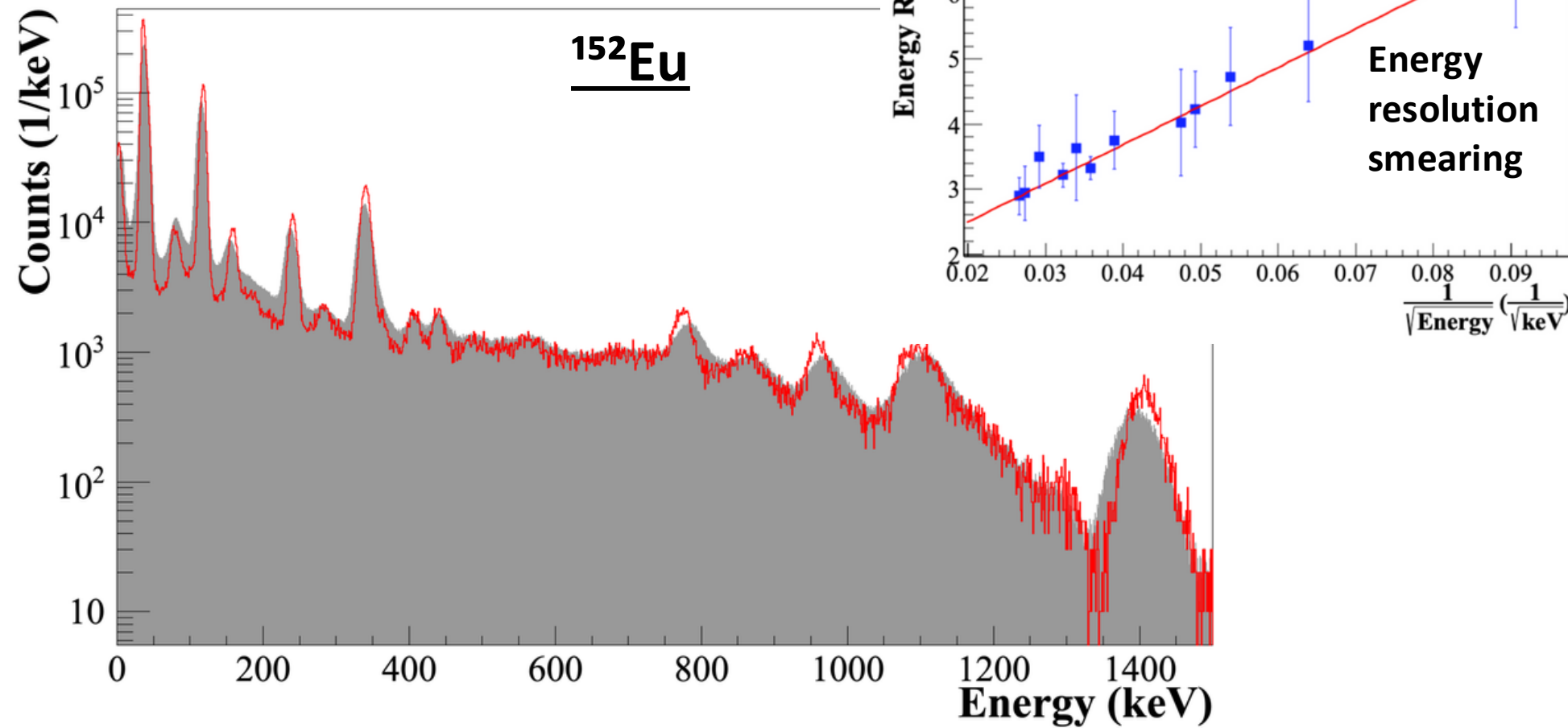
Validation of CC Detector Simulation



Geant 4

TOPAS MC Inc is a proud user of the Geant4 Simulation Toolkit

LaBr₃:Ce-SiPM

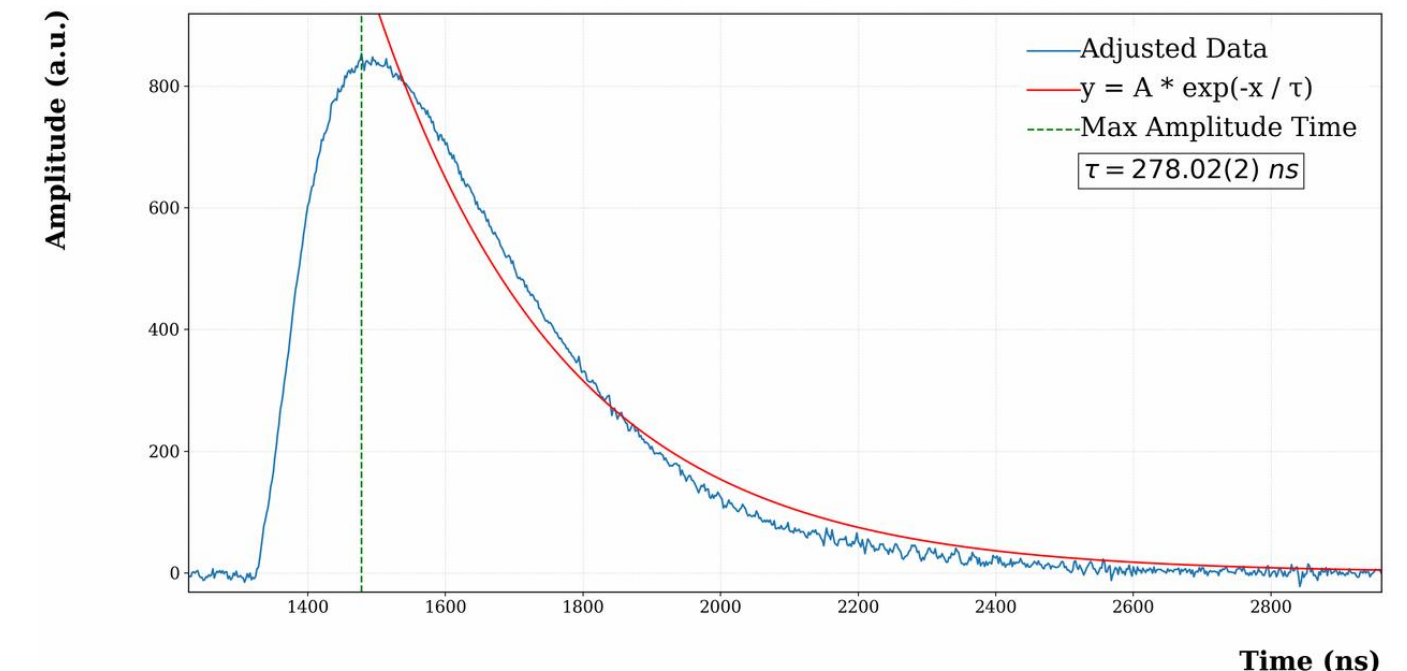


High efficiency for Compton scattering at low energies. Good candidate for addback.

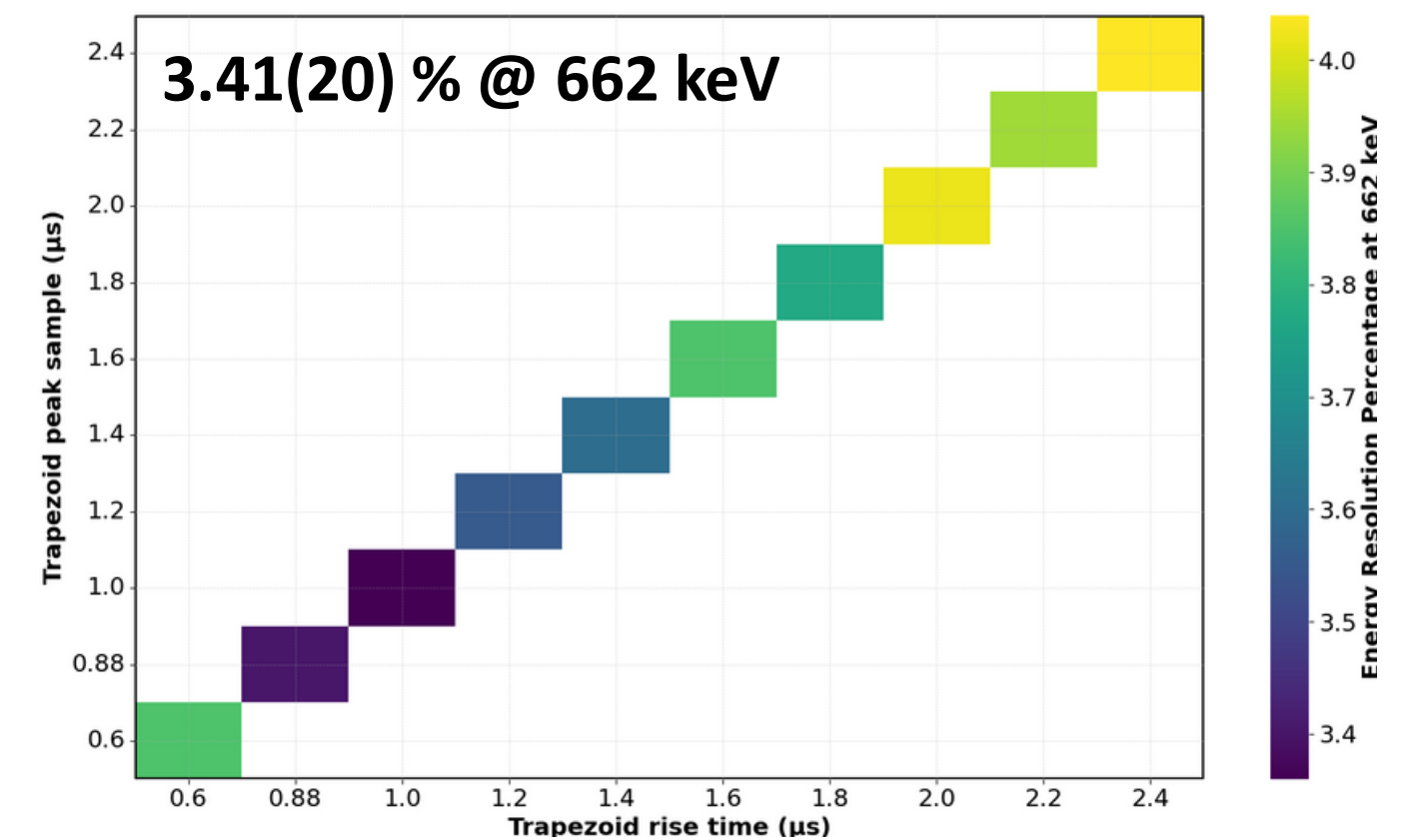
Distance (mm)	344.28 keV			968.08 keV		
	$\epsilon_{EXP,FEPE}$ (%)	$\epsilon_{SIMU,FEPE}$ (%)	Agreement (σ)	$\epsilon_{EXP,FEPE}$ (%)	$\epsilon_{SIMU,FEPE}$ (%)	Agreement (σ)
10.0	1.38(19)	1.50(10)	0.56	0.223(63)	0.196(13)	0.42
30.0	0.332(142)	0.449(90)	0.70	0.123(31)	0.078(21)	1.20
50.0	0.141(16)	0.204(53)	1.14	0.042(39)	0.039(12)	0.074
100.0	0.043(7)	0.044(9)	0.088	0.009(17)	0.009(10)	0

Table Comparison of experimental and simulation for the LaBr₃:Ce DA absolute full-energy peak efficiencies and associated uncertainties for gamma-ray energies 344.28 keV and 968.08 keV at various source-to-detector distances.

Triangular Optimisation of slow signal (Flat top = 0)

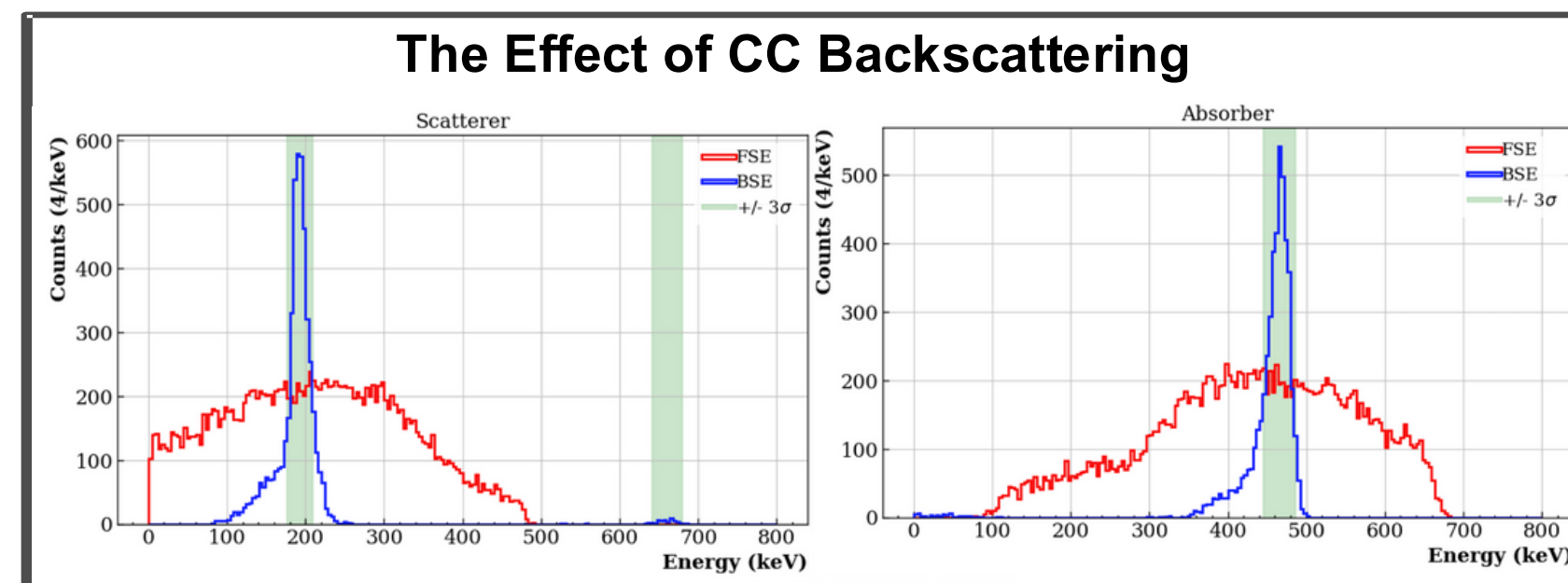
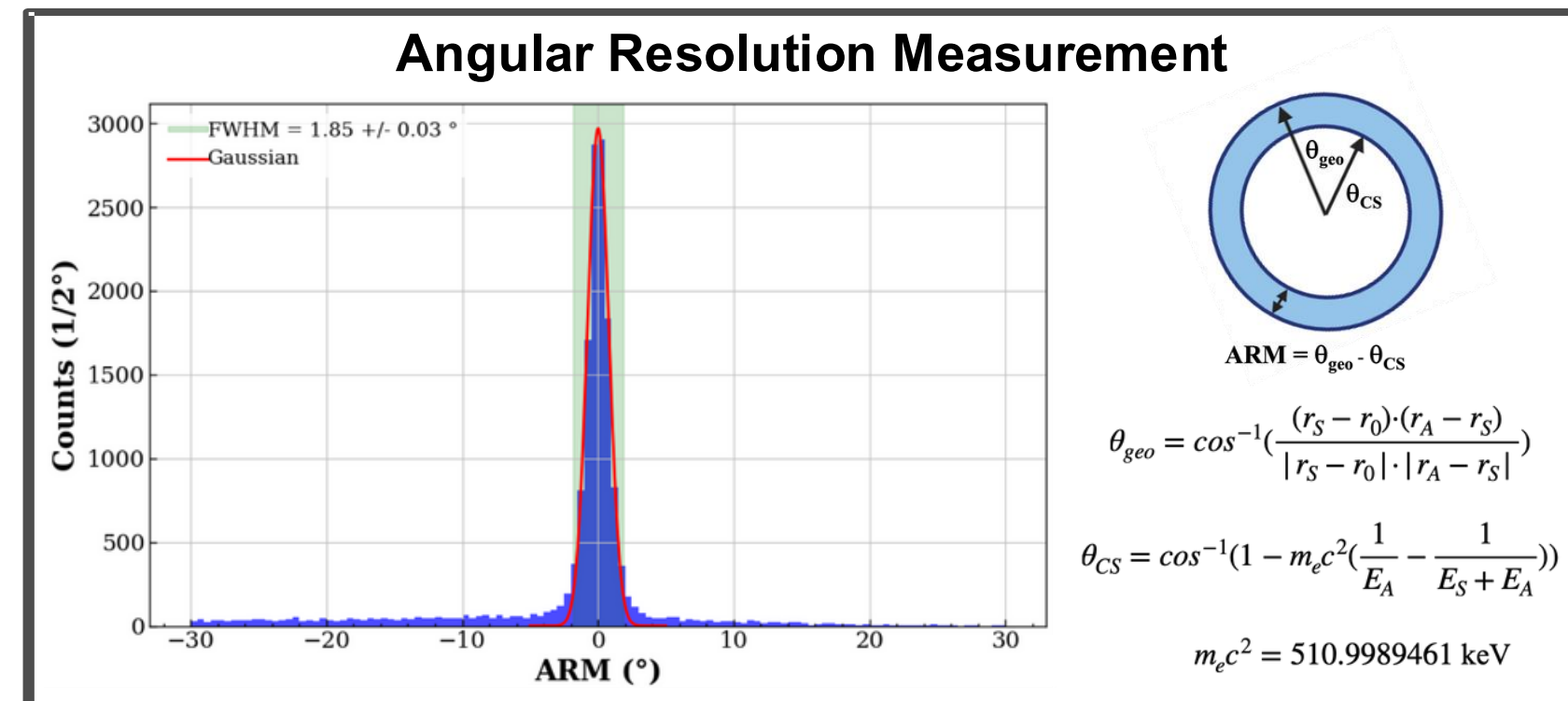
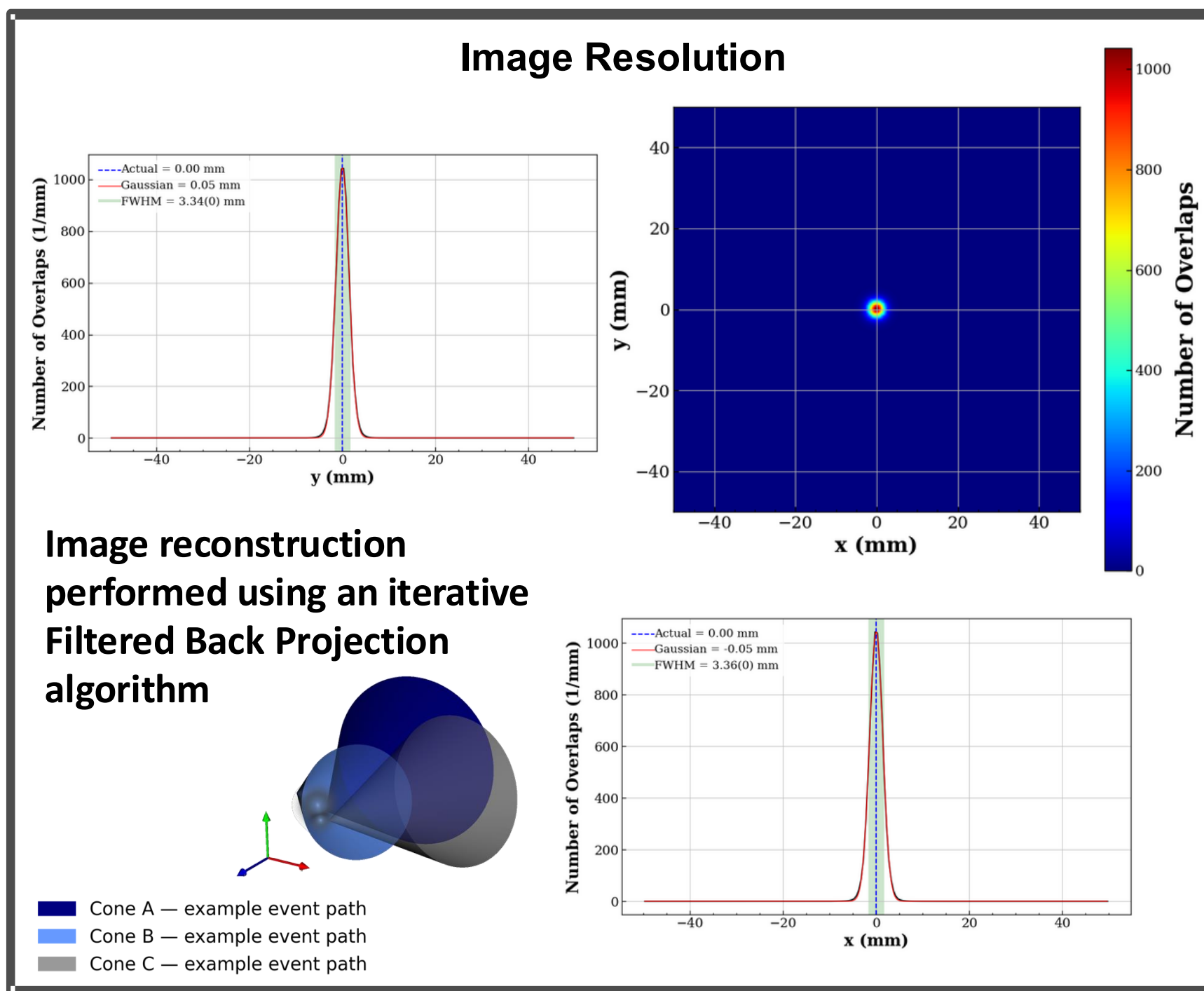
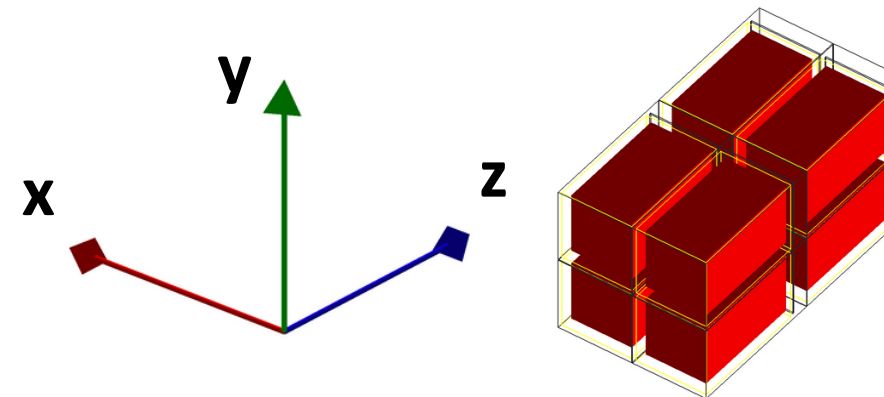


3.41(20) % @ 662 keV



Results of CC Simulation

Measurements performed with ¹³⁷Cs Source at (0,0,10) mm from scatterer face

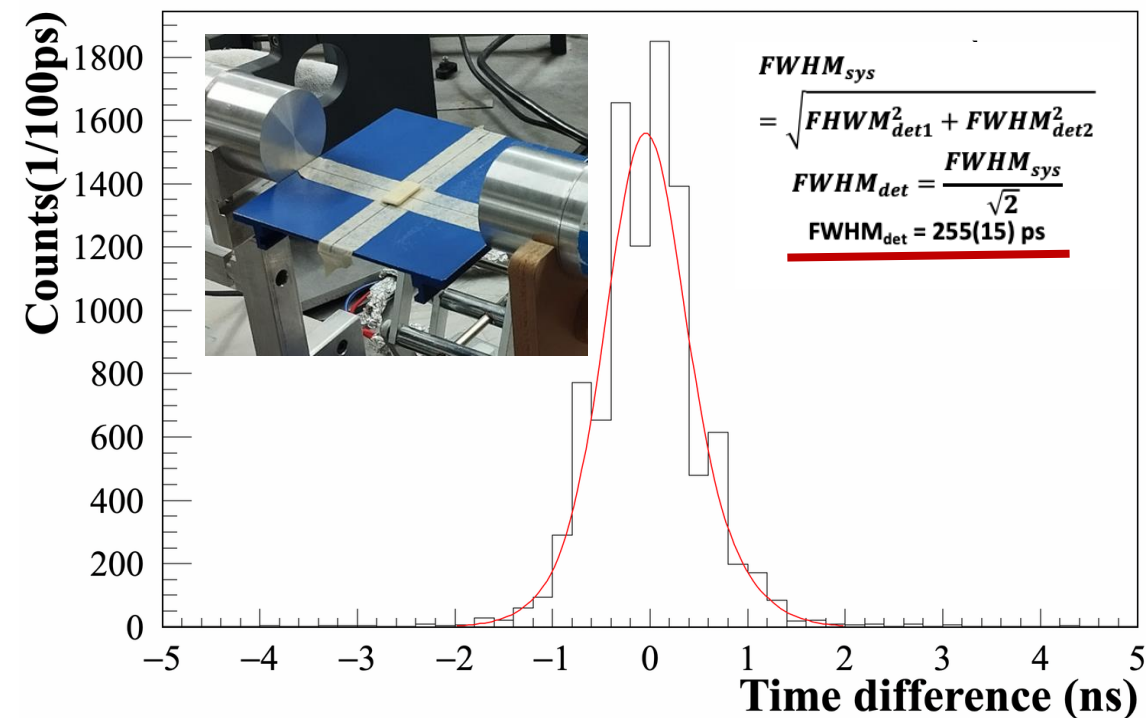


DA Fast Timing Performance

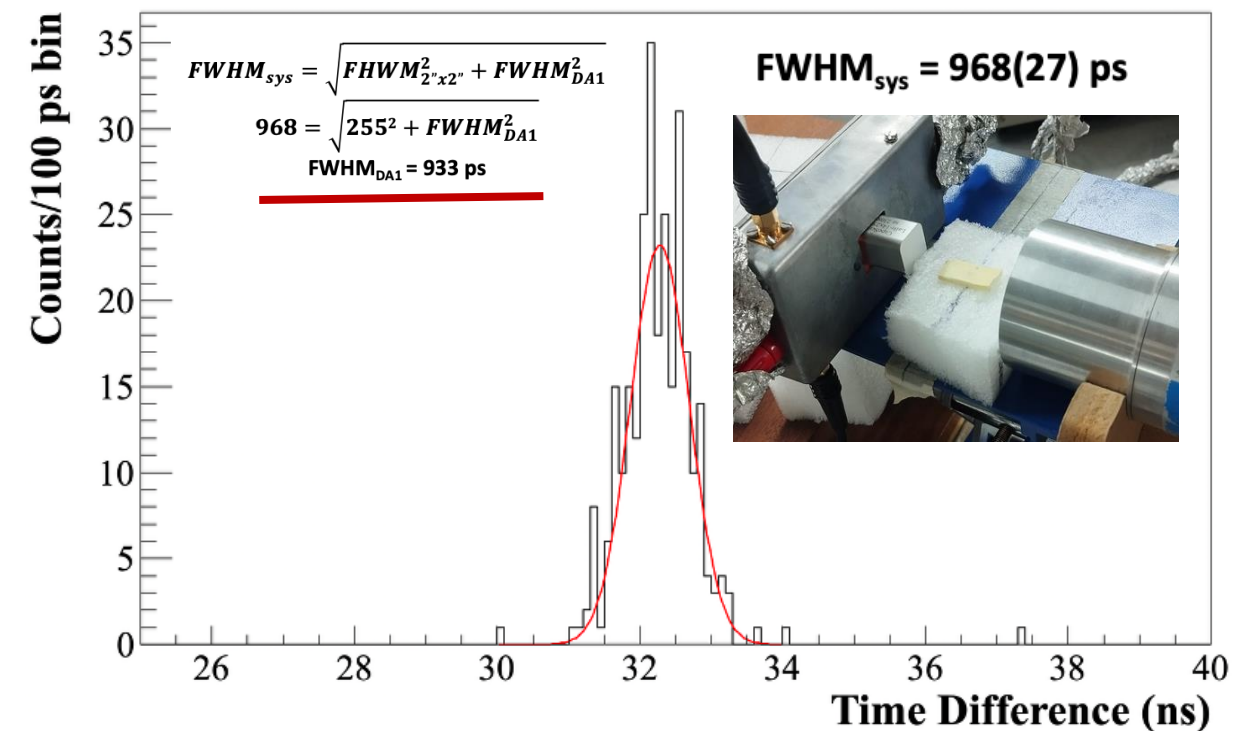
Calculated by gating on the ^{60}Co prompt-gamma decays. The time interval between the **1173 keV** and **1332 keV** emissions is **<0.9 ps**, effectively instantaneous compared to detector resolution.

Measurements performed using the **14-bit XIA PIXIE-16 500 MHz** data acquisition system, exploiting the use of the **digital CFD** for fast timing.

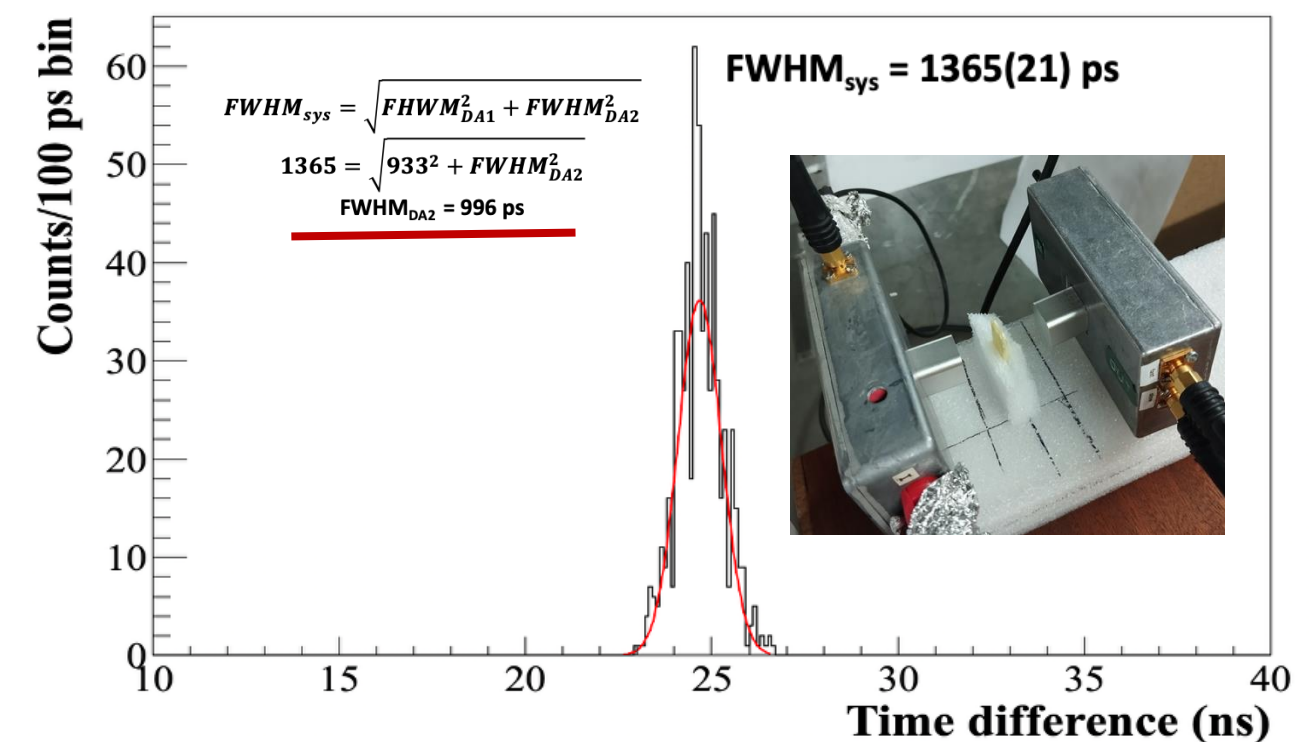
Two 2" x 2" LaBr₃:Ce detectors



2" x 2" and DA LaBr₃:Ce detectors



Two LaBr₃:Ce DAs



Postdoctoral Research



Current & Upcoming Work

Position-sensitive detection in LaBr₃:Ce scintillators

Improving spatial resolution using **Broadcom AFBR-S4N44P164M 4×4 SiPM arrays**

Custom development boards currently in production

Enhanced Geant4 simulations

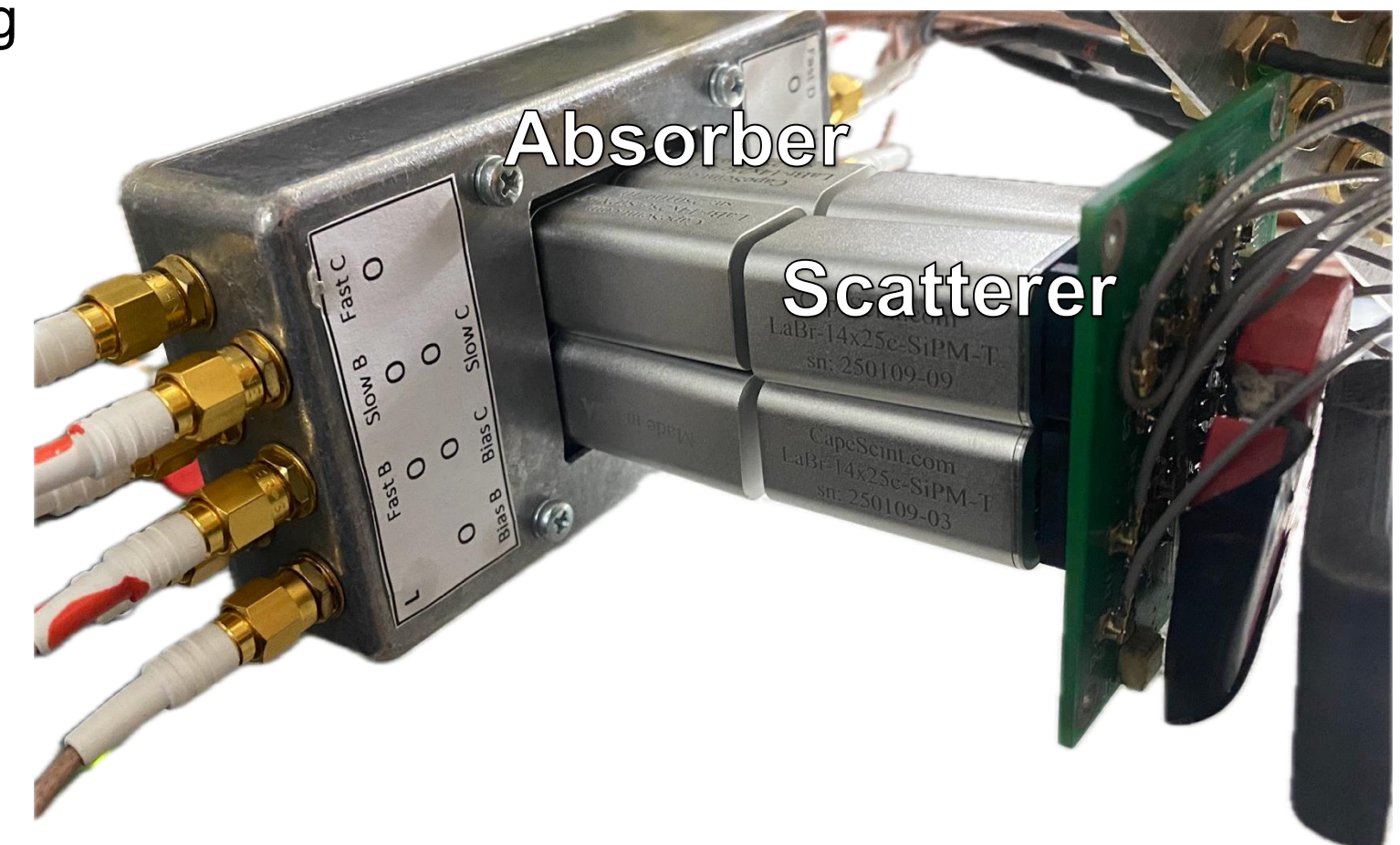
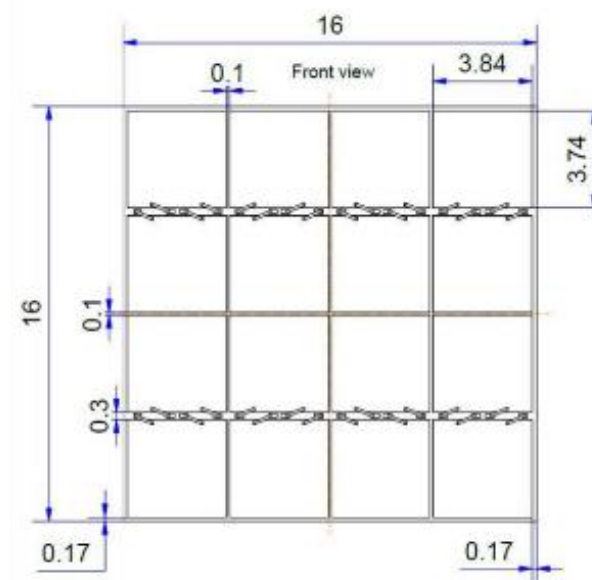
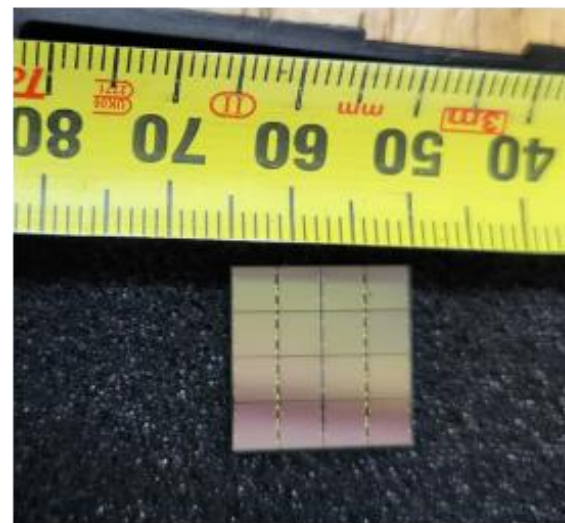
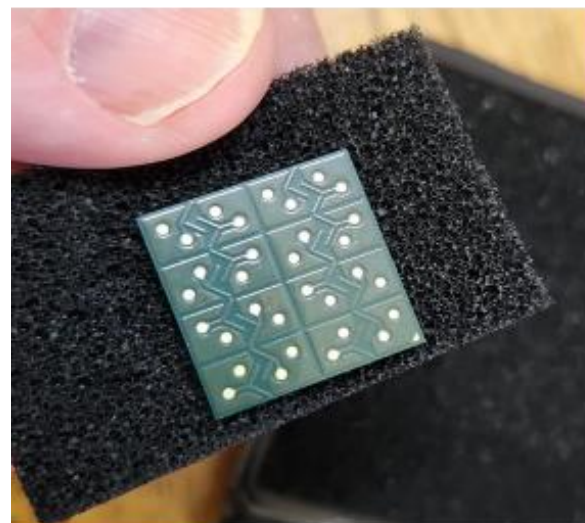
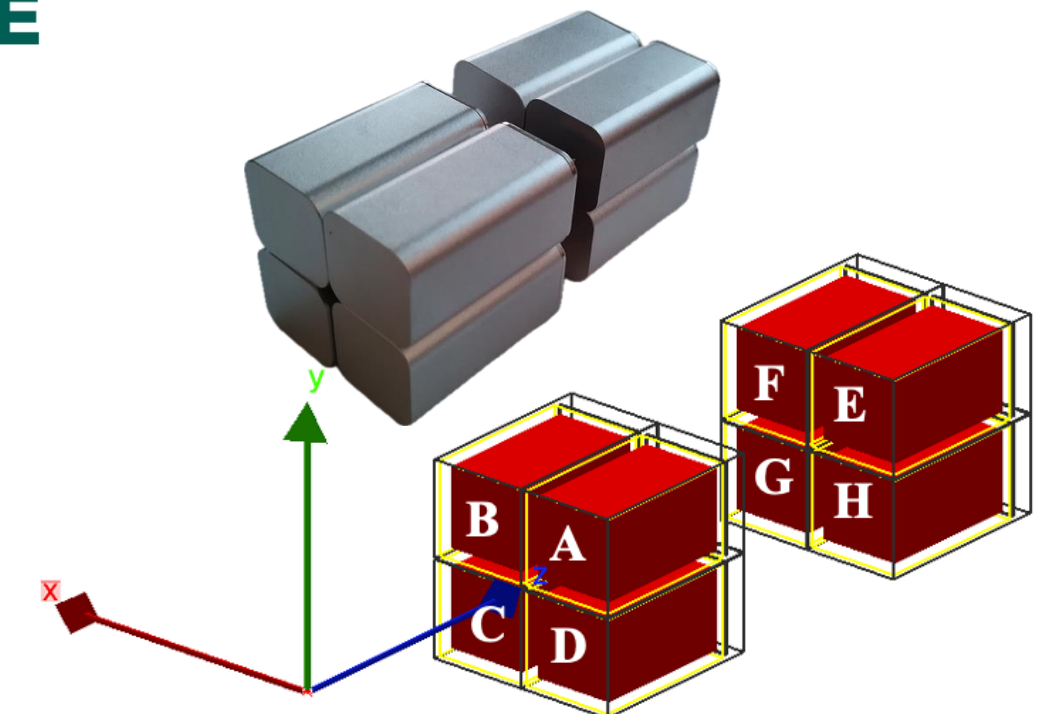
Realistic performance modelling for detector optimisation

Drone-based deployment of Compton Cameras

Environmental monitoring and mapping applications

In-beam proton testing

Evaluation with **70 MeV and 200 MeV proton beams** for medical imaging



The **P**ortable **A**frican **N**eutron-**G**amma **L**aboratory for **I**nnovative **N**uclear **S**cience

Milestones

Reduce footprint of the Mobile Radiation Detection Unit

Adopt next-generation detectors

→ LaBr₃, Srl₂, CLYC (Cs₂LiYCl₆)

Enable neutron sensitivity

→ Effective gamma–neutron discrimination

Transition from photomultipliers to SiPMs

→ Compact, low-power silicon avalanche photodiodes

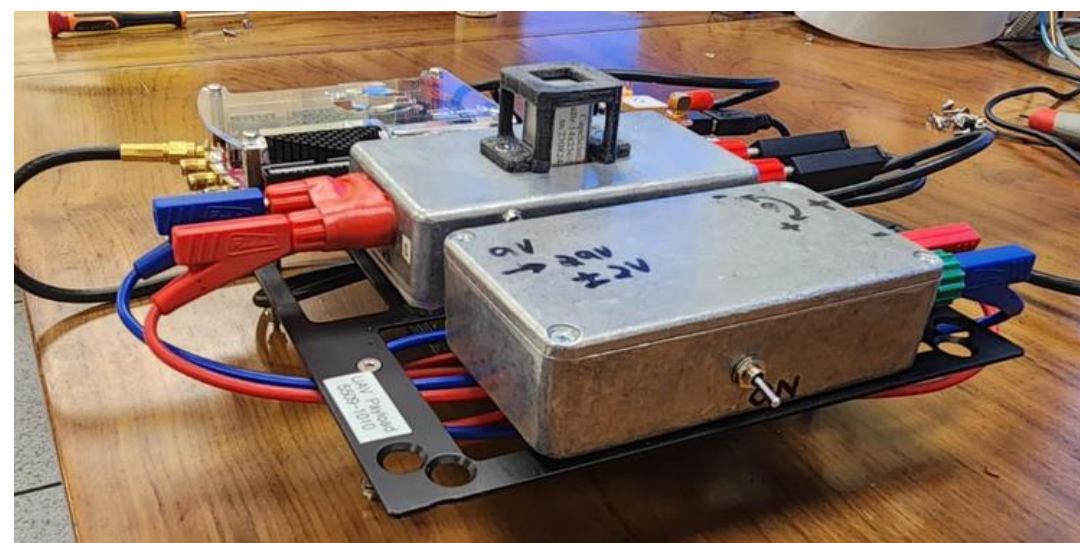
Eliminate high-voltage requirements

→ Move to stable low-voltage operation

Characterise and deploy advanced measurement systems

Expand field testing

→ On-foot surveys and drone-based in-situ deployments



CLYC-6 for Thermal Neutron Detection

Measurements:

$^{241}\text{Am}/^9\text{Be}$ neutron source (6.9 GBq) and ^{60}Co gamma source

PIXIE-16 500 MHz DAQ

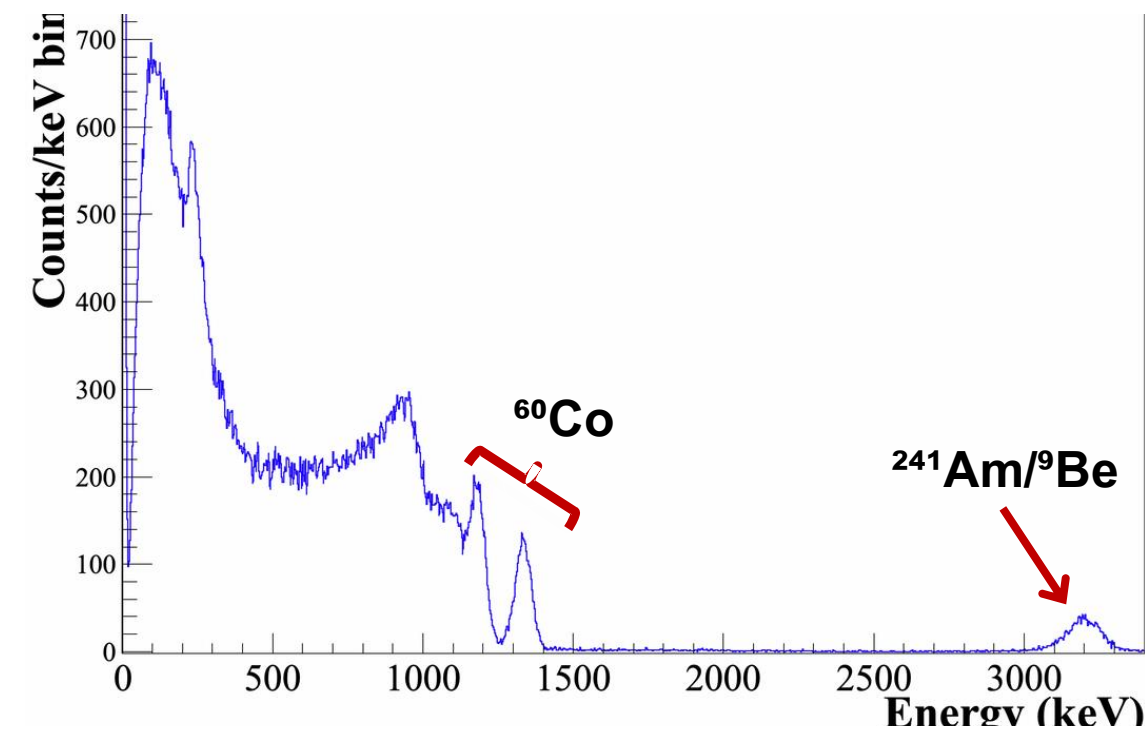
Elpasolite crystal $\text{Cs}_2\text{LiYCl}_6:\text{Ce}$ ($^6\text{Li} = 95\%$) detector **slow signal**.

$^6\text{Li} + n \rightarrow ^3\text{H} (2.73 \text{ MeV}) + \alpha (2.05 \text{ MeV})$ Q-value = 4.78 MeV, $\sigma = 940$ barns at

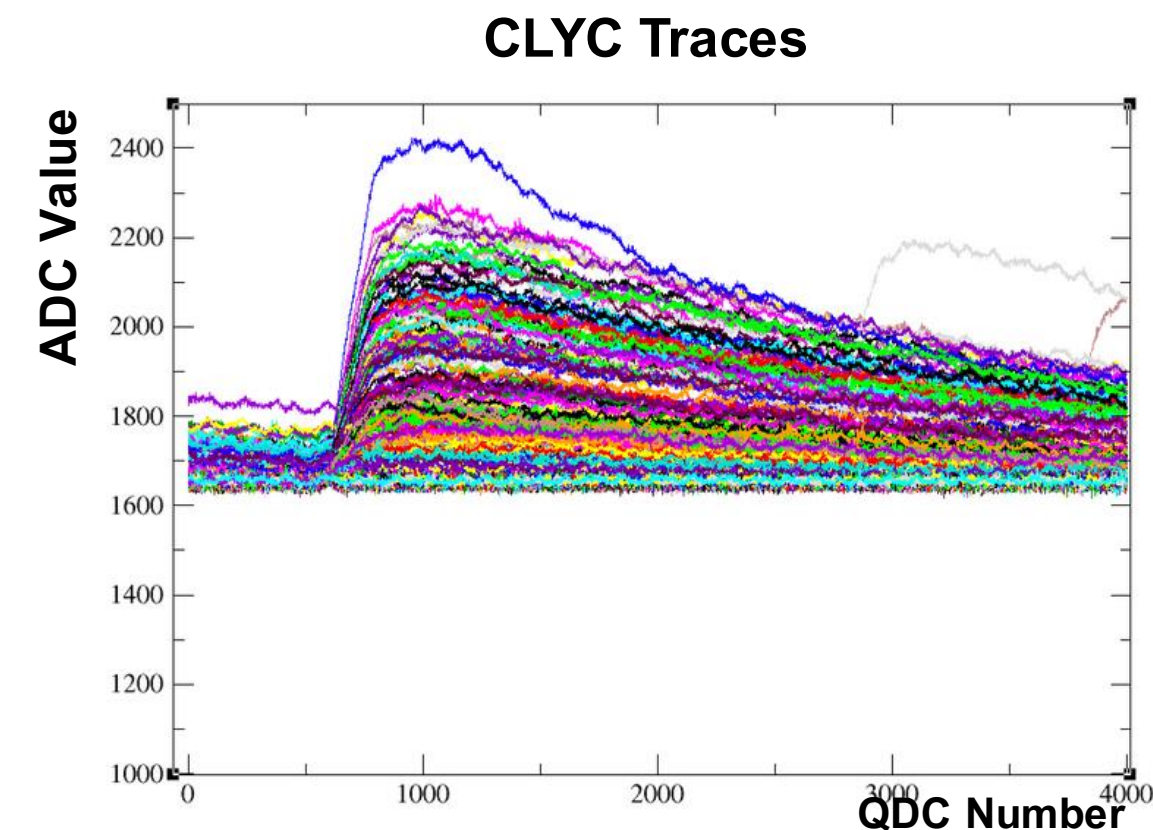
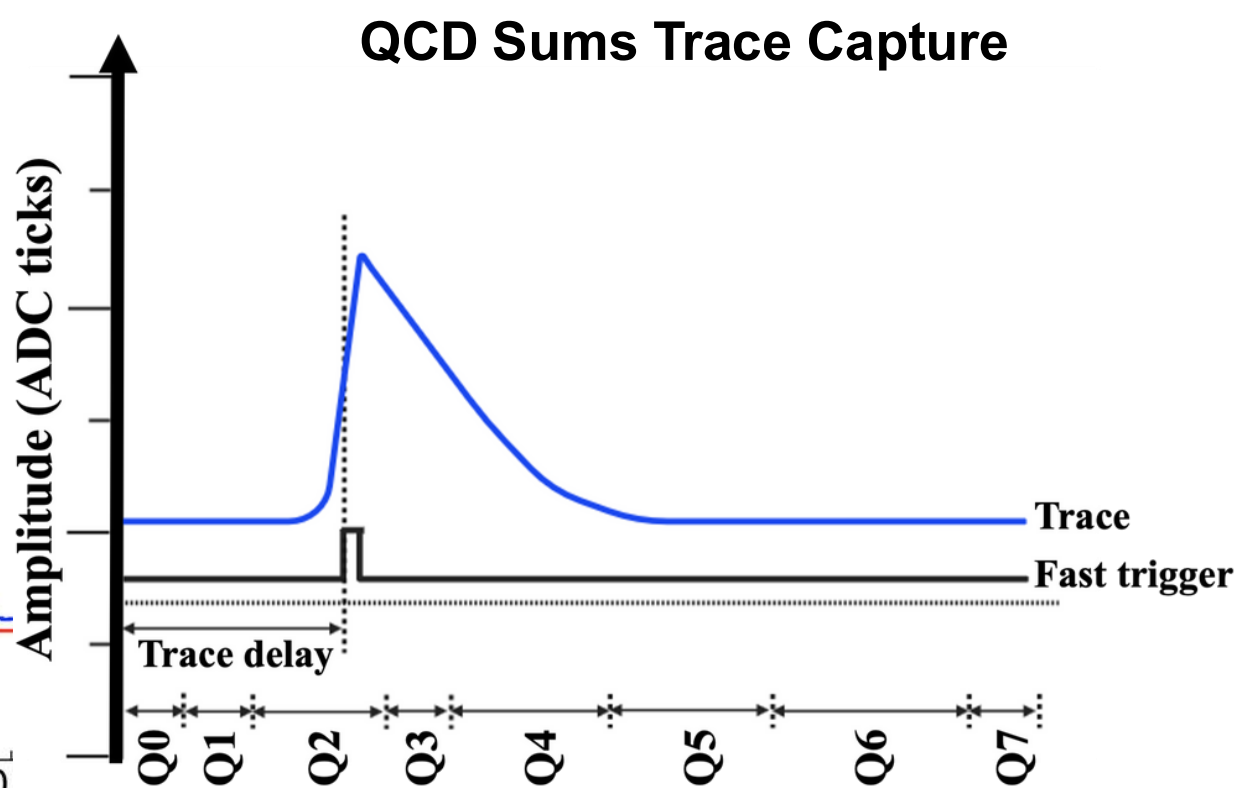
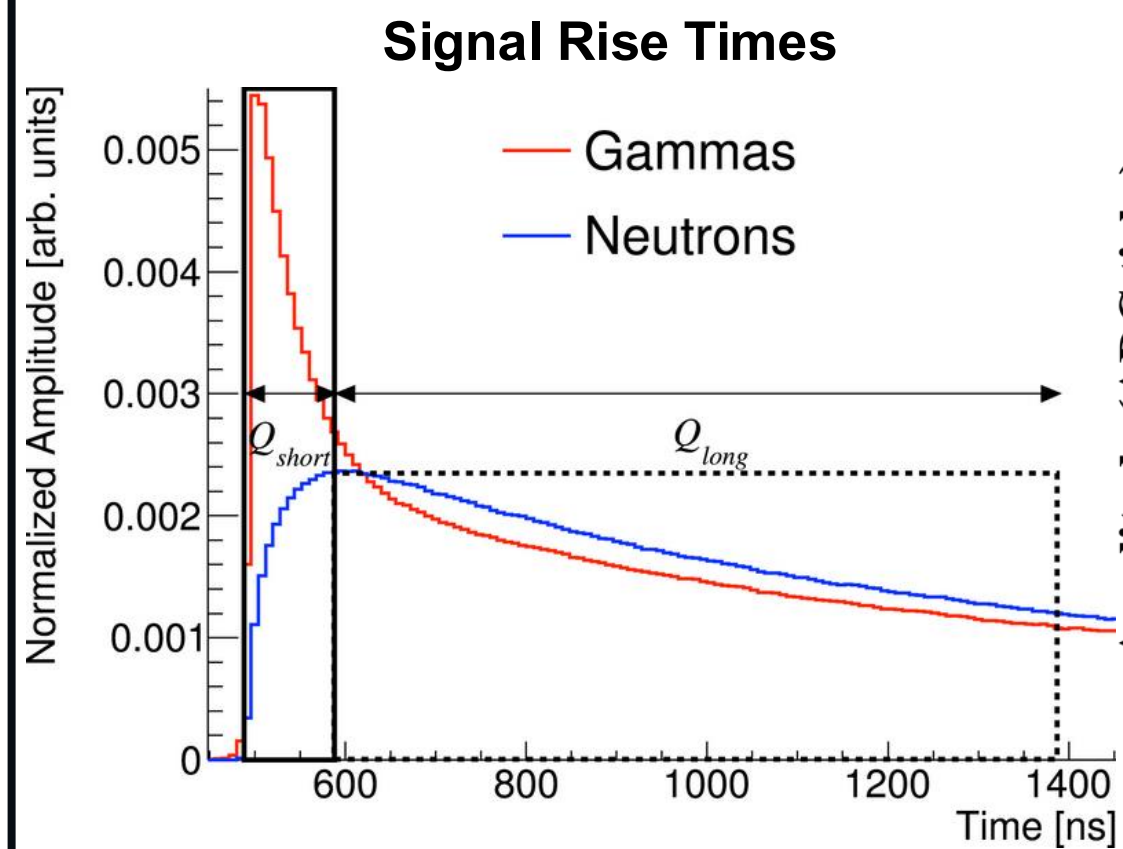
$E_n = 0.025 \text{ eV}$.

$^{35}\text{Cl} + n \rightarrow ^{35}\text{S} + p$

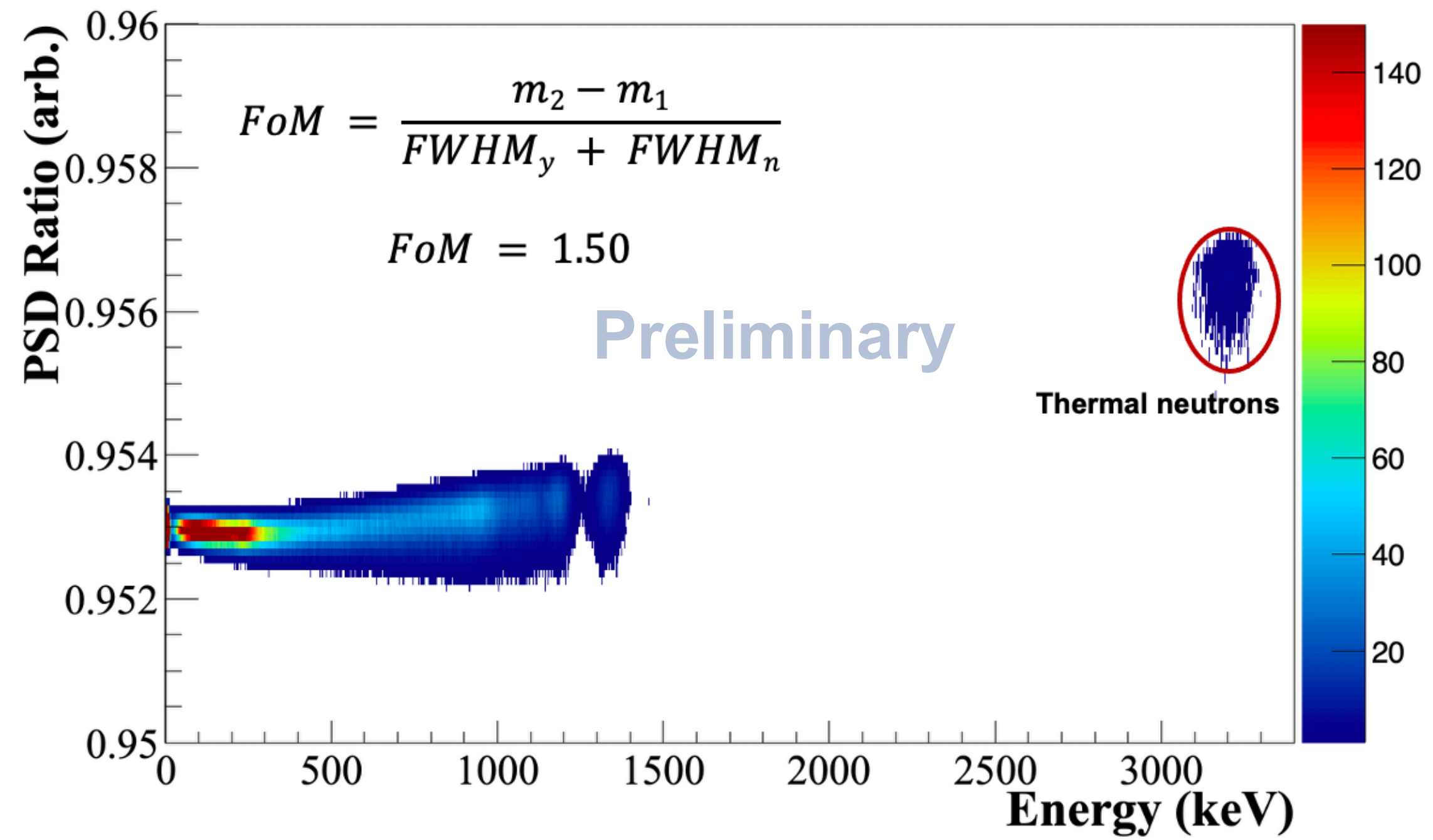
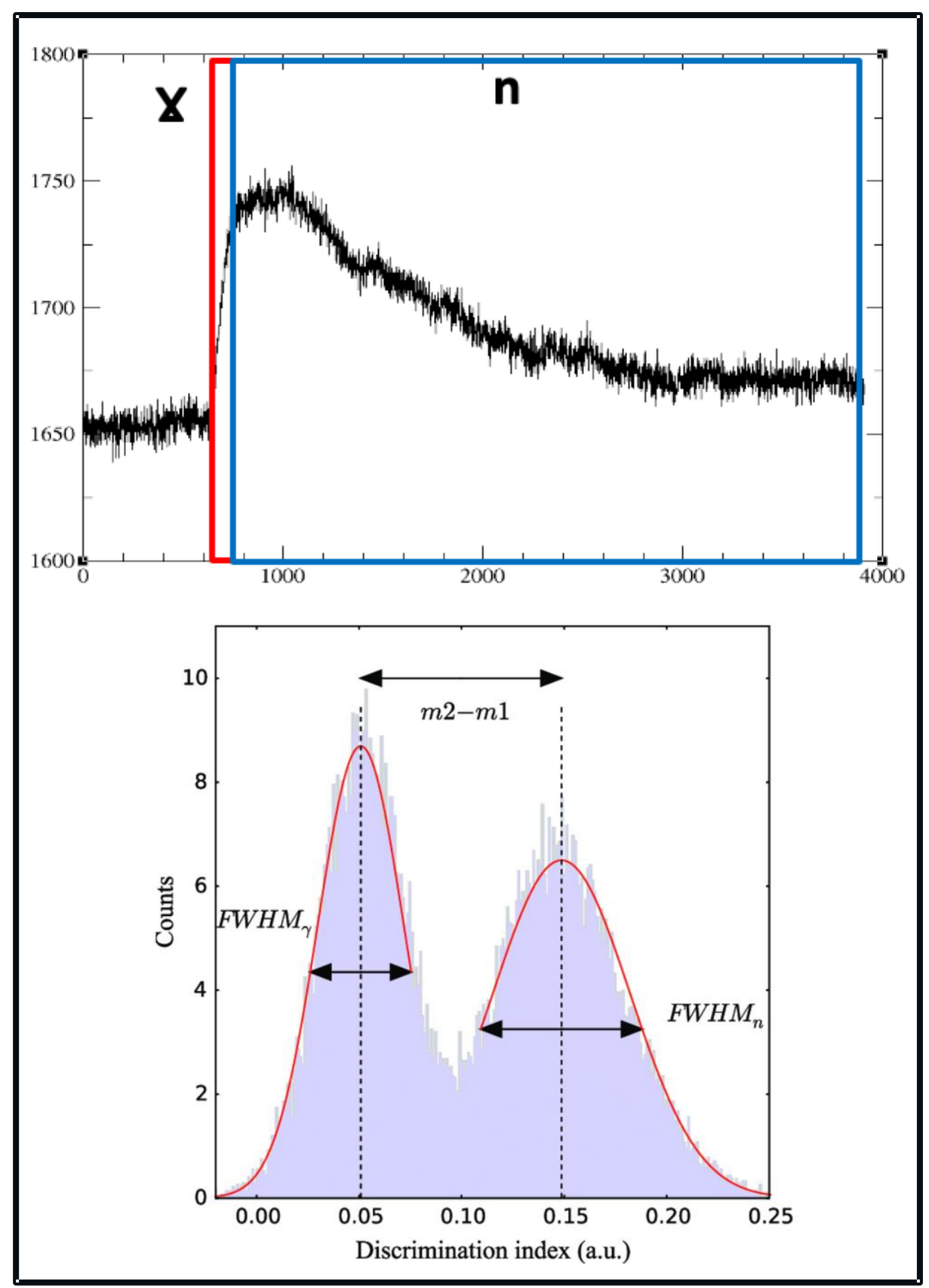
3.2 MeV thermal neutron peak observed due to quenching effects.



PSD is based on the difference in the scintillation decay response to gamma and neutrons



Another Application: CLYC-6 for Thermal Neutron Detection





DASSIE Project

Digital Acquisition Signal System for Innovative Experimentation

Goal: Develop a **low-power, low-cost, lightweight, and scalable** streaming digitiser for real-time radiation detection.

Applications: Medical imaging, environmental monitoring, and security.

Key Features:

- Local **pulse shape analysis**, real-time **network streaming**, and time-stamped data storage.
- Compatible with **small-volume scintillator detectors**
- **Wireless user interface** for control and data access.

Hardware Specs:

Digitisation: 1 GHz, 14-bit ADC, ± 1 V range

Firmware Features:

- Digital Leading-Edge / CFD
- Moving Window Deconvolution (adaptive preferred)
- Pile-up detection
- 8 user-defined integration windows
- External trigger handling to reduce data rate



Science and
Technology
Facilities Council



iThemba
LABS
Laboratory for Accelerator
Based Sciences

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Collaborators & Contributors

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Technology Innovation Agency (TIA)



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Thank you for your attention

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Questions?

Back-up slides

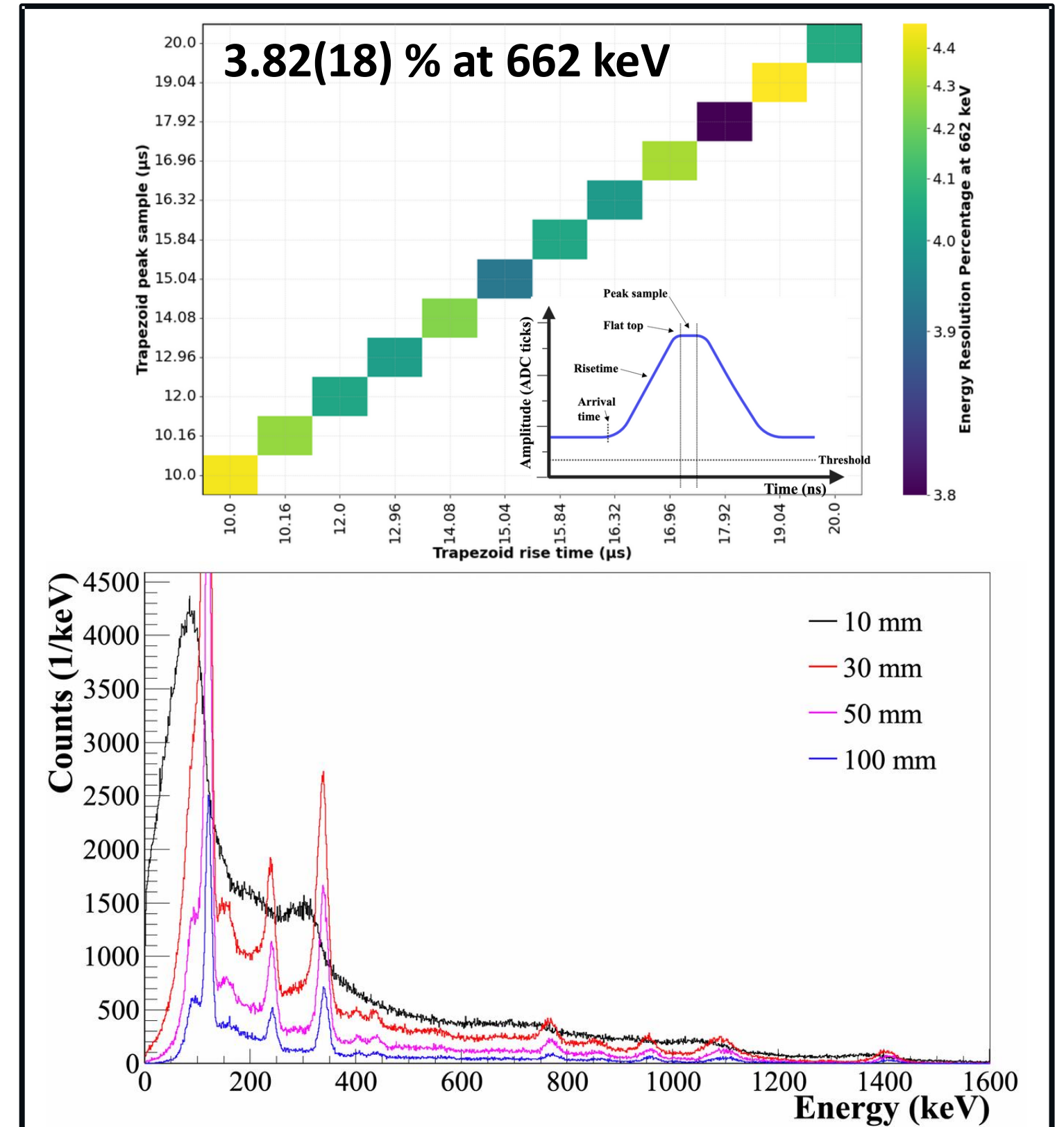
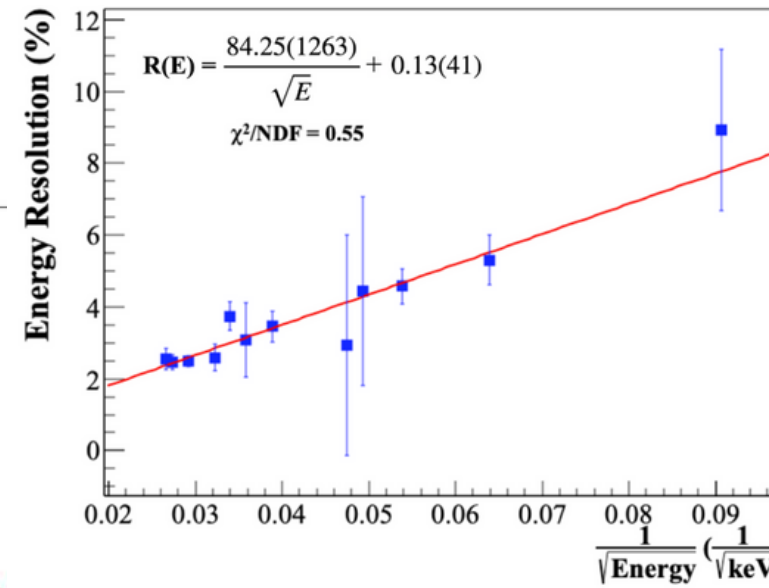
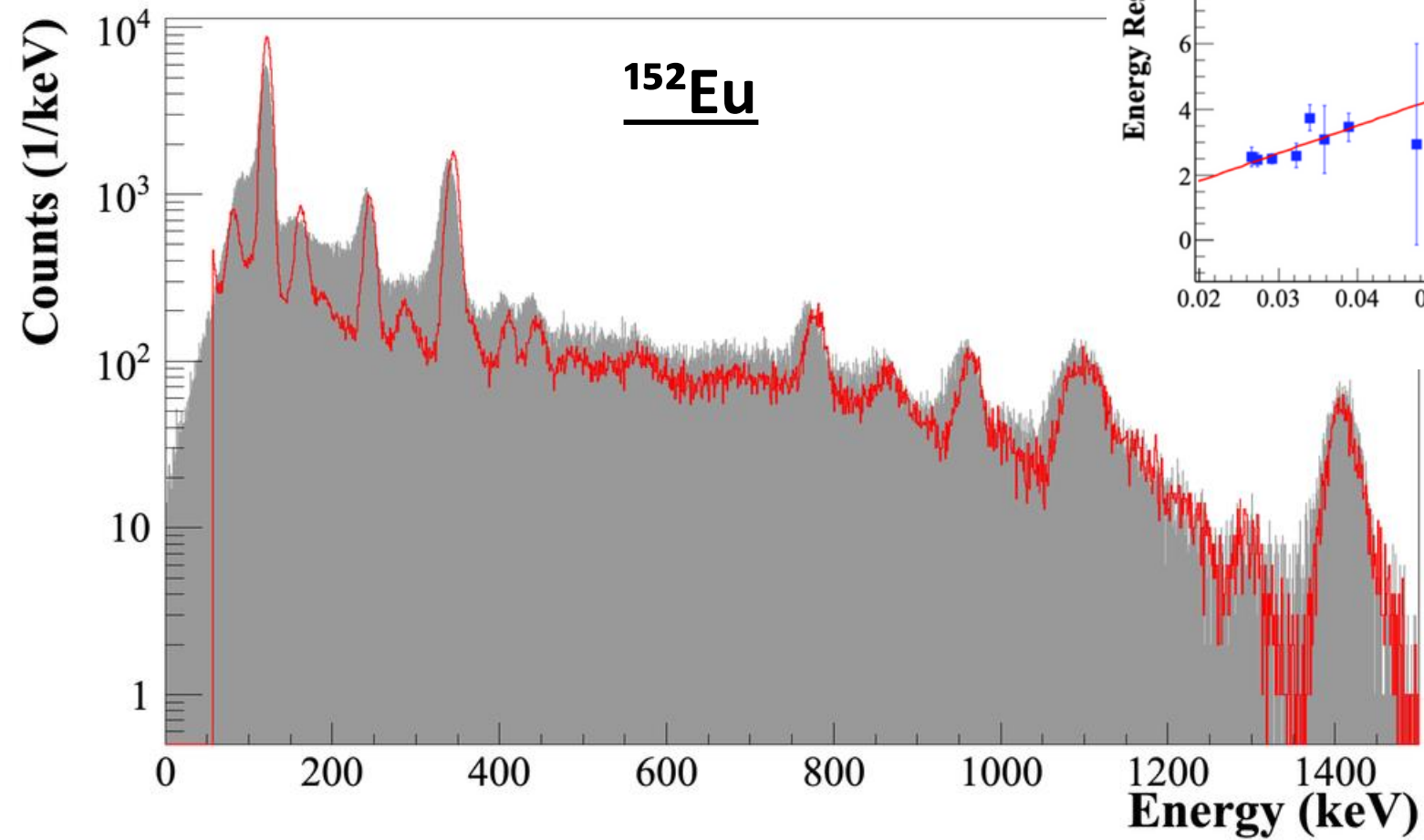
Validation of CC Detector Simulation



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SrI₂:Eu-SiPM



Distance (mm)	344.28 keV			968.08 keV		
	ε _{EXP,FEPE} (%)	ε _{SIMU,FEPE} (%)	Agreement (σ)	ε _{EXP,FEPE} (%)	ε _{SIMU,FEPE} (%)	Agreement (σ)
30.0	0.282(87)	0.480(11)	2.26	0.053(10)	0.043(6)	0.86
50.0	0.124(15)	0.196(9)	4.12	0.031(15)	0.019(3)	0.79
100.0	0.045(6)	0.060(34)	0.43	0.011(3)	0.010(5)	0.17

Table 2: Comparison of experimental and simulation for the SrI₂:Eu DA absolute full-energy peak efficiencies and associated uncertainties for gamma-ray energies 344.28 keV and 968.08 keV at various source-to-detector distances.

Poor agreement, saturation at high count rates

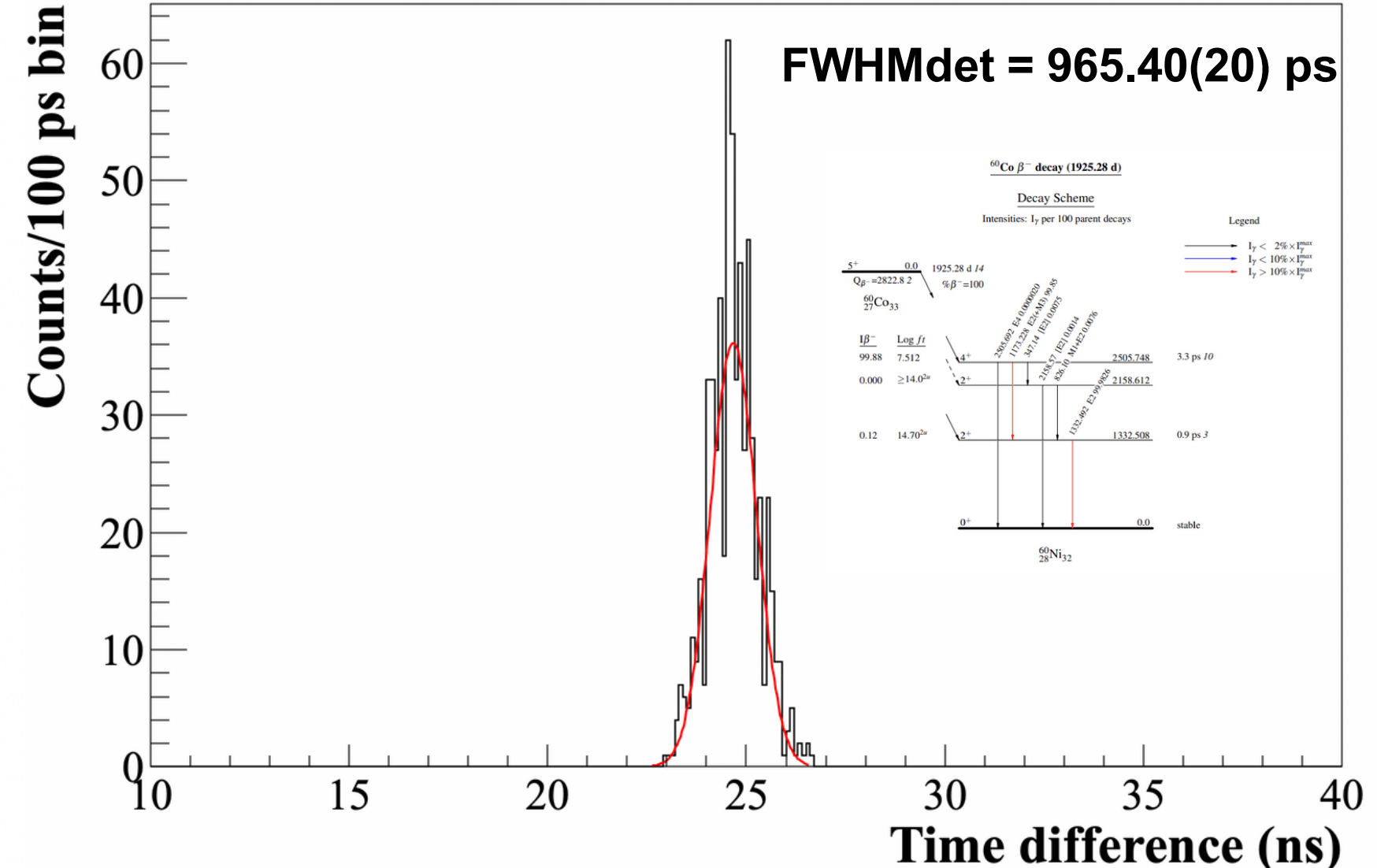
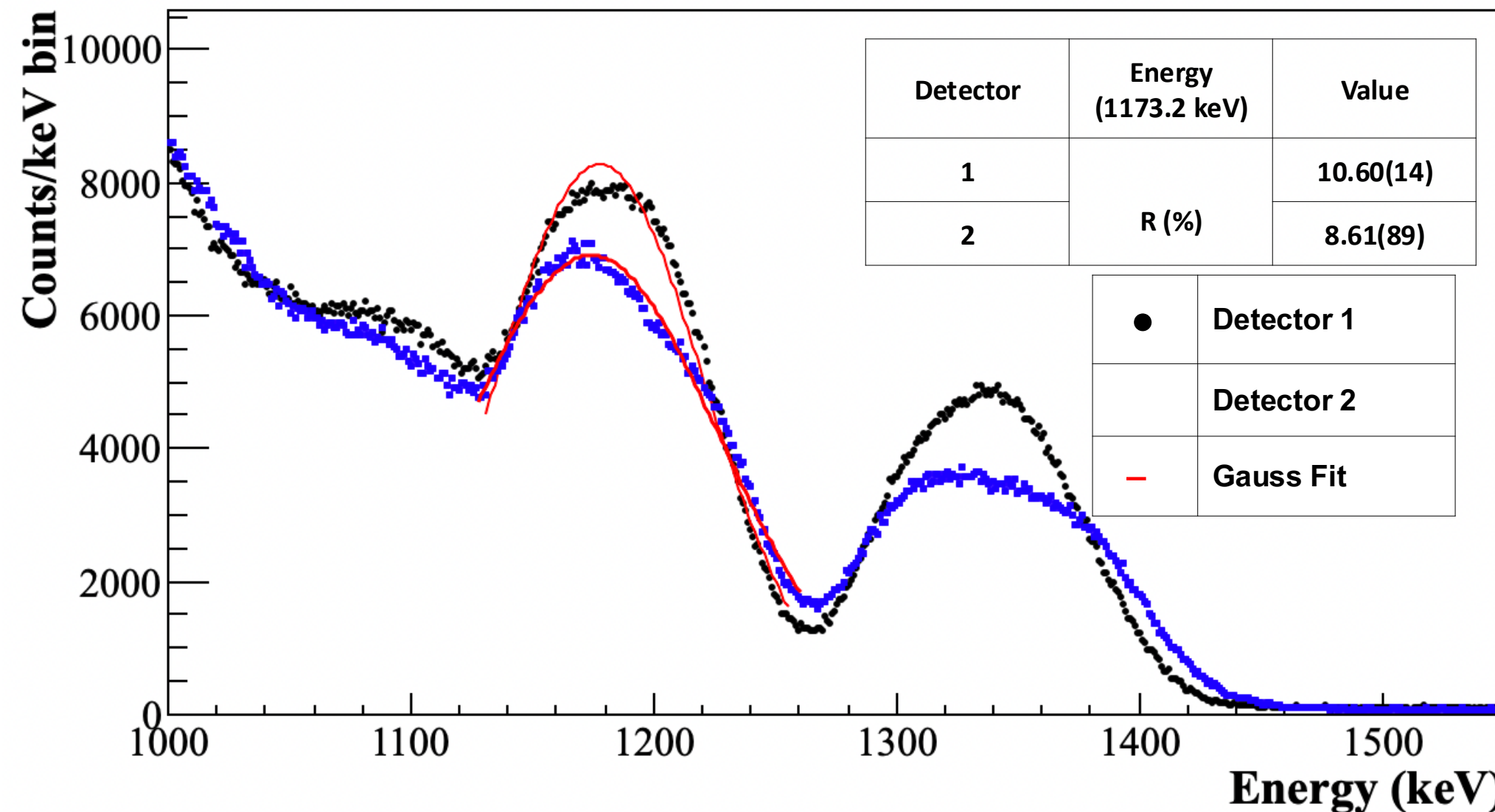
SrI₂:Eu Detector Fast-Timing Resolution

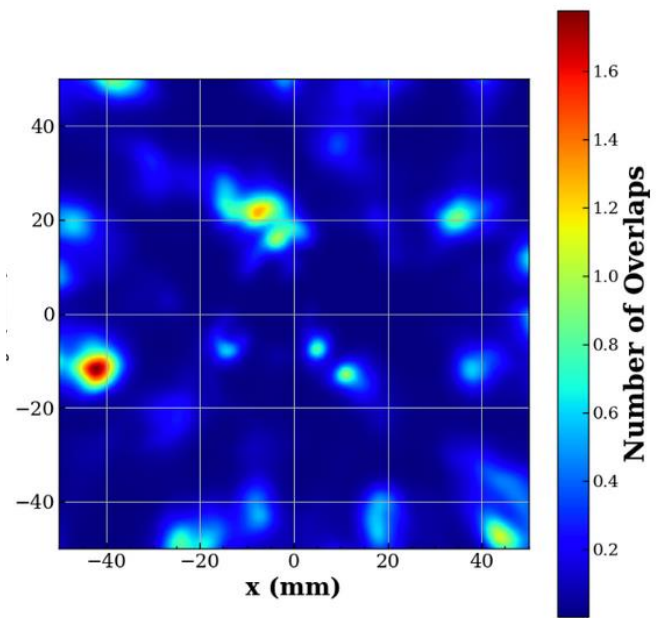


Calculated by gating on the ⁶⁰Co prompt-gamma decays.

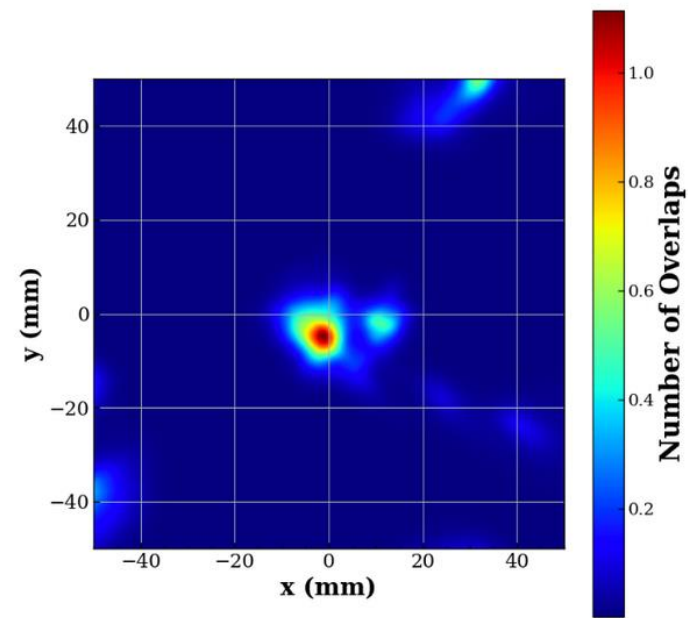
The time interval between the 1173 keV and 1332 keV emissions is <0.9 ps, effectively instantaneous compared to detector resolution.

Measurements performed using the PIXIE-16 500 MHz data acquisition system, exploiting the use of the digital CFD for fast timing.

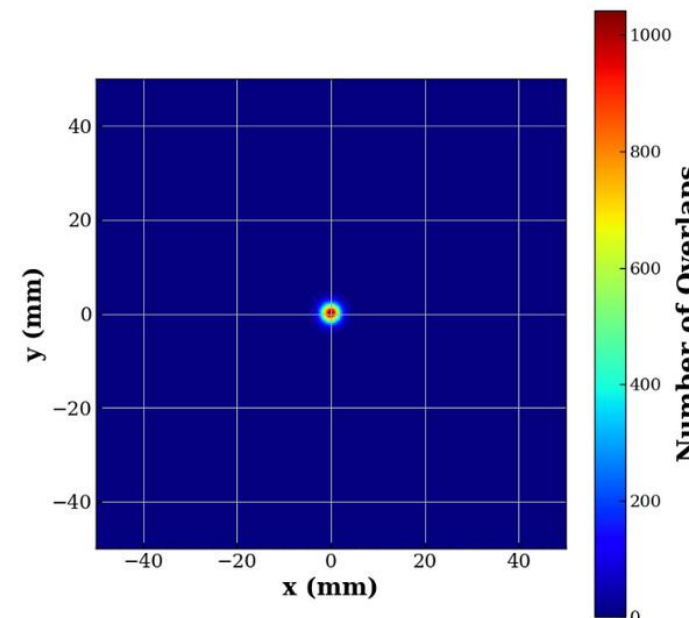




(a)

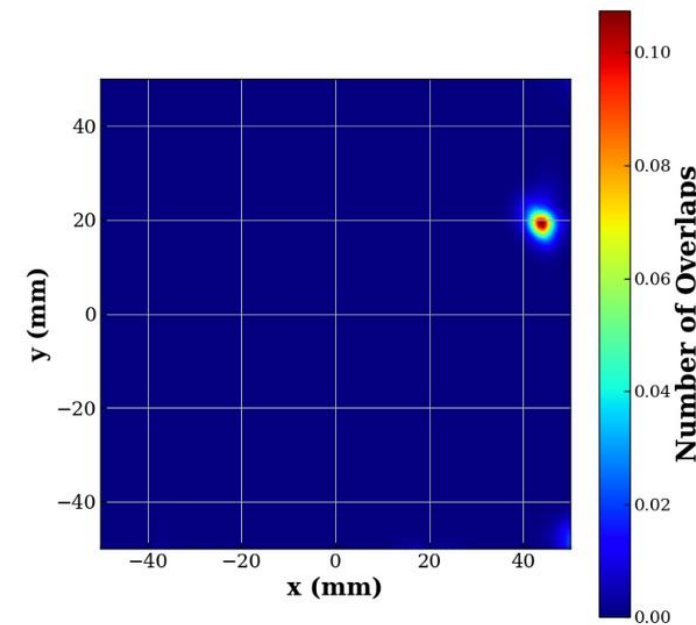
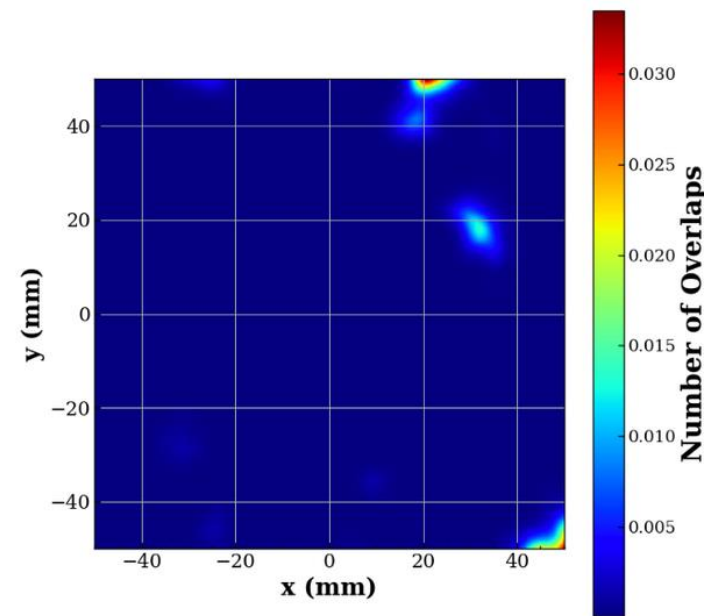


(b)



(c)

Image Reconstruction Optimisation

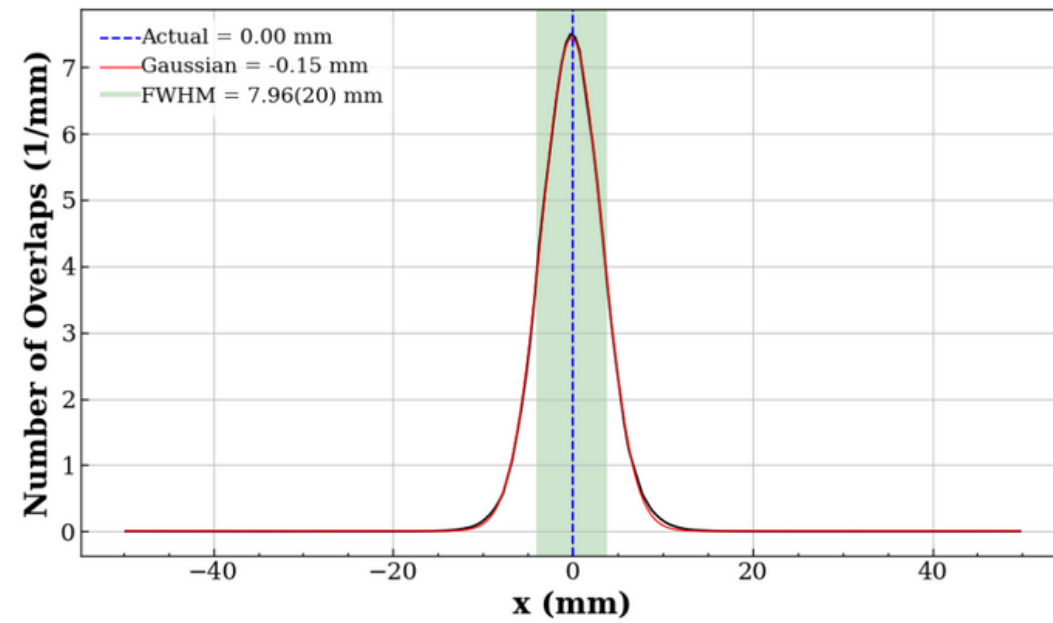


The x-y matrix of CC1 shown at different z slice values for the same Octane EM reconstruction

Image Reconstruction Optimisation

The x and y projections (sliced at the maximum y-z and x-z values respectively) of CC1 shown for different bin width in the Octane EM reconstruction.

5 mm bin width



2 mm bin width

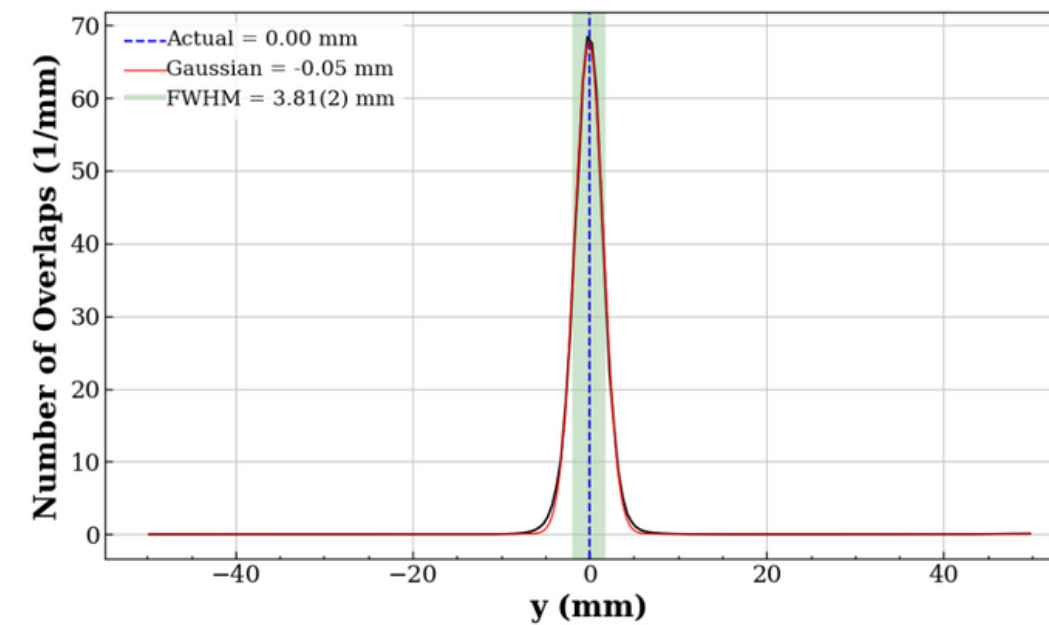
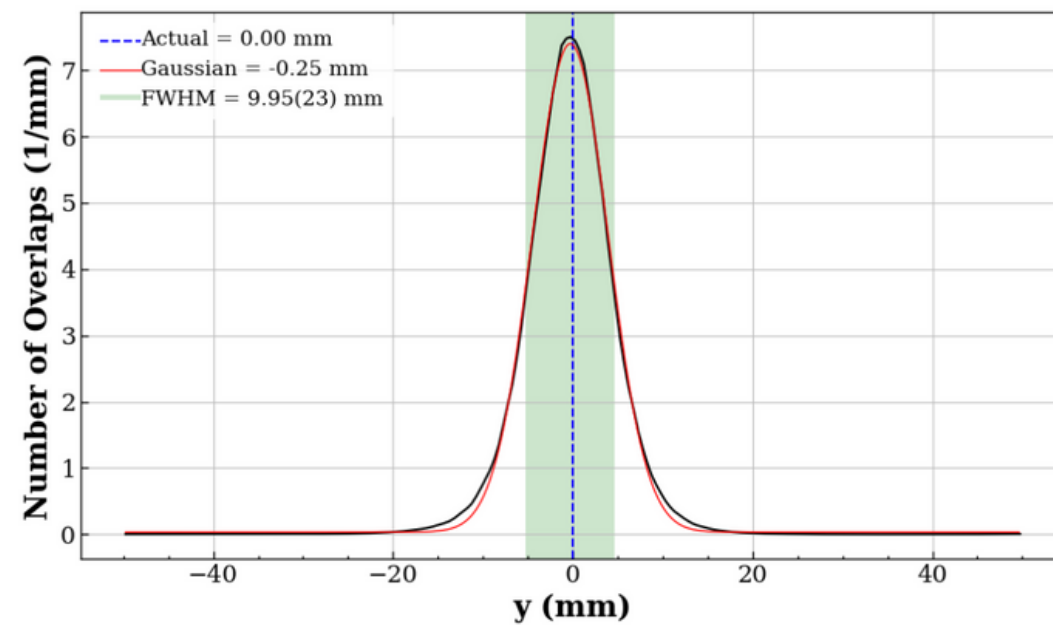
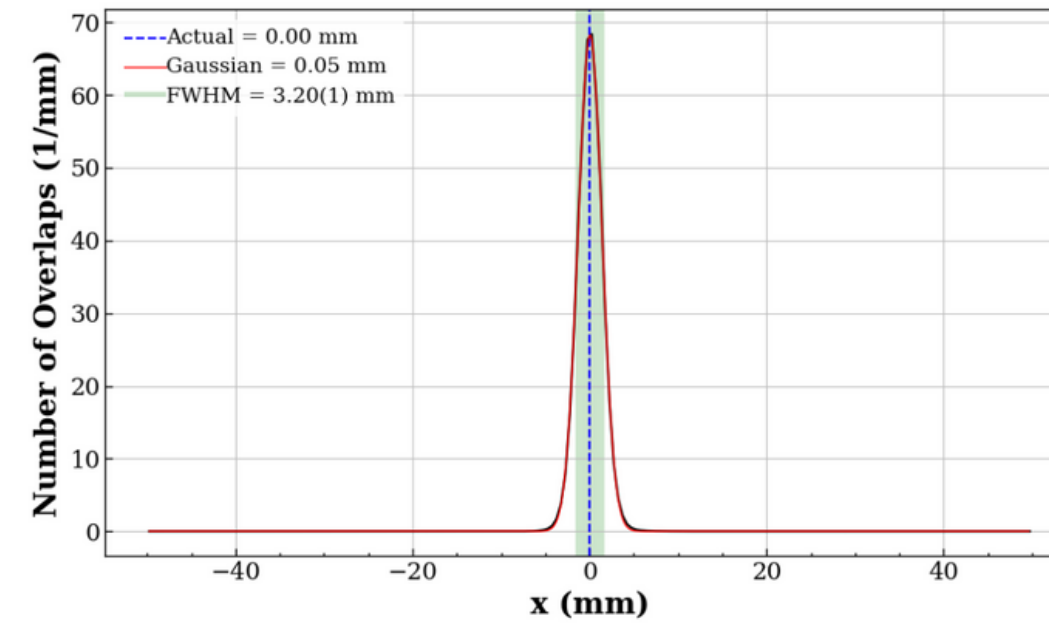


Image Reconstruction Optimisation

The x and y projections (sliced at the maximum y-z and x-z values respectively) of CC1 shown for different numbers of iterations in the Octane EM reconstruction.

