X-Ray and γ-Ray Detectors for use in Nuclear Physics and Applications

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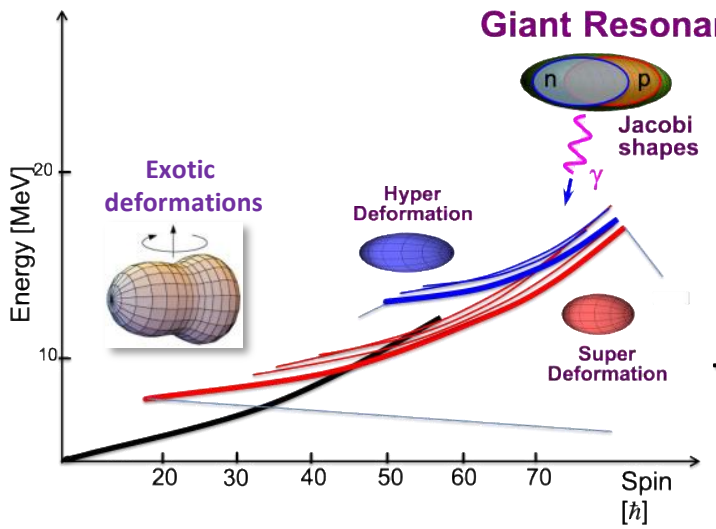
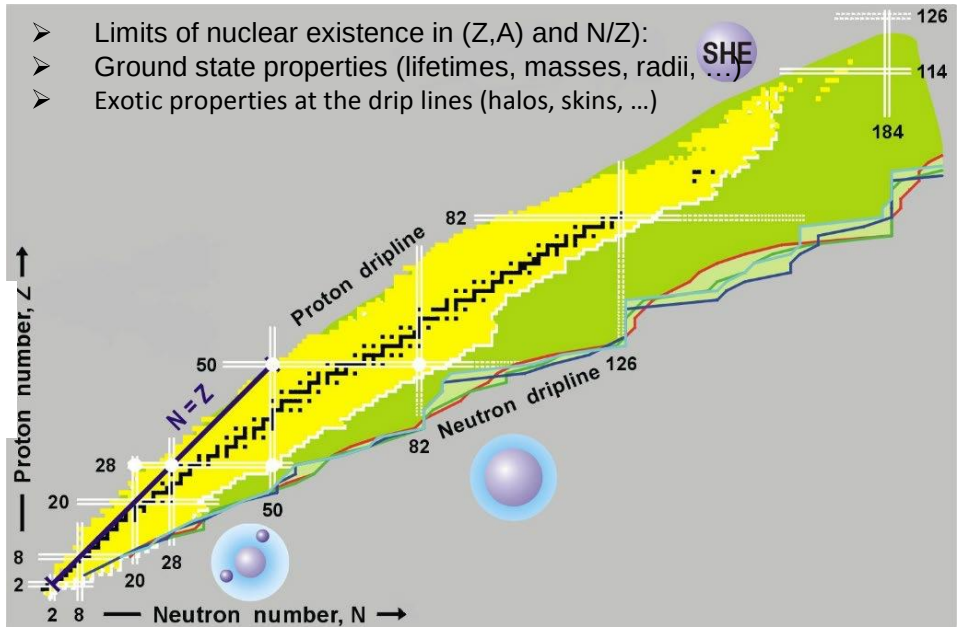
Talk Overview

- Introduction – Challenges in NP
- What is AGATA?
- Gamma Ray Tracking
- Pulse Shape Analysis
- Applications
- Conclusions

Challenges in Nuclear Structure Physics





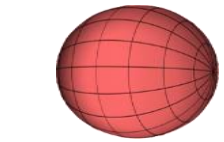
Energy/ Temperature

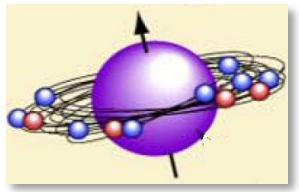
N/Z - isospin

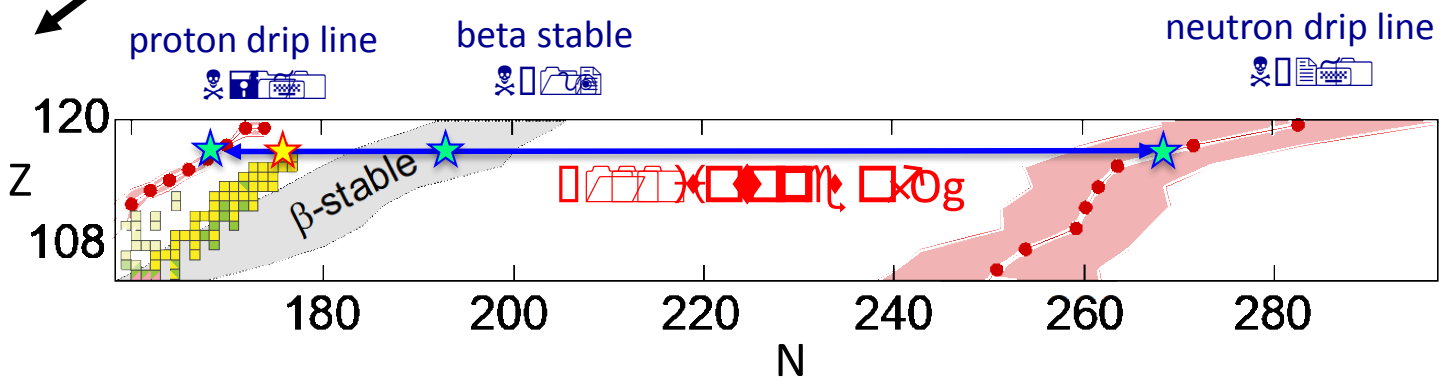
Spin

Properties of excited states

- γ-ray spectroscopy







The Need for Position Sensitive Detector Array

The challenge of the new generation of radioactive beam facilities

FAIR (Germany)
SPIRAL (France)
SPES (Italy)
HIE-ISOLDE (CERN)

Harsh conditions!

- Low intensity
- High background
- Large Doppler broadening
- High counting rates
- High gamma-ray multiplicities

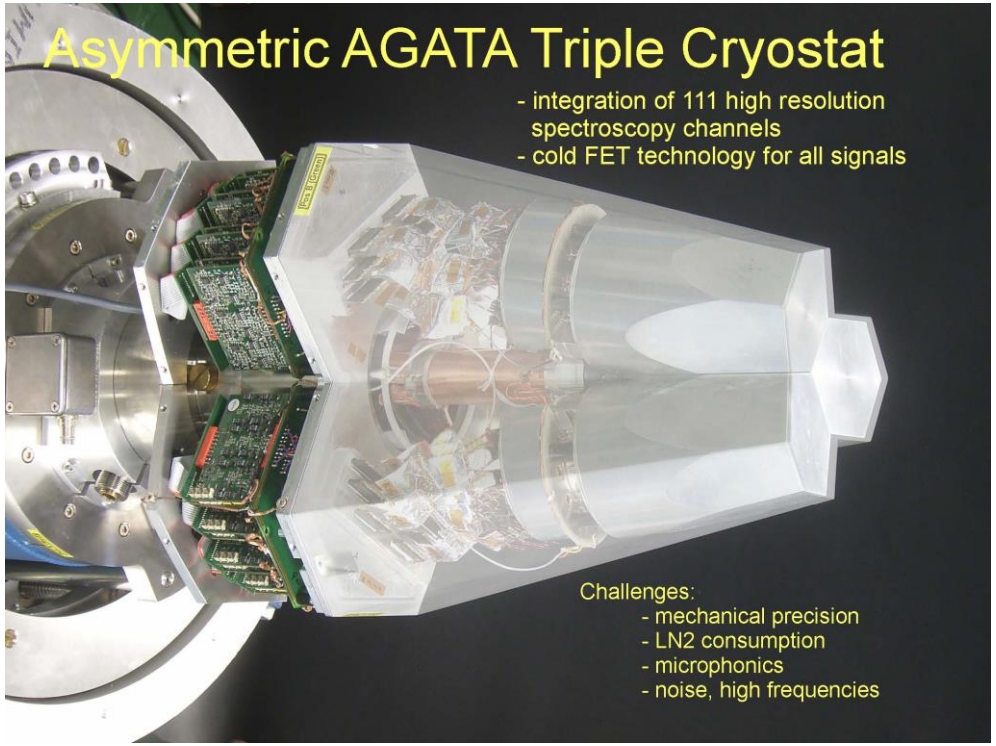
The ideal γ-ray spectrometer AGATA

- High efficiency
- Distinguish gammas from b/g
- Highly position sensitive
- High data throughput
- Can distinguish multiple gammas

AGATA
ADVANCED GAMMA TRACKING ARRAY

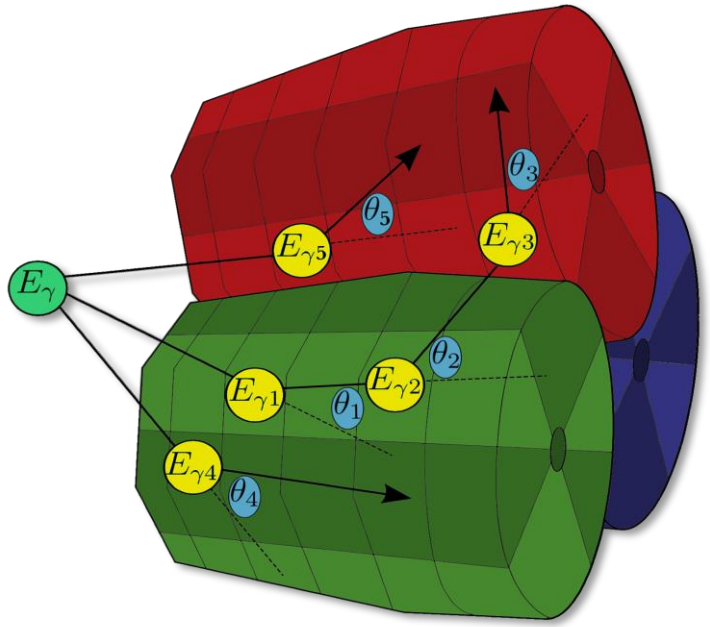
What is AGATA?

13 Countries, > 40 Institutions



AGATA Definition: NIM A 668 (2012) 26

- Solid **Sphere of Ge material**: Solid angle coverage ~ 82 %
- 36-fold **segmentation** of crystal
- **Track** each gamma interaction through the crystal
- **Reconstruct** and **disentangle** gammas



Rates	3 MHz (Mγ= 1)	300 kHz (Mγ= 30)
Efficiency	43% (Mγ= 1)	28% (Mγ = 30)
Peak/Total	58% (Mγ= 1)	49% (Mγ = 30)
Angular Resolution	~1°	
FWHM (1MeV), v/c = 50%	~6keV	

180 hexagonal crystals: 3 shapes
3 fold clusters (cold FET): 60 all equal
Inner radius (Ge): 23.5 cm
Amount of germanium: 362 kg
36-fold segmentation 6480 segments

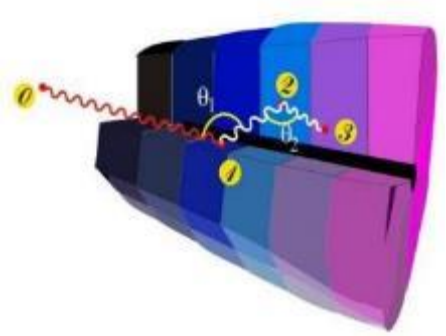
AGATA ADVANCED GAMMA TRACKING ARRAY

AGATA Tracking Concept

1

Highly segmented HPGe detectors

γ



2

Digital electronics to record and process signals

3

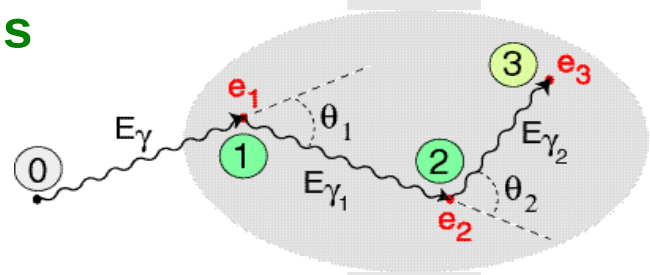
Identified interaction points

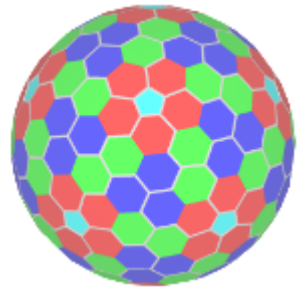
$(x,y,z,E,t)_i$

Pulse Shape Analysis to decompose recorded waves

4

Evaluation of permutations of interaction points





Reconstructed γ rays

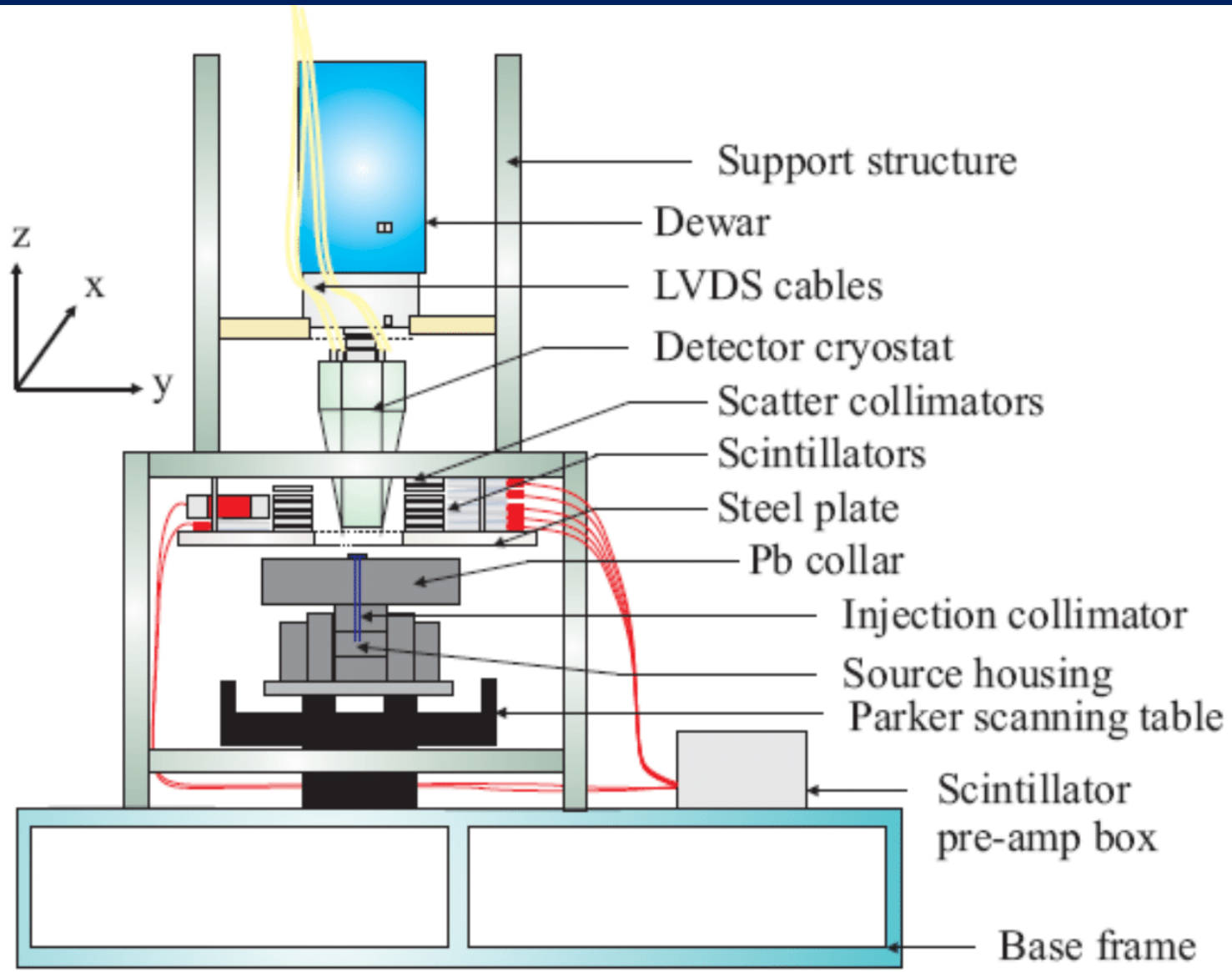
AGATA
ADVANCED GAMMA TRACKING ARRAY

Characterisation of Detectors

It is important we know of the position performance of each AGATA crystal vary with:

- Crystal shape / effective segmentation
- Impurity gradient
- HV
- Axis orientation
- Differential cross talk

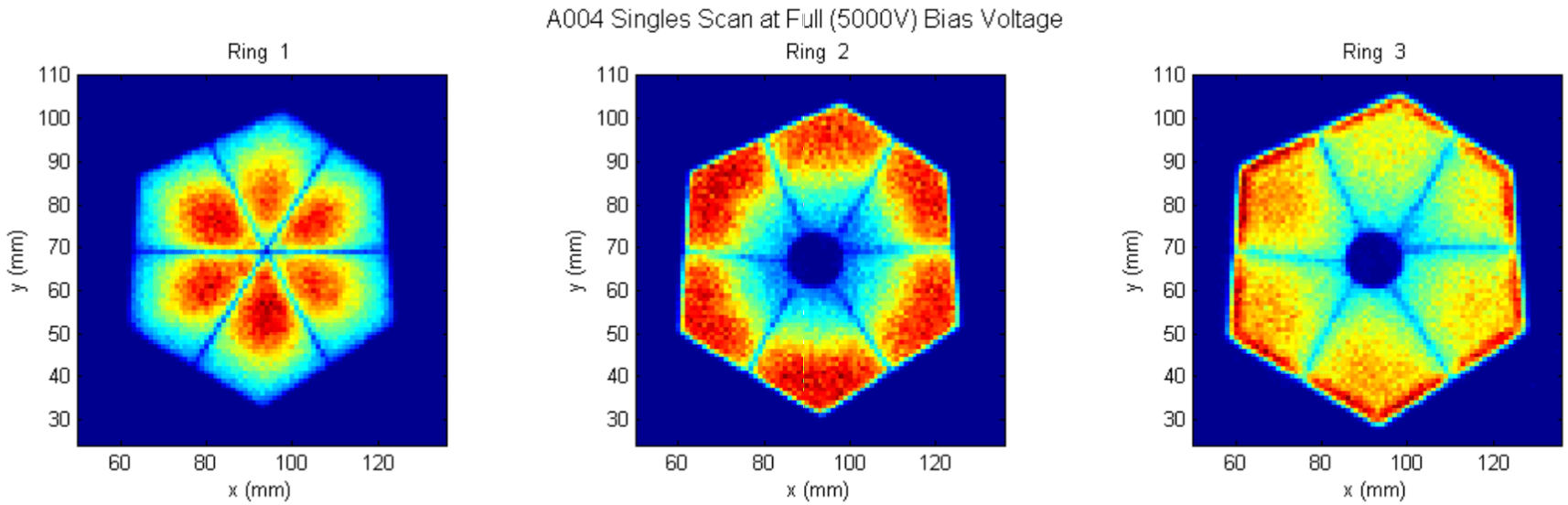
Detector Characterisation at UoL



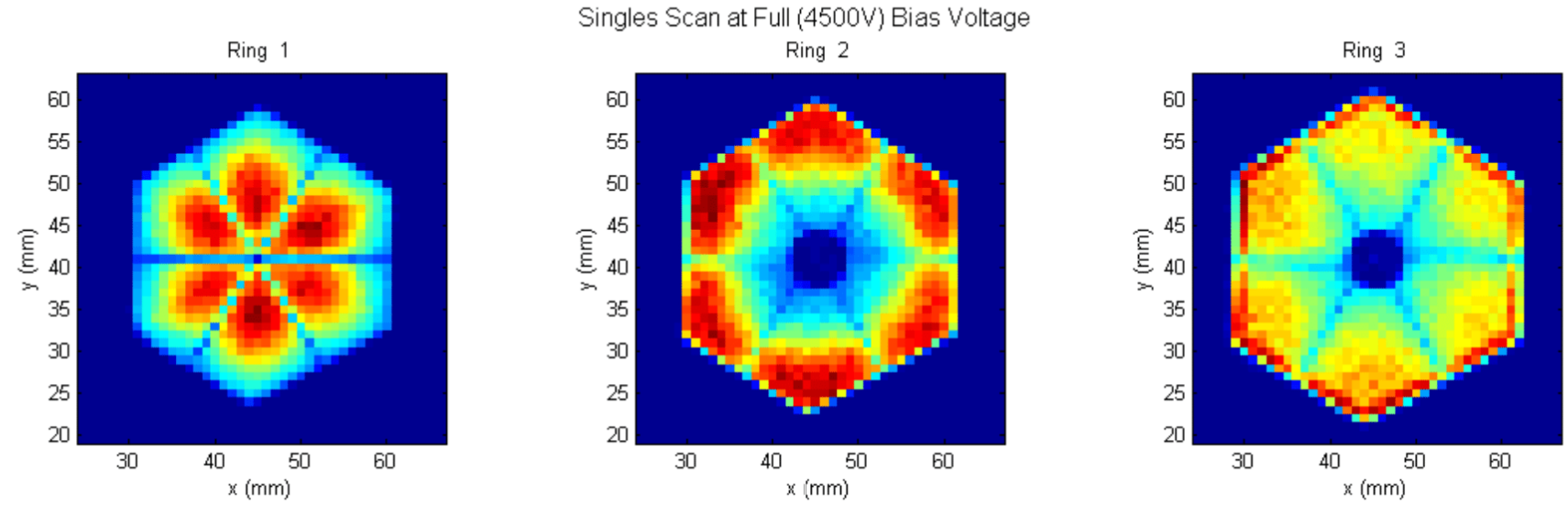
- **Singles**
- **Coincidence scanning**
- **Very precise and accurate**
- **Can be very slow**

Singles Scanning

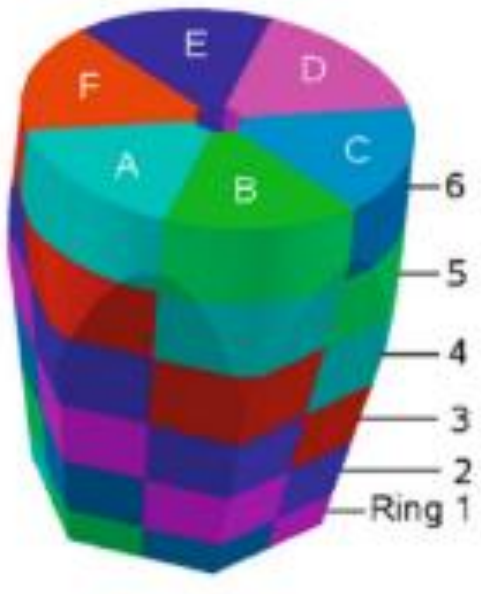
A4

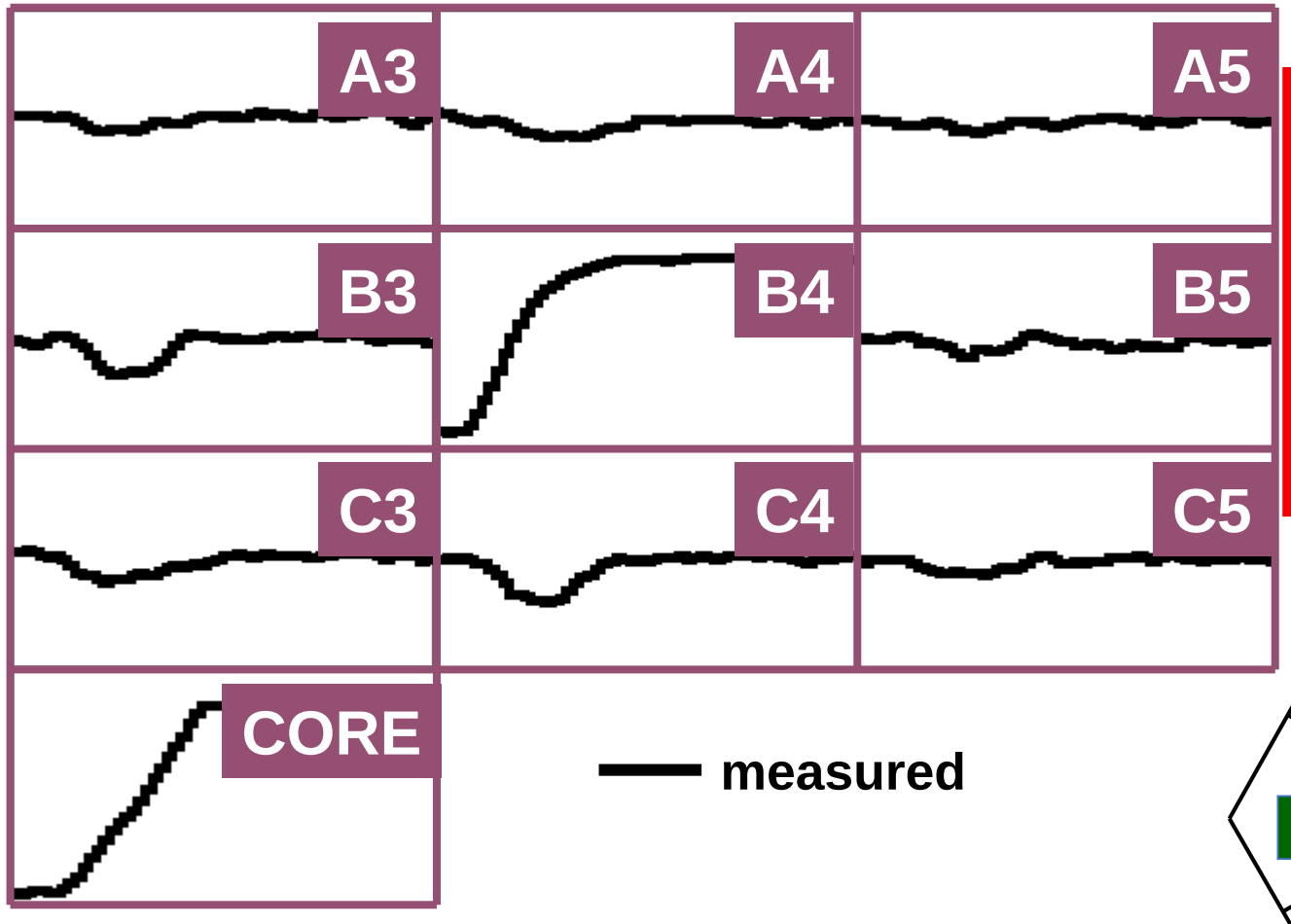


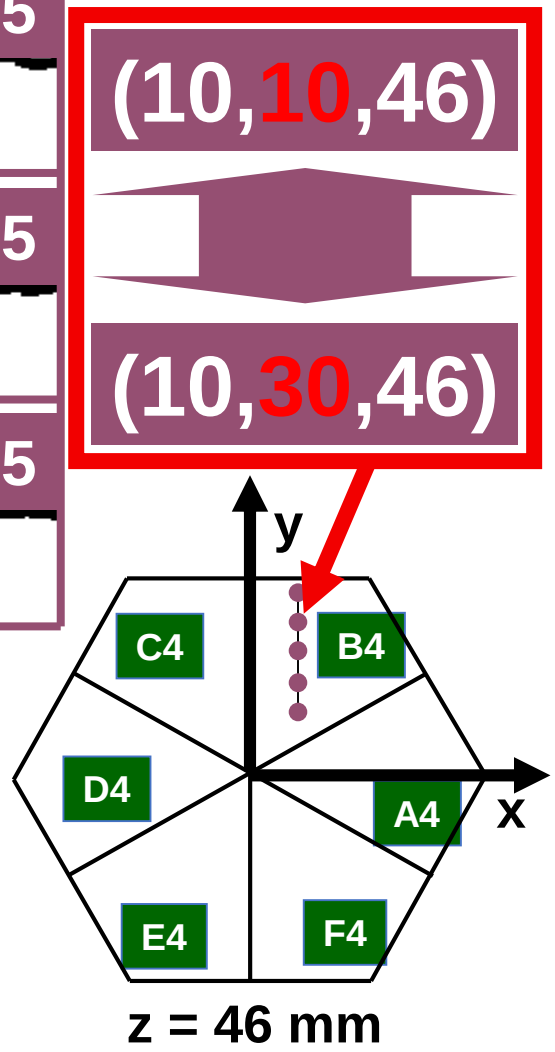
C1



Pulse Shape Analysis Concept

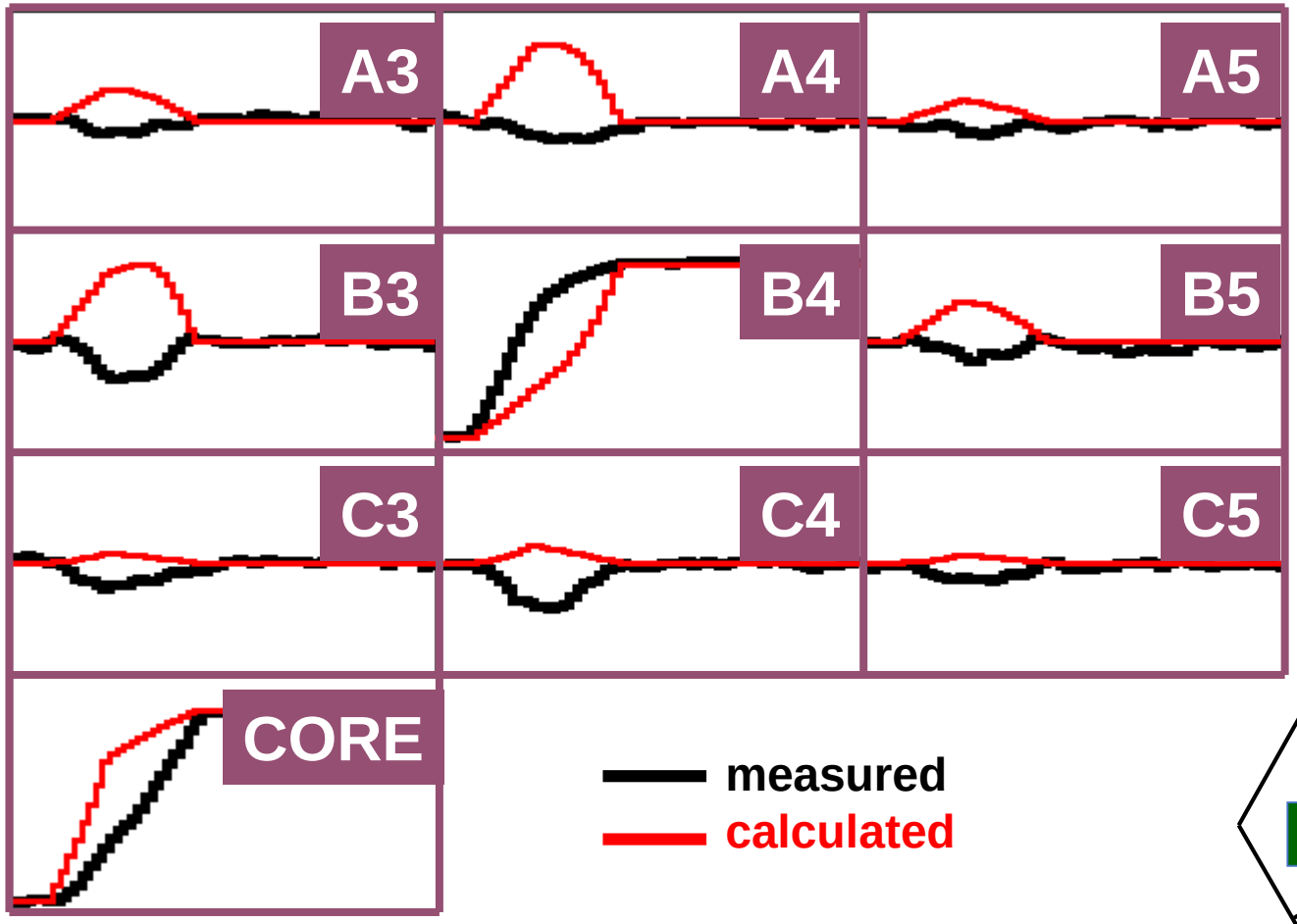






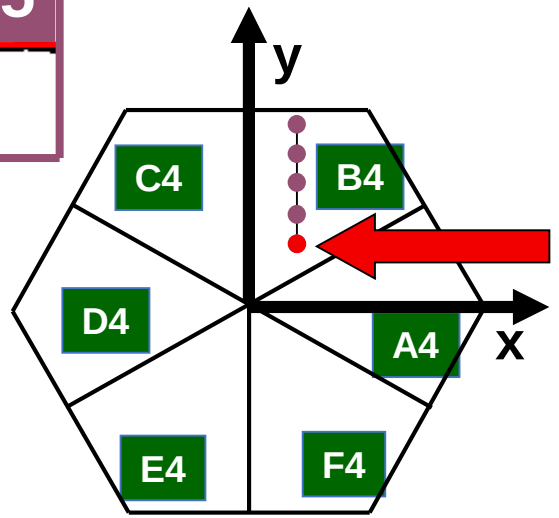
791 keV deposited in segment B4

Pulse Shape Analysis Concept



Calculated from Electric field simulation

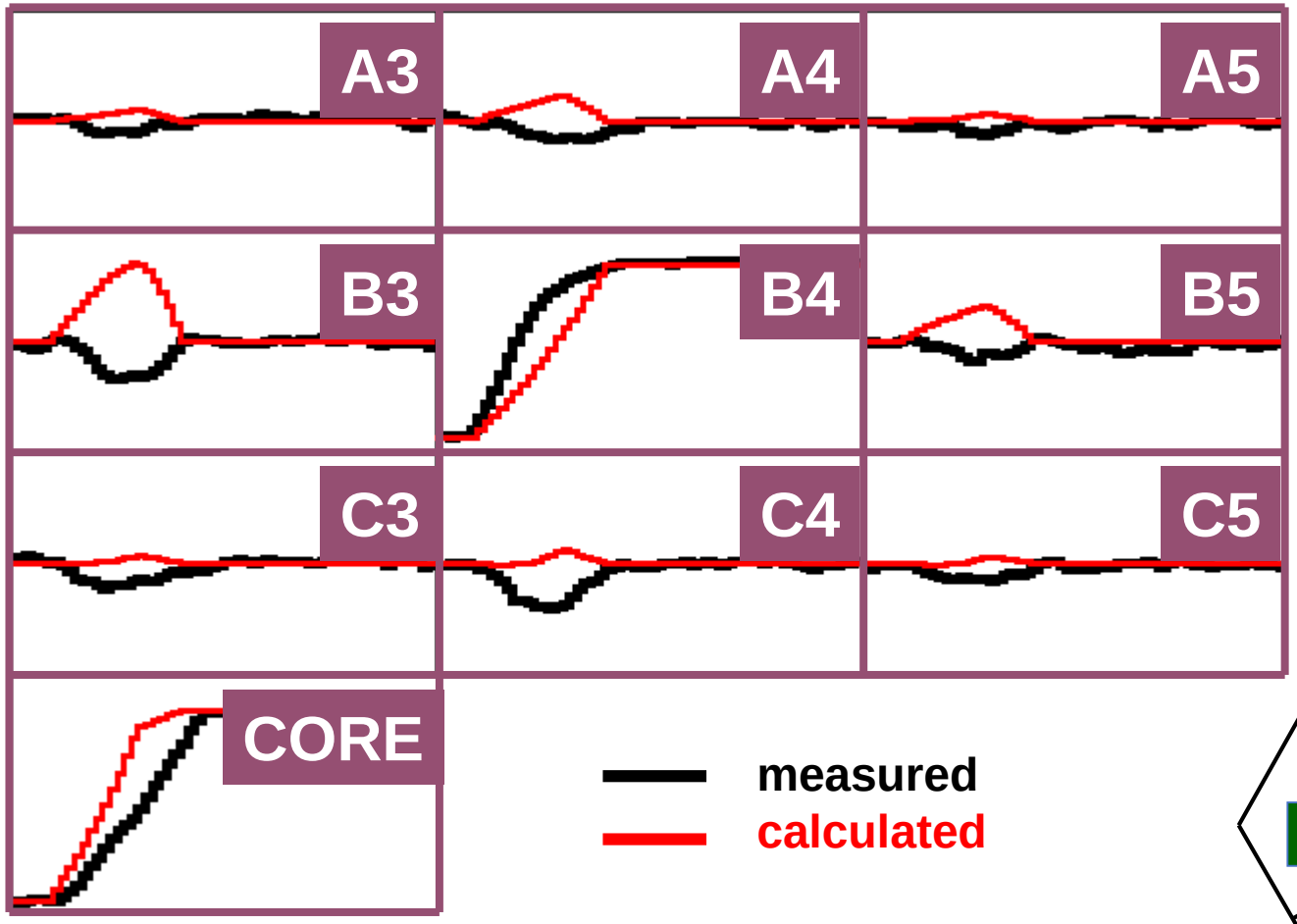
(10,10,46)



z = 46 mm

791 keV deposited in segment B4

Pulse Shape Analysis Concept



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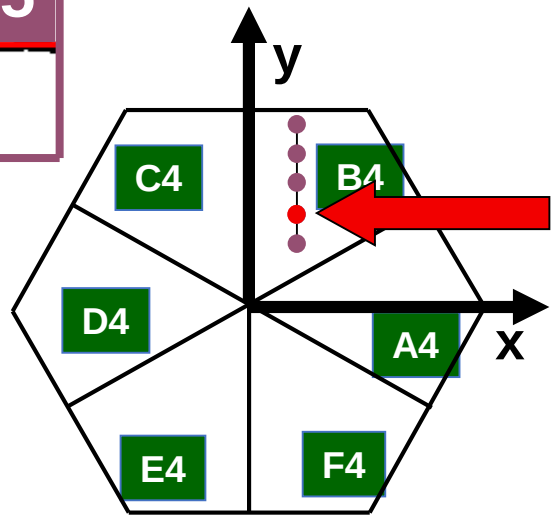

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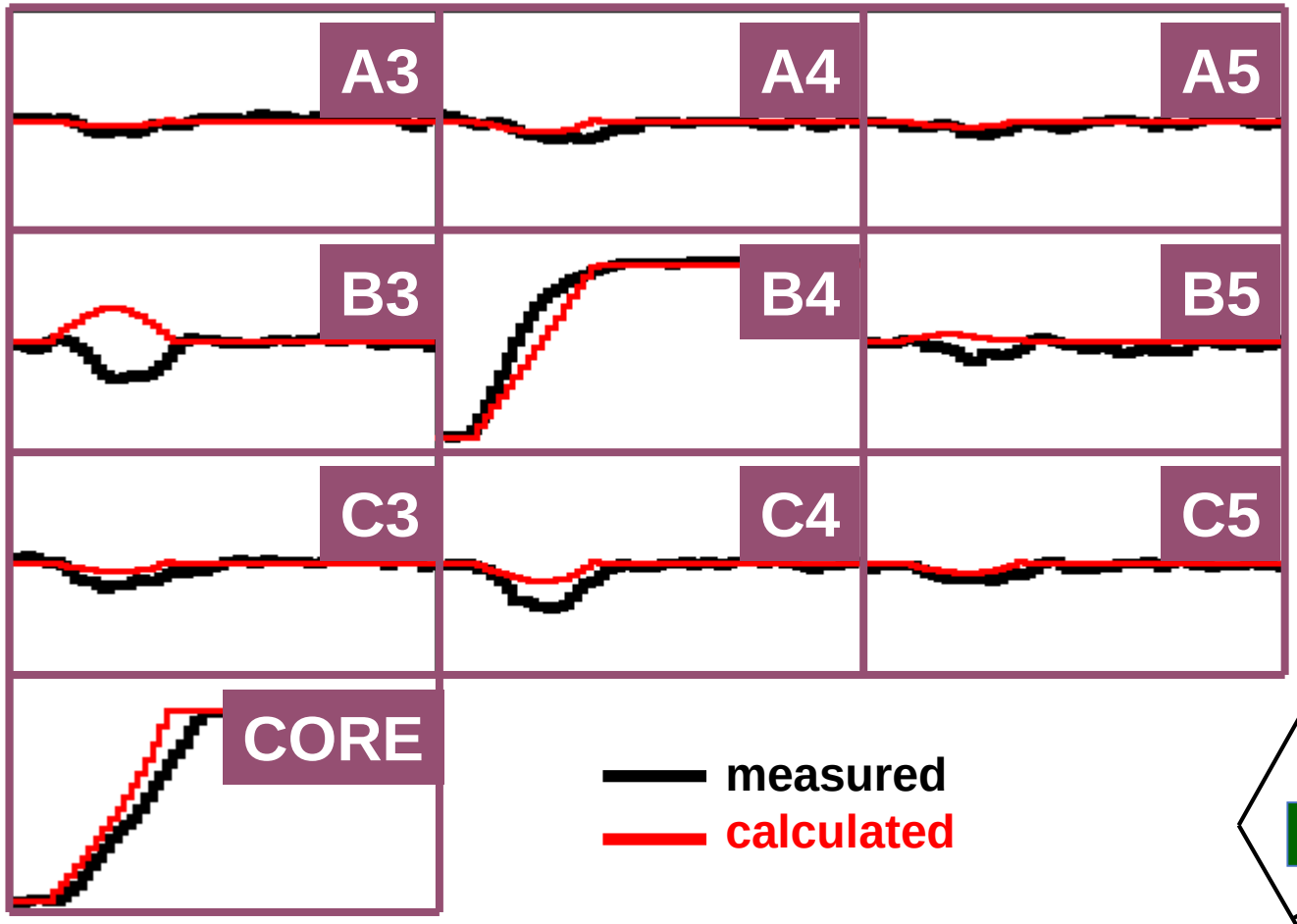
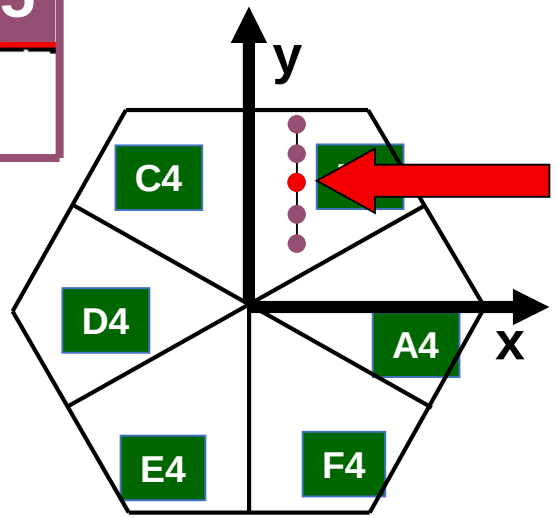


(10,20,46)



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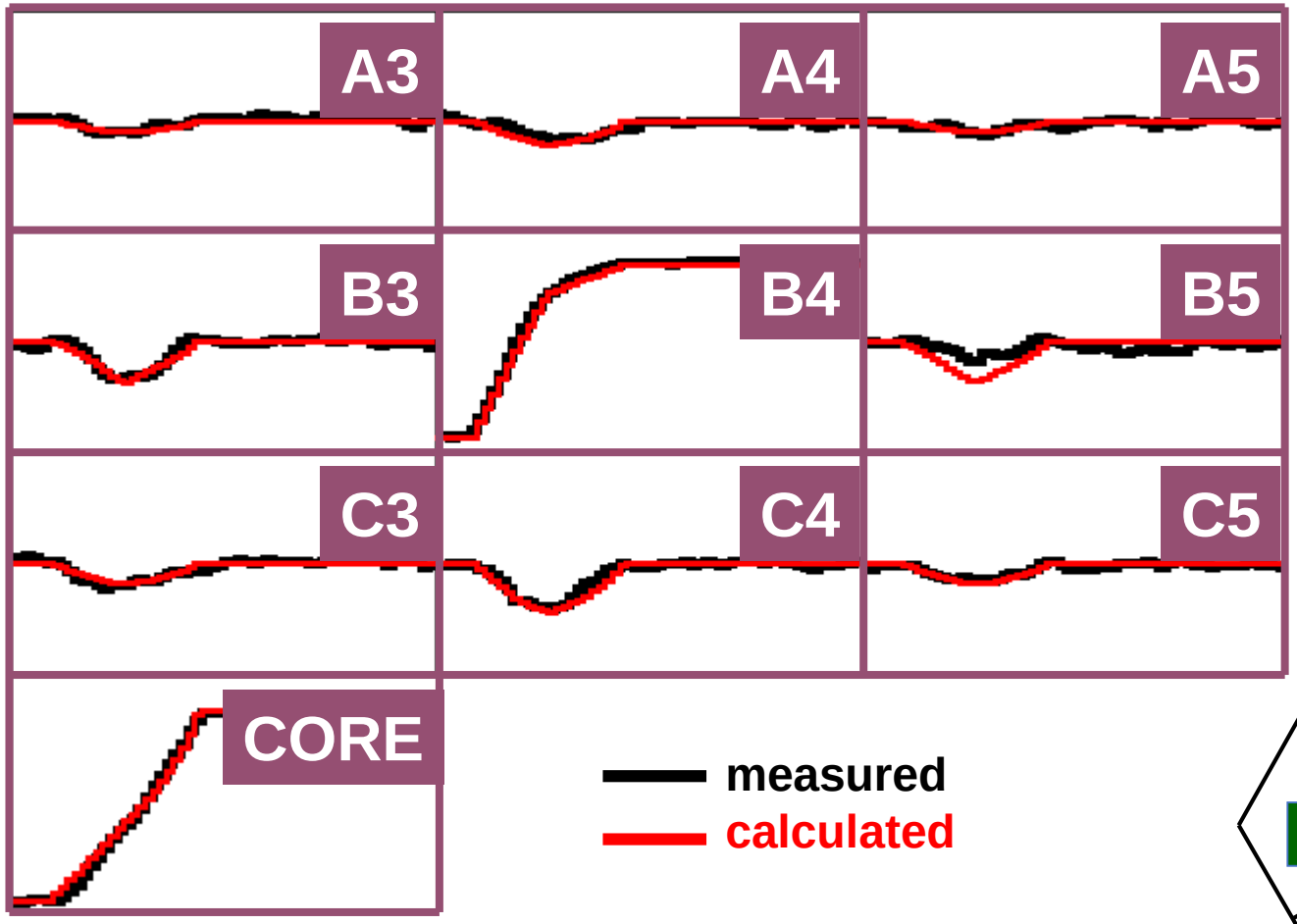
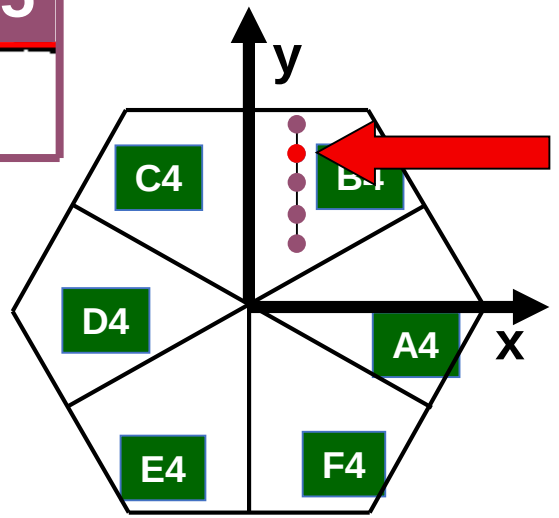


MATCHED!!!

(10,25,46)



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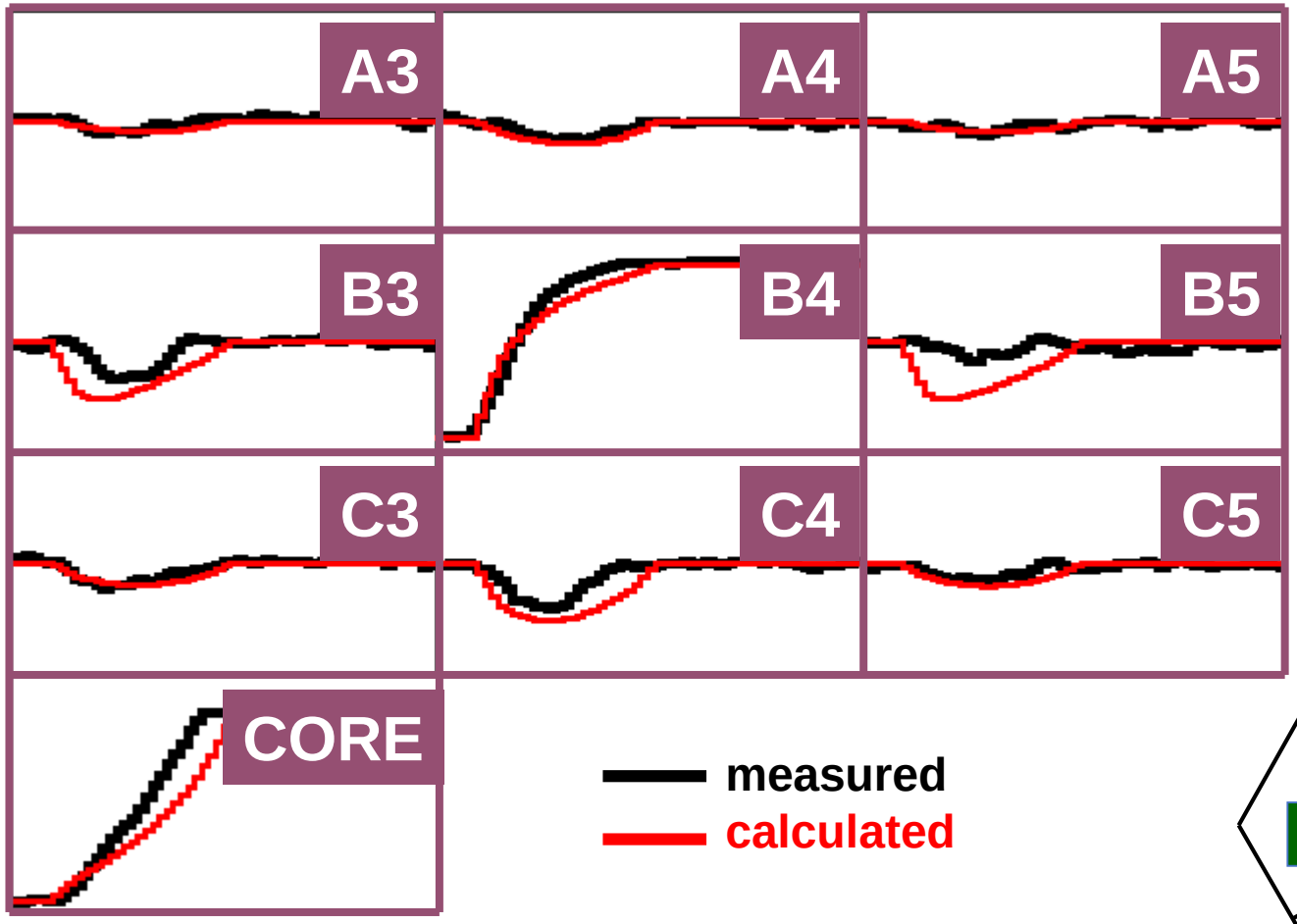
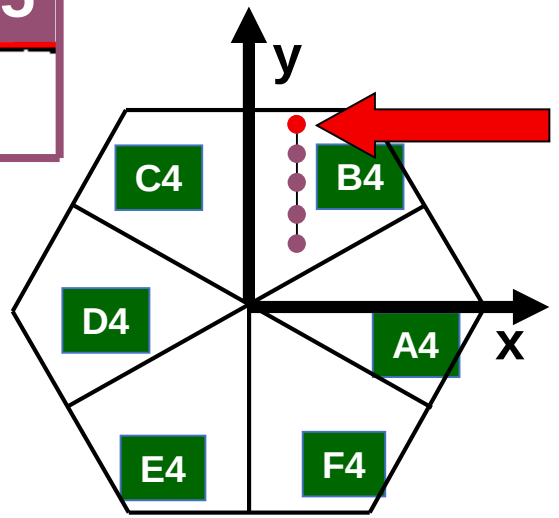


(10,30,46)



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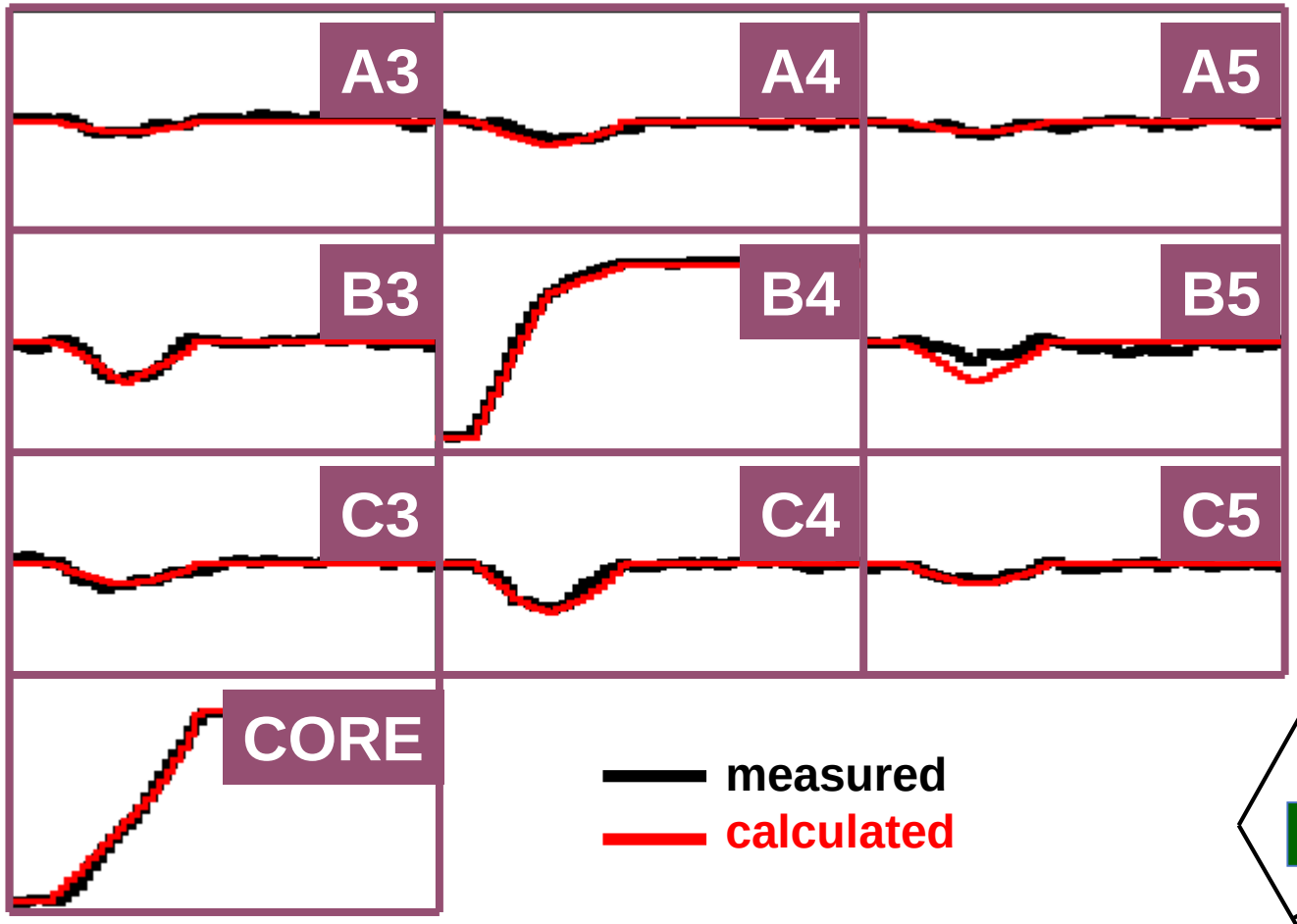
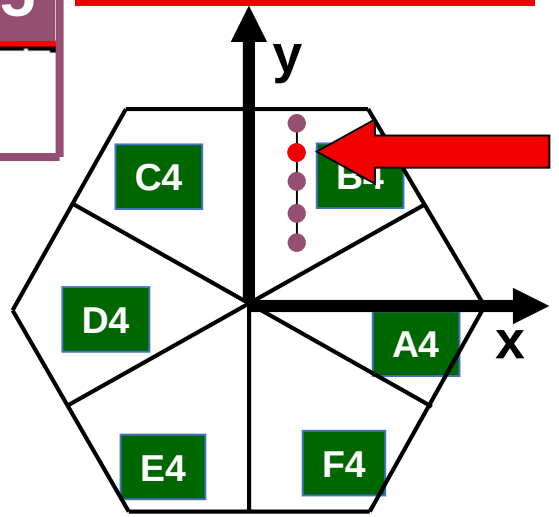
Pulse Shape Analysis Concept



Result of *Grid Search* algorithm

(10,25,46)



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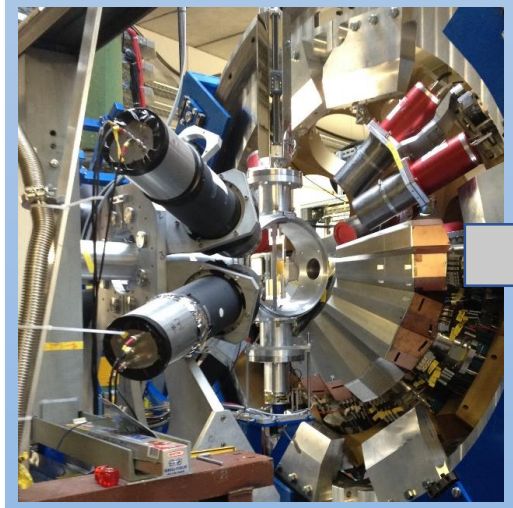
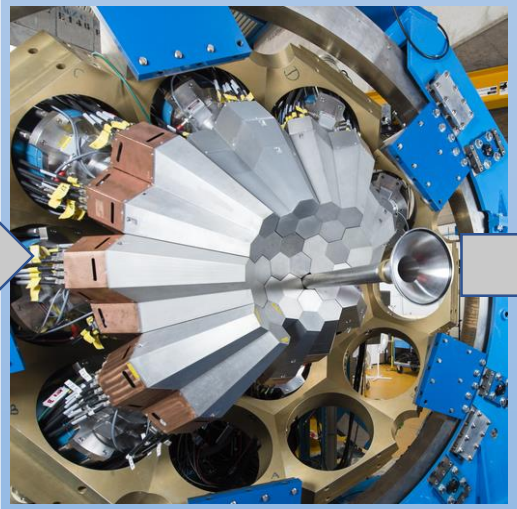
Evolution of AGATA

2012-2014
GSI, Germany
~25 detectors



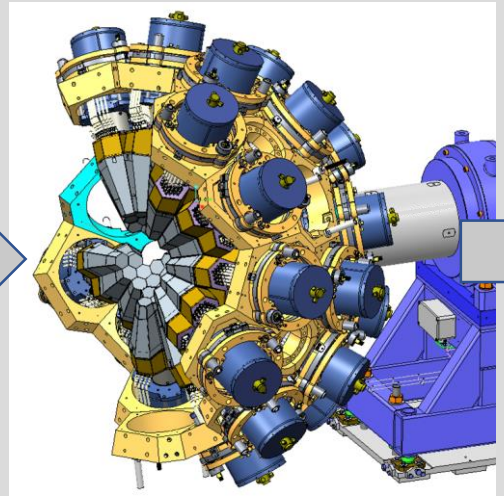
AGATA at GSI

2014-2021
GANIL, France
45 -> detectors



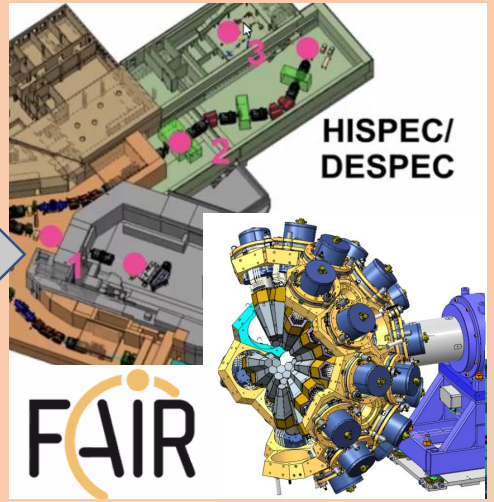
AGATA at GANIL

2021-2024
Legnaro, Italy
60 -> detectors



AGATA at LNL

2025 ->
FAIR, Germany
80-90 detectors

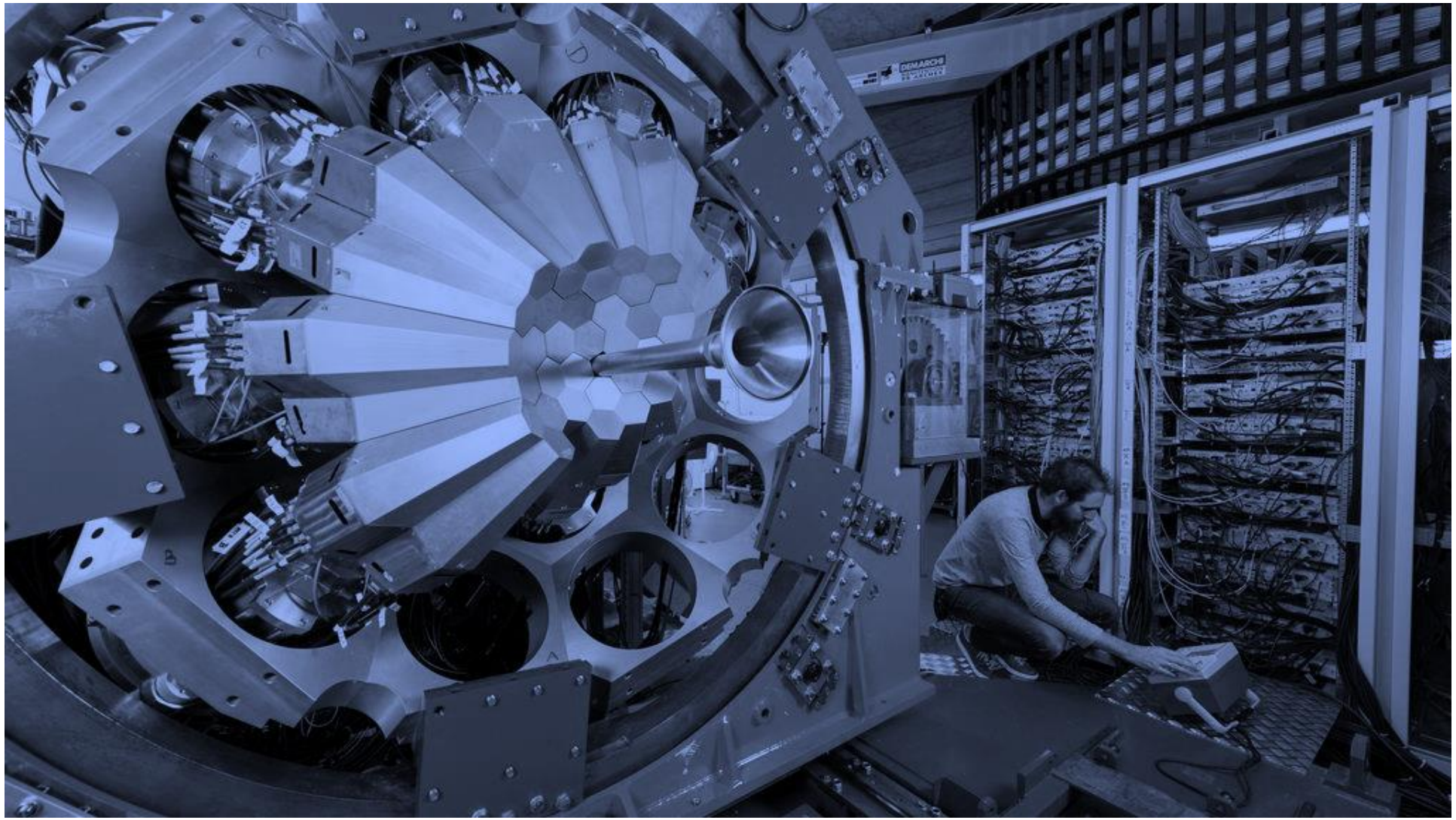


AGATA at NUSTAR

Reaccelerated RIBs:
- Coulomb Excitation, Direct Reactions, Deep Inelastic, Fusion
- **Direct and inverse kinematics β ~ 10%**

In-flight RIBs:
- Relativistic Coulomb Excitation, Knockout, Fragmentation.
- **β ~ 50%**

Evolution of AGATA



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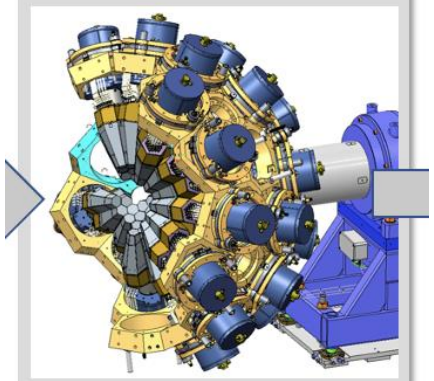


AGATA at LNL

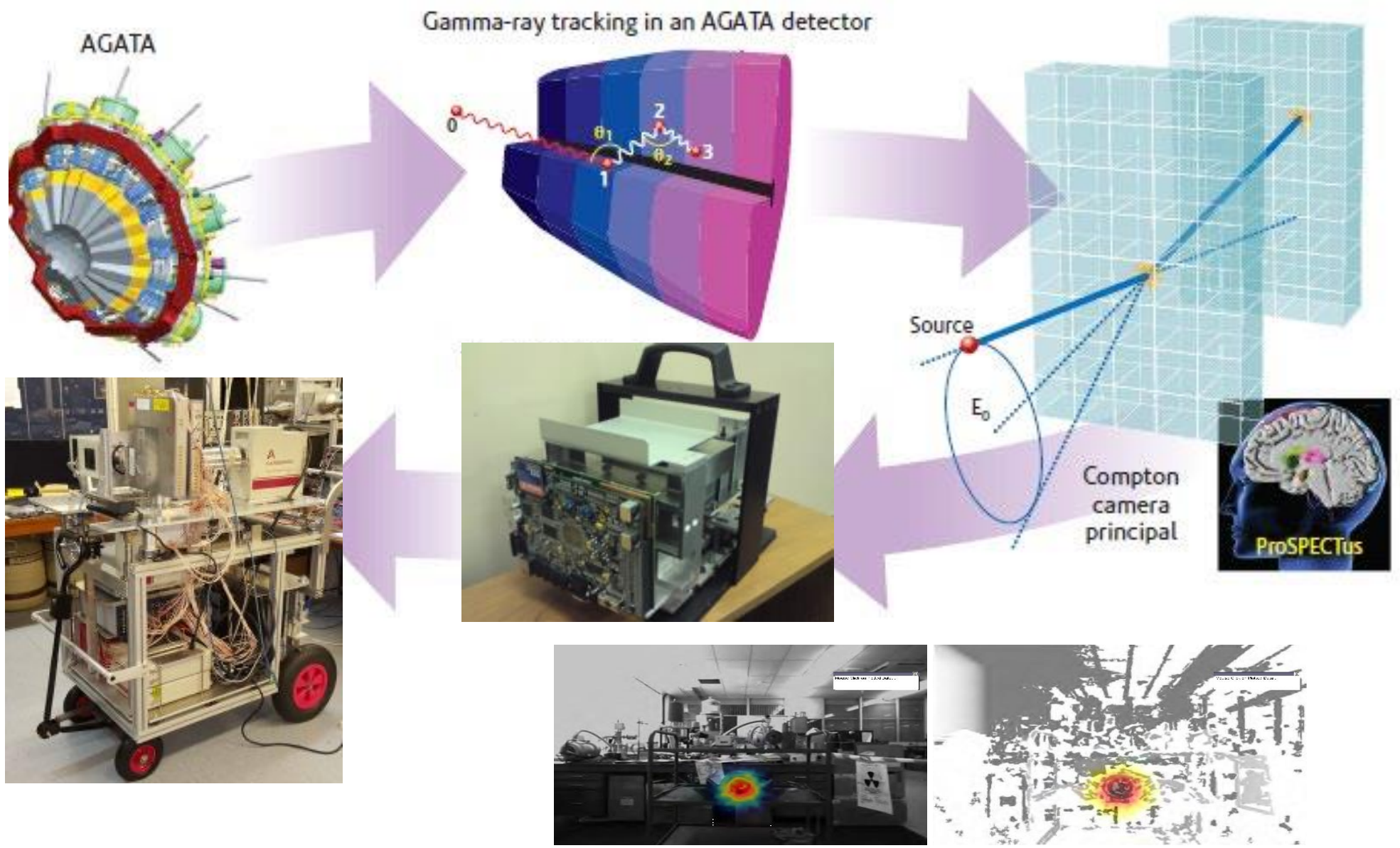
Next Large Scale Germanium Detector System

LEGEND – Large Enriched Germanium Experiment for Neutrinoless Double-Beta Decay

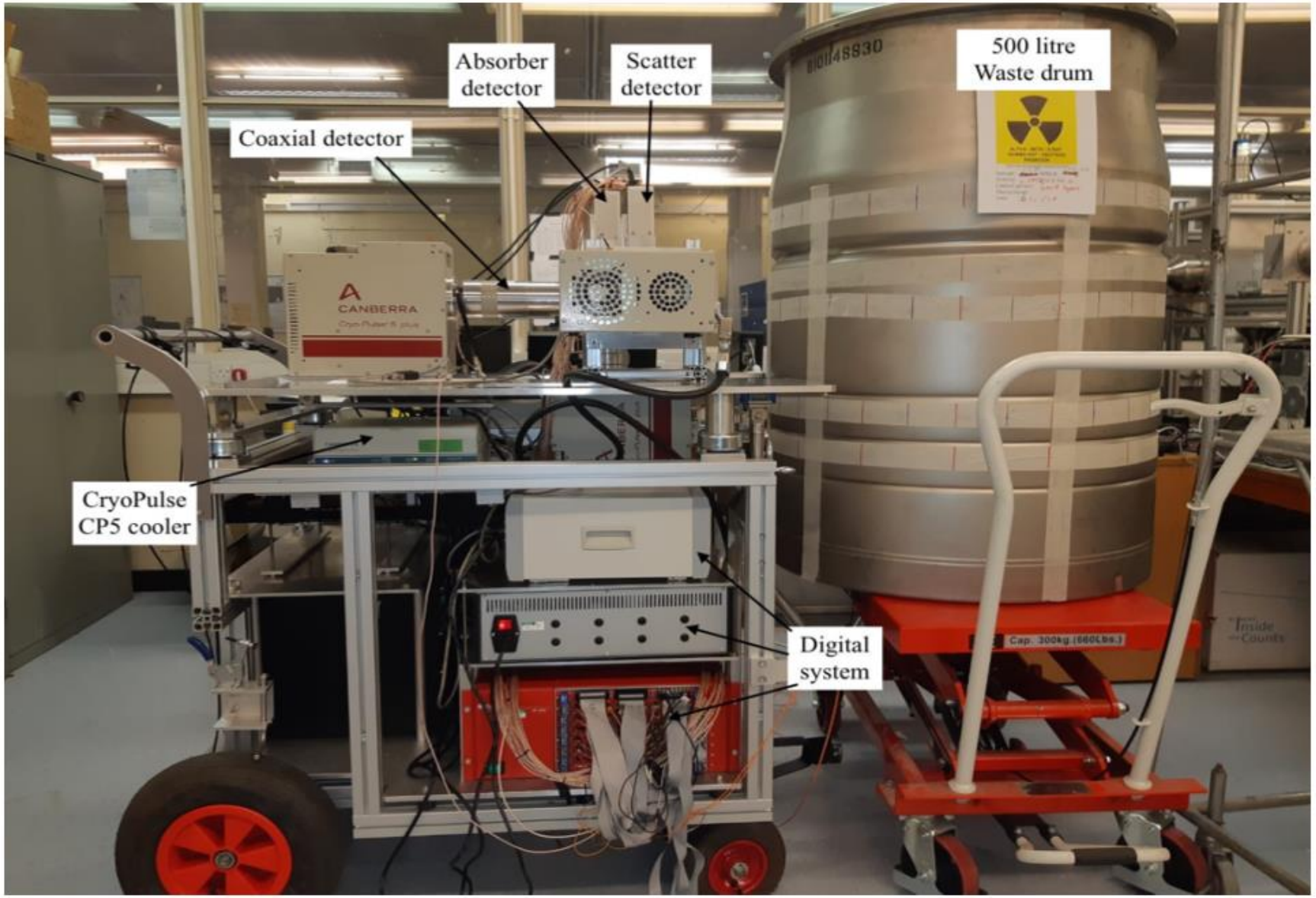
Purpose of LEGEND collaboration is to address the fundamental nature of the neutrino by investigating neutrinoless double beta-decay experiment

The aim of collaboration is to realise a 1 Tonne enriched ^{76}Ge detctors to be deployed in a new underground infrastructure.

From AGATA to Portable Imaging



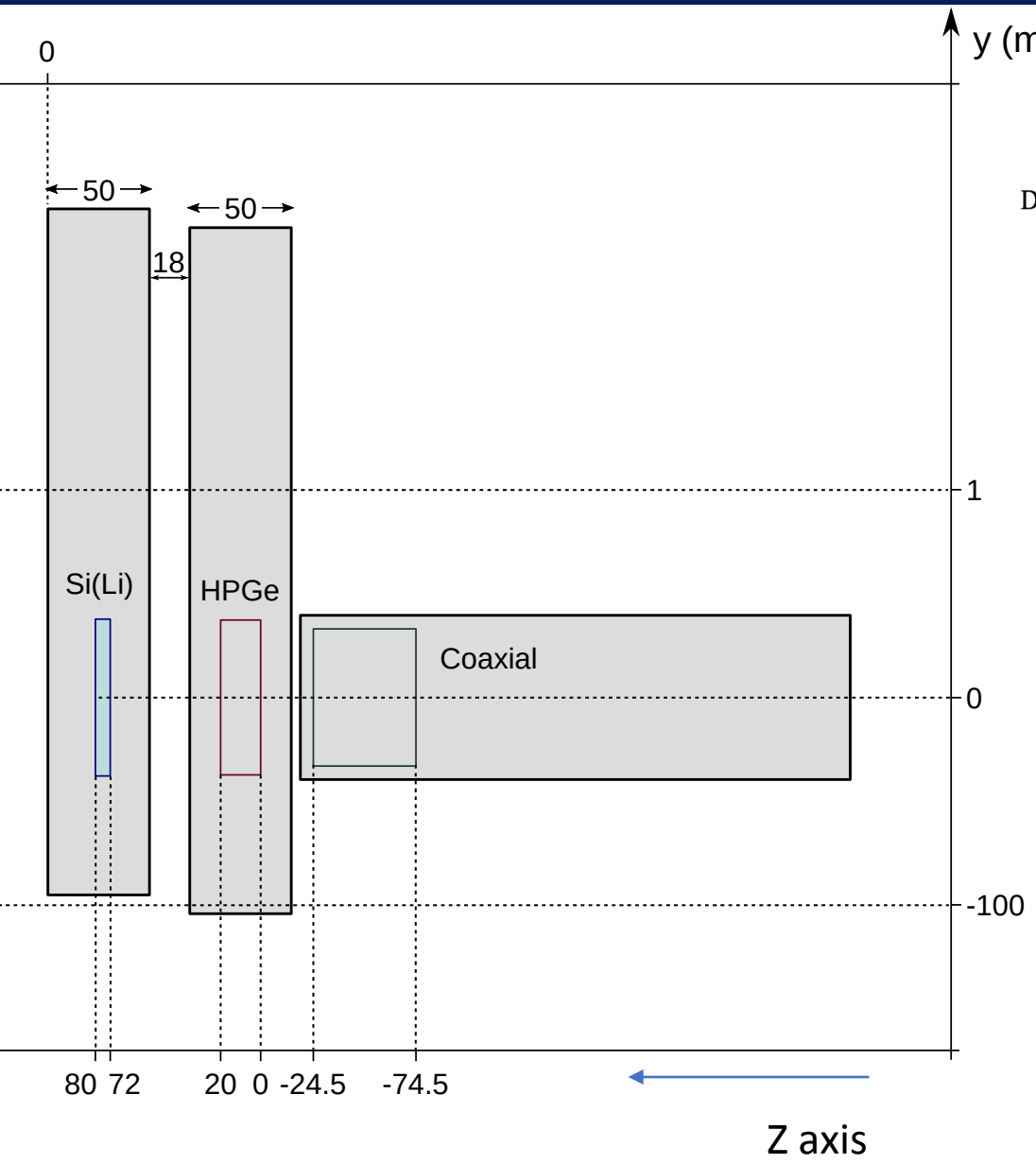
Gamma Ray Imager +



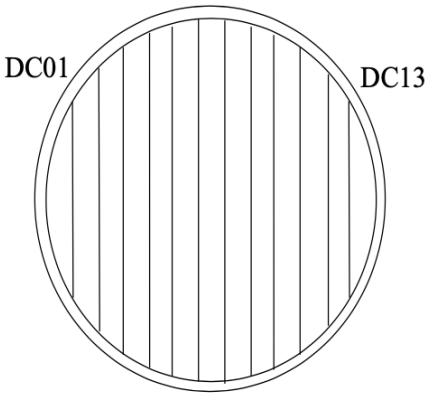
Triple layer Compton Camera

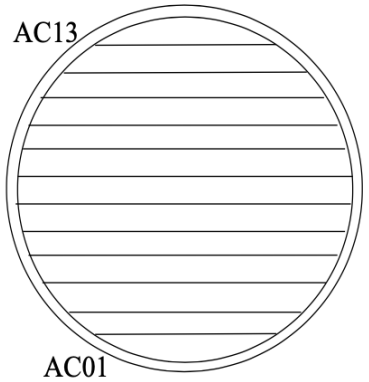
Nuclear waste characterisation

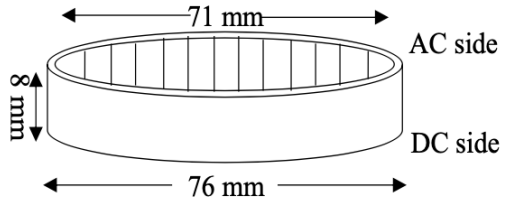
GRI+ Detectors



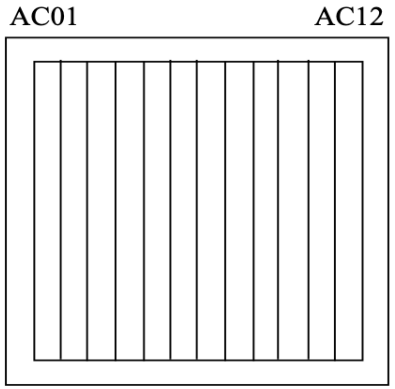
Si(Li) strip pitch 5 x 5 x 8mm

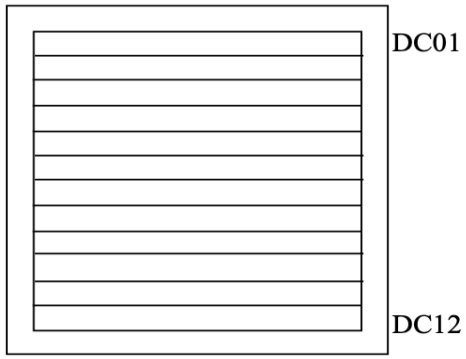


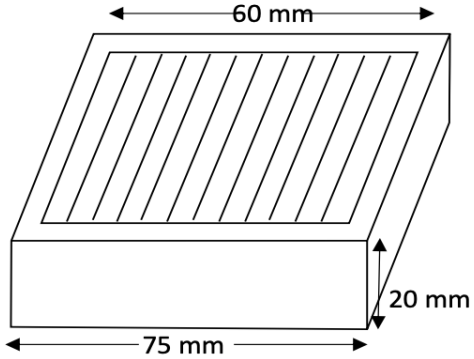




HPGe planar strip pitch 5 x 5 x 8mm

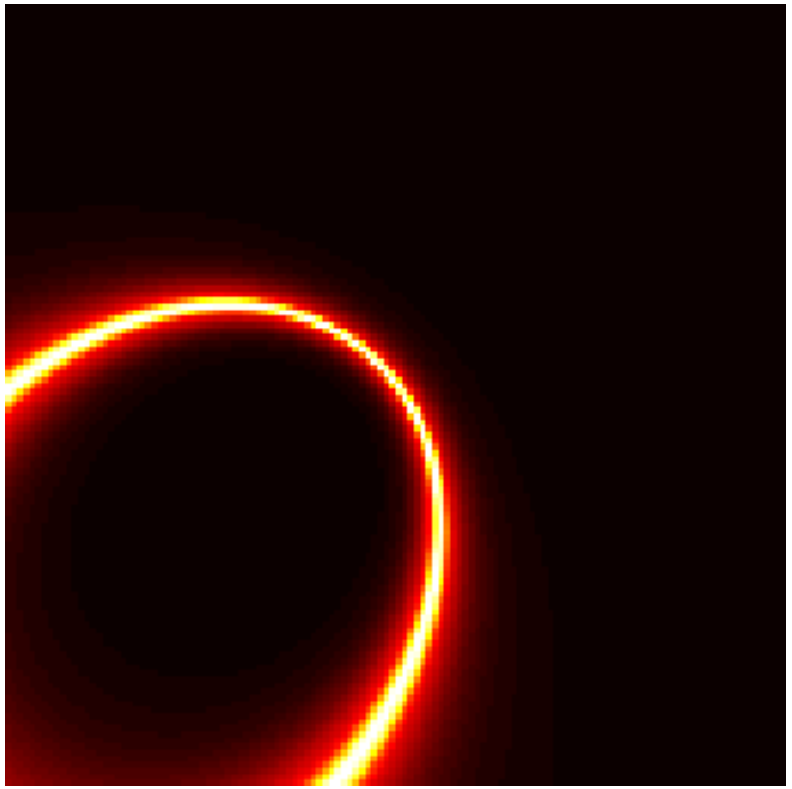




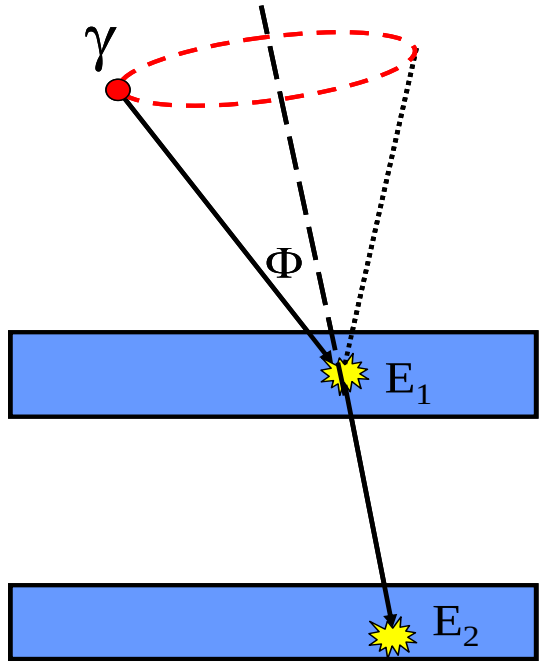


Compton imaging

Compton *Cones of Response* projected into image space



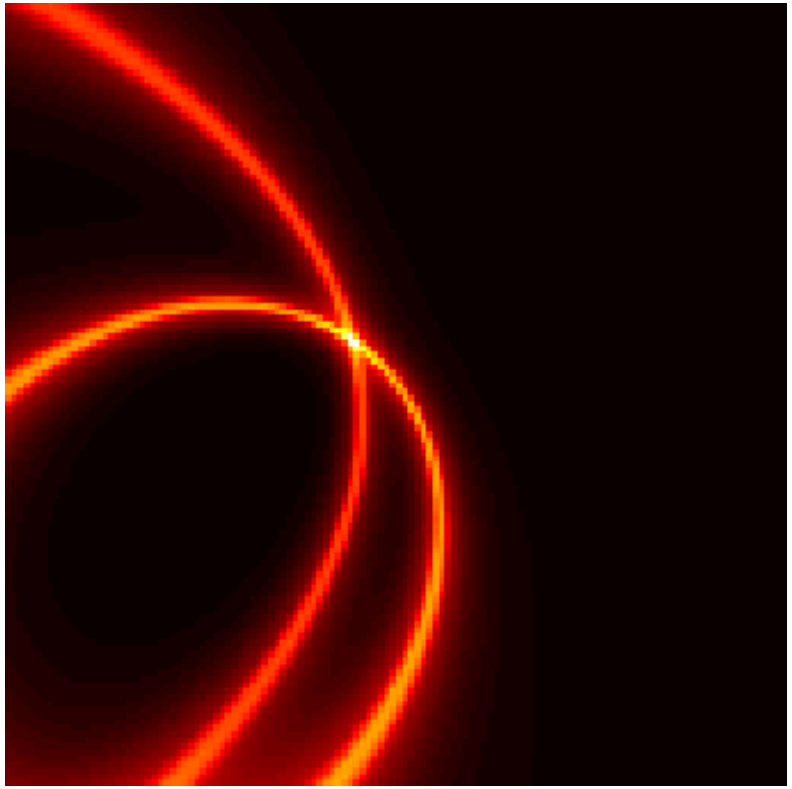
Analytical reconstruction

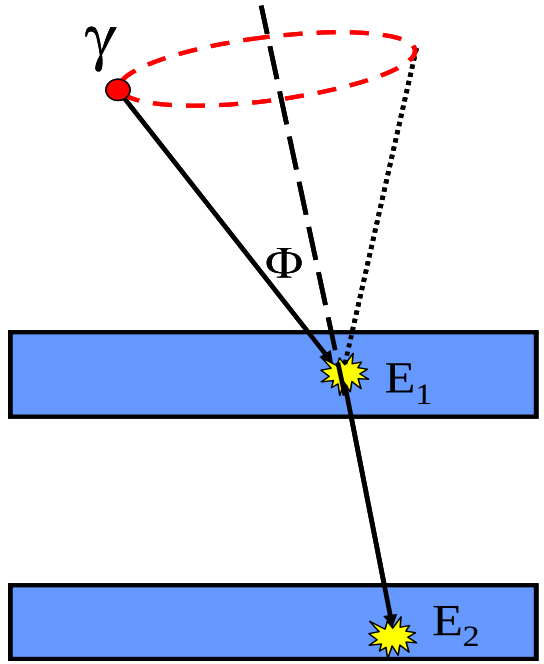


$$\cos\phi = 1 - m_e c^2 \left(\frac{1}{E_2} - \frac{1}{E_1 + E_2} \right)$$

Compton imaging

Compton *Cones of Response* projected into image space





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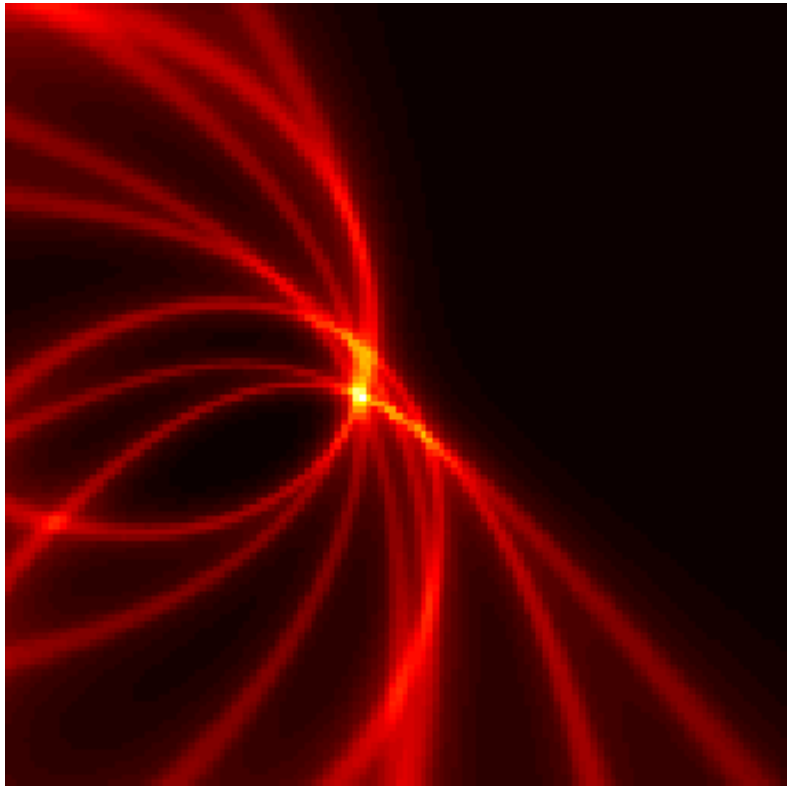

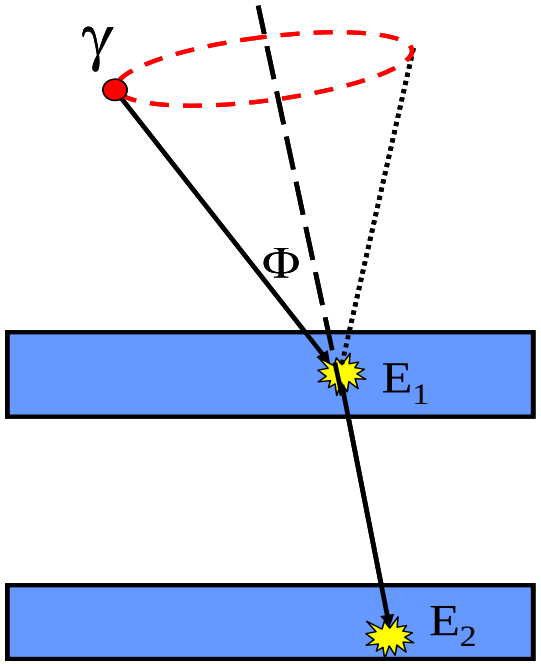

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Compton imaging

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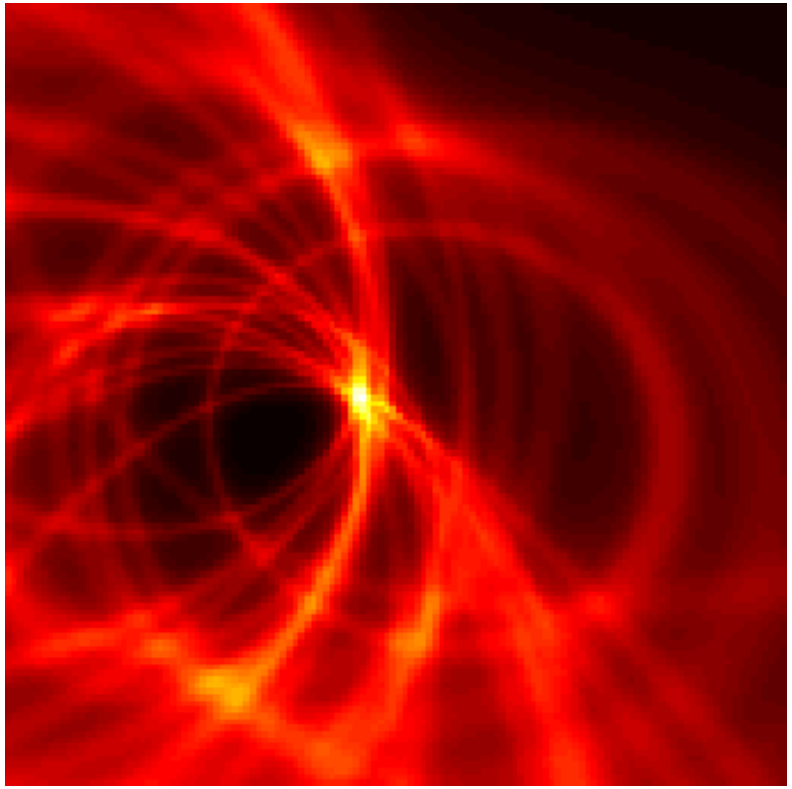
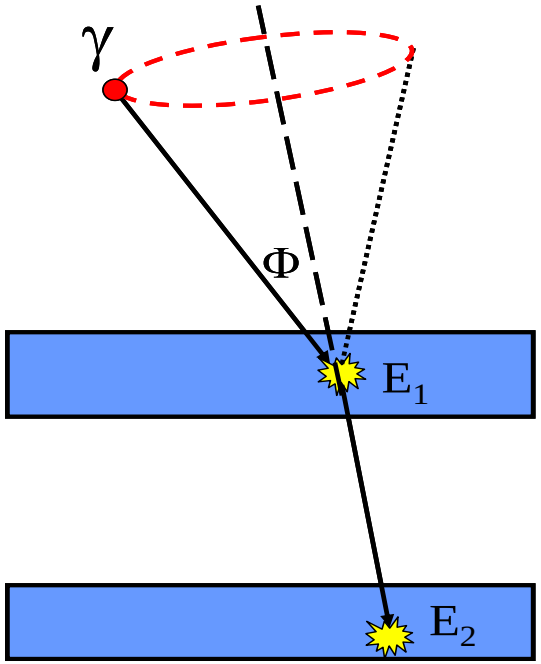
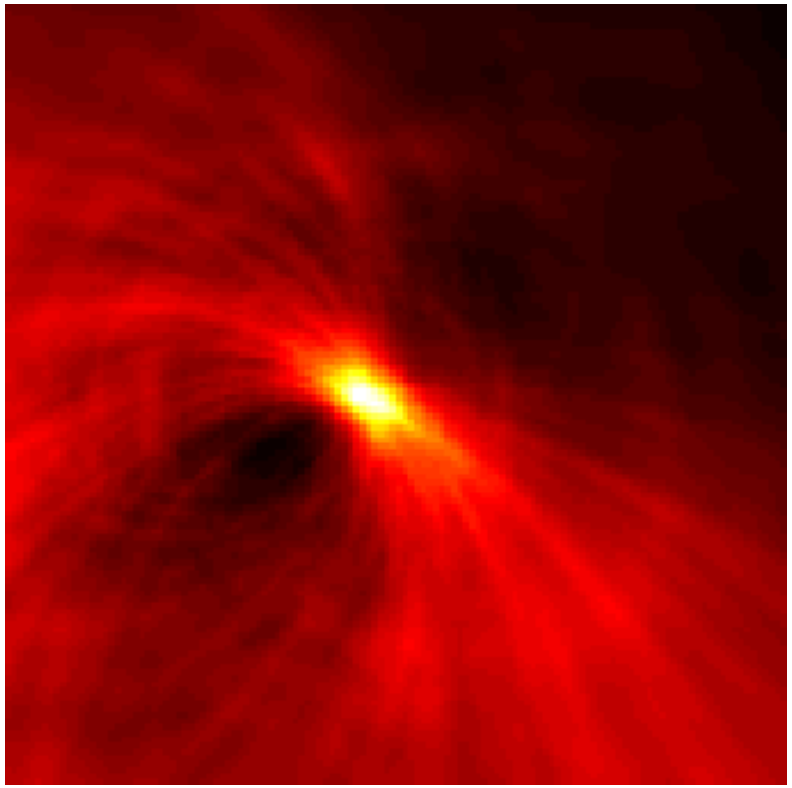


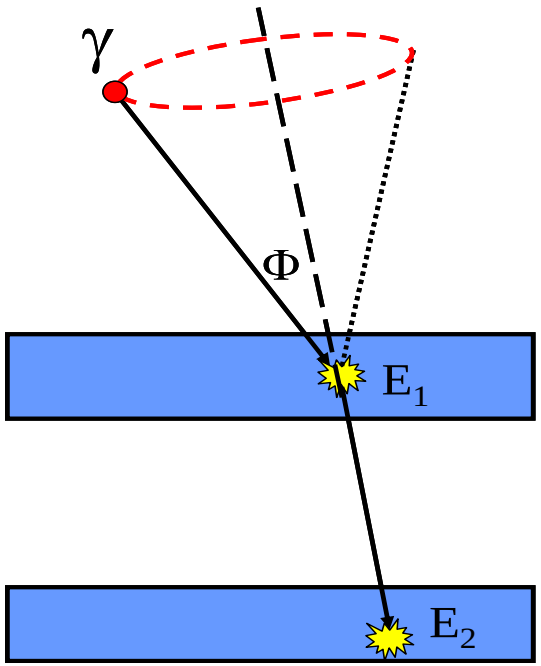


$$\cos\phi = 1 - m_e c^2 \left(\frac{1}{E_2} - \frac{1}{E_1 + E_2} \right)$$

Compton imaging

Compton *Cones of Response* projected into image space

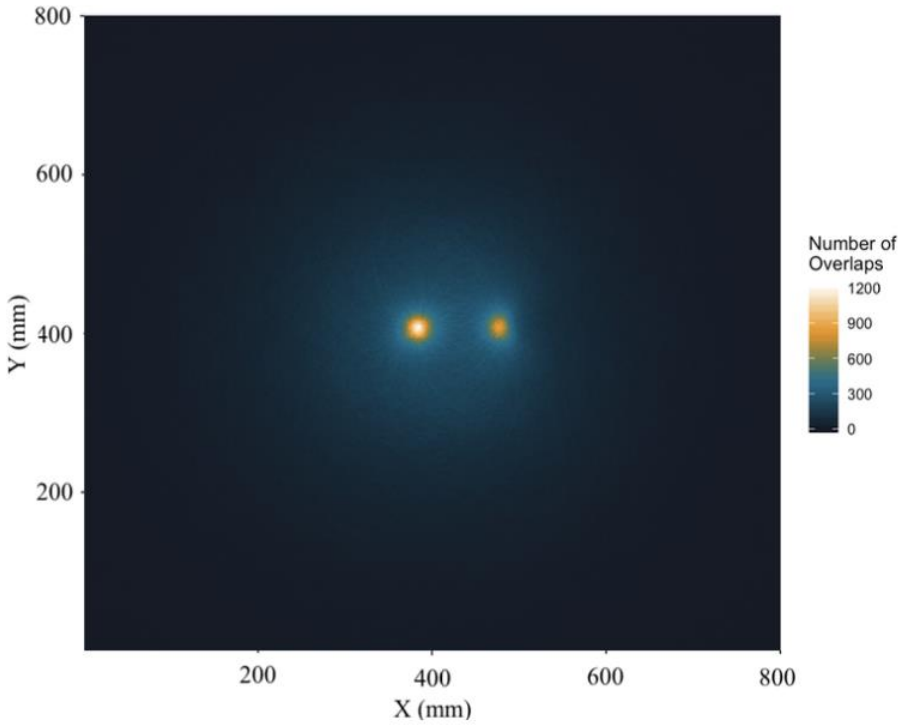




$$\cos\phi = 1 - m_e c^2 \left(\frac{1}{E_2} - \frac{1}{E_1 + E_2} \right)$$

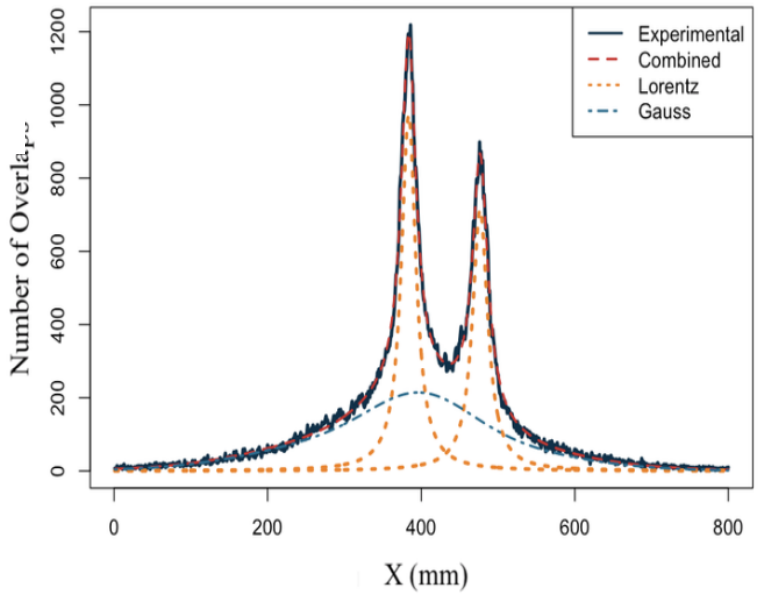
Now have location in space, but source activity cannot yet be estimated: essential to quantitatively understand redistribution

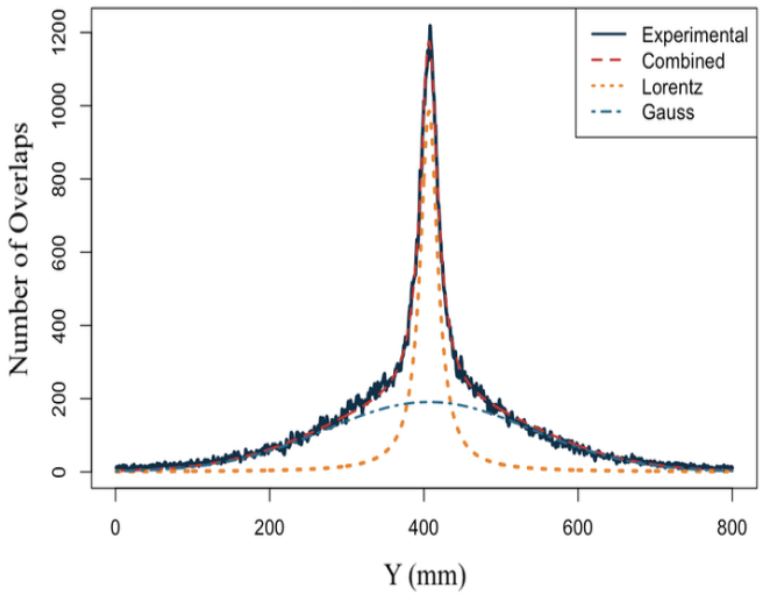
Point Source Image Reconstruction



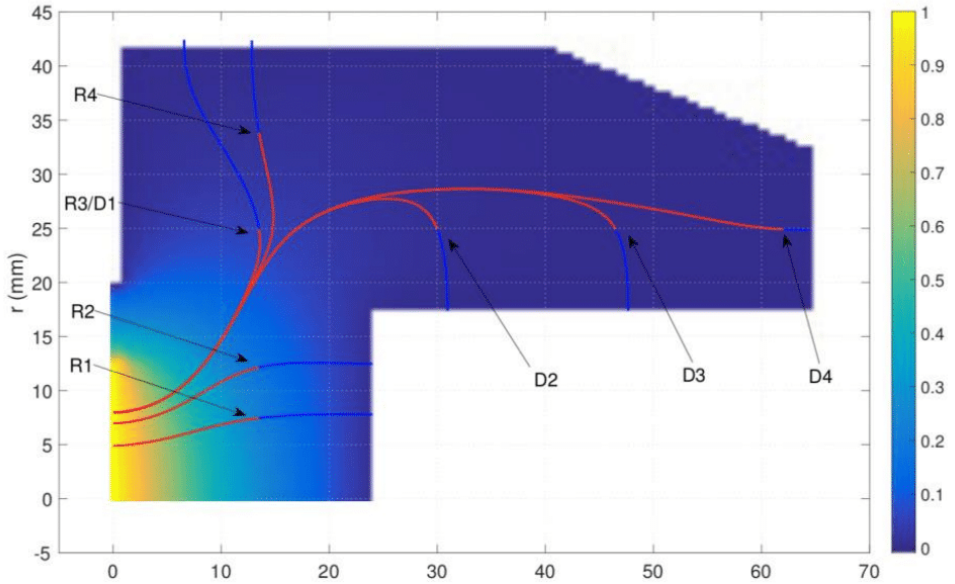
- ^{137}Cs sources placed side by side
- Energy gate applied (656 – 668keV)
- 140mm separation

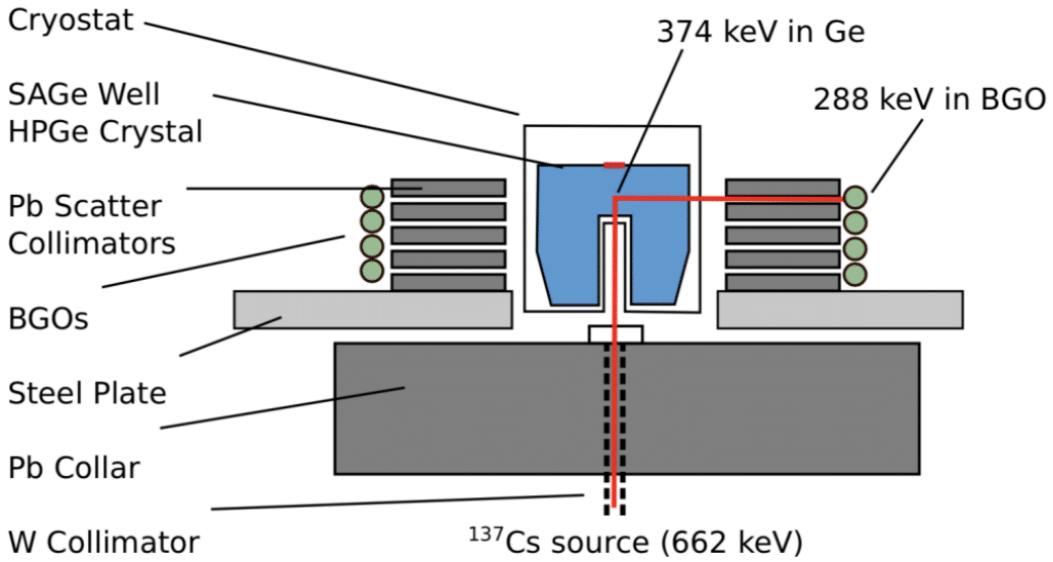
- Future work – Quantification of sources

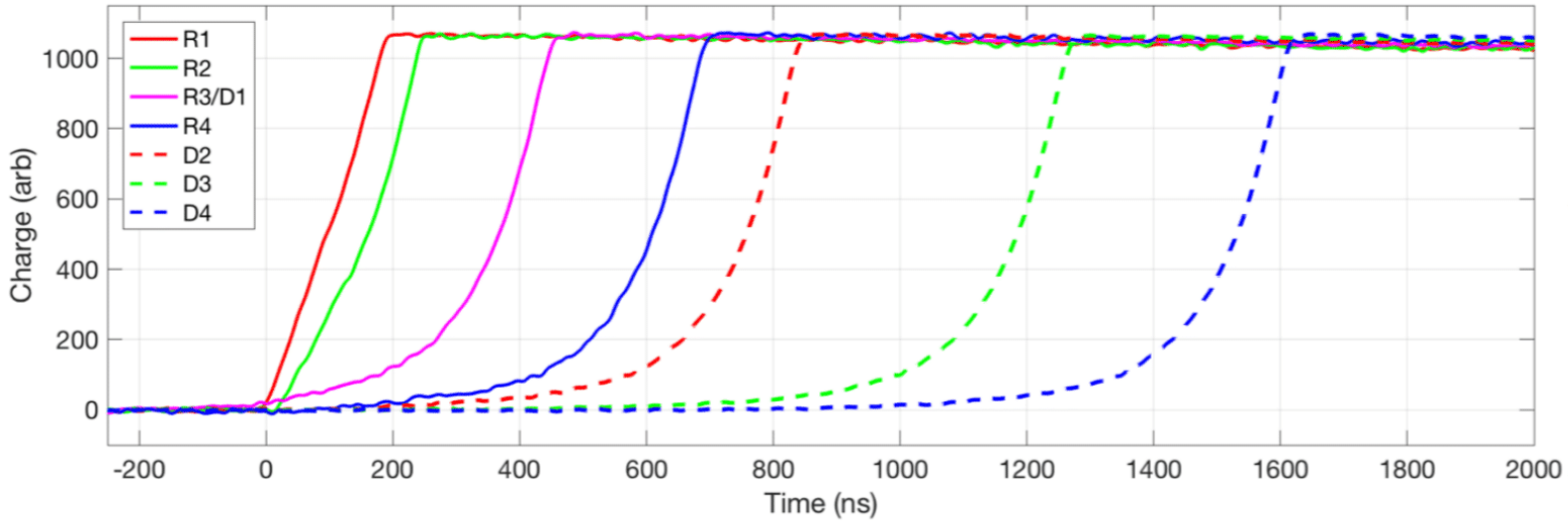


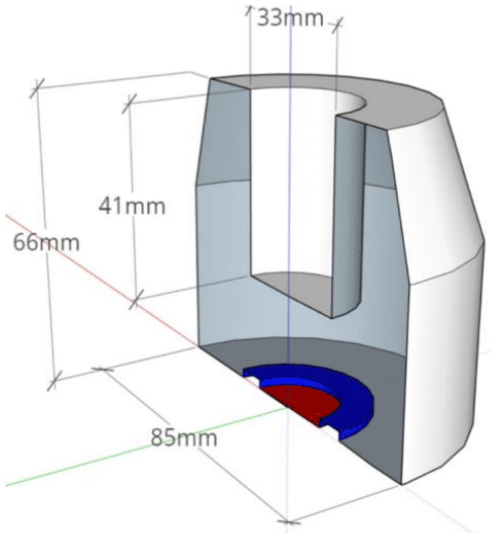


Pulse Shape Analysis Concept

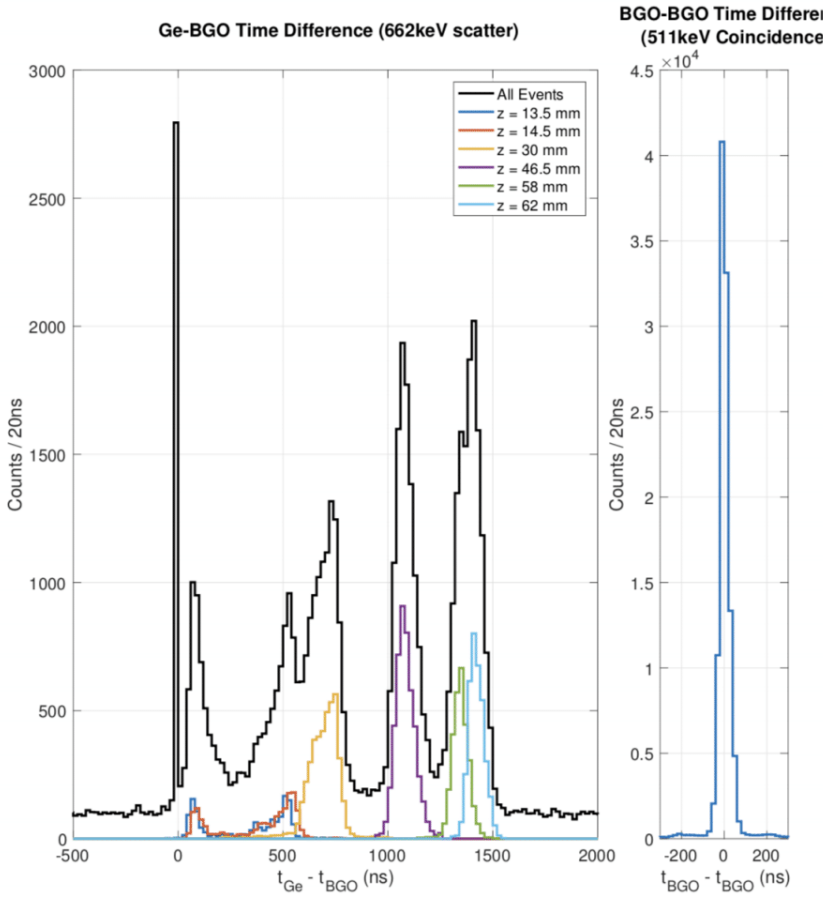


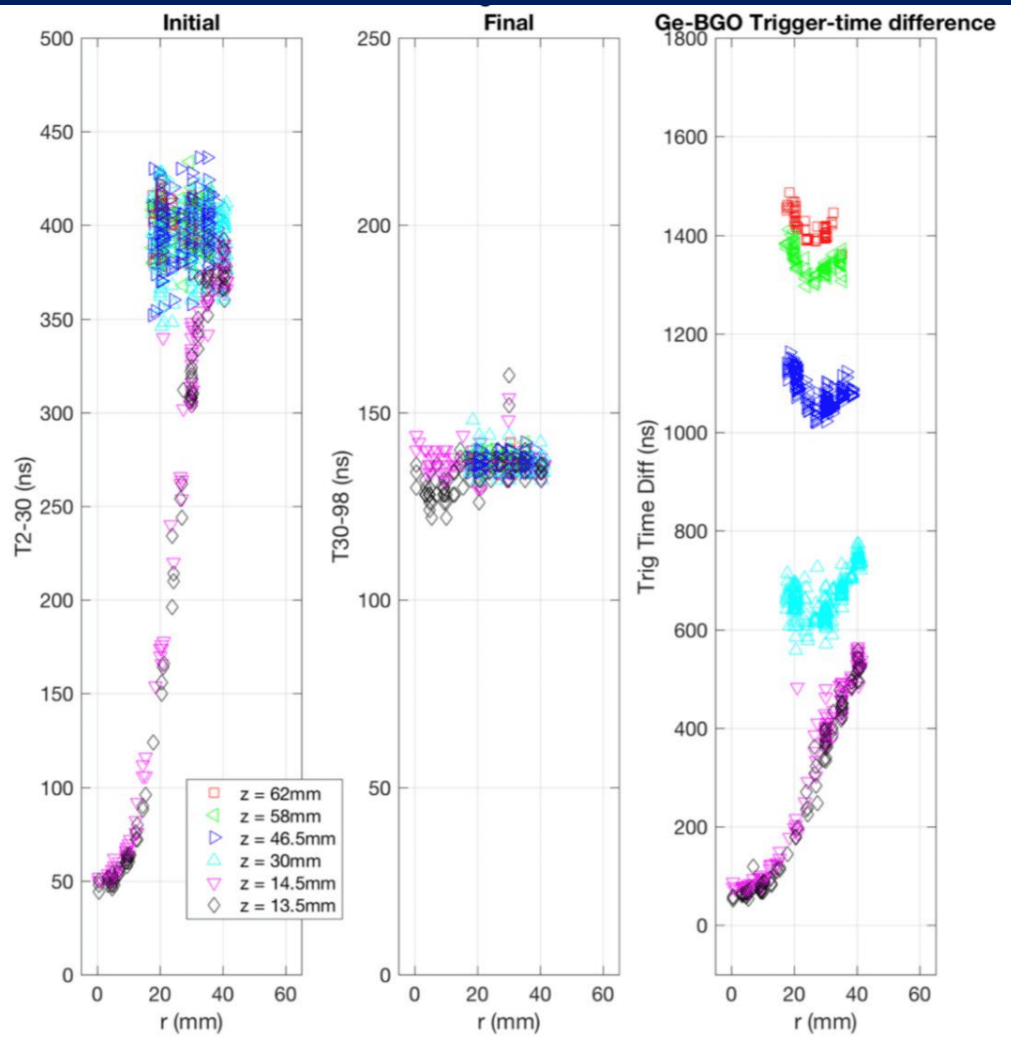






SAGe Performance Tests





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Conclusions

Full characterisation of detectors to develop PSA codes
Gamma ray tracking uses output of the PSA
Advanced Gamma Tracking Array – AGATA about to start new phase at LNL
Future Array – LEGEND for neutrinoless double beta decay experiments
From arrays to portable devices and their uses

- Medical Imaging
- Security applications
- Nuclear Waste monitoring and decommissioning
- Environmental assaying

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