EPSRC Engineering and Physical Sciences
Healthcare technologies

Cranfield University

Design and assembly of a fibre-type heterostructured scintillator for Time of Flight Positron Emission Tomography

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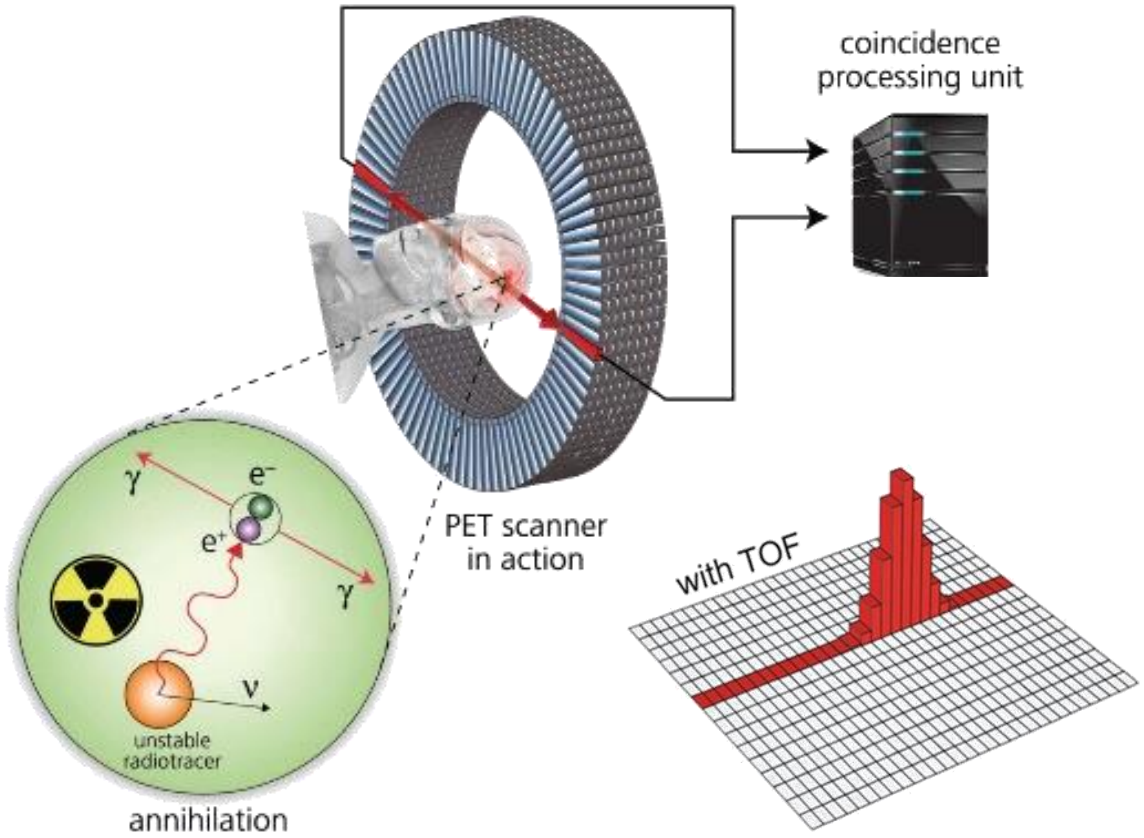
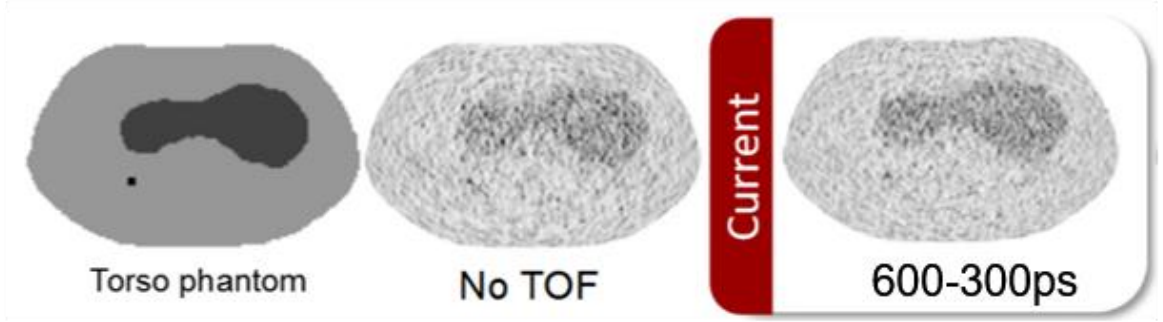
8. Lomonosov Moscow State University, Russia

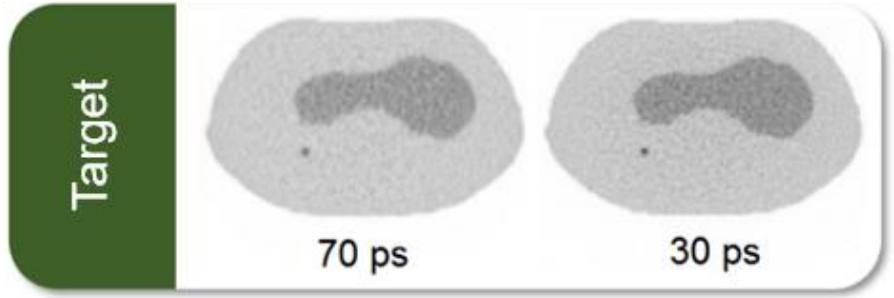
16th September 2021

A Material Focus



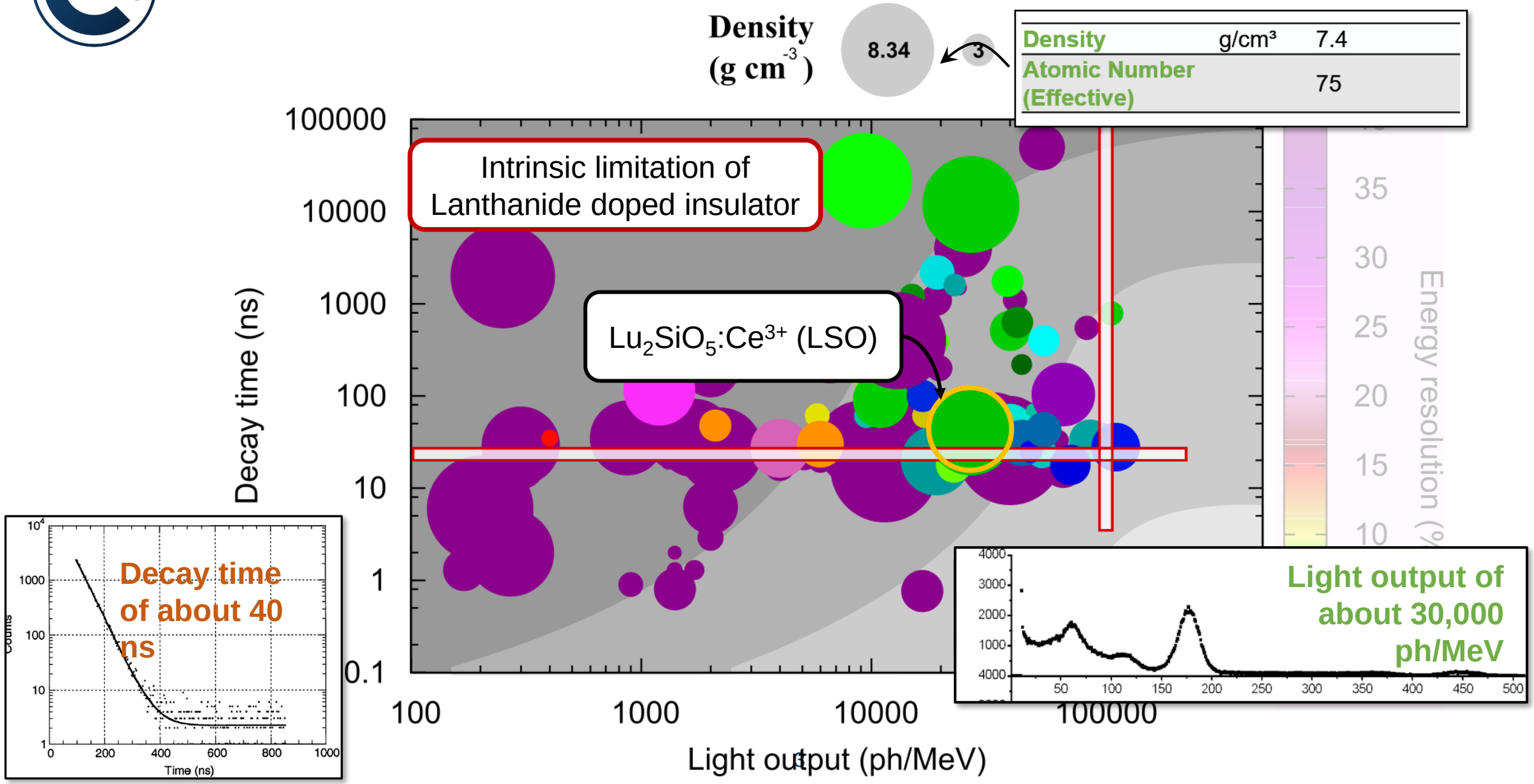


Courtesy,
UC Davis

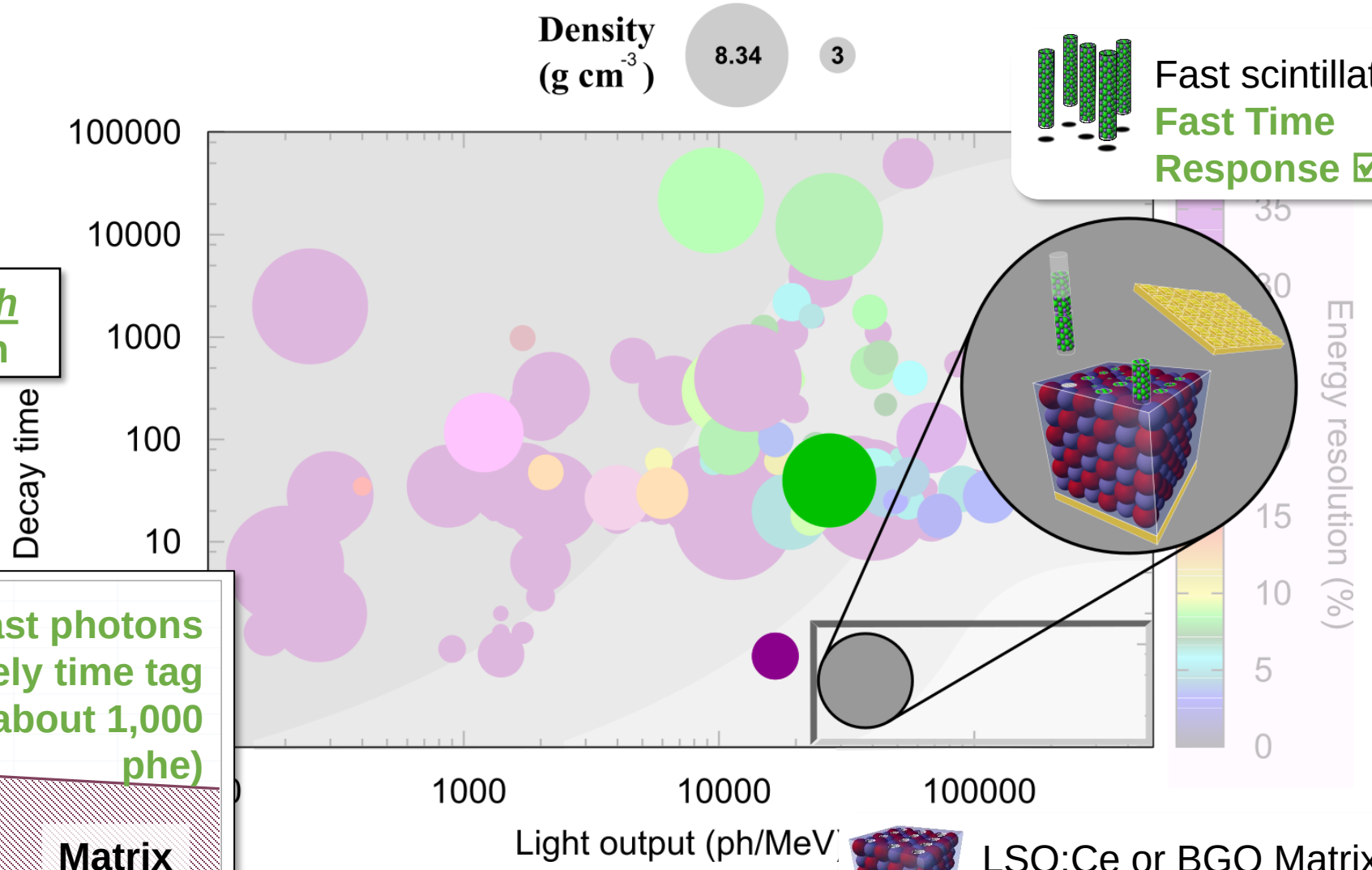


Detector material choice is a major bottleneck in improving PET performance

Current Detector Materials versus Needs

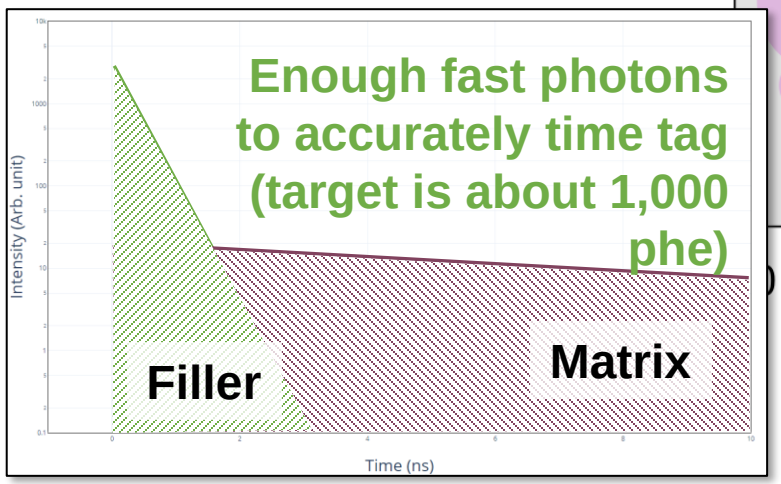


Current Detector Materials versus Needs

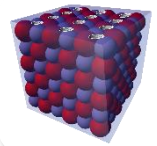


Fast scintillator filler;
Fast Time Response ☑

Light output *enough* for energy selection

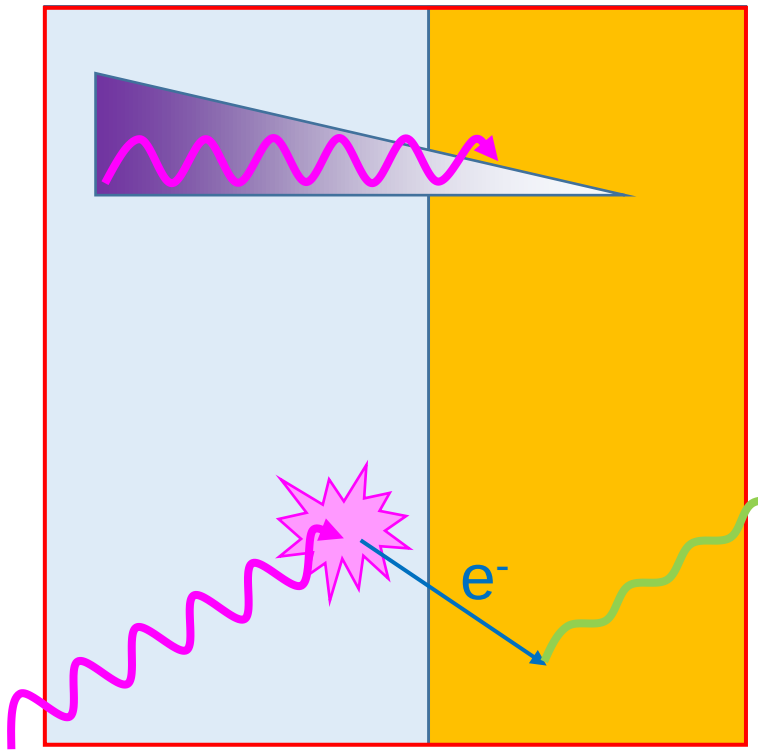


Enough fast photons to accurately time tag (target is about 1,000 phe)



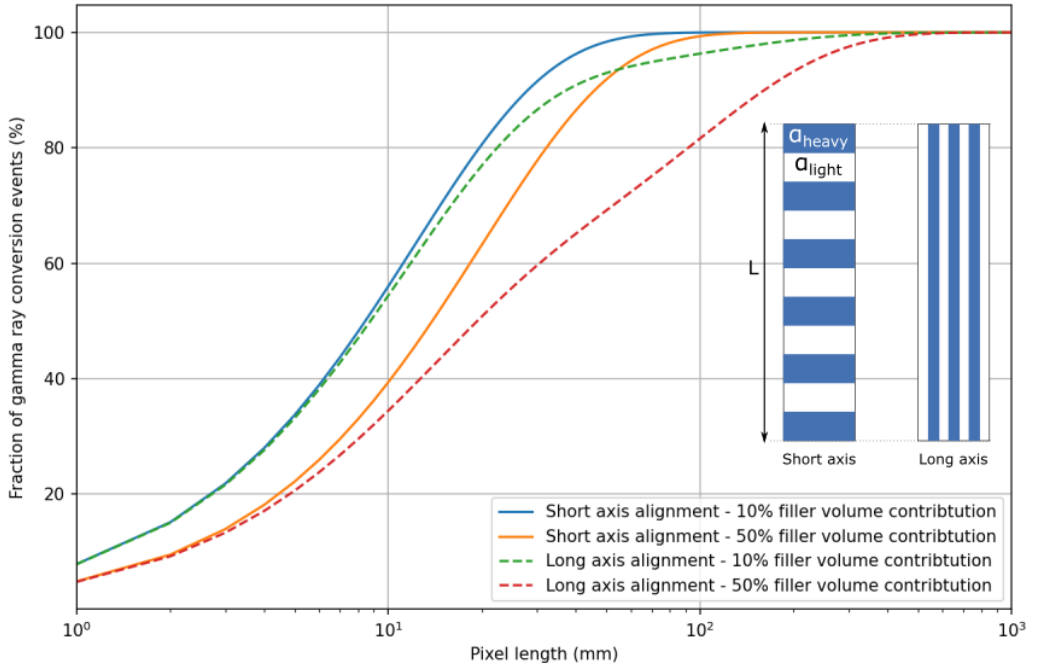
LSO:Ce or BGO Matrix;
High Stopping Power ☑

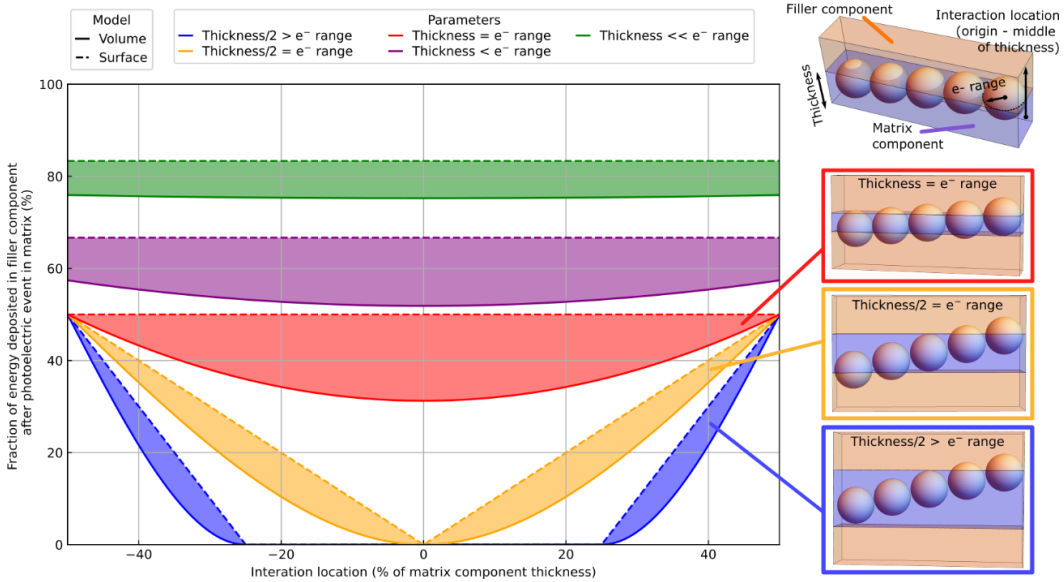
Heterostructured scintillator mechanism



Equivalent stopping power

Energy sharing



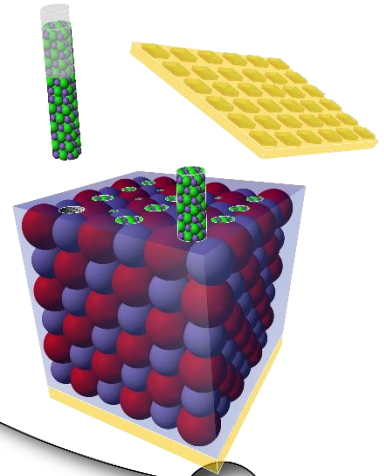


A heterostructured scintillator uses two materials in synergy to maximise both stopping power and energy sharing

Multidisciplinary Manufacturing Challenges

Manufacturing

Five Work Packages



Independent but complementary Work Packages

Heterostructure Design
- Heterostructure Layout
- Response Simulation

Ultra-Fast Scintillators
- Growth/Preparation
- Process Optimization

Precision Machining
- Micro-machining
- Process Optimization

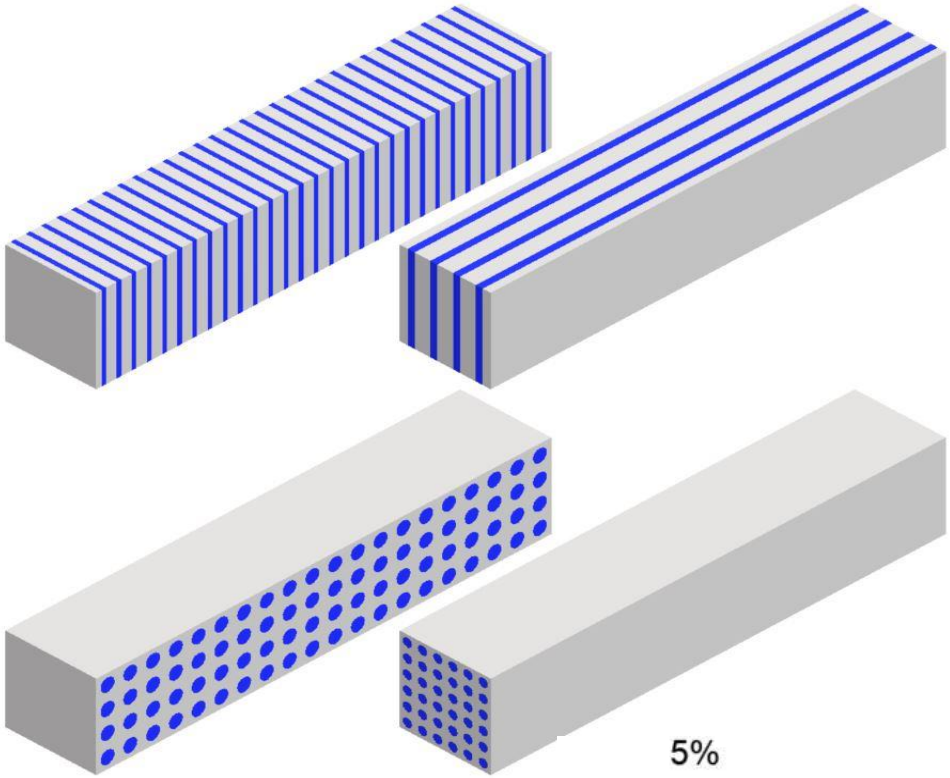
Heterostructure Evaluation
- Neutron Imaging
- Timing Resolution

Surface Functionalisation
- Thin Film Deposition
- Process Optimization

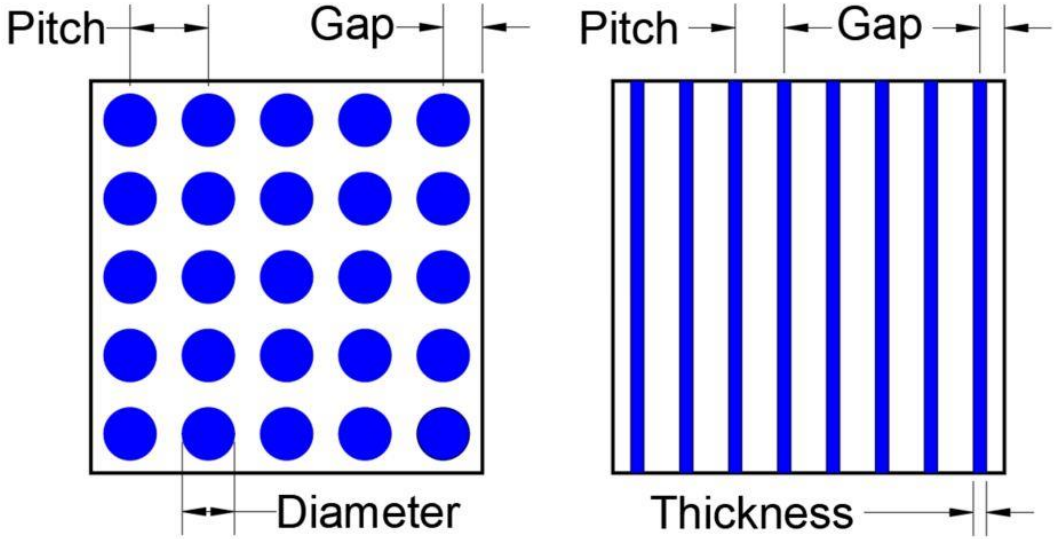
Heterostructure design parameter space

Heterostructure Design
- Heterostructure Layout
- Response Simulation

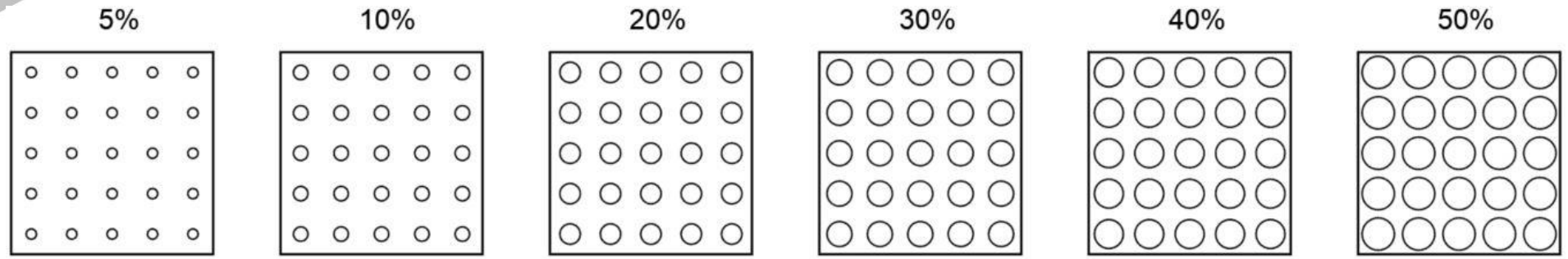
Different layout types:



Dimensions:



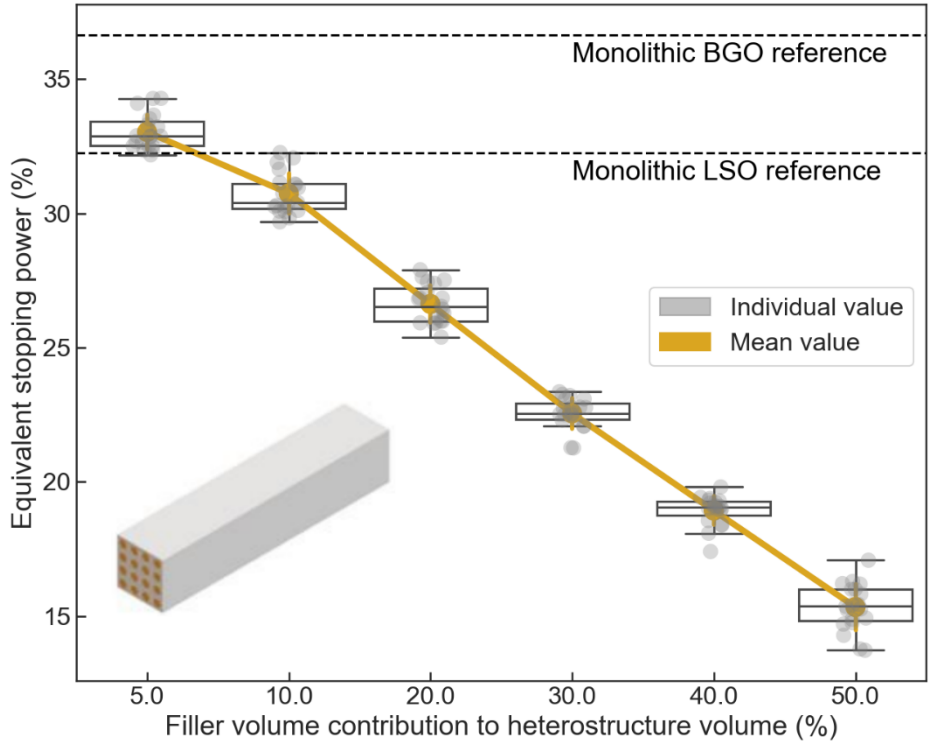
Ratio of filler volume to total volume



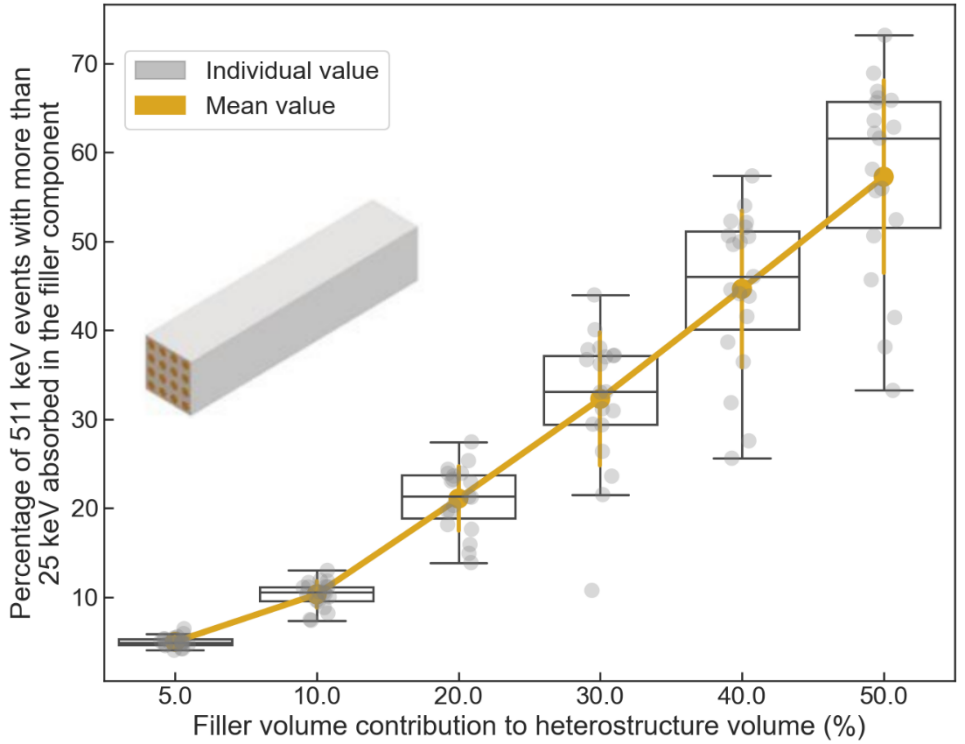
Effect of geometry on performance

Heterostructure Design
- Heterostructure Layout
- Response Simulation

Equivalent stopping power



Energy Sharing

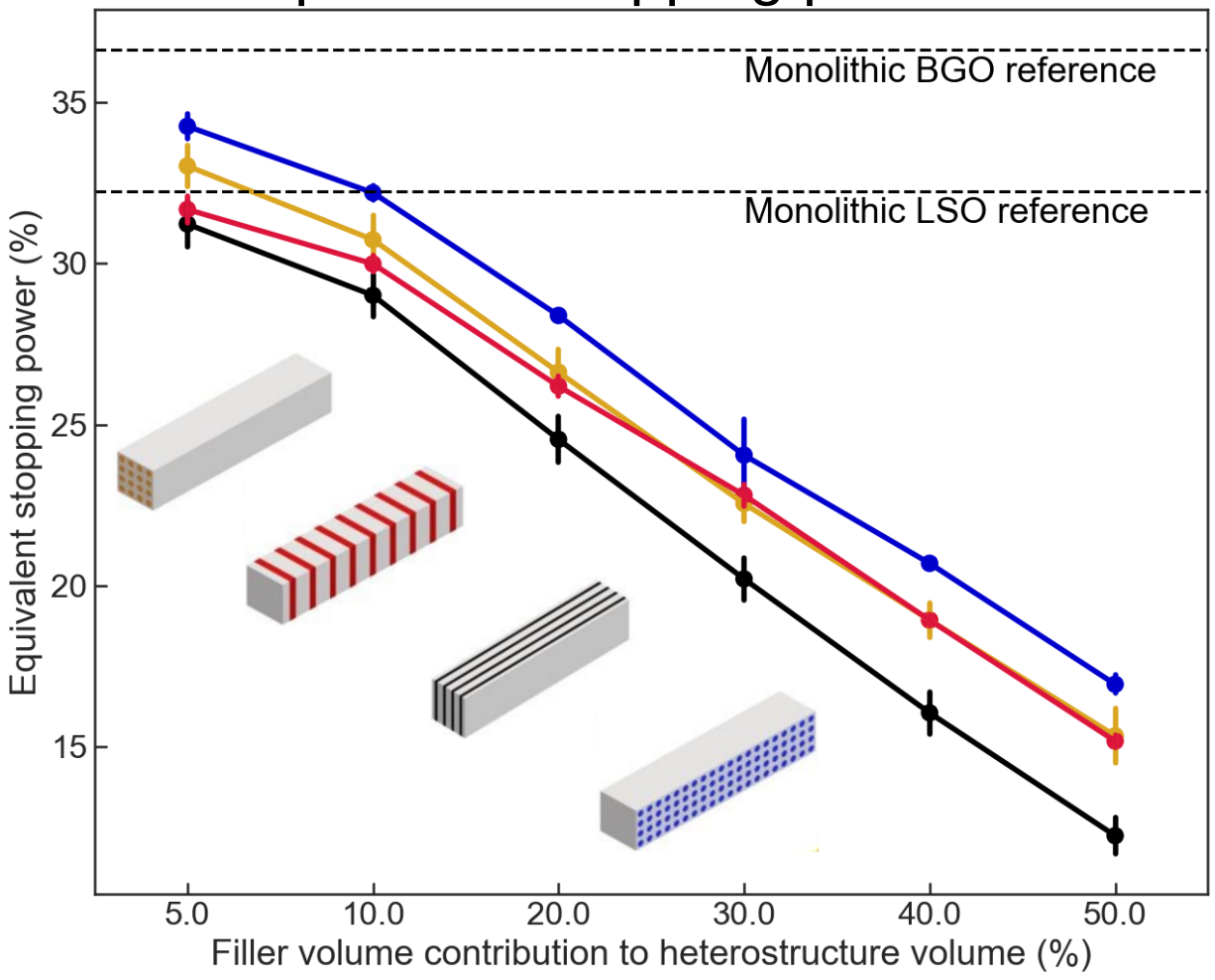


Both equivalent stopping power and energy sharing are heavily filler volume dependent but anticorrelated!

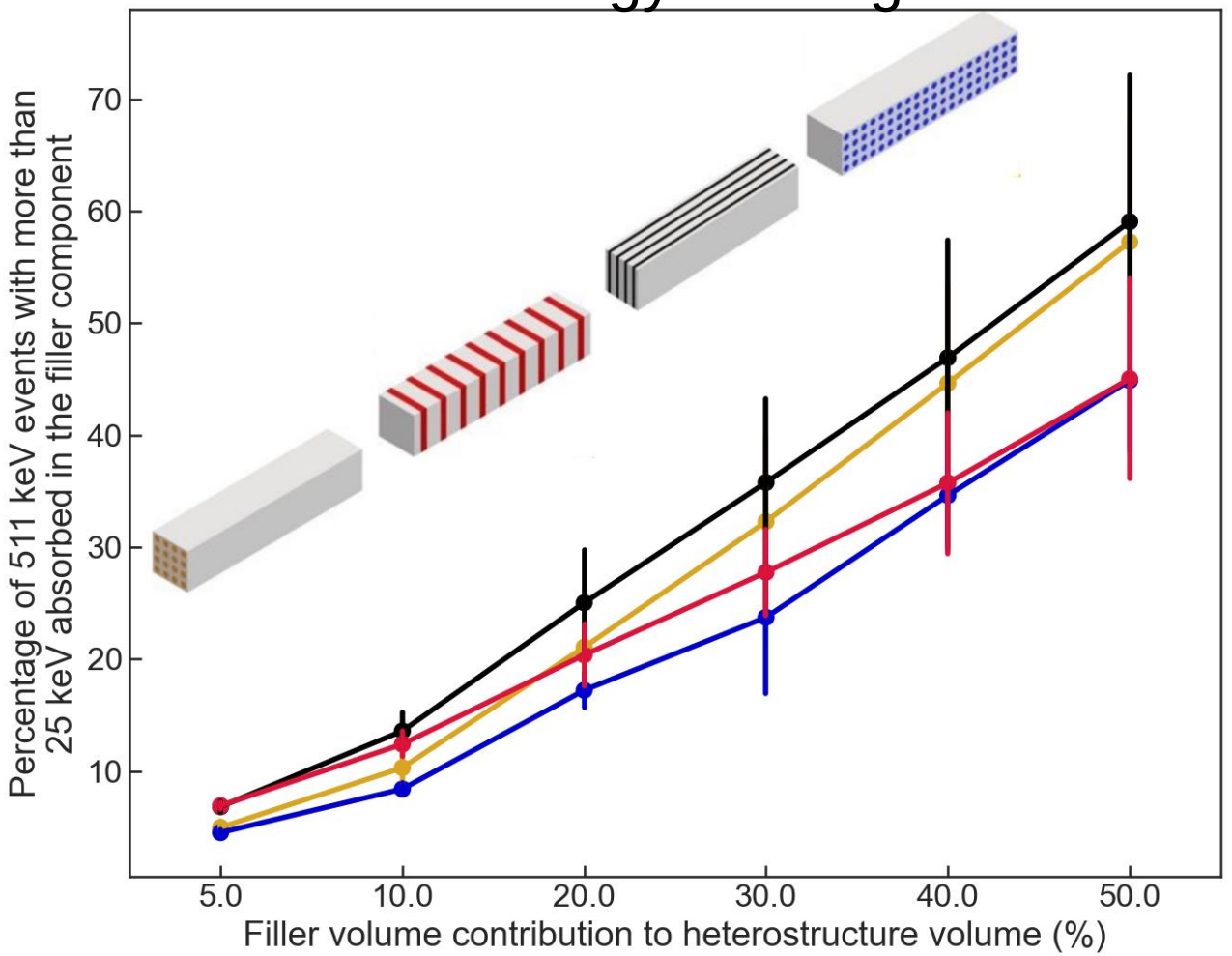
Effect of geometry on performance

Heterostructure Design
- Heterostructure Layout
- Response Simulation

Equivalent stopping power



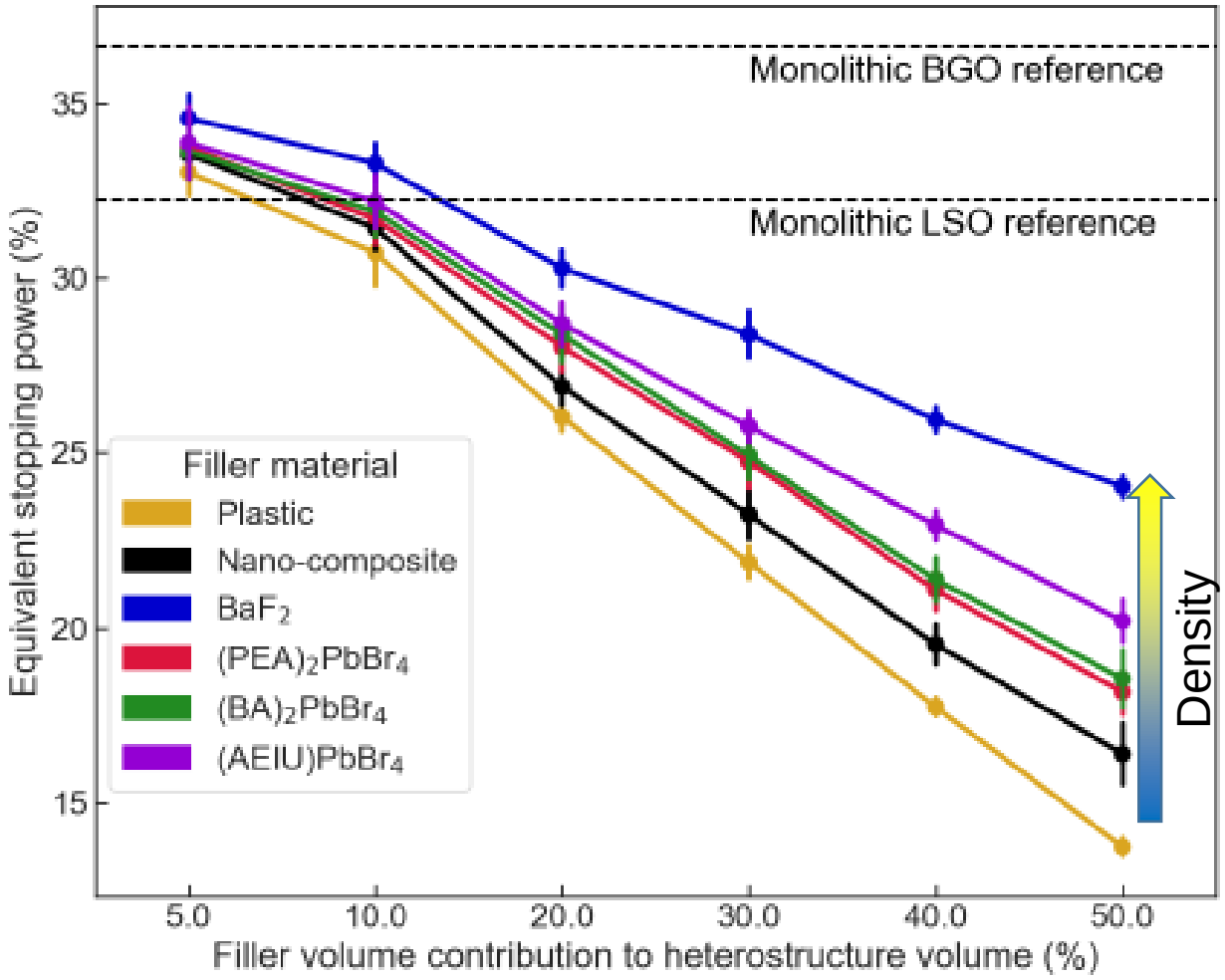
Energy Sharing



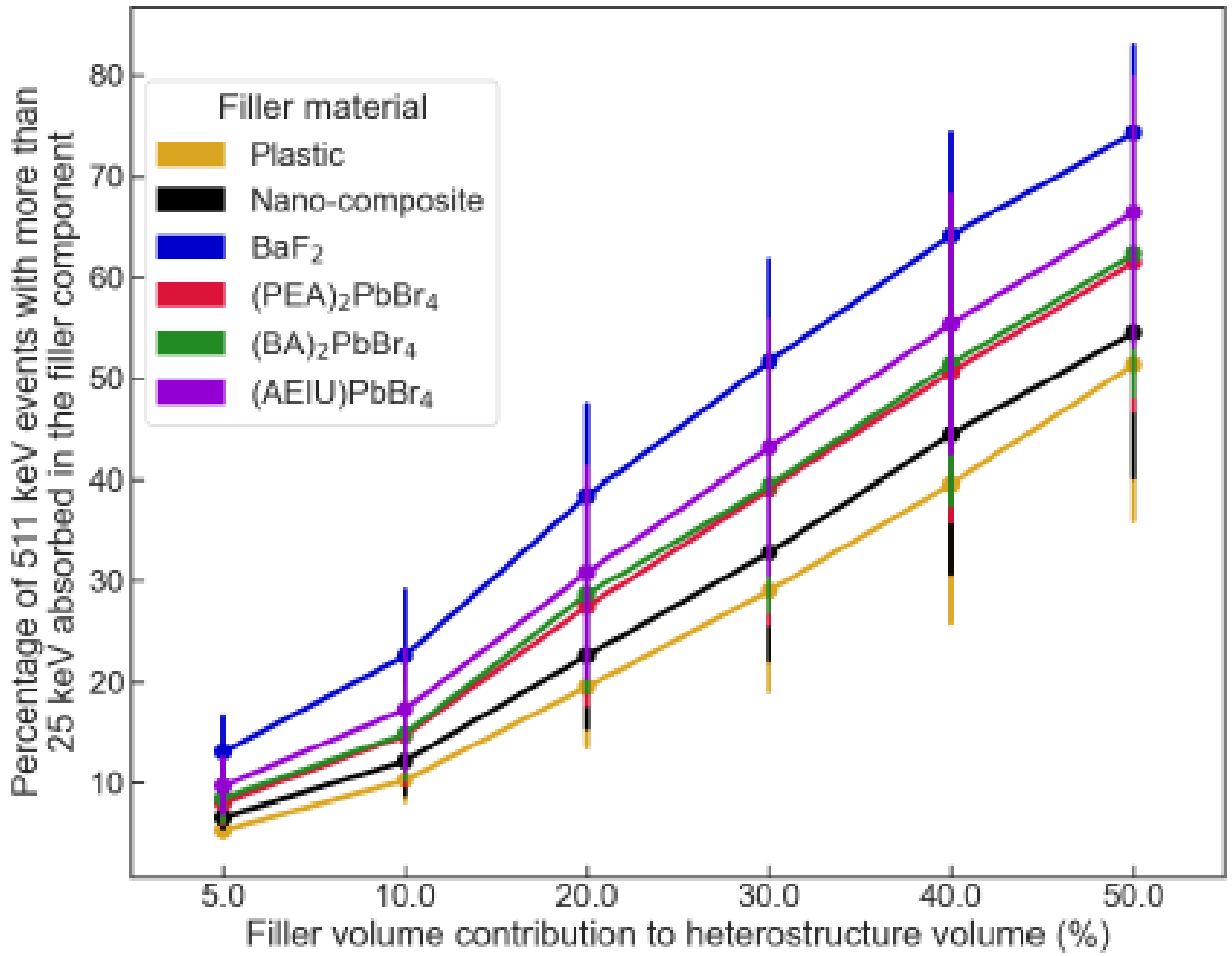
Filler material choice

Heterostructure Design
- Heterostructure Layout
- Response Simulation

Equivalent stopping power

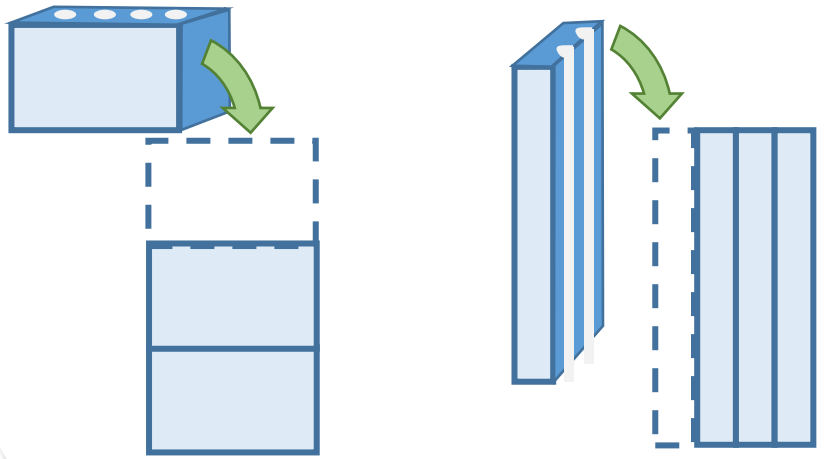


Energy Sharing

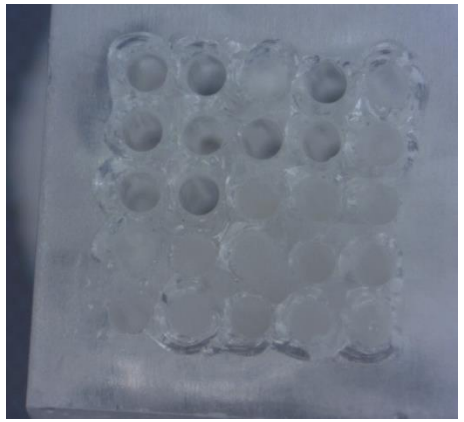


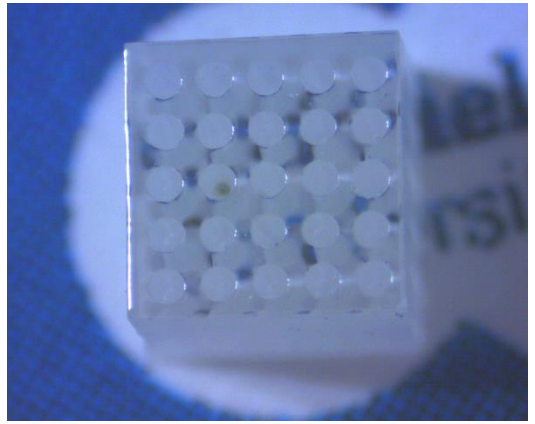
Brittle Single Crystal Precision Machining

Precision Machining
- Micro-machining
- Process Optimization

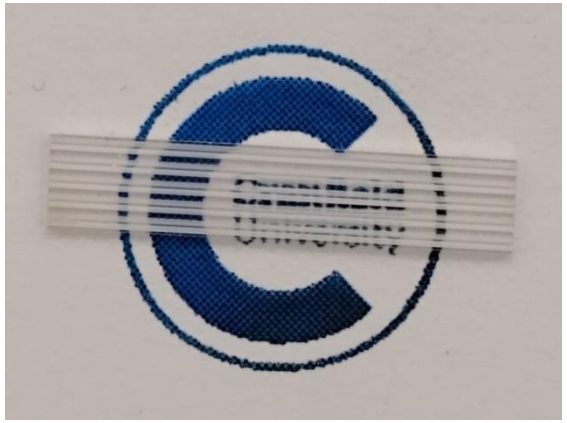


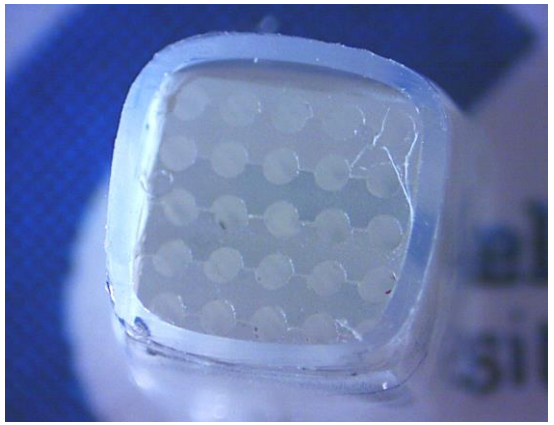
Drilling holes





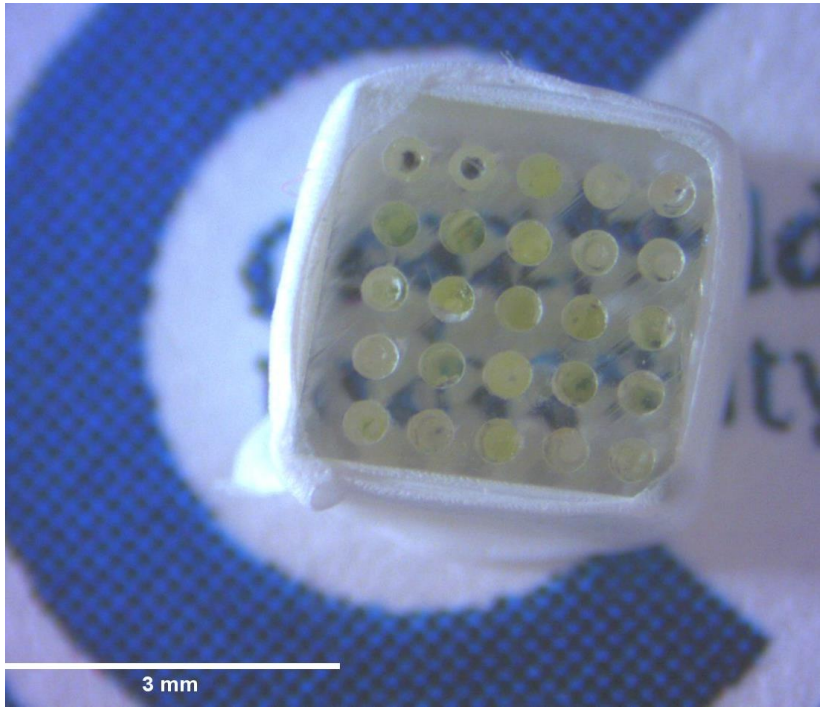
Milling grooves



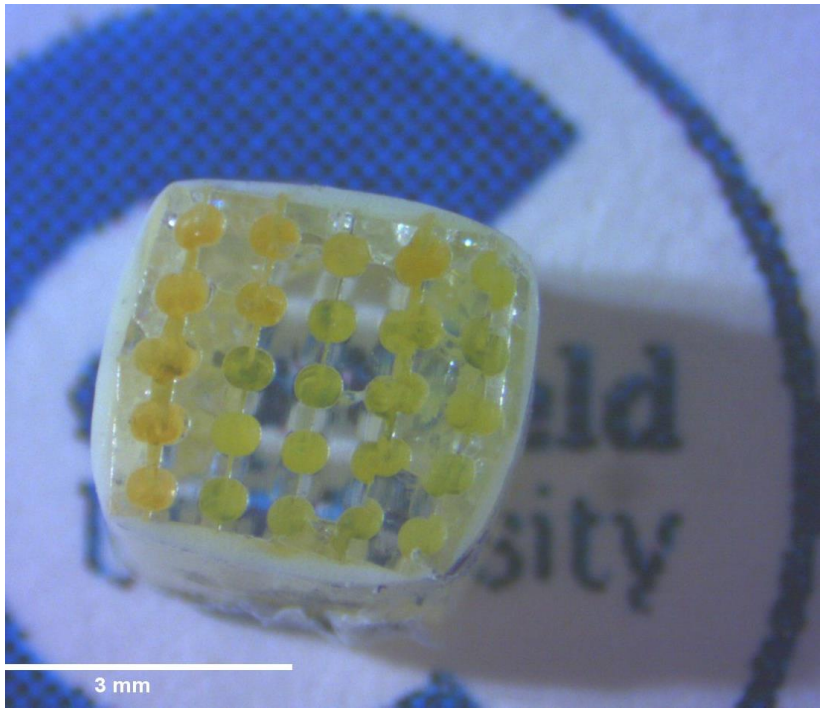


Proof of concept pixels filled with PVT by in-situ polymerisation or BA_2PbBr_4 perovskite by solution growth

Precision Machining
- Micro-machining
- Process Optimization



"Drilled" $Bi_4Ge_3O_{12}$ (BGO) matrix
3x3x3 mm
PVT filler
Functionalised by in-situ polymerisation

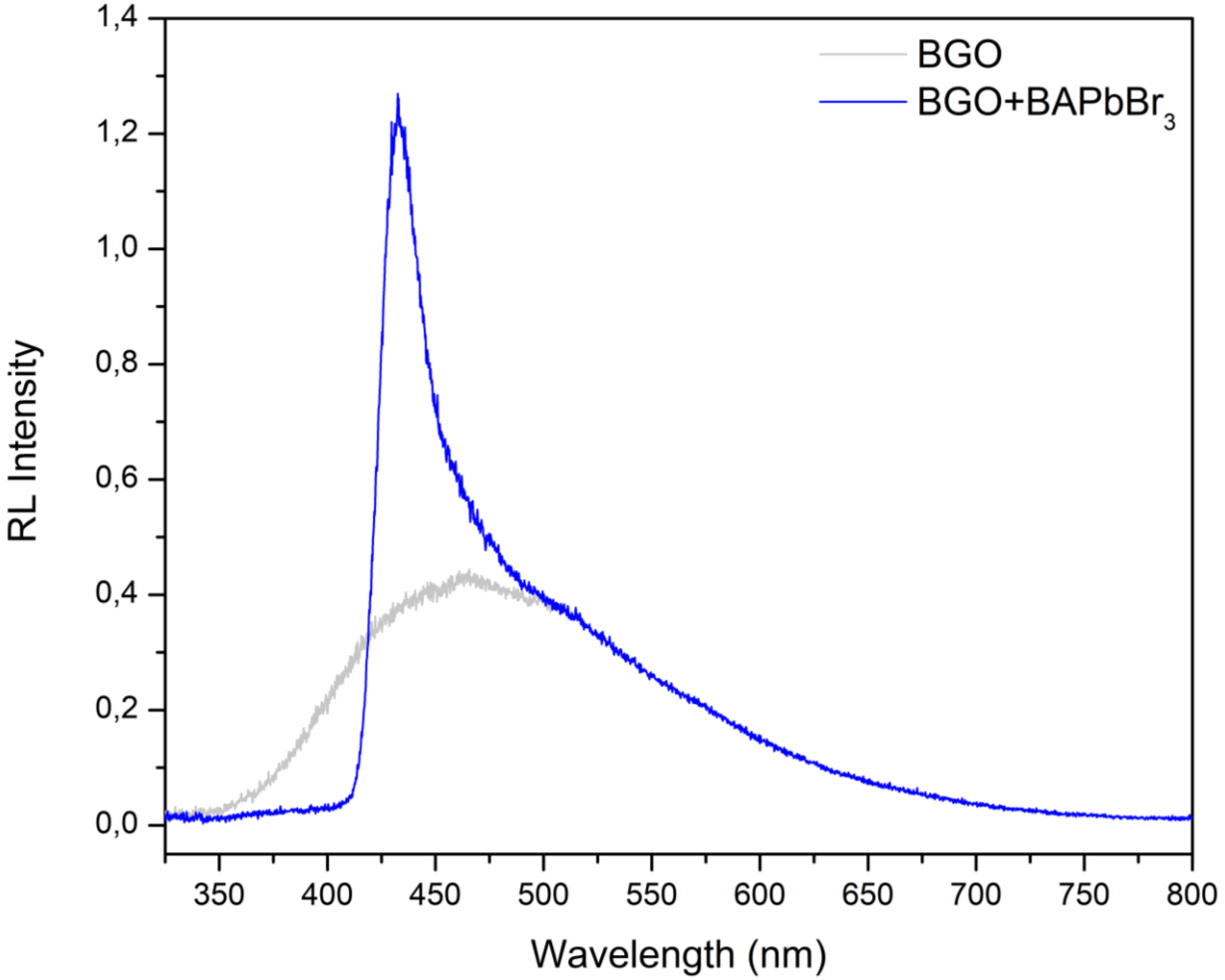


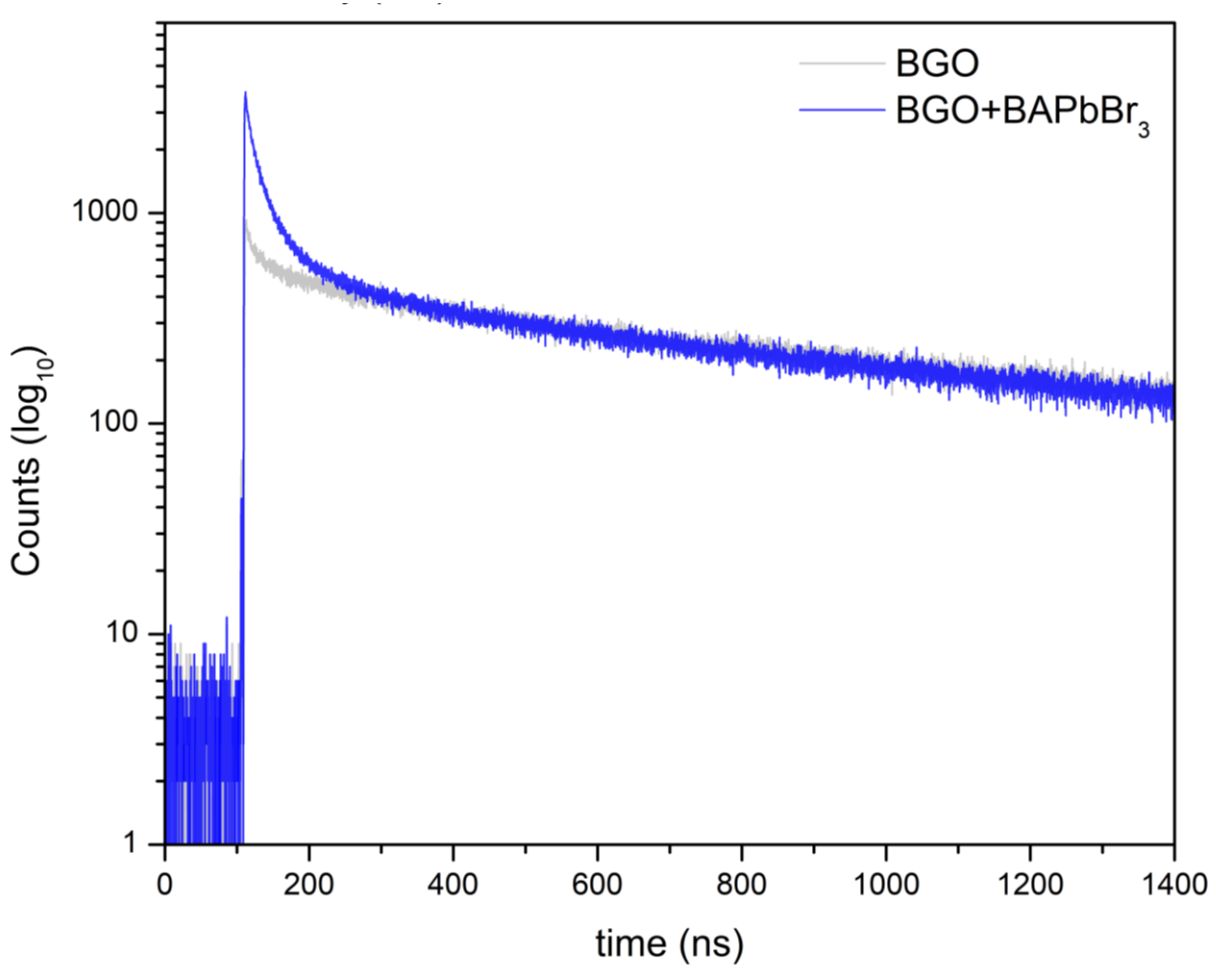
"Milled" $Bi_4Ge_3O_{12}$ (BGO) matrix
3x3x3 mm
PVT filler
Functionalised by in-situ polymerisation

"Drilled" $Bi_4Ge_3O_{12}$ (BGO) matrix
3x3x1 mm
$(BA)_2PbBr_4$ filler
Functionalised by in-situ solution growth

$(BA)_2PbBr_4$ Pixel – X-ray response

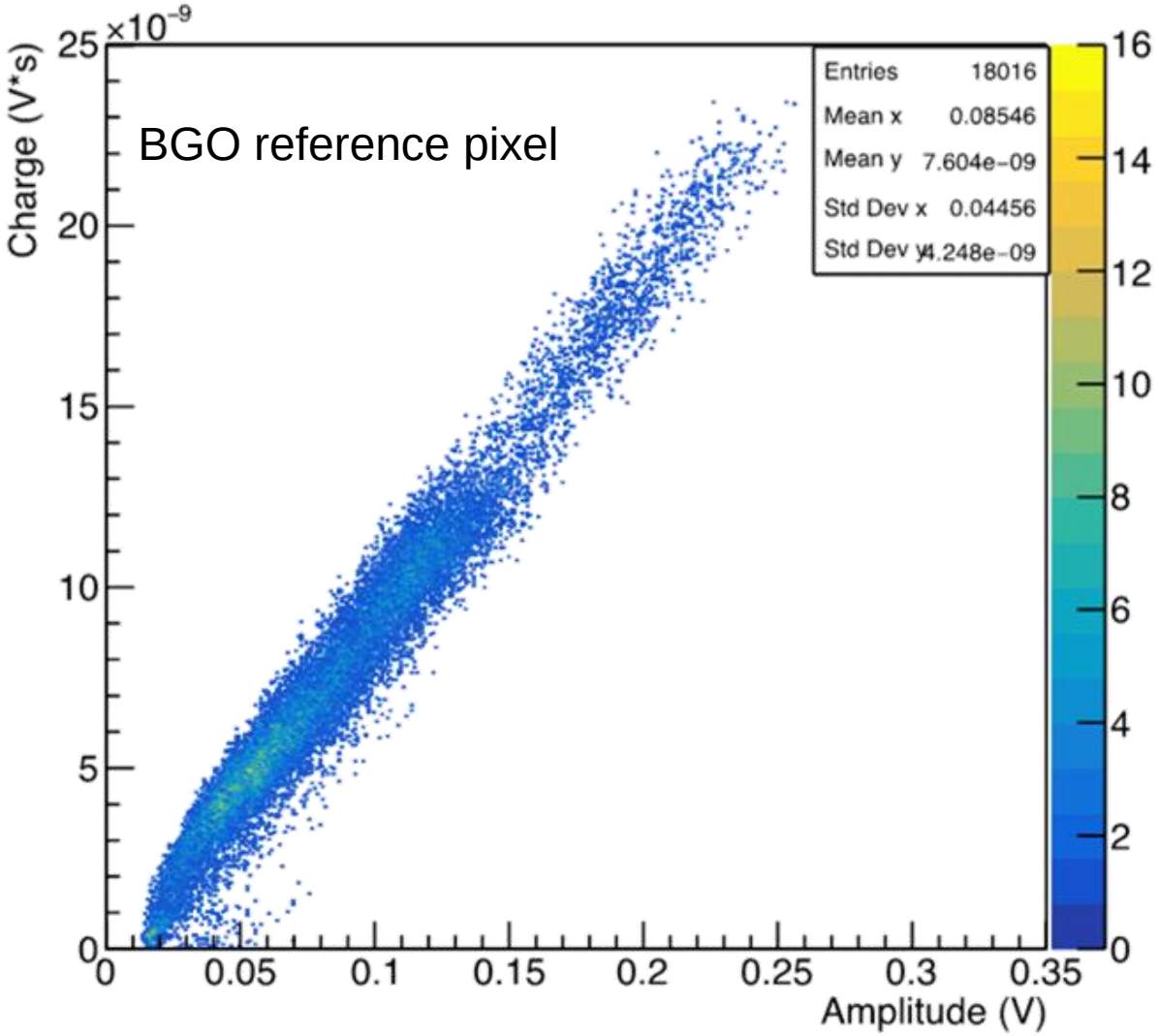
Heterostructure Evaluation
- Neutron Imaging
- Timing Resolution

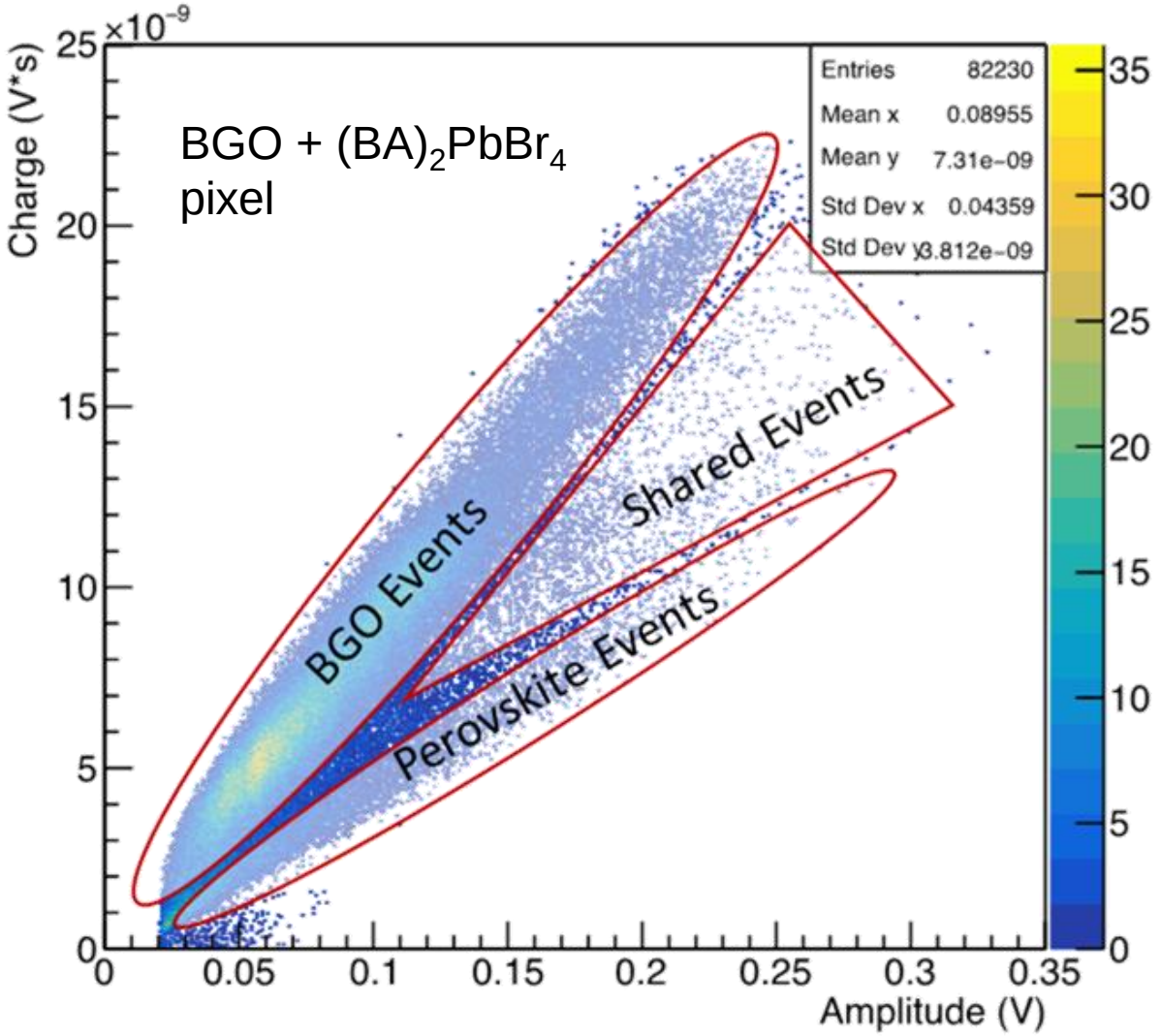




$(BA)_2PbBr_4$ Pixel – Shared events

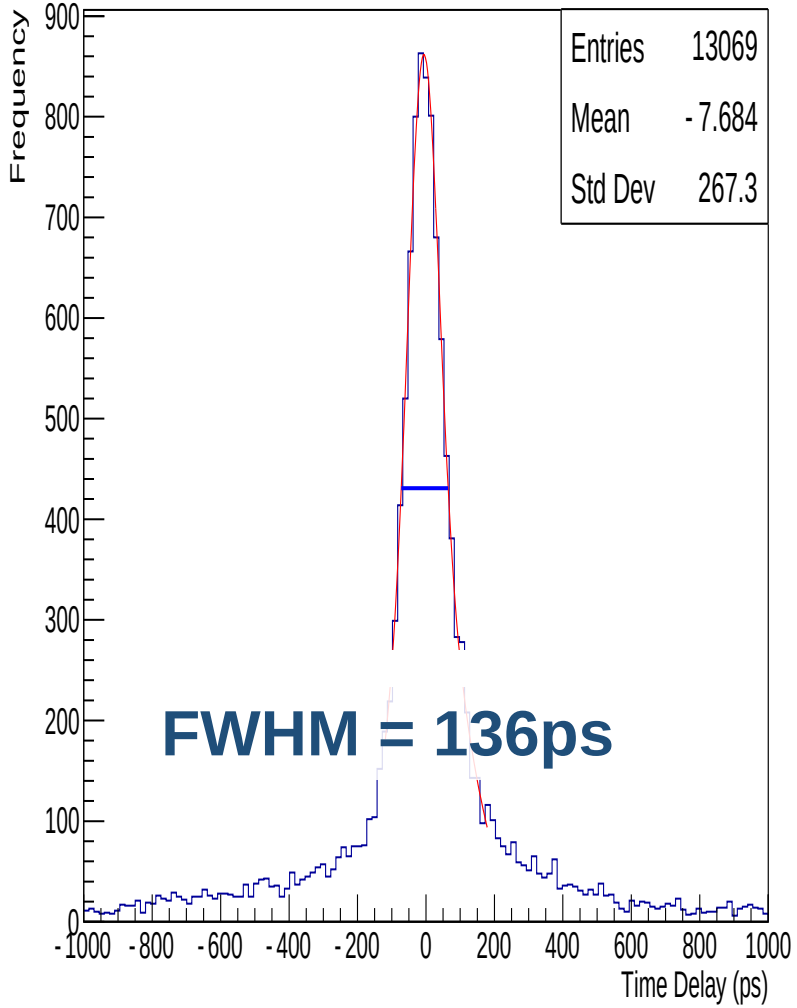
Heterostructure Evaluation
- Neutron Imaging
- Timing Resolution

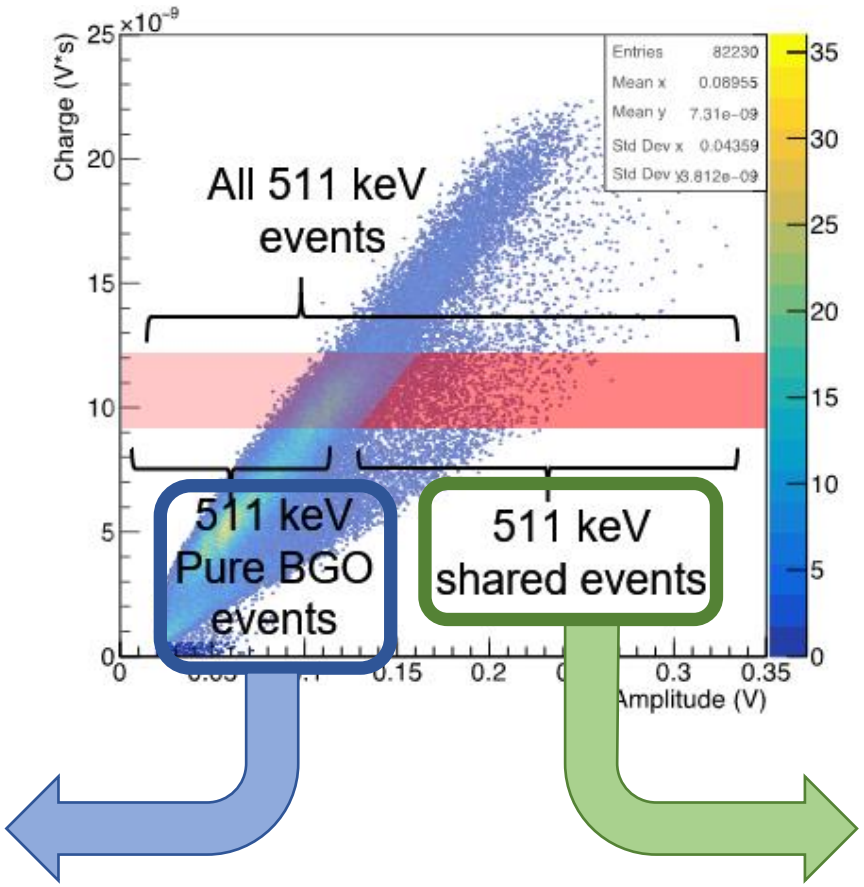


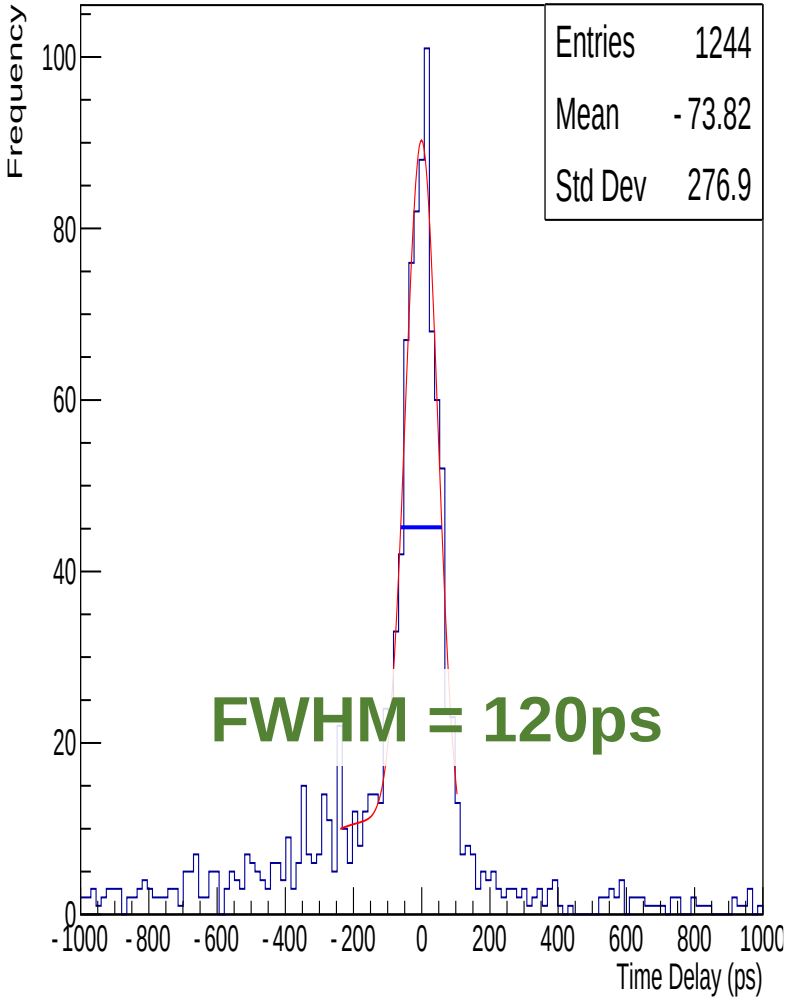


$(BA)_2PbBr_4$ Pixel – Coincidence timing

Heterostructure Evaluation
- Neutron Imaging
- Timing Resolution







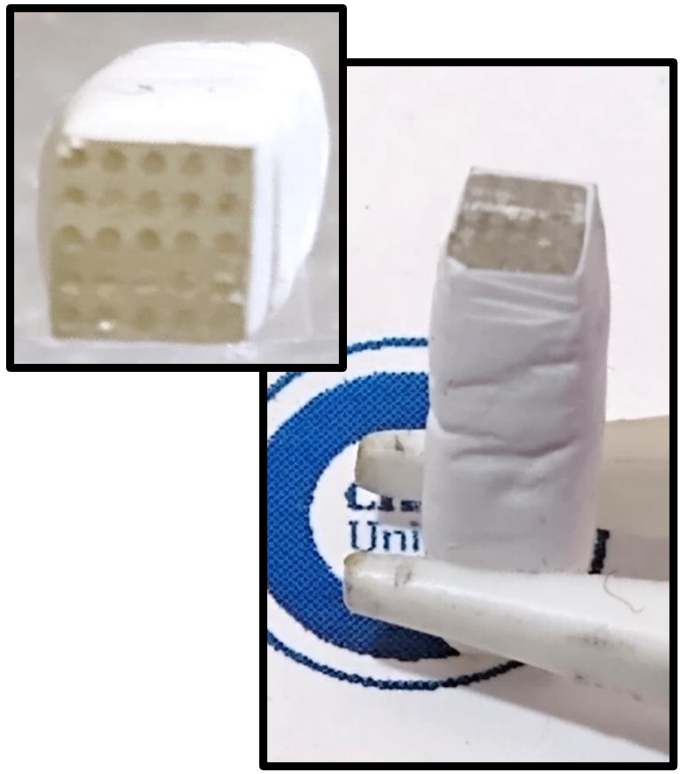
From 3x3x1 mm proof of concept to 3x3x15 mm $(BA)_2PbBr_4$ prototype pixel

Heterostructure Evaluation
- Neutron Imaging
- Timing Resolution

1) Filling (NTU)

2) Polishing

3) Assembly

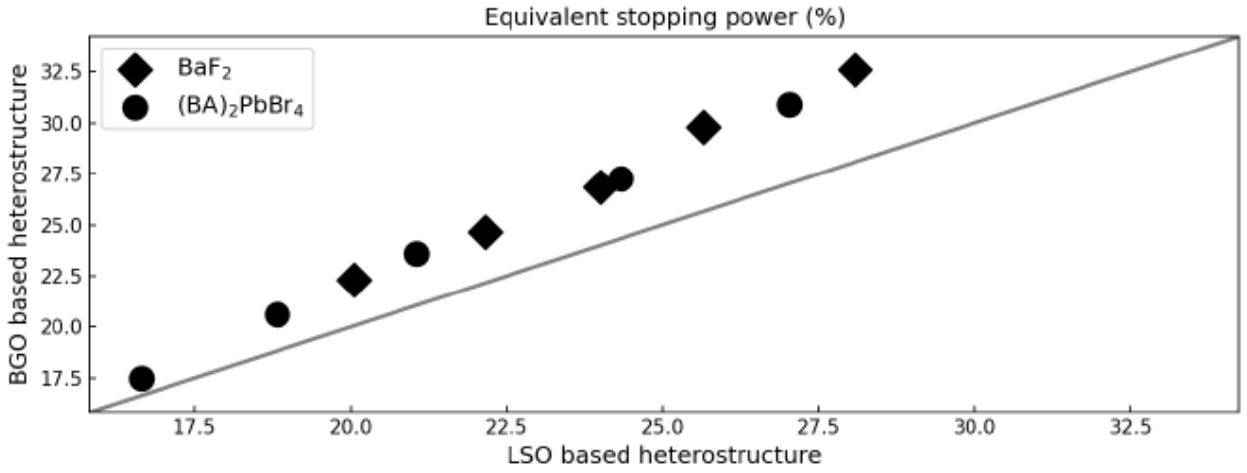


Conclusions and Perspectives

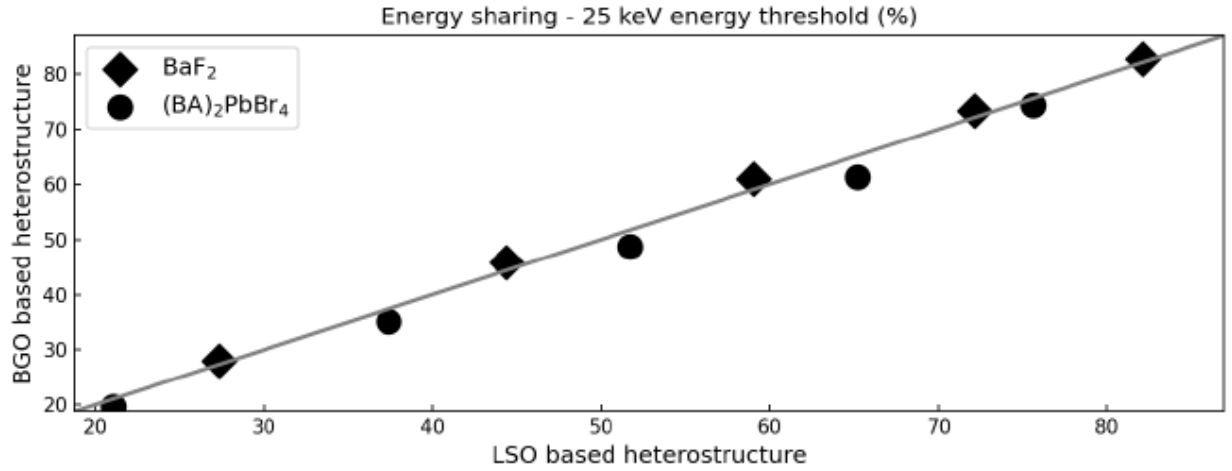
- The parameter space for fibre type heterostructured scintillators were surveyed
- We showed the development of three different manufacturing routes
  - Precision machining of BGO single crystals to form matrices
  - Functionalisation of PVT and $(BA)_2PbBr_4$ fast fillers inside matrices
- Proof of concept and prototype pixels have been manufactured
  - Implementation of intelligent designs in actual pixels
- Initial validation of stopping power, Energy Sharing and Coincidence Timing Resolution improvement

- Thanks to:
  - John Hedge, Brandon McCrae, Kane Murrell and Alan Heaume for their help with building the matrix
  - This work was supported by the UK Engineering and Physical Sciences Research Council (EPSRC) grant EP/S013652/1 for Cranfield University.
  - Part of the work was carried out in the framework of Crystal clear collaboration and supported by the CERN Budget for Knowledge Transfer to Medical Applications

Matrix material choice



BGO offers better ESP than LSO for the equivalent design



Energy sharing is geometry rather than matrix material dependent

BGO is the current matrix material of choice