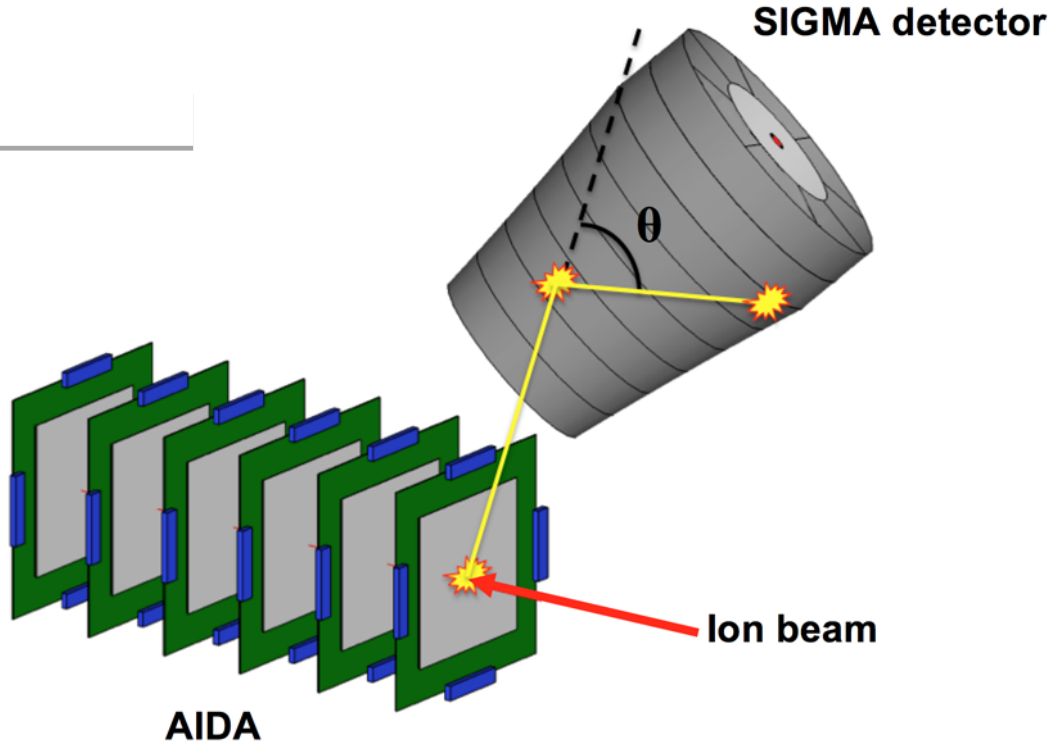
SIGMA: A new detector for γ-ray spectroscopy & imaging

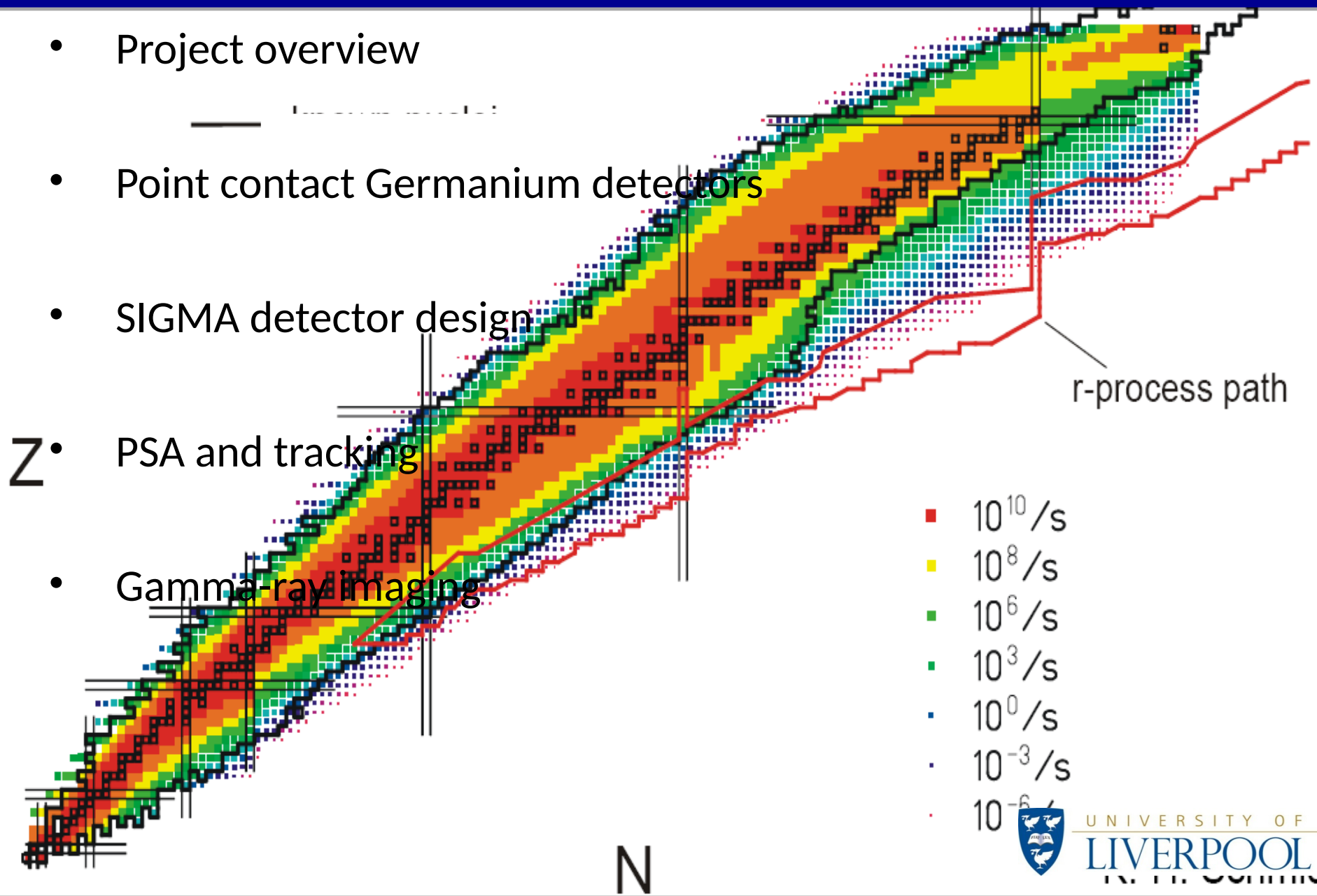
Dr Laura Harkness-Brennan

PSEGE workshop 2016



Outline

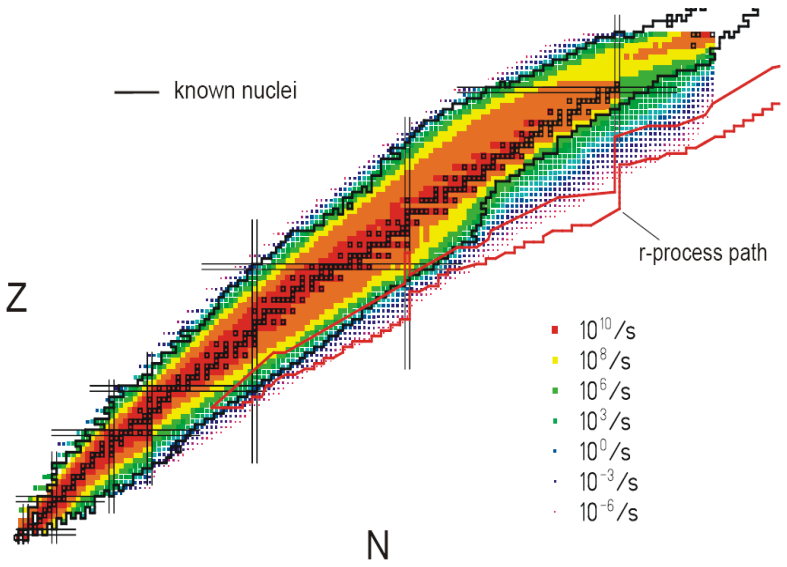
- Project overview
- Point contact Germanium detectors
- SIGMA detector design
- PSA and tracking
- Gamma-ray imaging



Project overview

Opportunity: HPGe array at DESPEC experiment, NuSTAR, FAIR

DESPEC: Implanting short-lived exotic nuclei into AIDA (highly pixellated Si array), observe subsequent decays



Measurements: Half-lives, isomer decays & β-decays measured for 1st time in exotic nuclei

DESPEC challenges: low yields in high background, correlating events for (1) isomeric decay ($t_{1/2}$ 10ns-100ms, 1mHz-1Hz rate) and (2) β-delayed γ-ray emission from exotic ions implanted in AIDA

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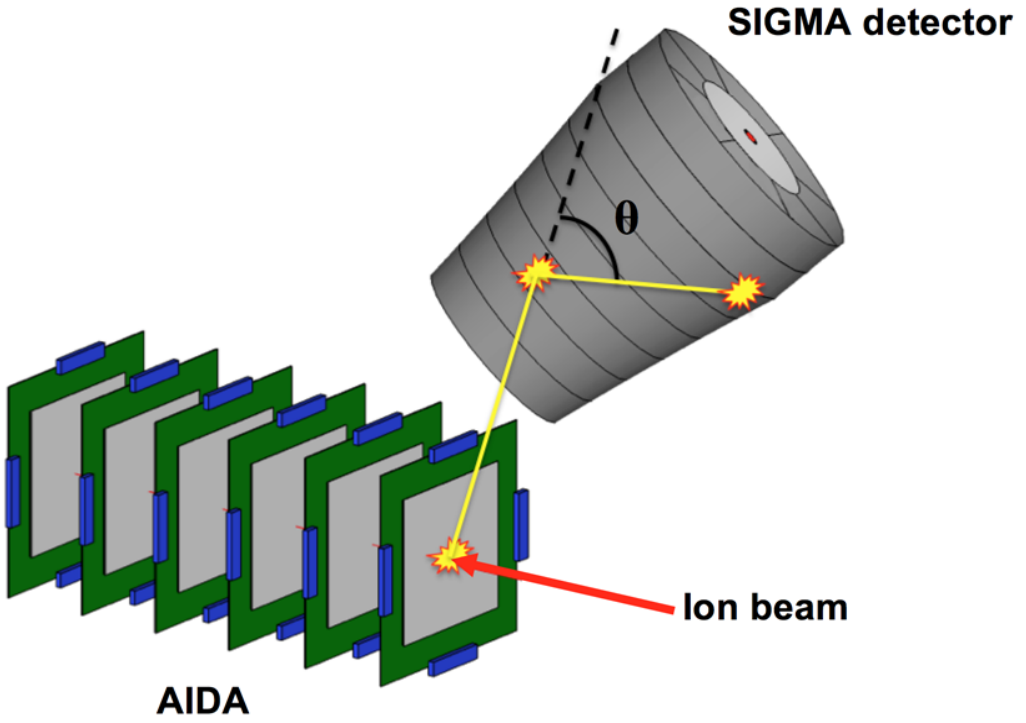
Project overview

Methods:

- Measure γ-ray interaction energies & positions
- Use *gamma-ray tracking* to (1) suppress background (100-500Hz) & (2) correlate to β detected in AIDA

Requirements: segmented detector with **excellent energy resolution** and **<1mm^3 position resolution**, digital acquisition electronics for *pulse shape analysis* and deconvolution of pile-up events



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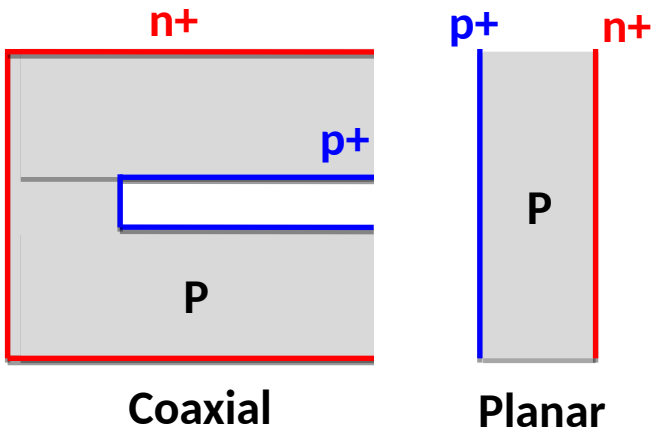
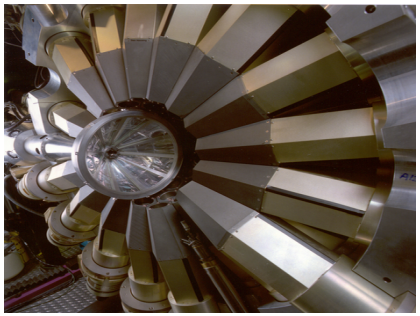
HPGe detectors

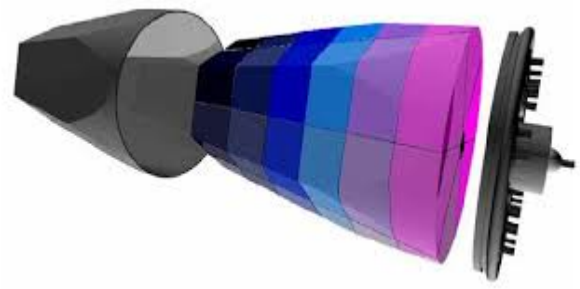
- Coaxial and planar detector design
- Compton suppression
- Segmentation: position resolution
- Gamma-ray tracking and PSA



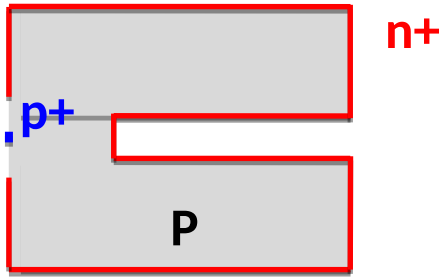
Compton suppression
Euroball, Gammasphere



Gamma-ray tracking
AGATA, GRETINA



Point-contact inverted coaxial?



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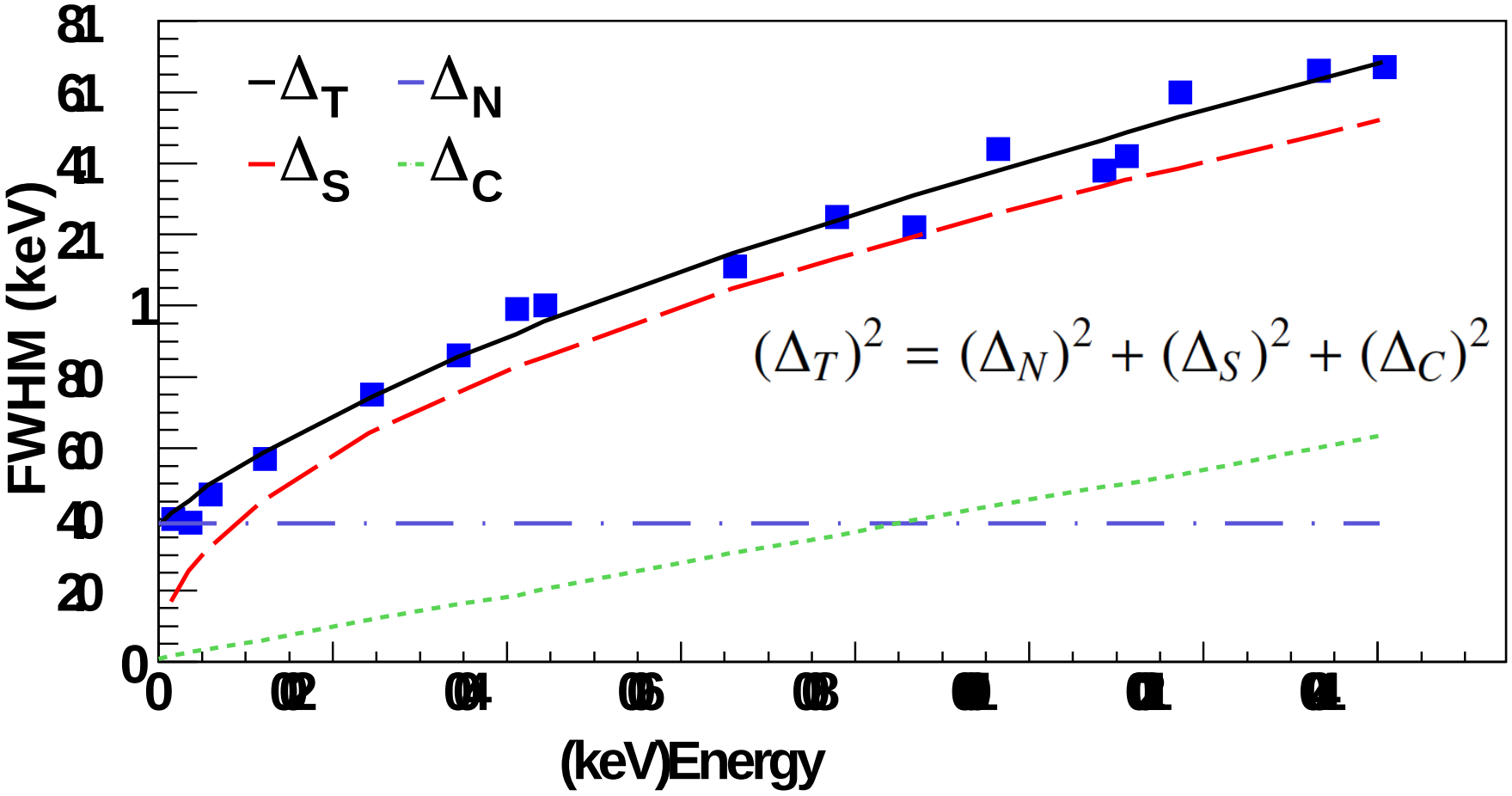
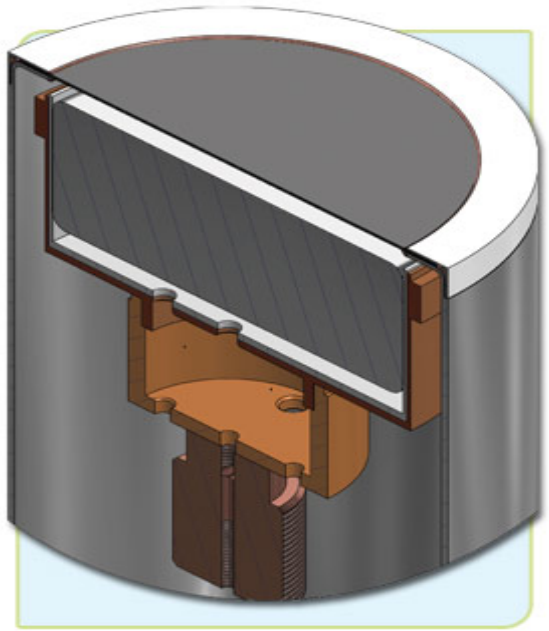
Energy resolution

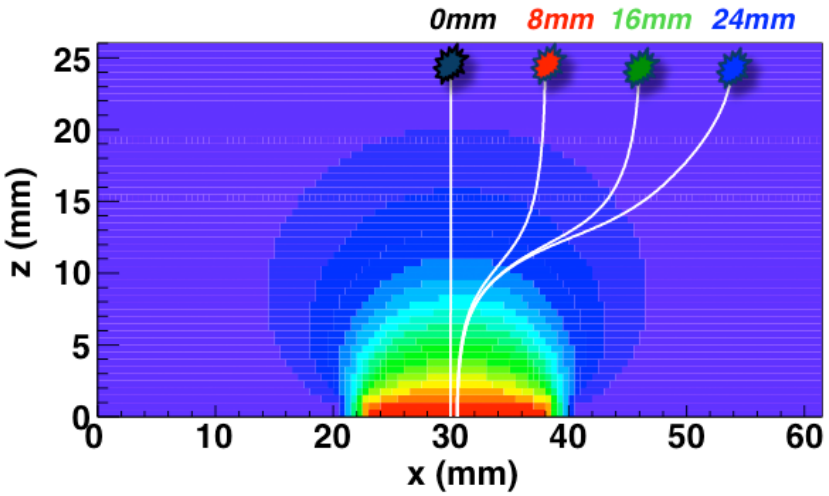
Total energy resolution: electronic **N**oise, **S**tatistical fluctuations in # of charge carriers and incomplete **C**harge collection

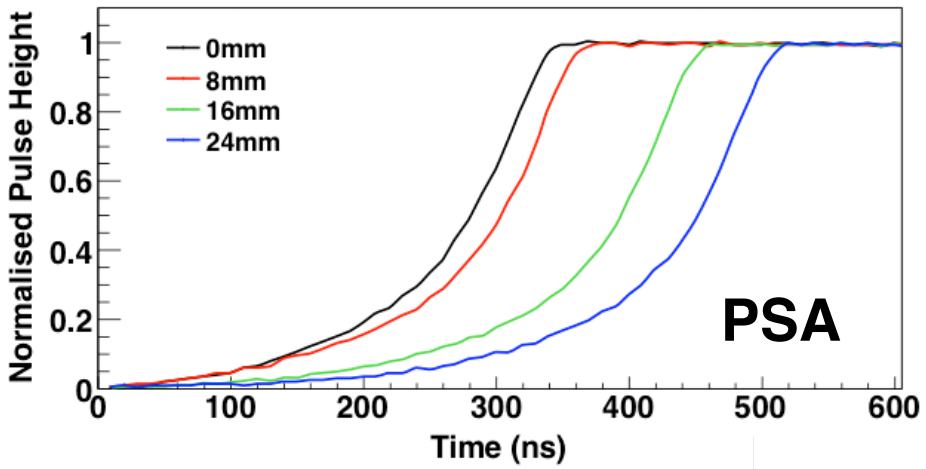


Point contact detectors

- Low capacitance *(~1pF)*
- Excellent energy resolution *(~0.5keV @ 122keV, 1.7keV @ 1332keV)*
- Small contact: Broad Energy Germanium BEGe and SAGe-well detectors
- GERDA and MAJORANA 0v2β, ALBEGA

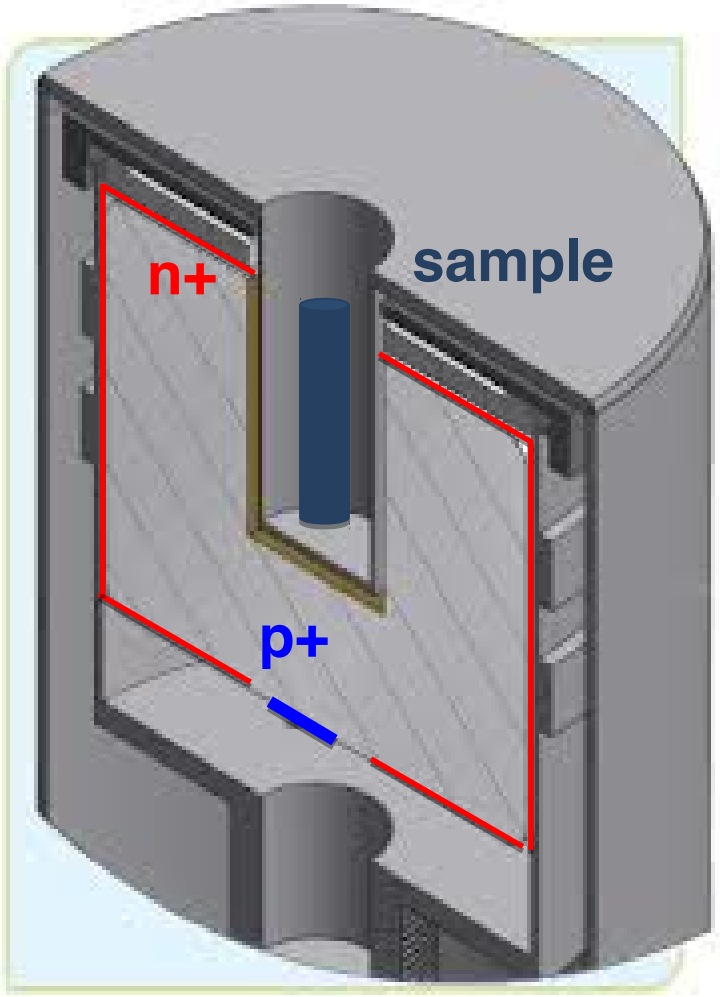






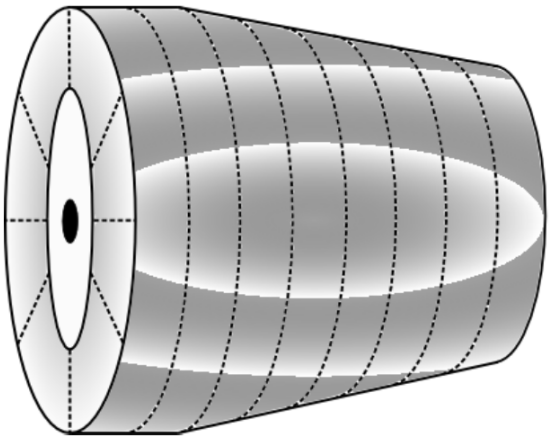
SAGe well detectors

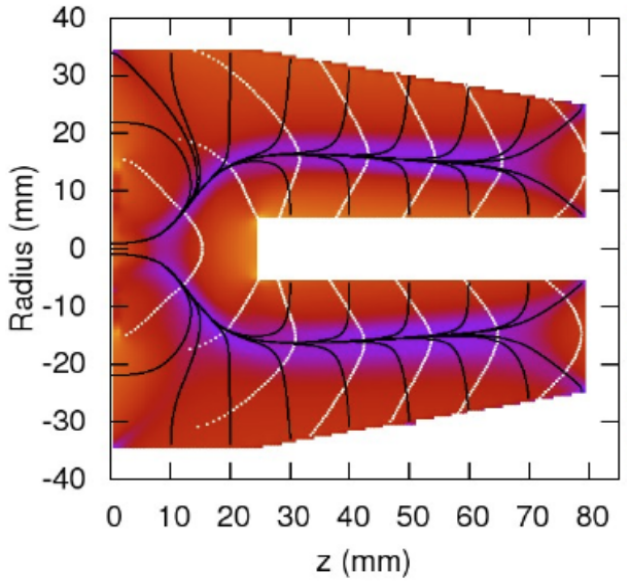
- SAGe well detector developed for environmental sample measurements
- Sample placed inside the well
- PSA techniques under development to distinguish coincidence summing events – Carl Unsworth
- Long charge collection times ideal for PSA



Development of the SIGMA detector

- Segmented Inverted-coaxial GerMAnium Detector
- Low electronic noise -> excellent energy resolution
- Expected factor of 2-3 improvement in position resolution over AGATA/GRETINA
- Simpler to analyse multiple interactions
- Fewer readout channels
- Reduction in cost and complexity



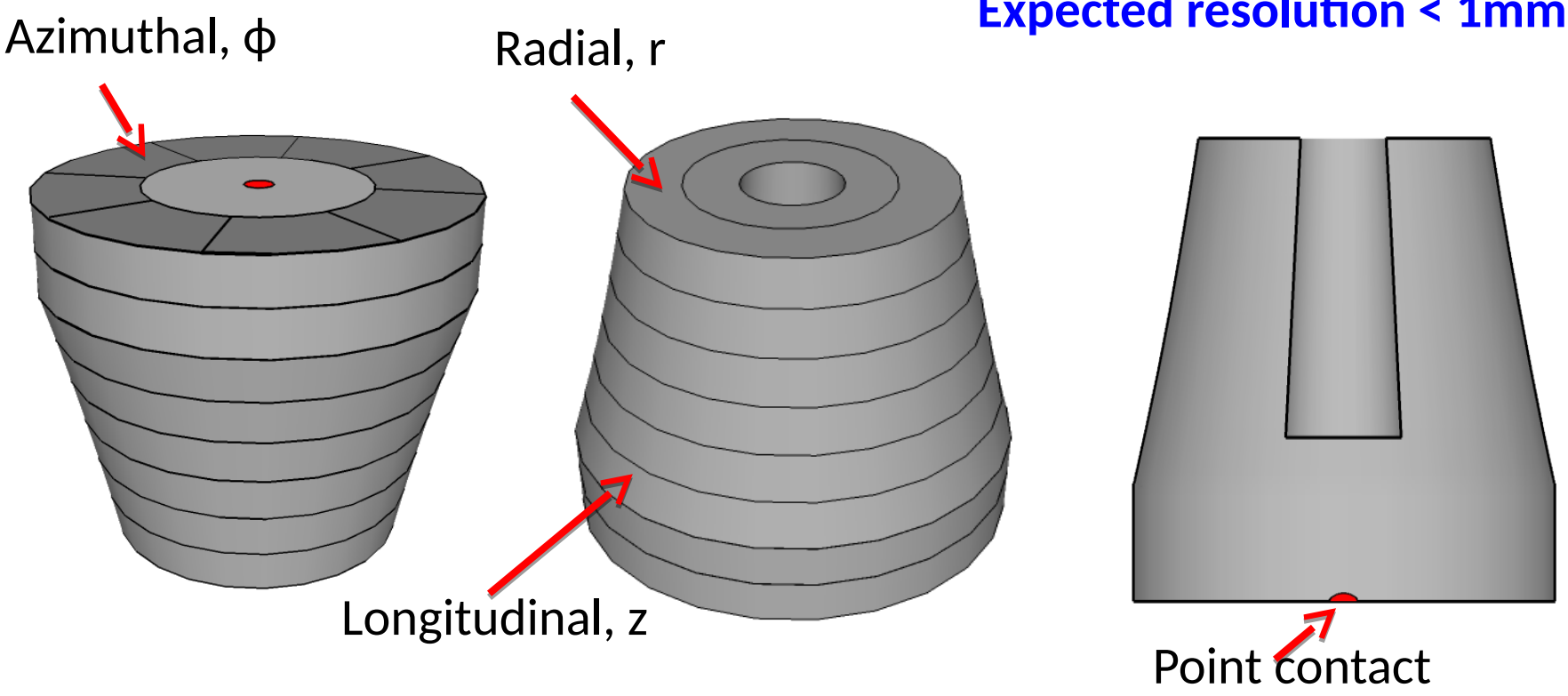


Simulations: Radford and Cooper

Development of the SIGMA detector

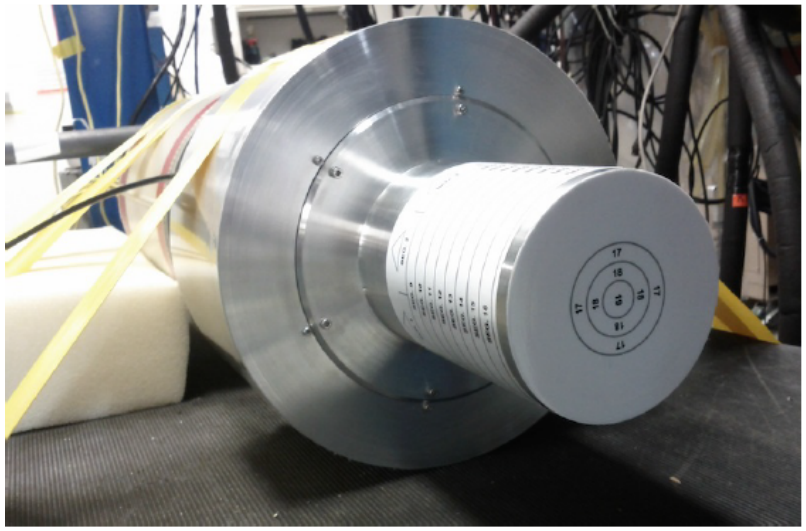
- 8 longitudinal rings, 2 concentric segments on front face, 8 sectors, 1 core segment, 1 point-like contact
- Digitised signals processed through PSA algorithms

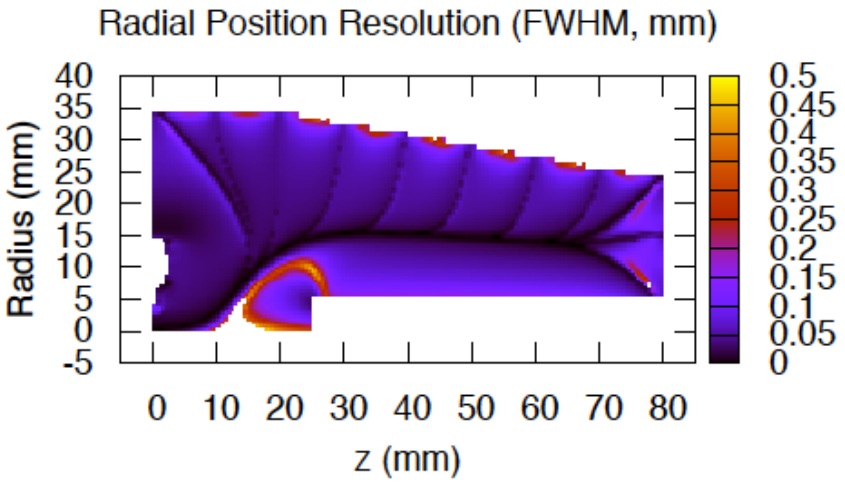
Expected resolution < 1mm^3

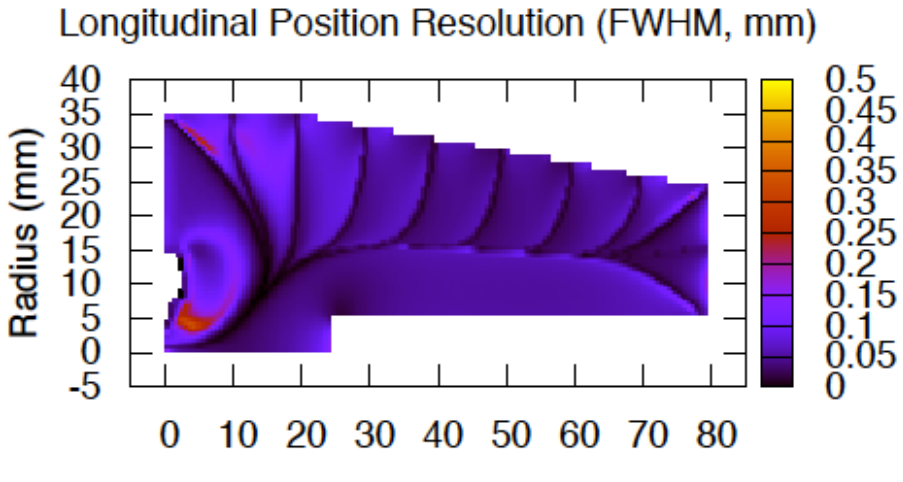


ORNL n-type prototype

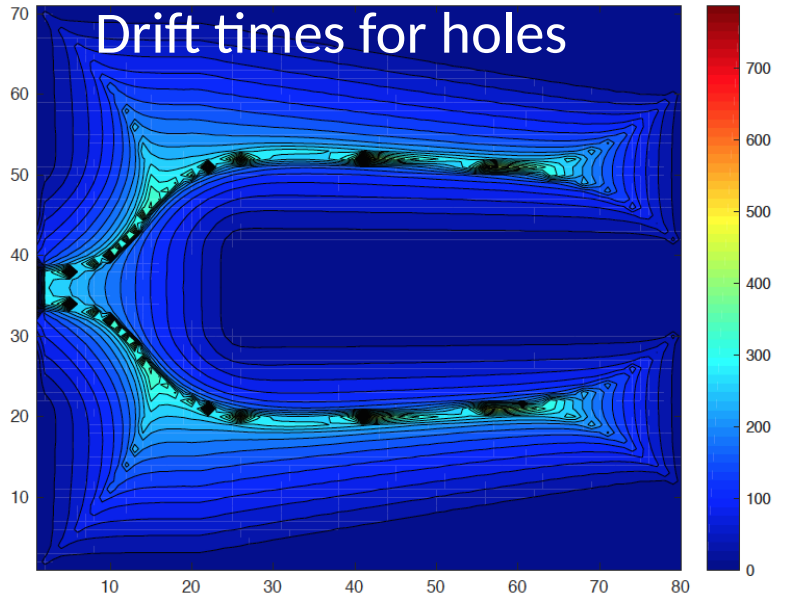
- ORNL (David Radford) segmented n-type prototype
- Modelling study: R. J. Cooper et al, NIM A 665 (2012) 25
- Excellent match with experimental signals (ORNL/Berkeley)
- SIGMA of similar design but p-type

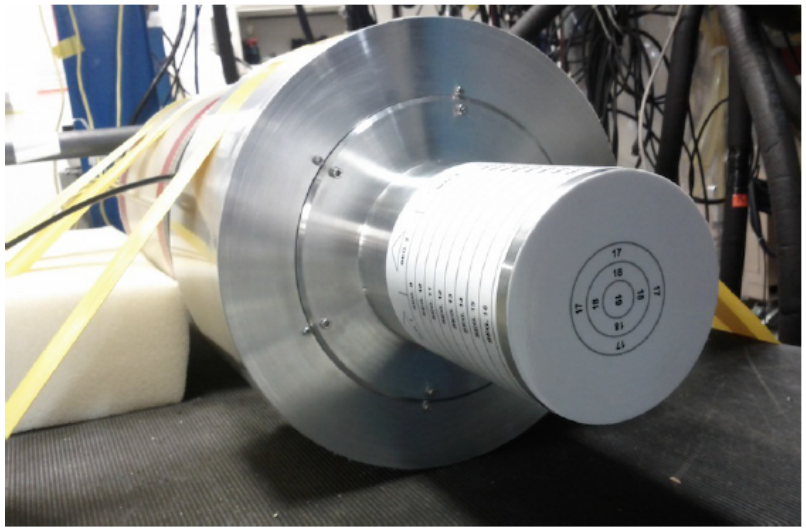


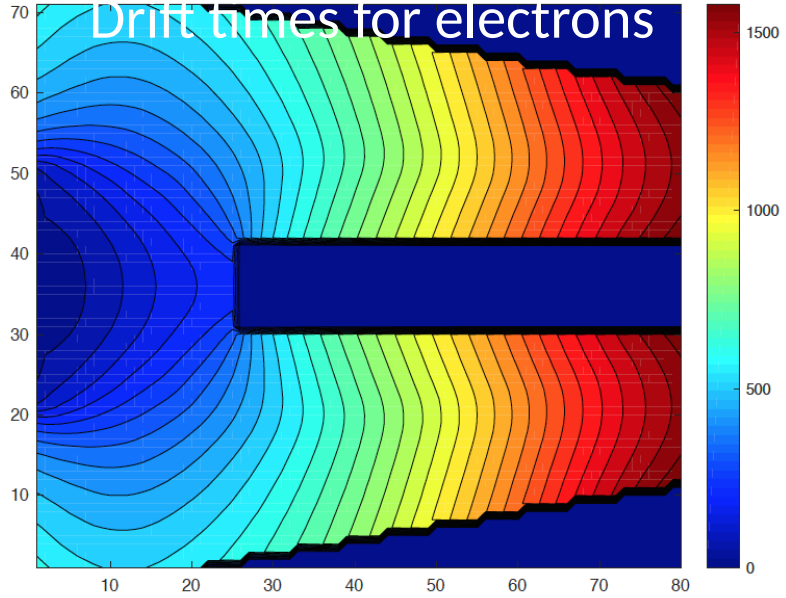




ORNL n-type prototype





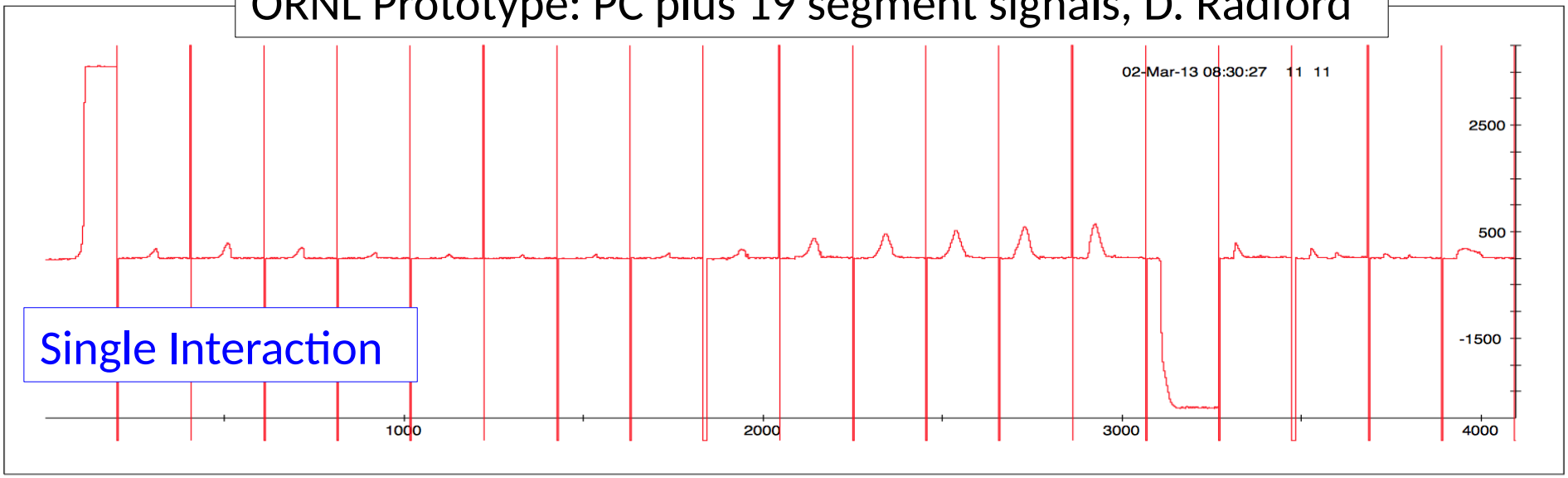


- Comparisons of drift times for the two detectors underway
- Experimental signal database to be acquired and compared

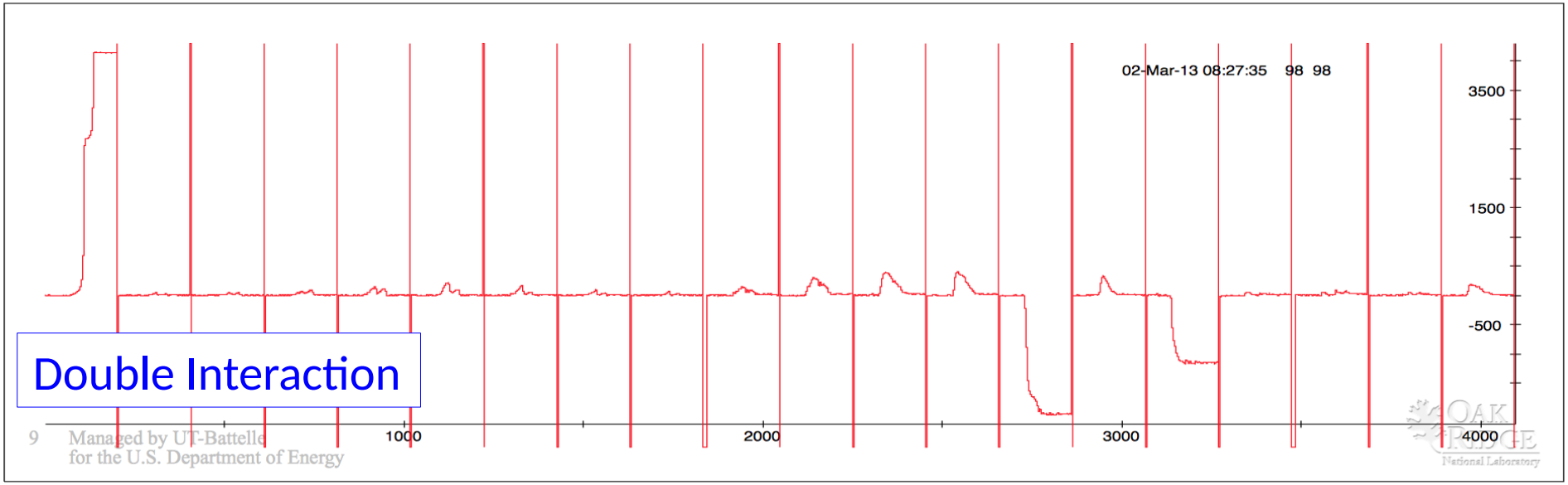
Jon Wright

ORNL n-type prototype

ORNL Prototype: PC plus 19 segment signals, D. Radford



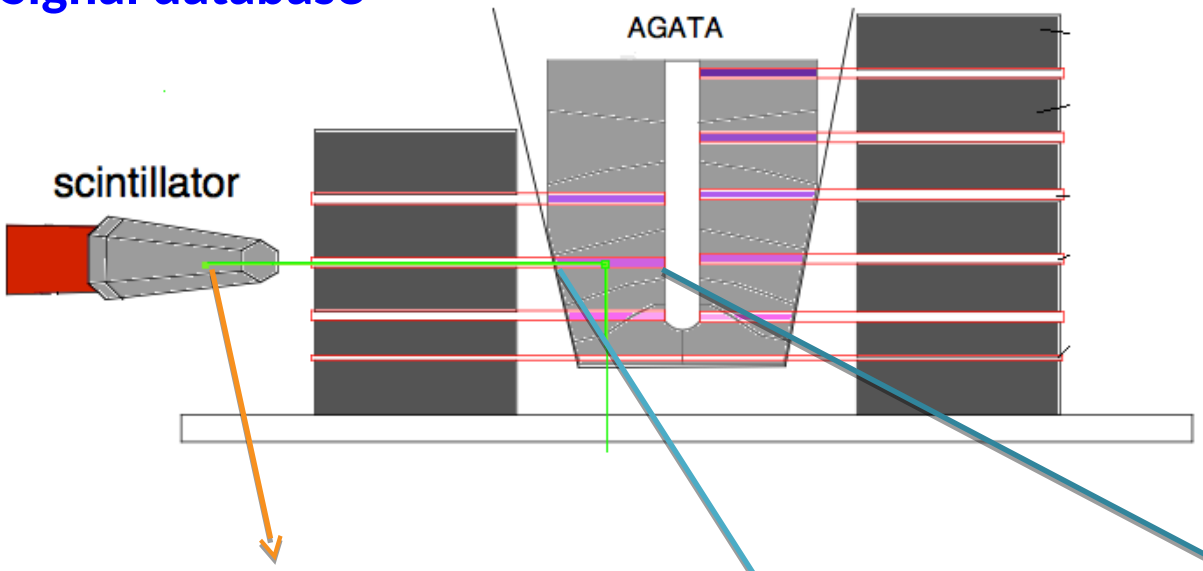
Single Interaction

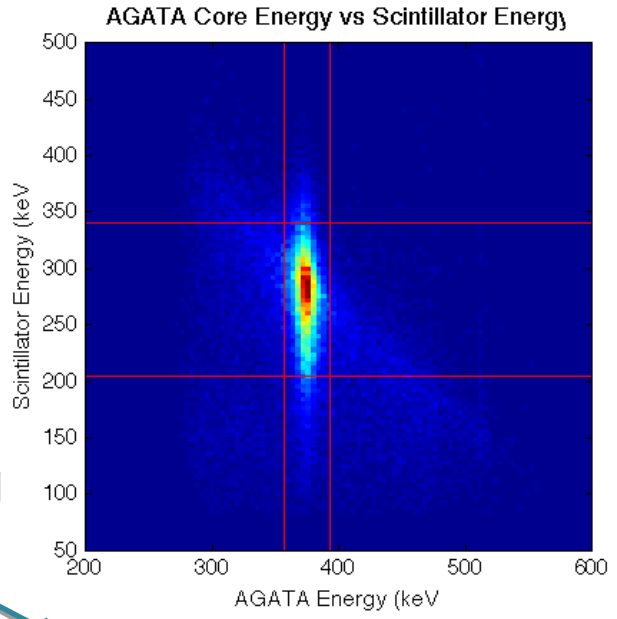


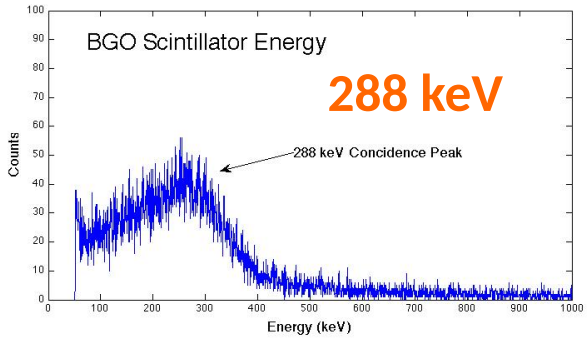
Double Interaction

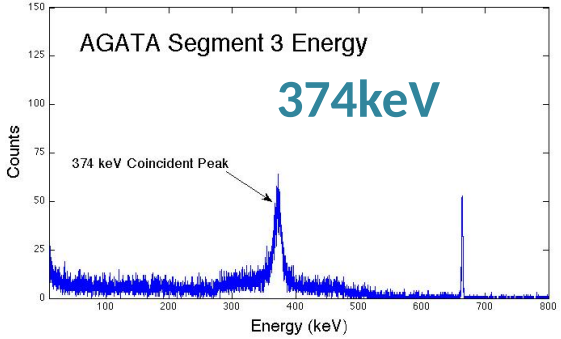
Building a signal database

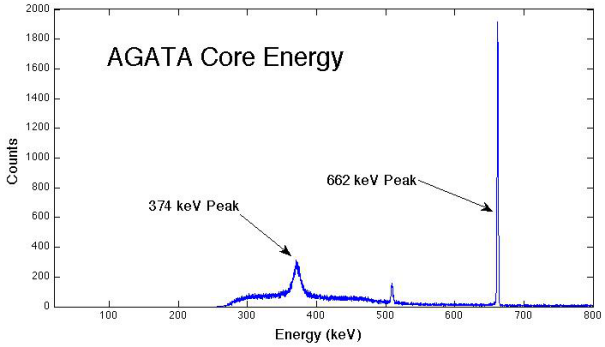
Signal database











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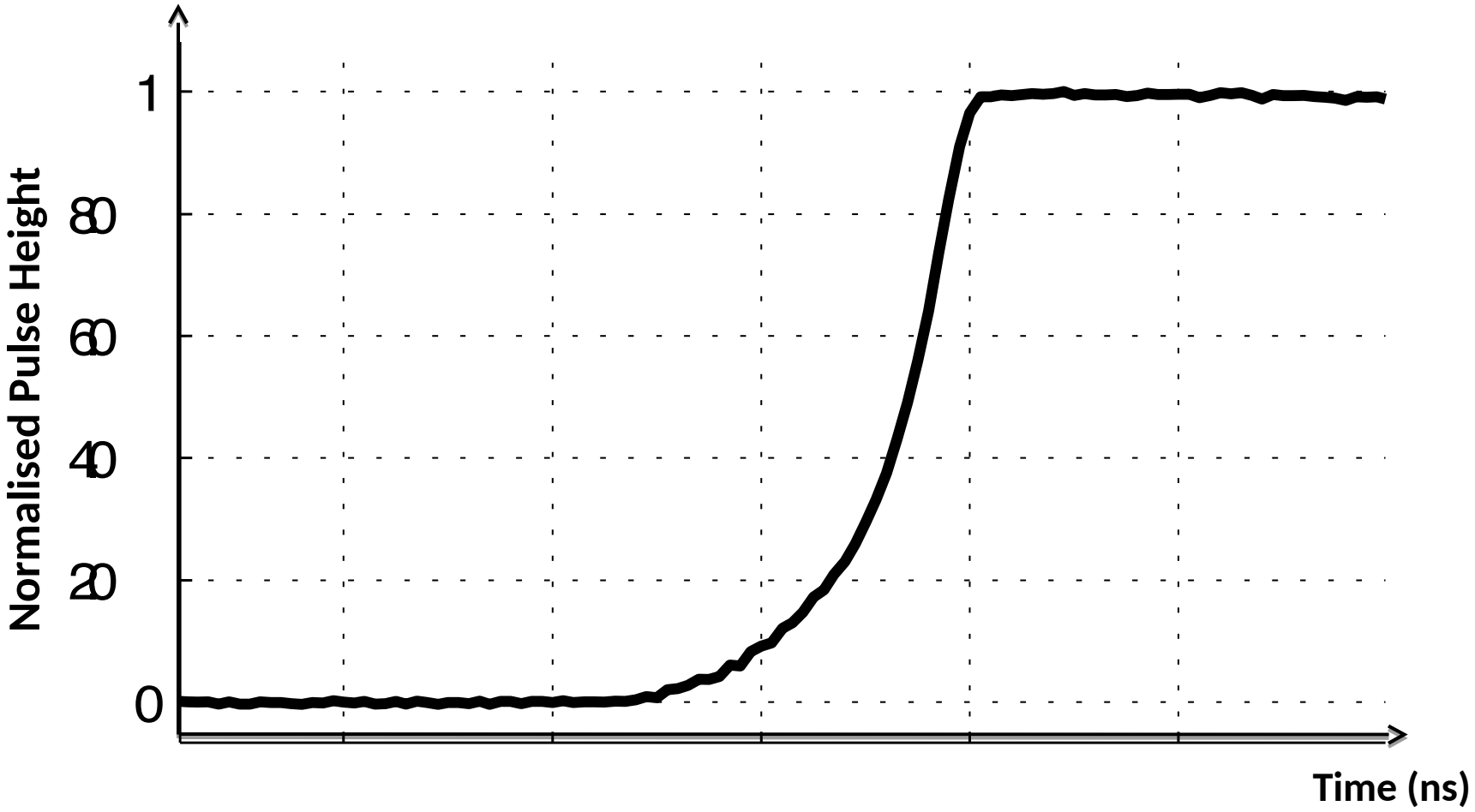
Building a signal database



Build experimental database - 2017

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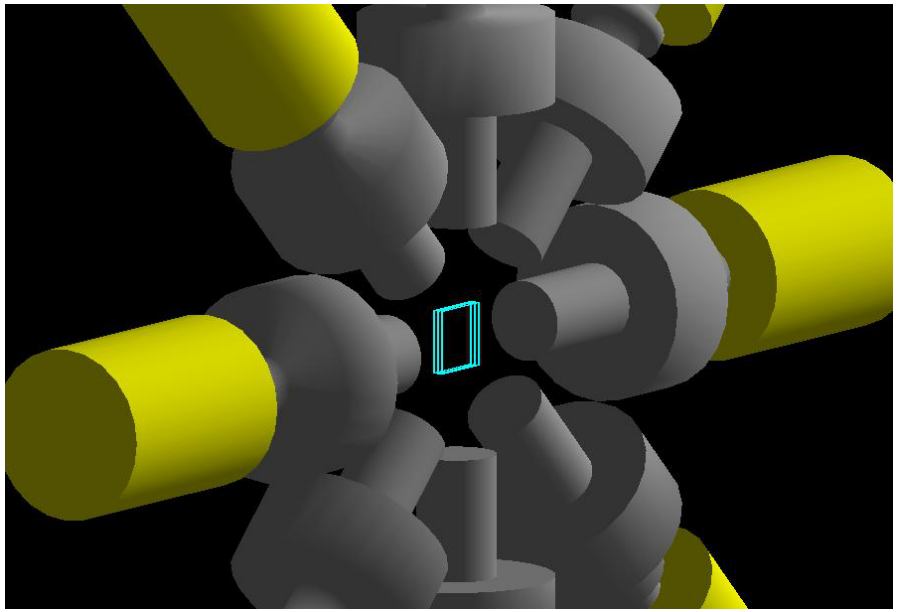
Geant4

- Marc Labiche (Daresbury) leading Geant4 modelling of SIGMA with AIDA
- SIGMA as a new AGATA ancillary detector
- Simulations will be used to assess the tracking and imaging capabilities for DESPEC



- Benchmark against alternative designs, including planar strip detectors and AGATA detectors

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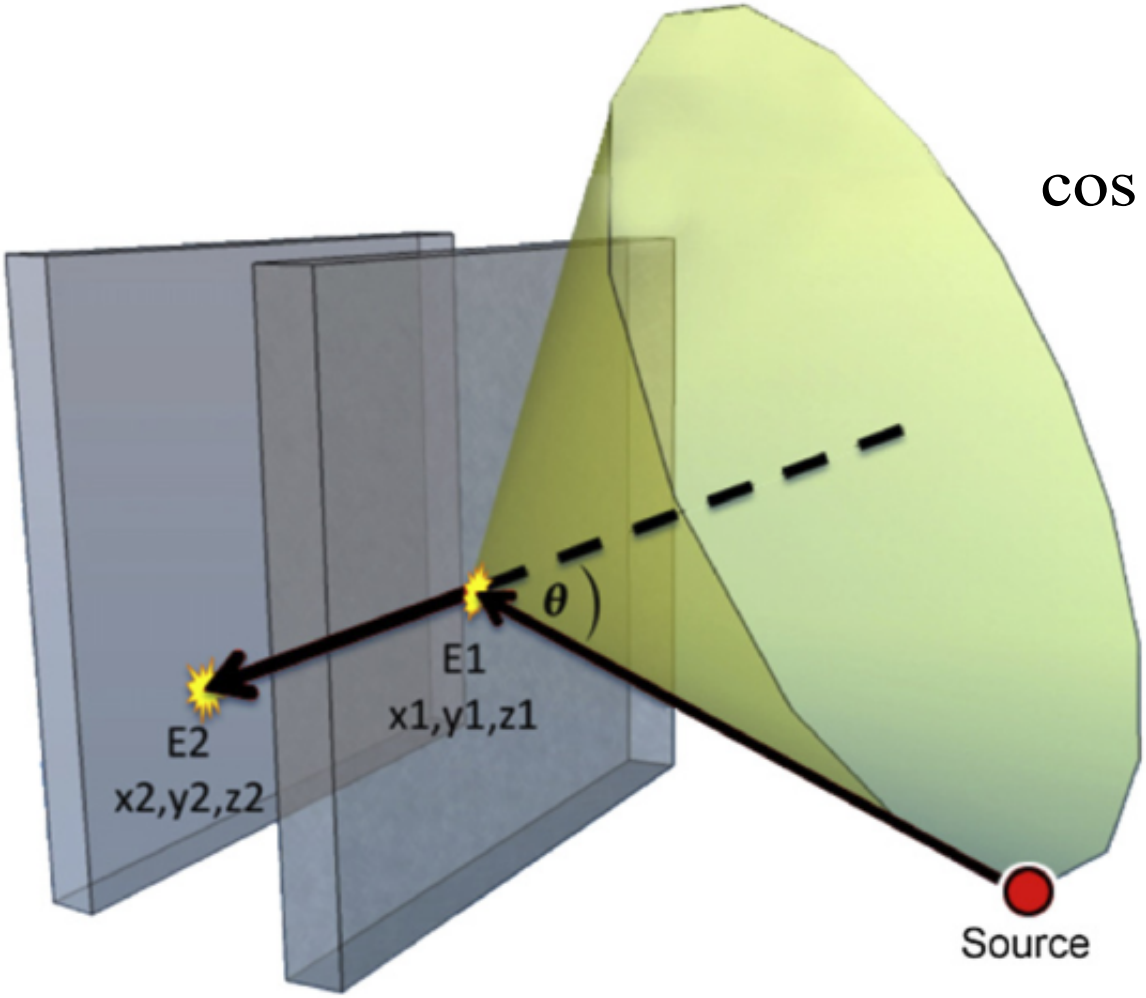
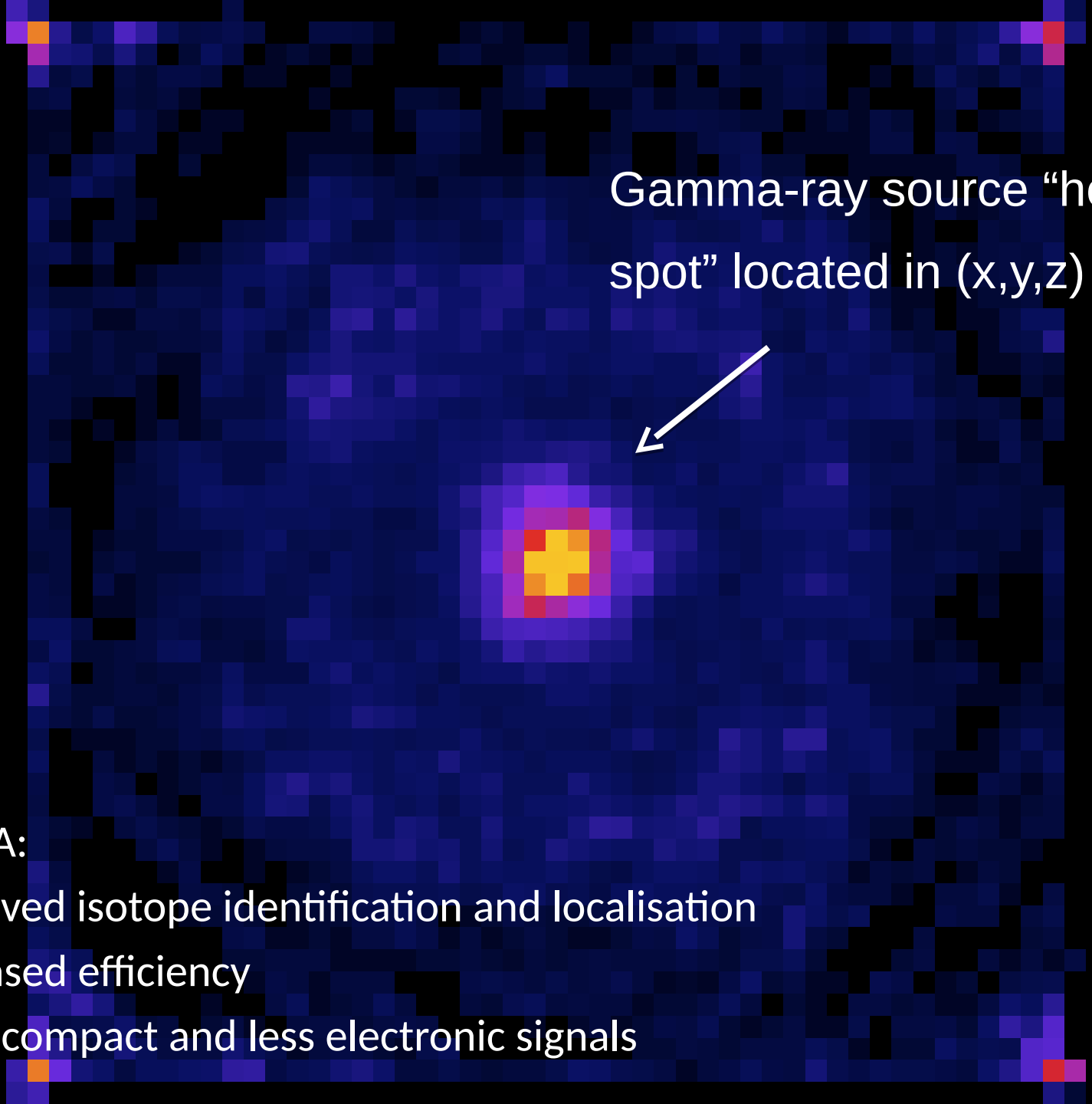
Gamma-ray imaging



$$\cos\vartheta = 1 - m_e c^2 \left(\frac{1}{E_1} - \frac{1}{E_0} \right)$$

Path of each γ-ray is reconstructed as a cone

γ-ray interacts at least twice in detector system



SIGMA:

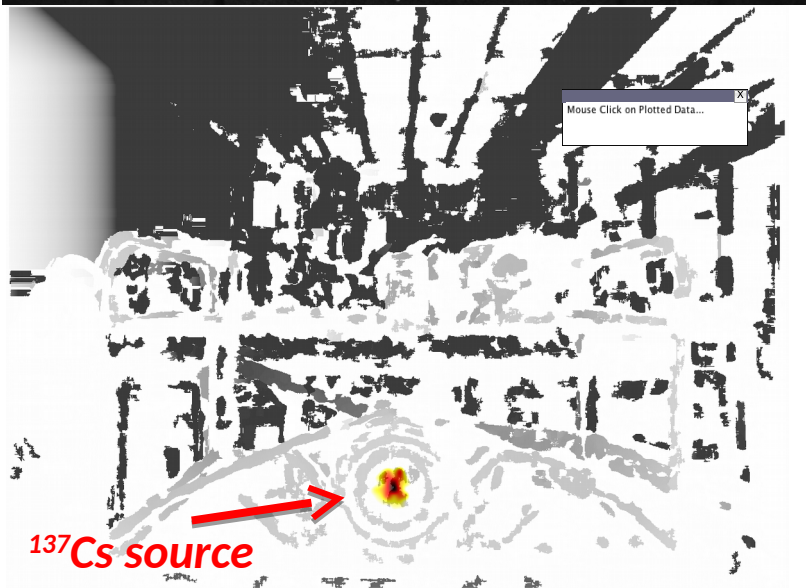
Improved isotope identification and localisation

Increased efficiency

More compact and less electronic signals

Nuclear Decommissioning

Boston, Dormand, National Nuclear Laboratory



- Radiation map of source
- Optical image
- Stereoscopic image “3D”
- Remote response
- High sensitivity and good image quality essential

- 2 semiconductor detectors, which measure position and energy of gamma-ray interactions

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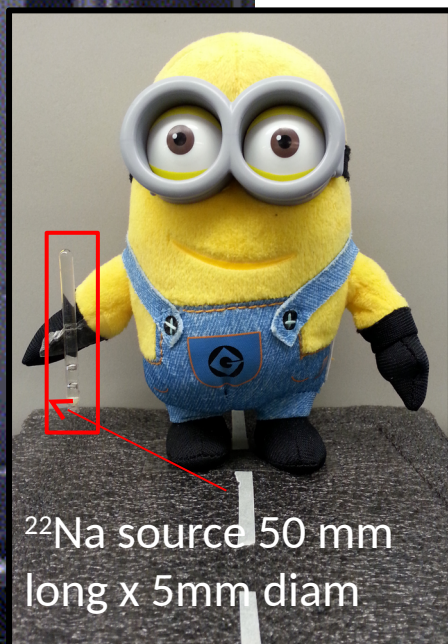
No need to raster scan

Position gated spectra



Key Milestones

2016

Integrated Monte-Carlo/Geant4 model complete

ORNL prototype detector characterised

Detector delivered

2017

PSA and gamma-ray tracking evaluation

2018

Imaging demonstrated, in-beam tests?

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Summary

- DESPEC requires an array for spectroscopy of γ transitions following β, alpha and isomer decay of exotic nuclei in the AIDA implantation detector
- SIGMA detector will use point-like contact technology to provide excellent energy resolution and segmentation/PSA will provide position resolution
- SIGMA detector will be evaluated for future γ-ray tracking and event-by-event correlation with AIDA events, and industrial imaging

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Collaboration

University of Liverpool: Laura Harkness-Brennan, Andy Boston, Helen Boston, Dan Judson, Paul Nolan, Robert Page, Carl Unsworth, Jon Wright

STFC Daresbury Laboratory: Marc Labiche, John Simpson

Oak Ridge National Laboratory: David Radford

Thanks to STFC for Project Funding and to Dr Ren Cooper and Heather Crawford at LNBL

Thanks for listening