Semiconductor detectors for Compton imaging in nuclear medicine

Laura Harkness

ljh@ns.ph.liv.ac.uk

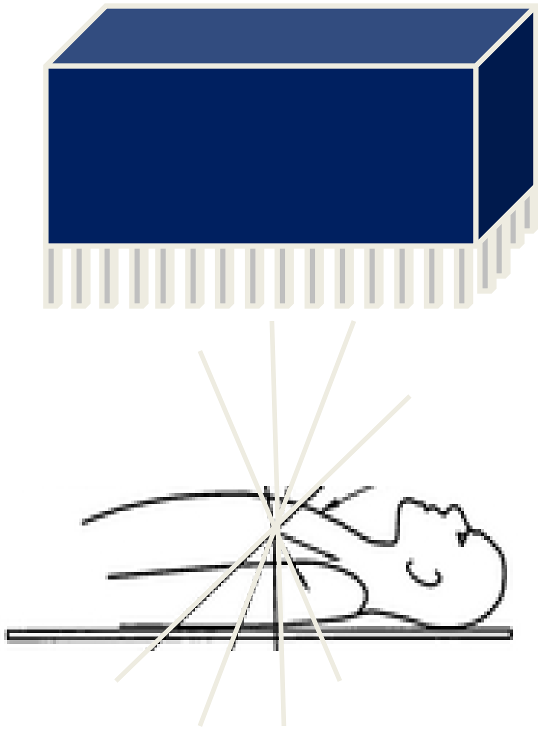
PSD9 Conference, Aberystwyth, 12th September 2011

UNIVERSITY OF LIVERPOOL

Outline

- Nuclear medicine
- Compton imaging
- Design Criteria
- A High Purity Germanium detector
- A Si(Li) detector

Nuclear medicine - SPECT

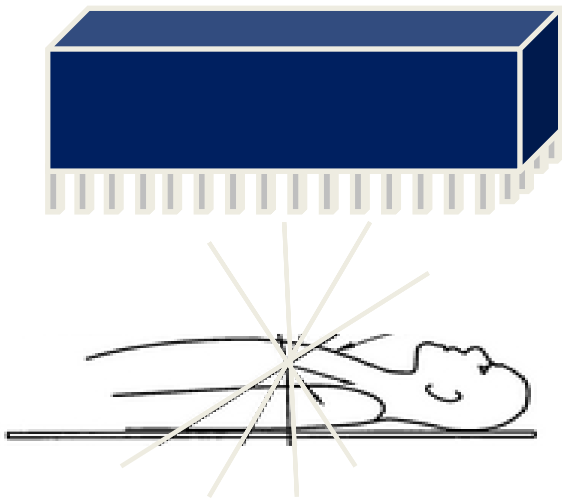


- Single Photon Emission Computed Tomography (SPECT)
- Diagnosis/monitoring of cancer and neurological conditions
- Biological information complements MRI structural information
- Mechanical collimator 1 x 10 $^{-4}$
- Scintillator detector with photomultiplier tubes

Patient injected with radiopharmaceutical → Radiopharmaceutical accumulates in organ of interest → Gamma-rays emitted from organ and detected outside body by gamma camera

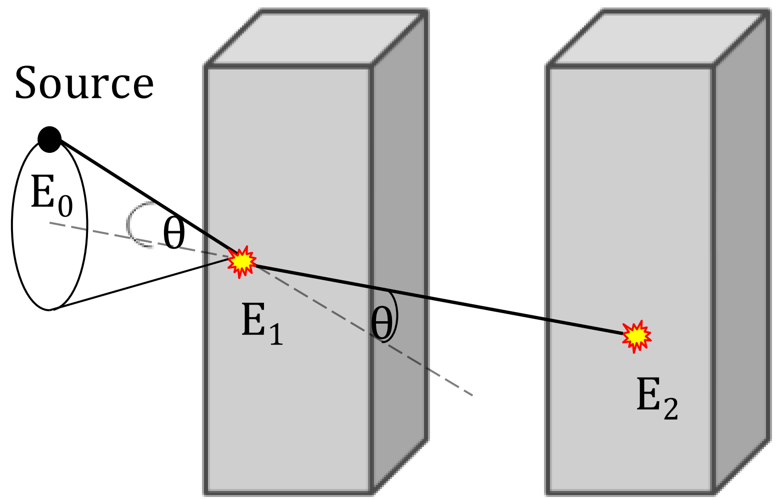
Compton imaging in medicine

Conventional SPECT



- Gamma-rays detected by a gamma camera
- Inefficient detection method
- Use 1 gamma ray in every 3000
- Incompatible with MRI

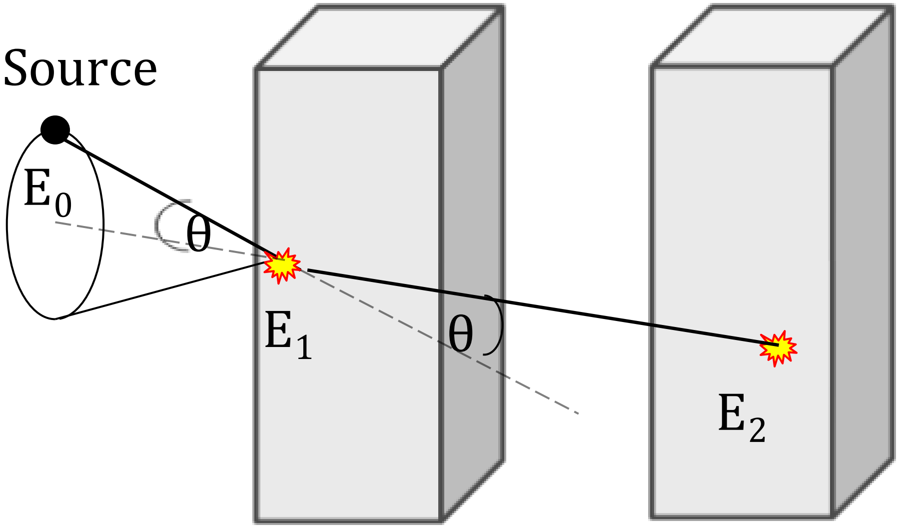
Compton imaging

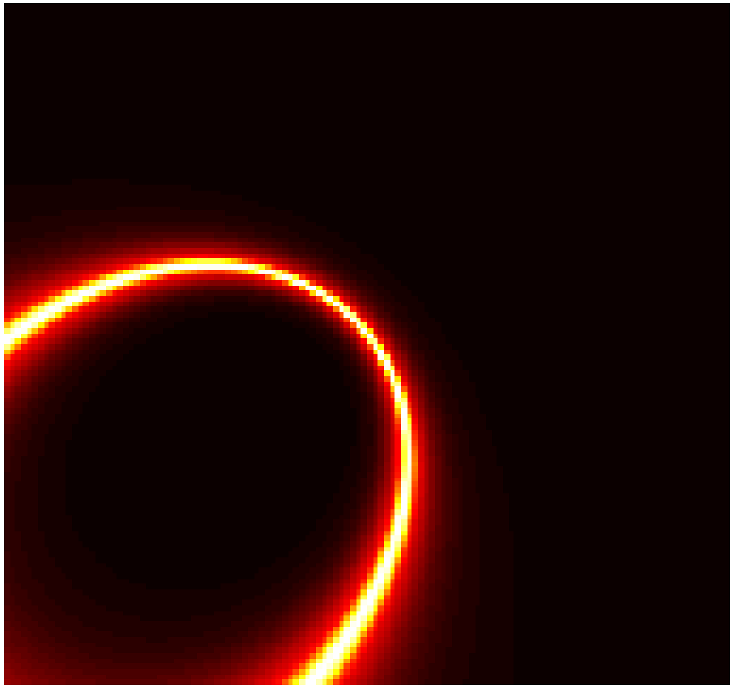


- Gamma-rays detected by a Compton camera
- Use 1 gamma ray in every 30
- Semiconductor detectors compatible with MRI

How does it work?

- Gamma rays interact in both detectors (scatterer and absorber)
- The path for each gamma ray is reconstructed as a cone
- Source located at max cone overlap



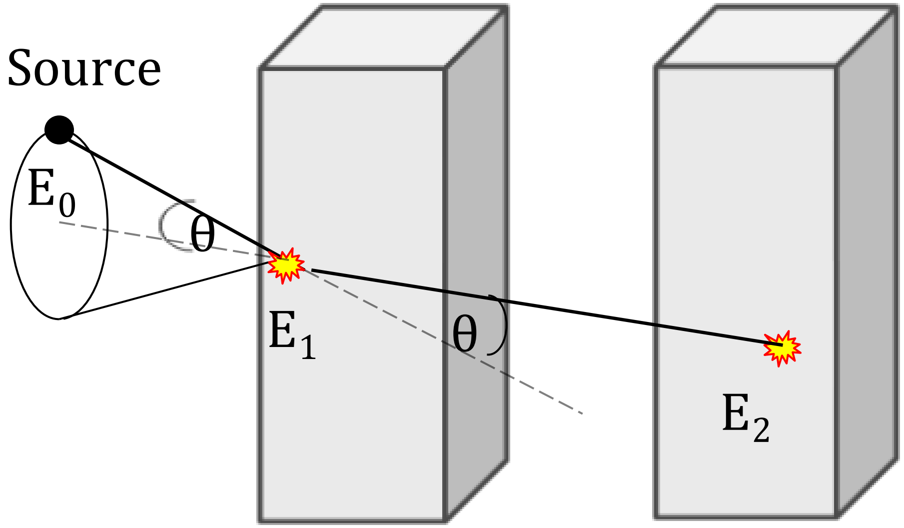


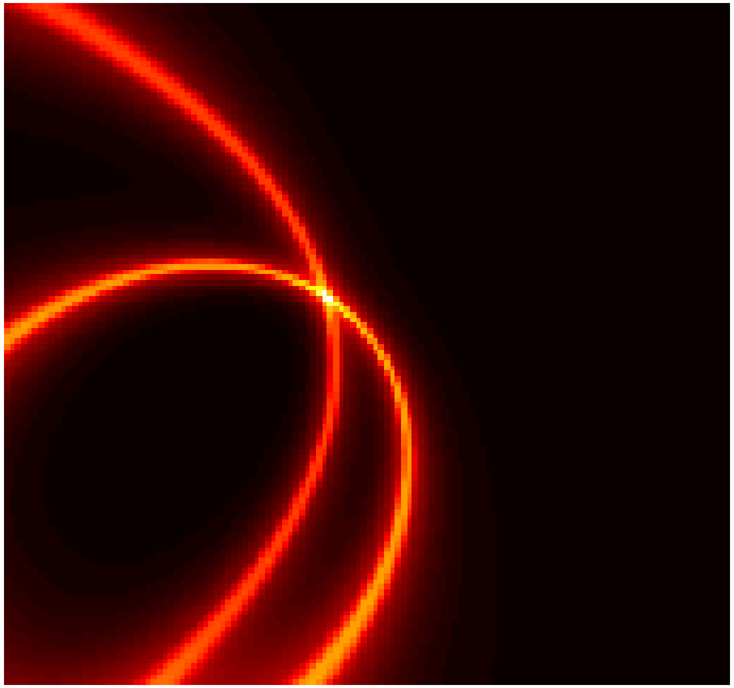
$$\cos\vartheta = 1 - m_e c^2 \left(\frac{1}{E_1} - \frac{1}{E_0} \right)$$

UNIVERSITY OF LIVERPOOL

How does it work?

- Gamma rays interact in both detectors (scatterer and absorber)
- The path for each gamma ray is reconstructed as a cone
- Source located at max cone overlap



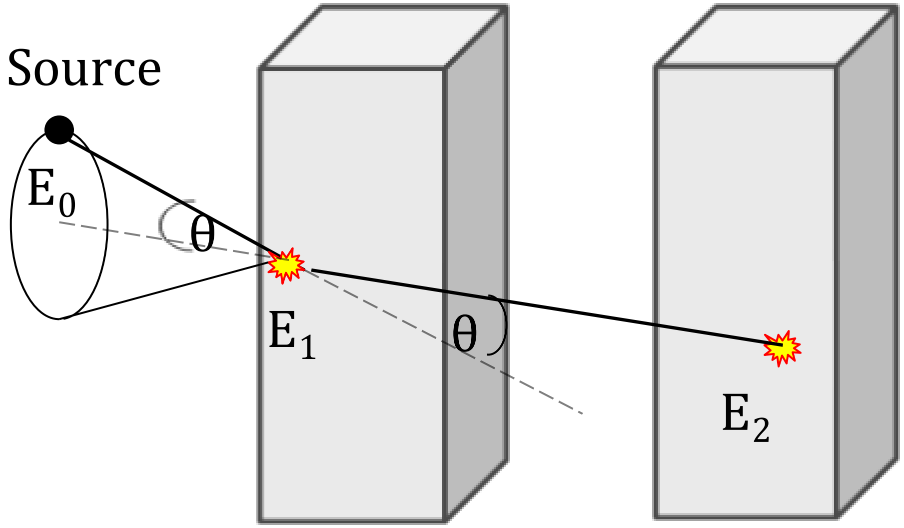


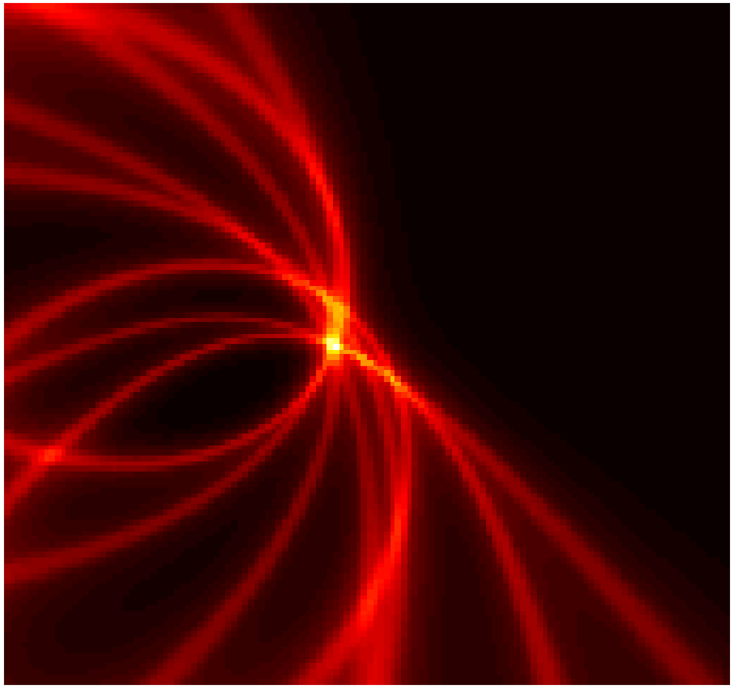
$$\cos\vartheta = 1 - m_e c^2 \left(\frac{1}{E_1} - \frac{1}{E_0} \right)$$

UNIVERSITY OF LIVERPOOL

How does it work?

- Gamma rays interact in both detectors (scatterer and absorber)
- The path for each gamma ray is reconstructed as a cone
- Source located at max cone overlap



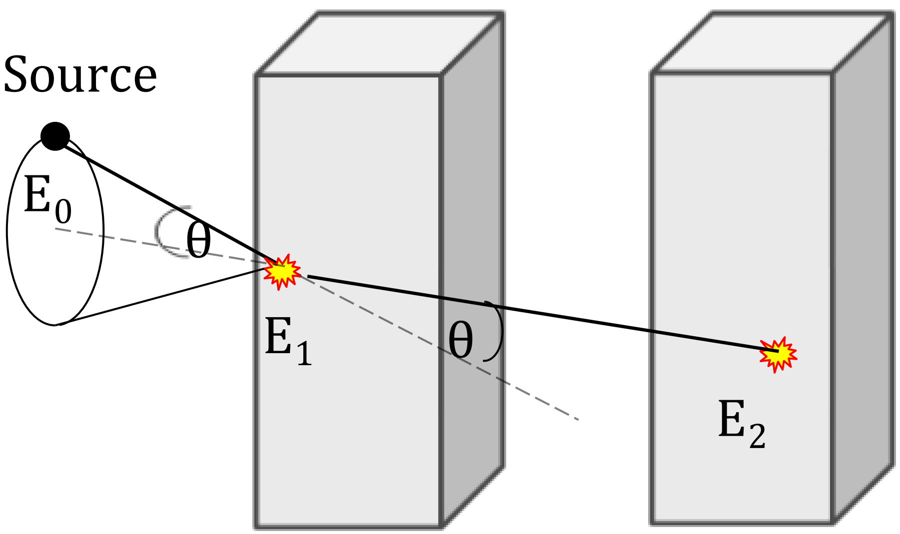


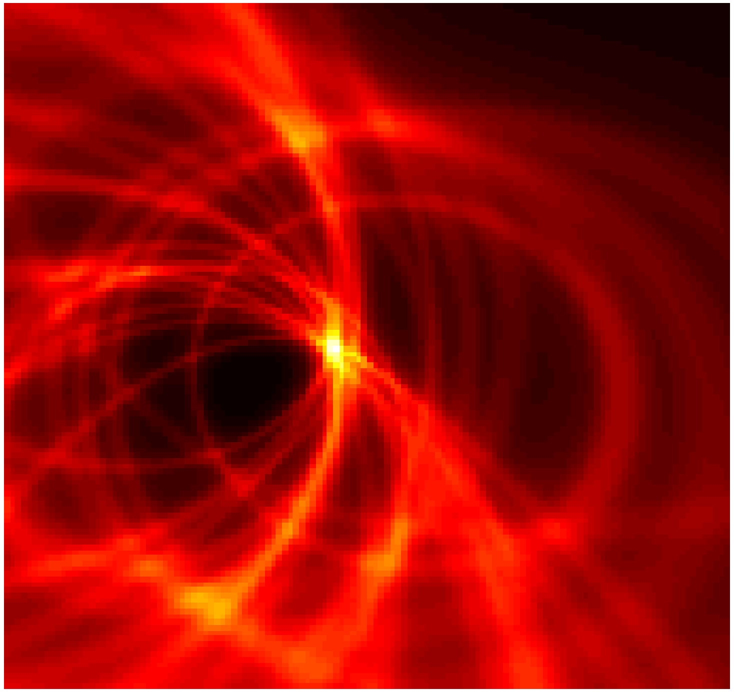
$$\cos\vartheta = 1 - m_e c^2 \left(\frac{1}{E_1} - \frac{1}{E_0} \right)$$

UNIVERSITY OF LIVERPOOL

How does it work?

- Gamma rays interact in both detectors (scatterer and absorber)
- The path for each gamma ray is reconstructed as a cone
- Source located at max cone overlap





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

UNIVERSITY OF LIVERPOOL

Design Criteria

L J Harkness et. al, AIP Conf Proc (2009) 1194, 90-95

- System for use with **current medical radionuclides**, with **high sensitivity** and **excellent image quality**
- Sensitivity is a factor of:
  - Detector materials, thicknesses and configuration geometry
  - **Low energy noise thresholds in scatterer detector**
- Image resolution is a factor of :
  - **Energy resolution**
  - Detector position resolution
  - Doppler broadening
  - **Detector uniformity**

Semiconductor Detectors ☺

UNIVERSITY OF LIVERPOOL

Final design

1. L J Harkness et. al, NIMA (2009) 604
2. L J Harkness et. al, NIMA (2011) 638

- Optimised for imaging 141 keV gamma rays[1] from ^{99m}Tc
- DSSD Si(Li) scatter detector (two available: 8 mm and 9 mm thick)
- DSSD HPGe absorber detector, 20 mm thick
- Should operate at the edge of an MRI scanner[2]
- Final system: 9 mm thick Si(Li) detector and HPGe detector housed in a single cryostat custom-built by STFC Daresbury Laboratory

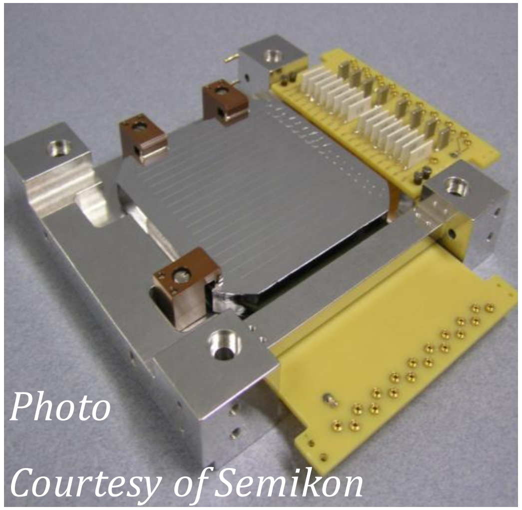


Photo Courtesy of Semikon

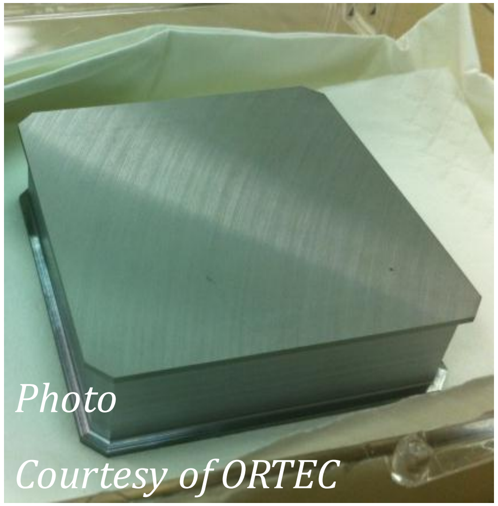
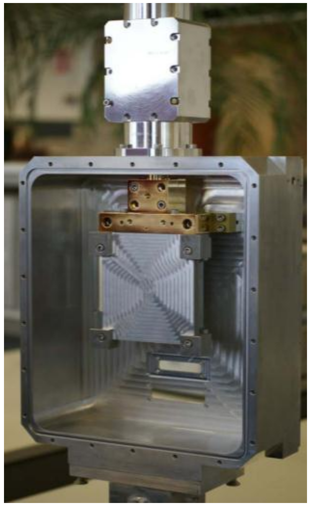
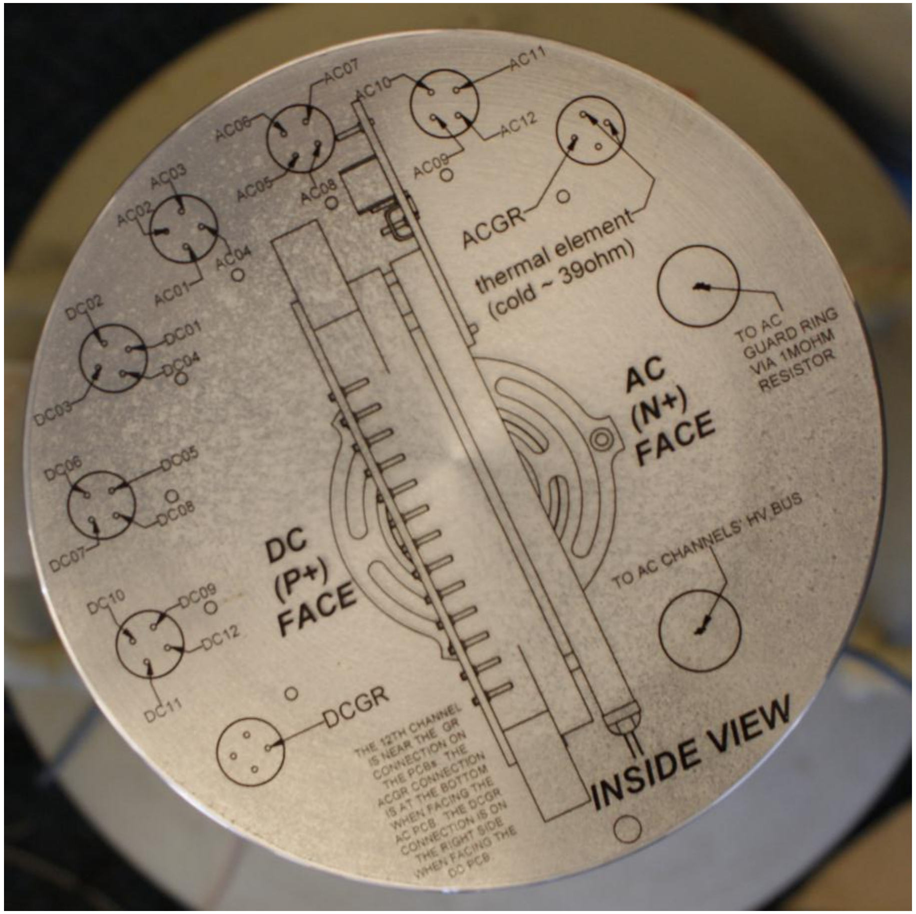
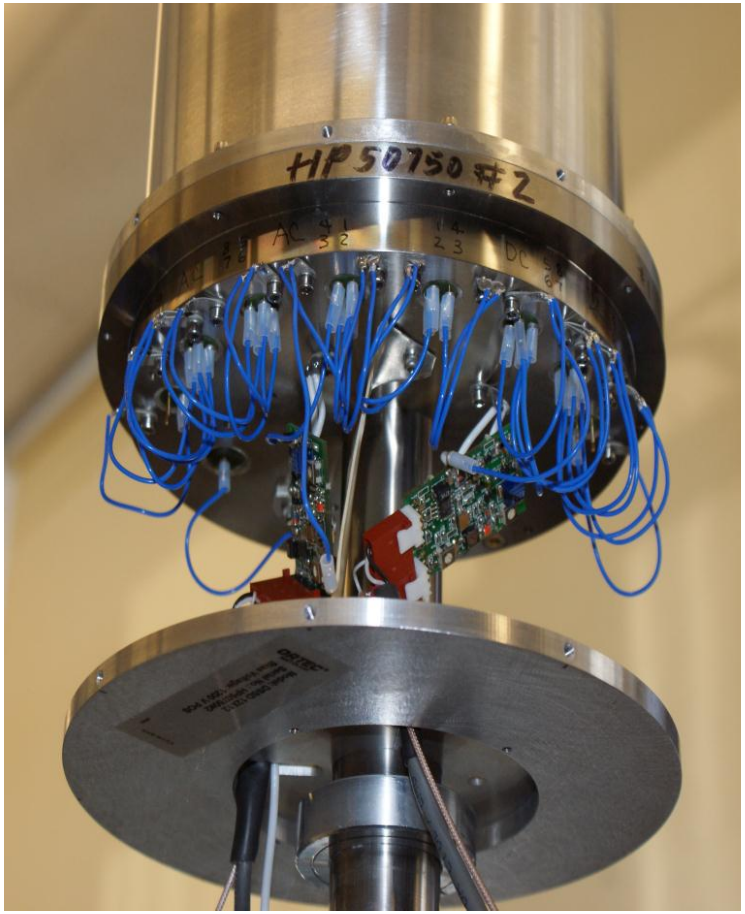


Photo Courtesy of ORTEC



HPGe Absorber detector





- Each face has 12 strips (60 x 5) mm
- 1 test preamplifier for each face of the detector

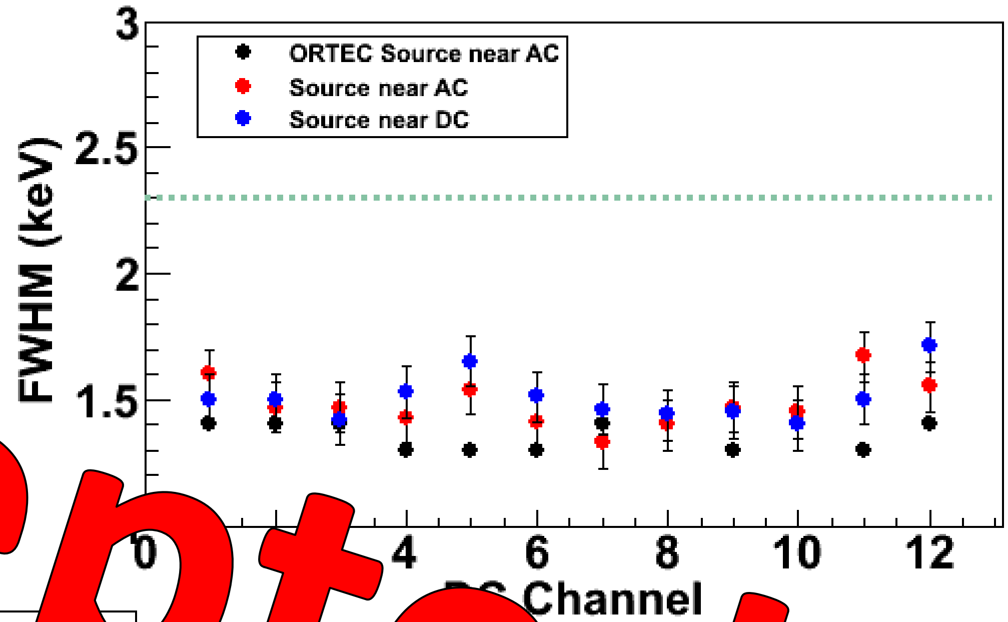
UNIVERSITY OF LIVERPOOL

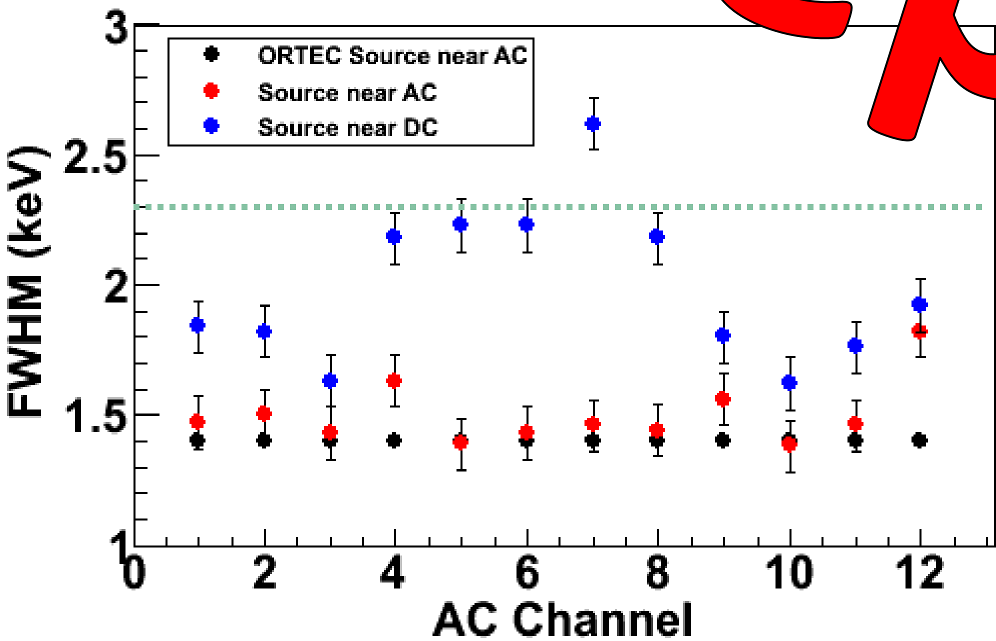
HPGe Performance Tests

- FWHM measured at 122 keV using a ^{57}Co source
- Measurements taken for each channel with:
  - The source near the AC face of the detector
  - The source near the DC face of the detector
- Specified performance at 122 keV:
  - Average FWHM <= 1.7 keV
  - All channels FWHM <= 2.3 keV
  - No more than 2 strips per side > 1.8 keV

Energy Resolution at 122 keV

- Source near AC face: All channels acceptable (< 2.3 keV)
- Source near DC face: All channels acceptable except AC07





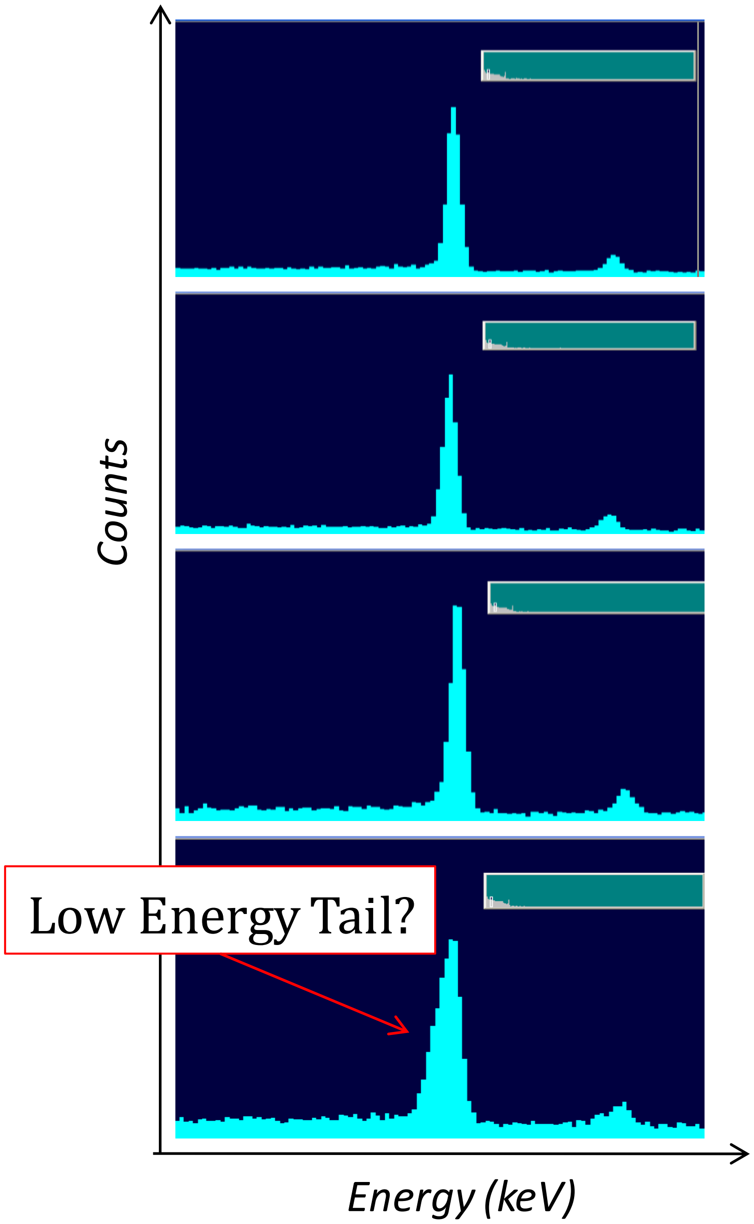
Accepted

UNIVERSITY OF LIVERPOOL

Energy Resolution at 122 keV

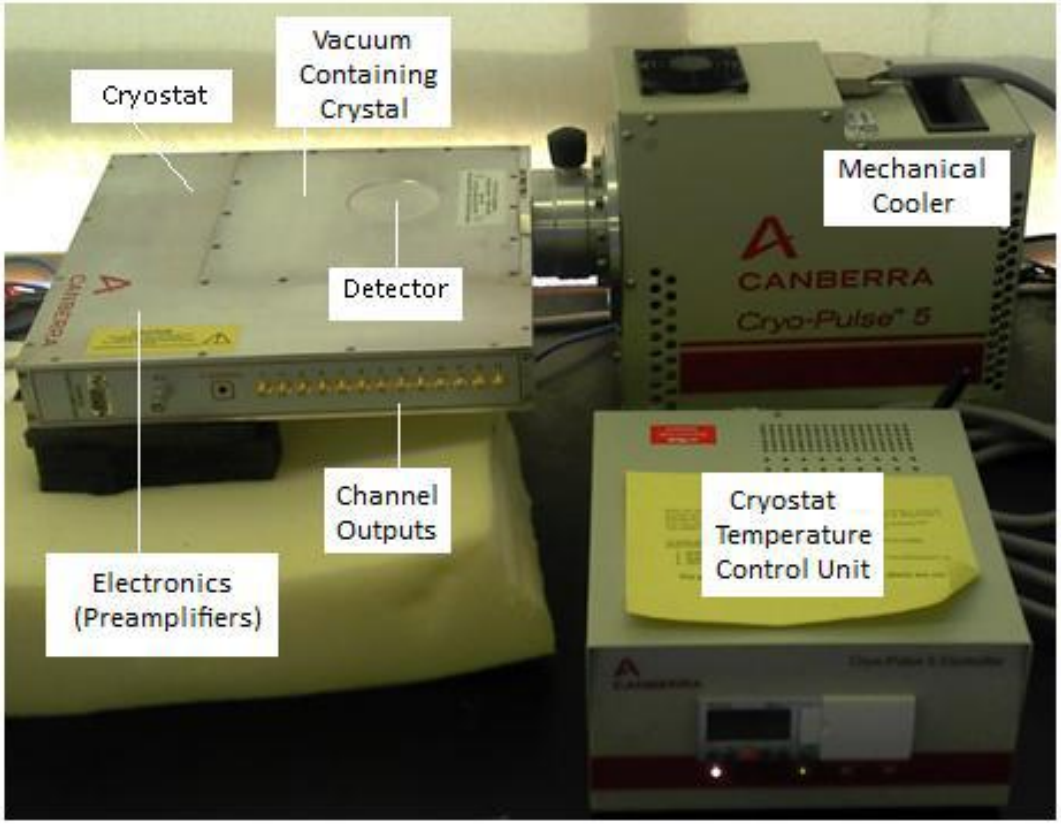
Channels	Source incident on face	Range (keV)	Mean (keV)
DC	AC	1.33 - 1.67	1.48
	DC	1.40 - 1.71	1.51
AC	AC	1.38 - 1.82	1.50
	DC	1.62 - 2.62	1.99

Specification: Max 2.3 1.7



Si(Li) detector

- Canberra Si(Li) DSSD detector 13 strips on each face
- 8 mm thick, 66 mm diameter
- Cryogenically cooled using a CryoPulse CP5 cooler



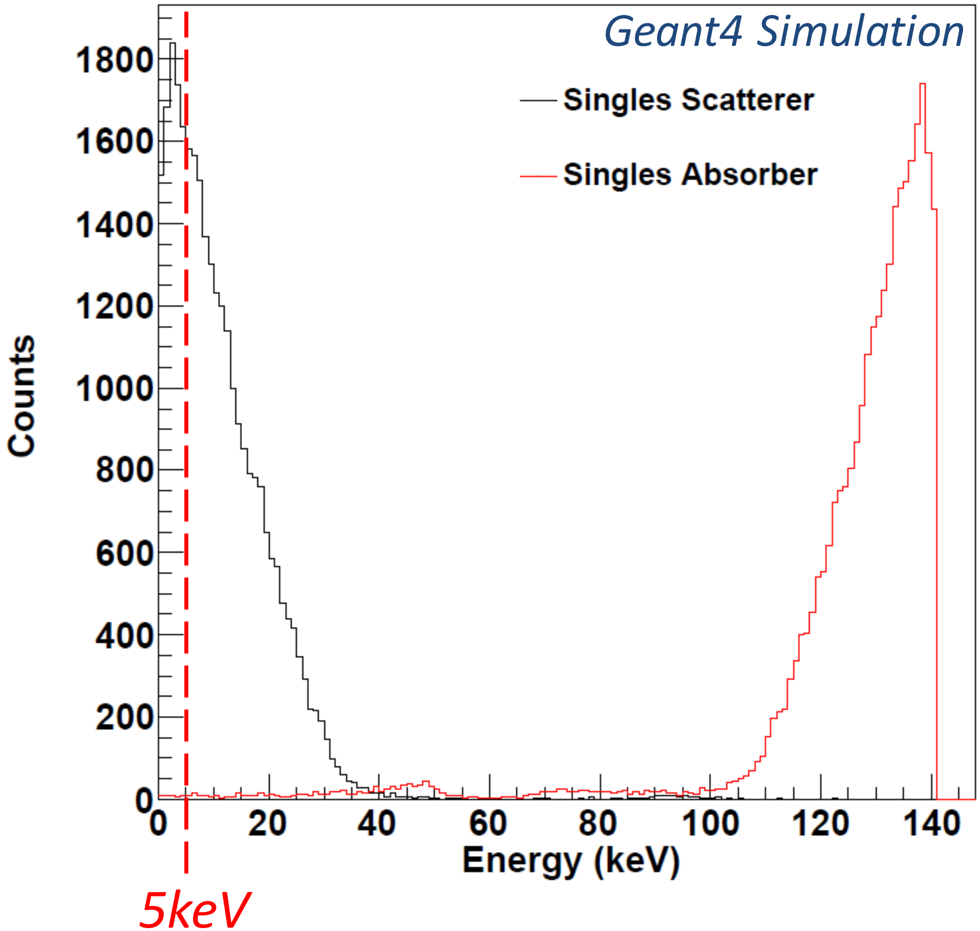
- Energy resolution of all strips measured to be (1.4 to 1.6) keV at 59.4 keV using ^{241}Am (excluding channel 14)

UNIVERSITY OF LIVERPOOL

Detector noise levels

L J Harkness et. al, IEEE NSS/MIC Proc (2009)

- For imaging 141 keV gamma rays, less than 40 keV is deposited in the scatter detector
- Low energy threshold applied reduces the sensitivity
- Low noise scatter detector essential in minimising event loss

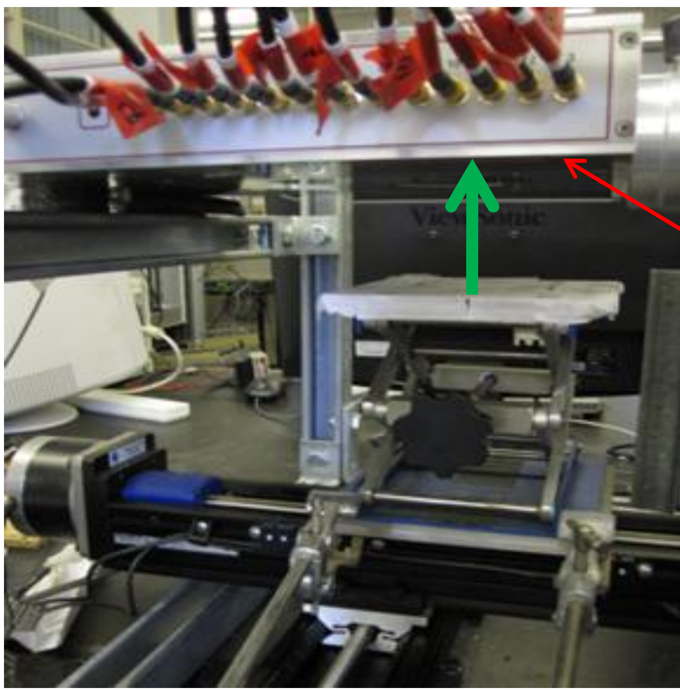


- Noise levels for DC strips measured to be 2 keV and for AC strips to be (2.5 to 4.5) keV

UNIVERSITY OF LIVERPOOL

^{241}Am Surface Scan

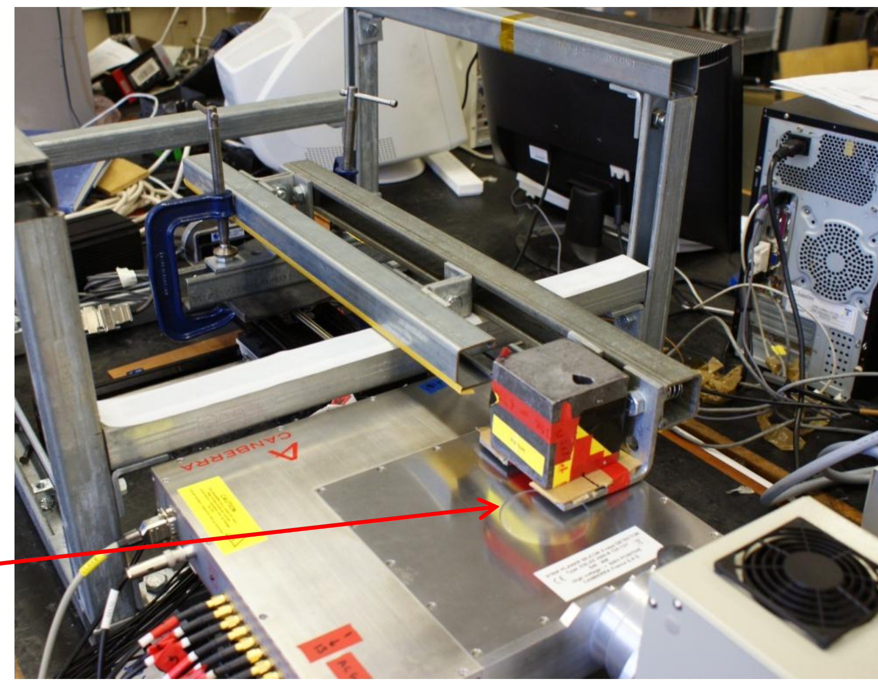
- 1 mm collimated ^{241}Am source scanned in 1 mm steps across a (76 x 76) mm grid giving 5929 positions
- Data taken with the source incident on the DC face then the AC face



DC face

DC Surface scan

AC face



AC Surface scan

^{241}Am Surface Scan

- Data recorded from all 26 channels using Gretina Digitizer cards
- DC channels used to trigger the acquisition
- Events only recorded when energy deposited in at least one DC channel was more than the energy threshold (~10 keV)

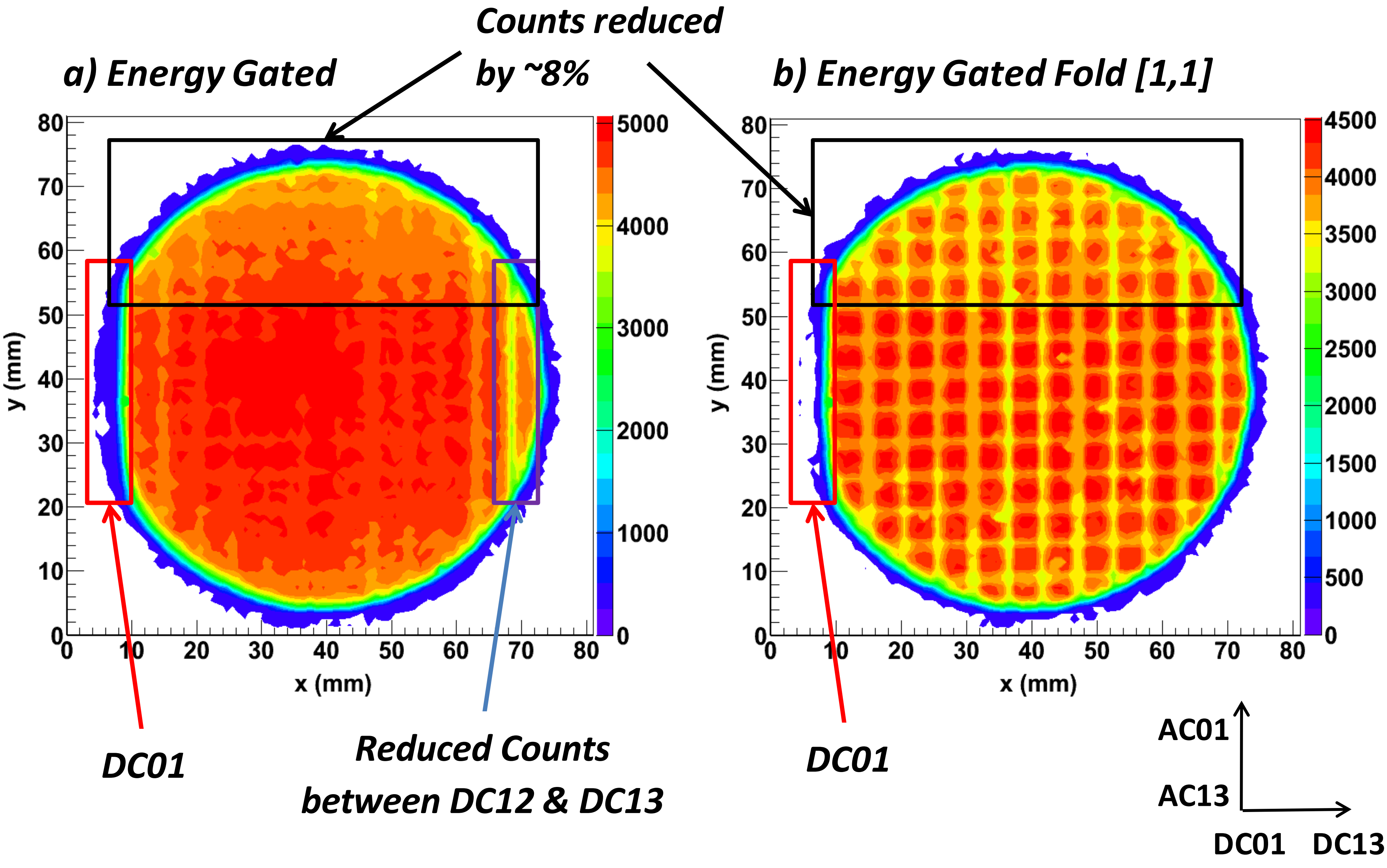
	Incident on DC face	Incident on AC face
Scan step duration (s)	40	45
Count Rate (s^{-1})	200	288
Total Run time (h)	66	82

^{241}Am Surface Scan: Event Processing

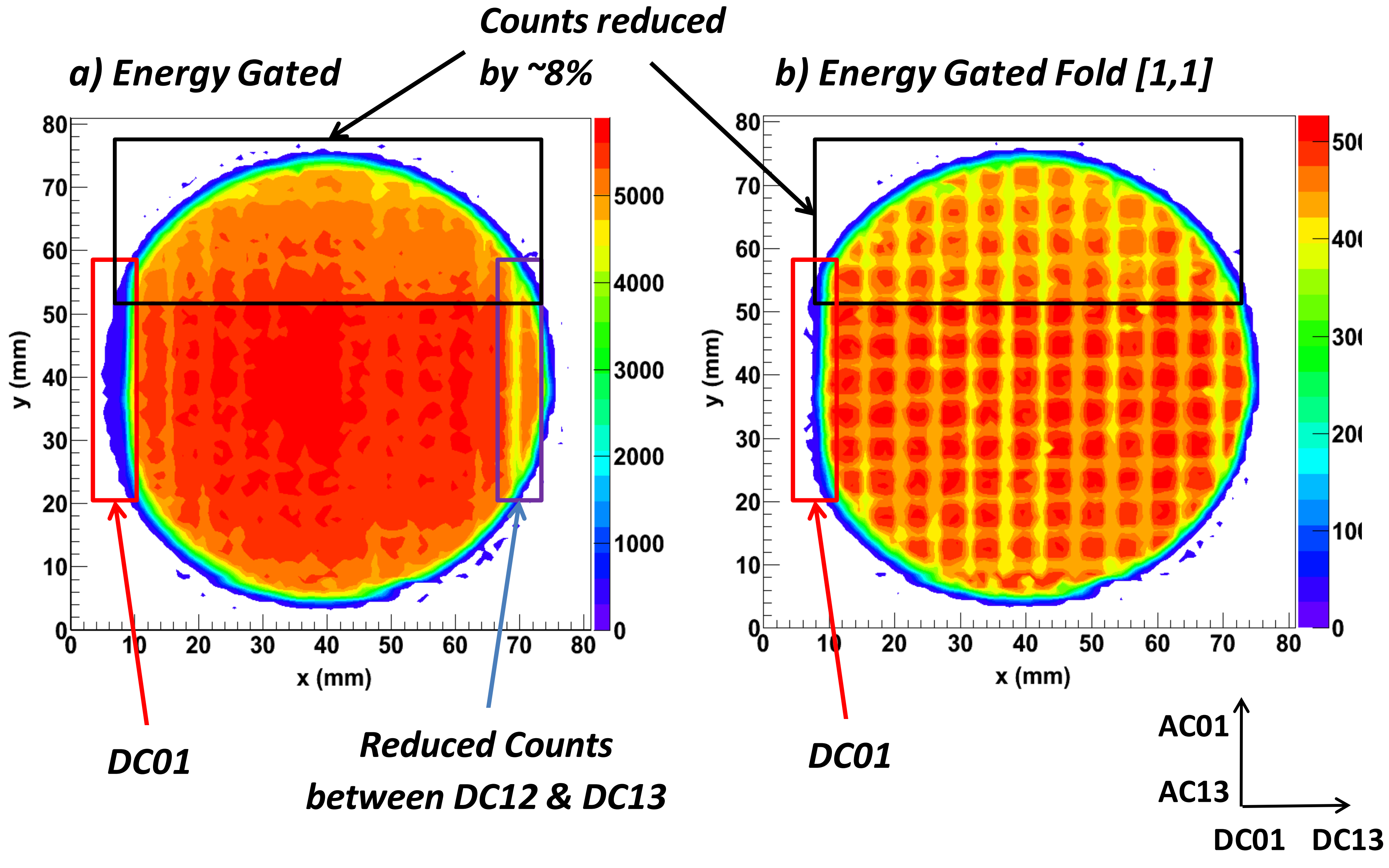
- An 8 keV energy gate was set around the 59.4 keV photopeak
- Events categorised according to fold - the number of channels that record net charge over energy threshold (10 keV for DC channels)
- Intensity plots were produced for energy gated events for fold[*DC*,*AC*] type events, e.g. fold [1,1].

	Incident on DC face		Incident on AC face	
	DC	**AC**	**DC**	**AC**
Fold 1 (%)	84.47	87.49	84.47	87.88
Fold 2 (%)	11.18	9.62	11.18	9.53
> Fold 2 (%)	4.35	2.89	4.35	2.59

DC face Intensity Plots

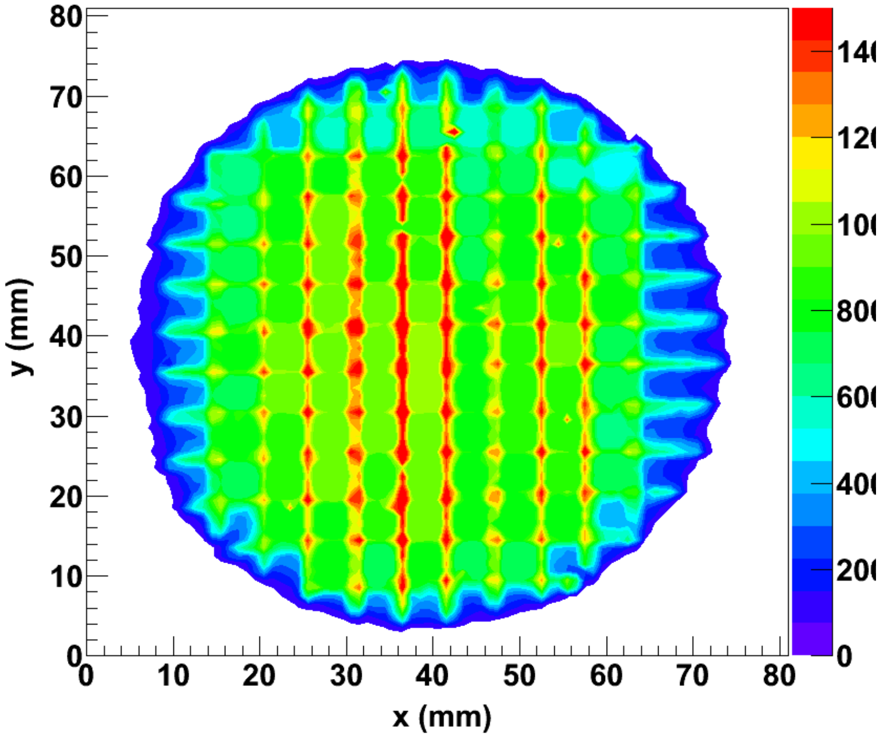


AC face Intensity Plots

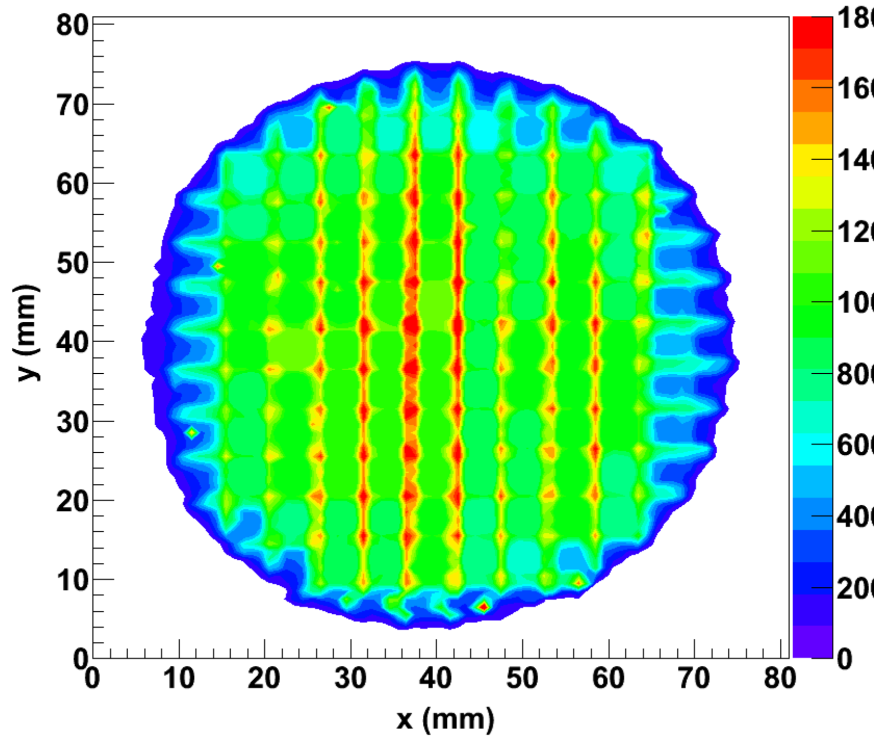


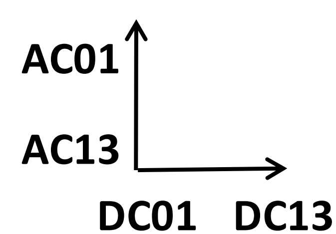
Multiple Pixel Intensity Plots

a) DC surface scan



b) AC surface scan





Current Status and Future Work

- HPGe absorber detector: acceptable for Compton imaging. Surface and side scan measurements planned
- Further analysis of the Si(Li) detector surface scan results
- ProSPECTus cryostat: vacuum testing underway
- ProSPECTus Si(Li) detector: acceptance tests imminent
- First ProSPECTus imaging measurements –Winter 2011
- ProSPECTus imaging with MRI system – 2012

UNIVERSITY OF LIVERPOOL

The ProSPECTus Collaboration

Department of Physics, The University of Liverpool, UK

AJ Boston, HC Boston, JR Cresswell, DS Judson, PJ Nolan, JA Sampson, DP Scraggs, A Sweeney

STFC Daresbury Laboratory, UK

I Burrows, N Clague, M Cordwell, J Groves, J Headspith, A Hill, IH Lazarus, V Pucknell, J Simpson

MARIARC, The University of Liverpool, UK

B Bimson, G Kemp

Special Thanks to Hannah Kennedy

UNIVERSITY OF LIVERPOOL