SmartPET: A HPGe Imaging System

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PET imaging

Compton Camera for other images

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Overview PET

The SmartPET project

- Positron Emission Tomography
- Image Reconstruction

Pulse Shape Analysis

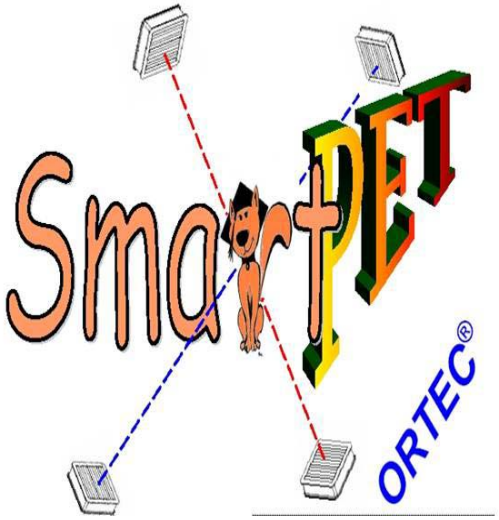
- Real Charge Analysis
- Image Charge Analysis

Application to PET Imaging

- Experimental Details
- Reconstructed Images

Current Status & Future Work

- Online PSA
- DAQ development
- Phantom Imaging



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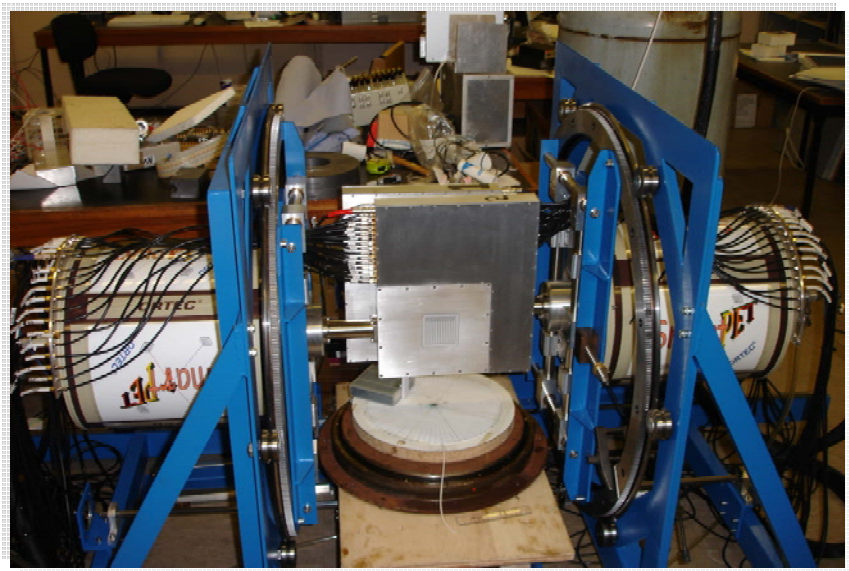
The SmartPET Project

The Development of a HPGe based Small Animal Imaging System

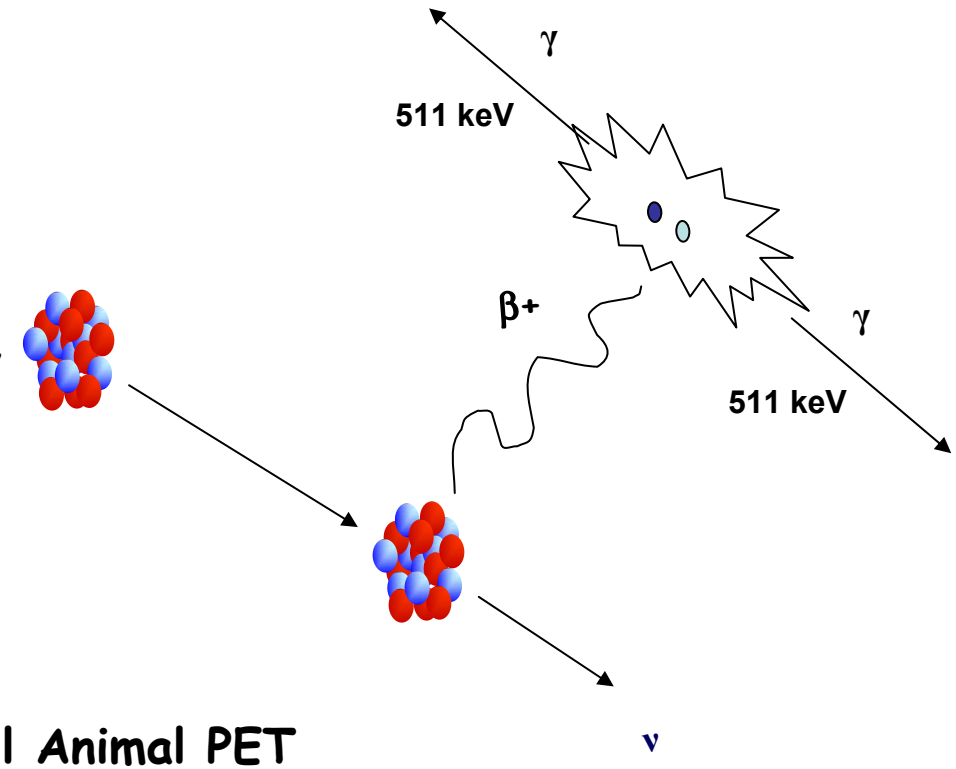
- Dual Head PET Camera
- Proof of Principle for HPGe imaging
- Development of sophisticated digital electronics
- Real time signal processing techniques
- Pulse Shape Analysis (PSA) techniques
- E-Field simulation
- Image Reconstruction
  - PET
  - Compton Imaging

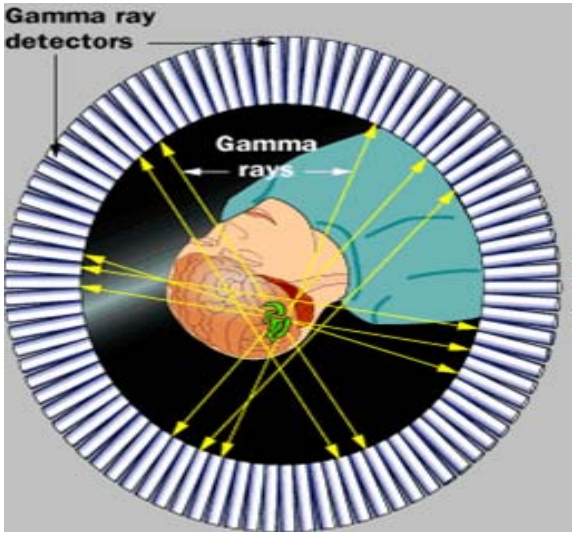


The SmartPET Project

Positron Emission Tomography

- Diagnostic imaging modality
- Radio-tracer administered
- Assessment of organ function
- Detection of *annihilation gamma-rays*
- LOR definition





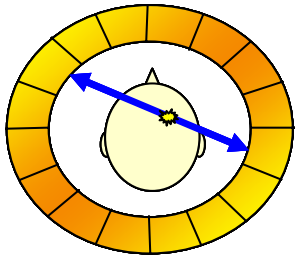
Small Animal PET

- Human disease modelling
- Pharmaceutical development
- Requires fine spatial resolution

The SmartPET Project

Image Reconstruction for PET

- Intersection of LORs define source distribution
- Use these LORs to reconstruct image

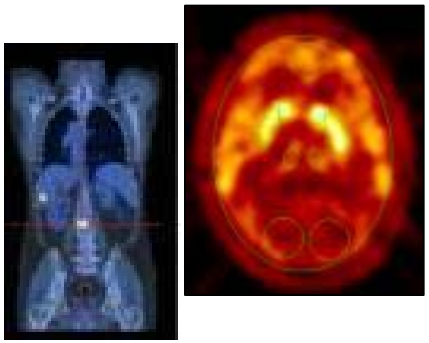


Analytic Reconstruction

- Filtered Back Projection (FBP)
- Fast
- Assumes infinite distribution of data
- Poor performance with low statistics

Statistical Reconstruction

- Iterative (slow) techniques, ML-EM
- Handles low statistics
- Accurate
- System modelling



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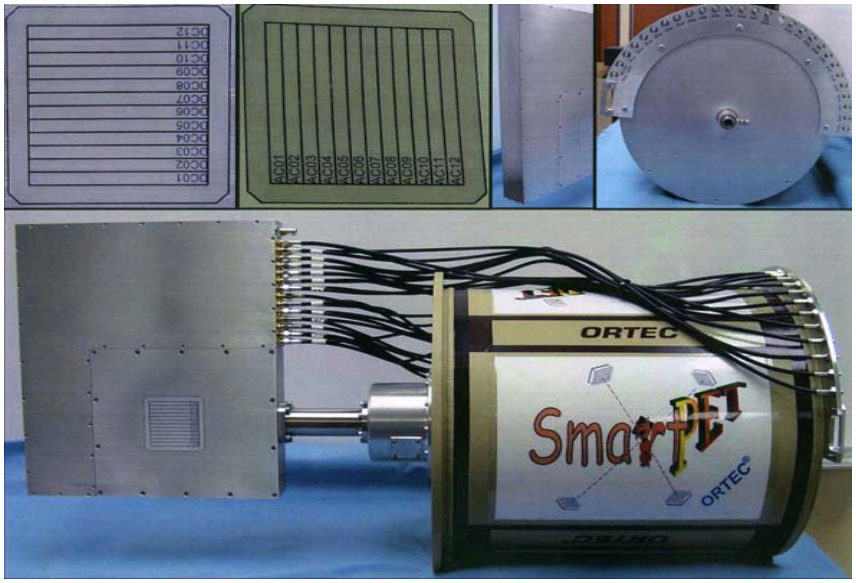
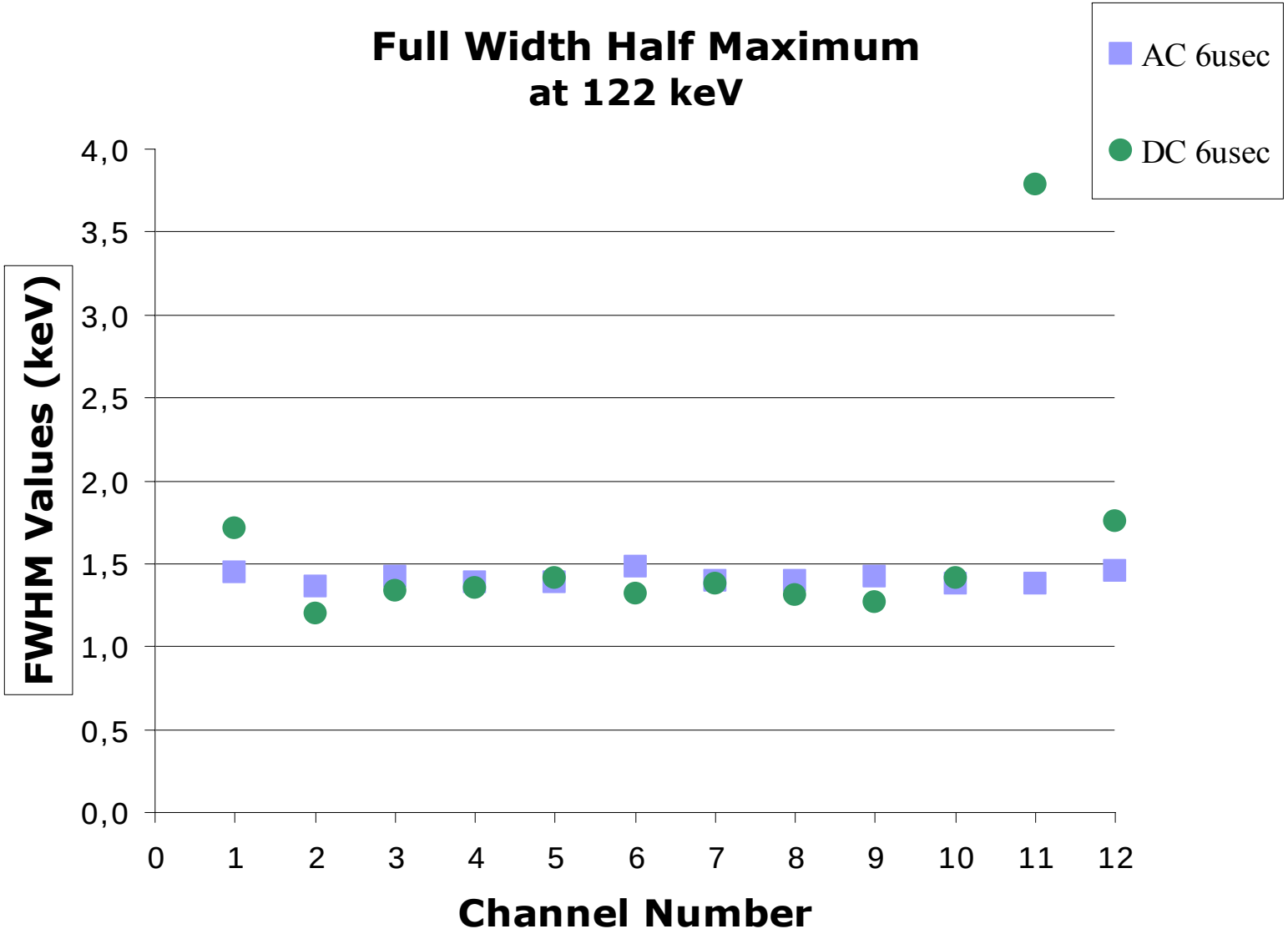
SmartPET System

- Two planar 6x6x2cm HPGe crystals
- Electrical segmentation
  - No loss of efficiency
- 5 mm strip pitch
  - 5x5x20mm granularity
- Charge sensitive pre-amps



- Digital DAQ System - Daresbury
- 14 bit, 80MHz FADCs
- 200k FPGAs
- MWD Algorithm
- Store Pulses – facilitate PSA

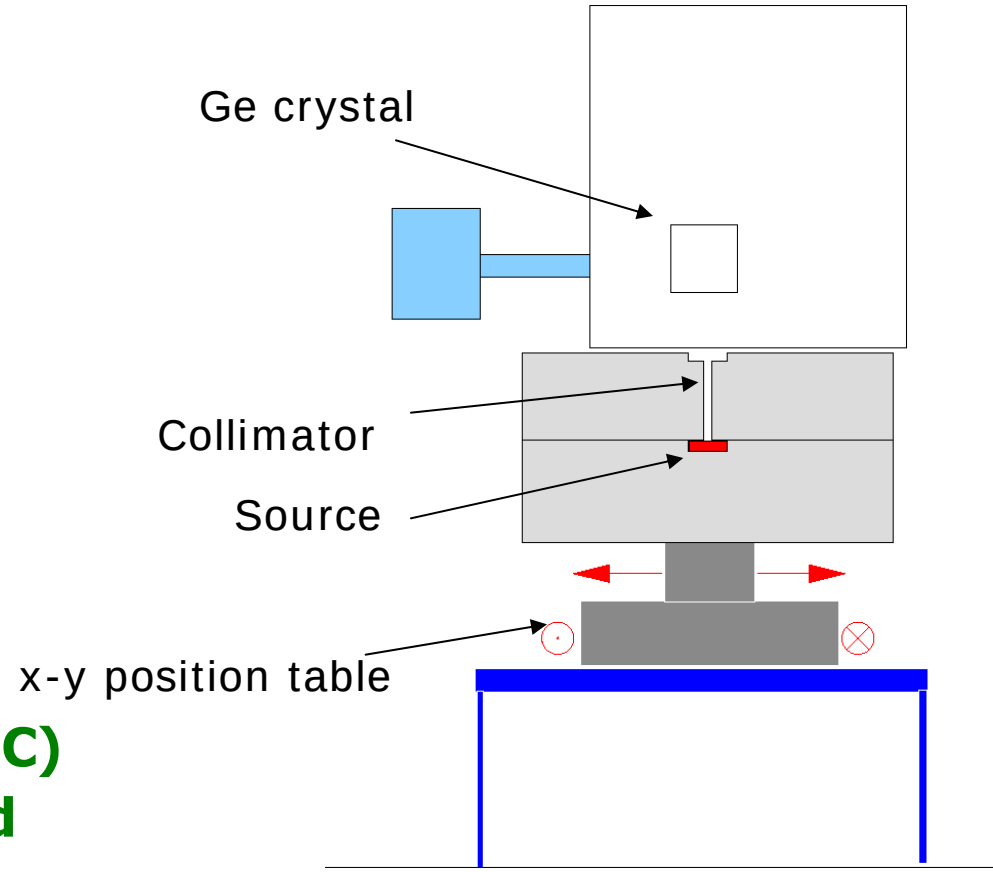
Detector energy resolutions



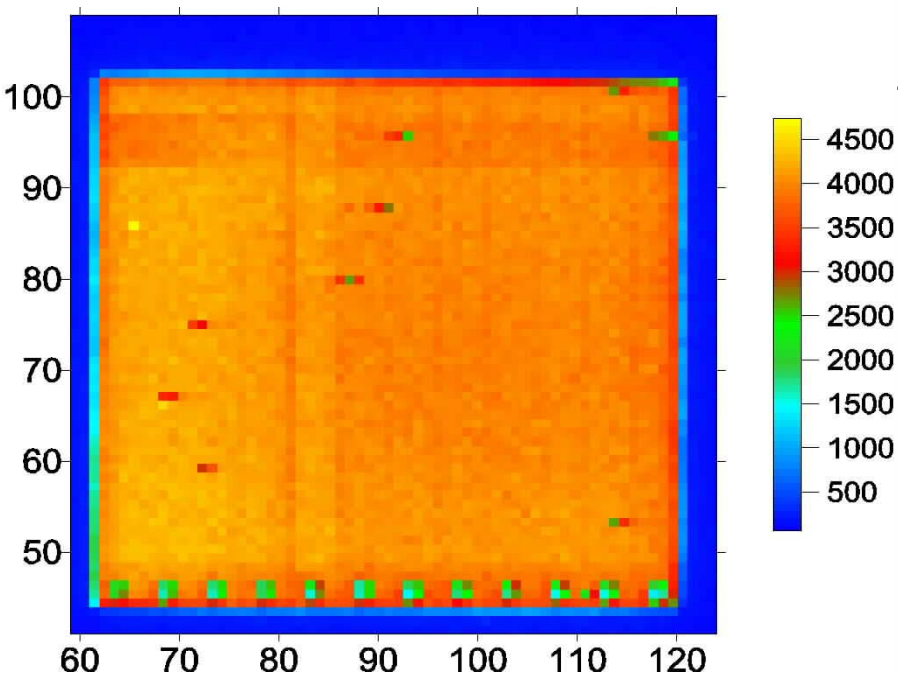
Position dependent performance:
Singles Source Scans

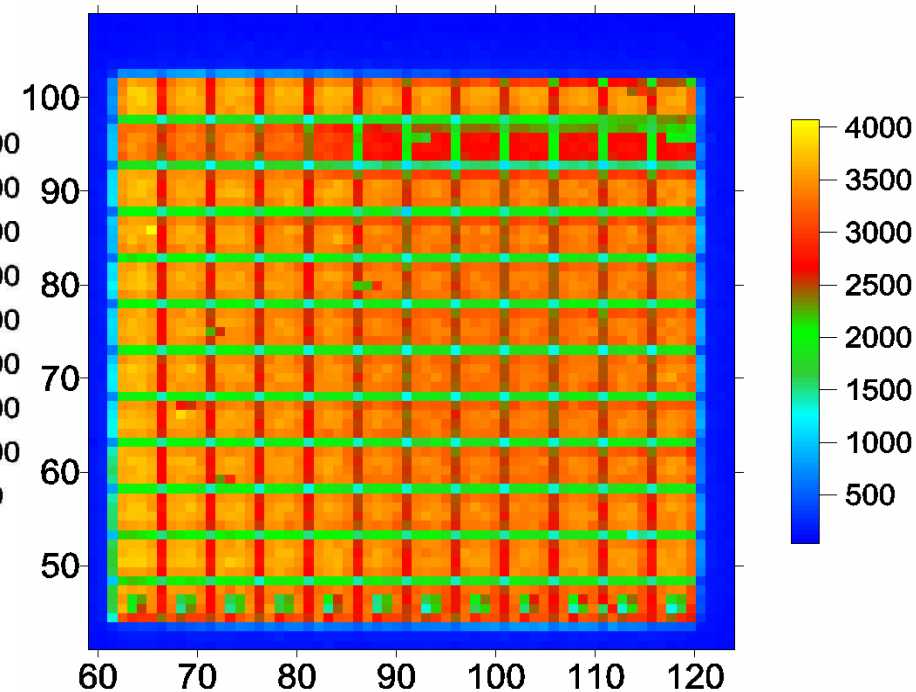
- 1mm Tungsten collimation (9cm)
- 1mm step positions
- Sources
  - 1GBq ^{241}Am annular source – 40cps
  - 1.8GBq ^{57}Co source (pellet) – 150cps
  - 70.21MBq ^{137}Cs – 35cps

- Scans
  - ^{241}Am 120 seconds at each position (AC and DC)
  - ^{57}Co 60 seconds (AC and DC) 120 seconds (side)
  - ^{137}Cs 180 seconds



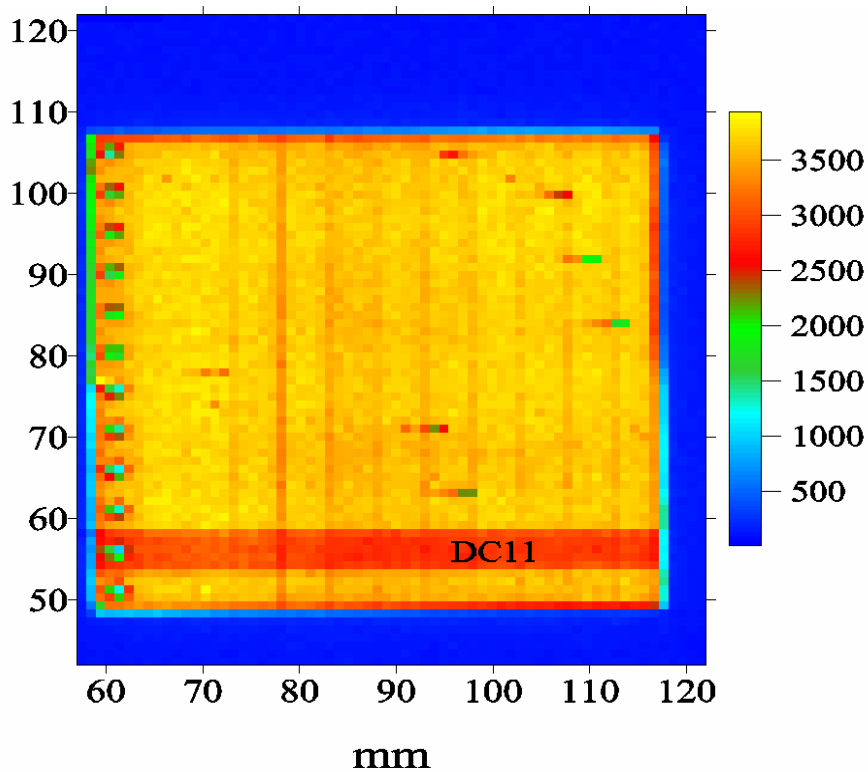
Co-57 AC x-y surface intensity distribution

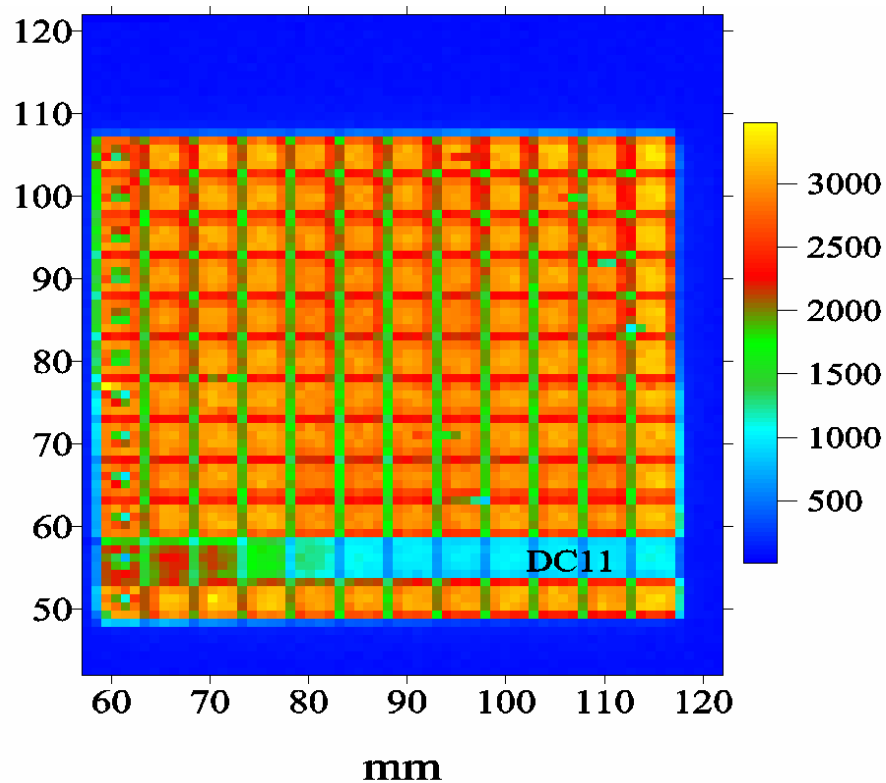




- The results are presented for 122 keV with 1 minute of data per position. Source on AC side.

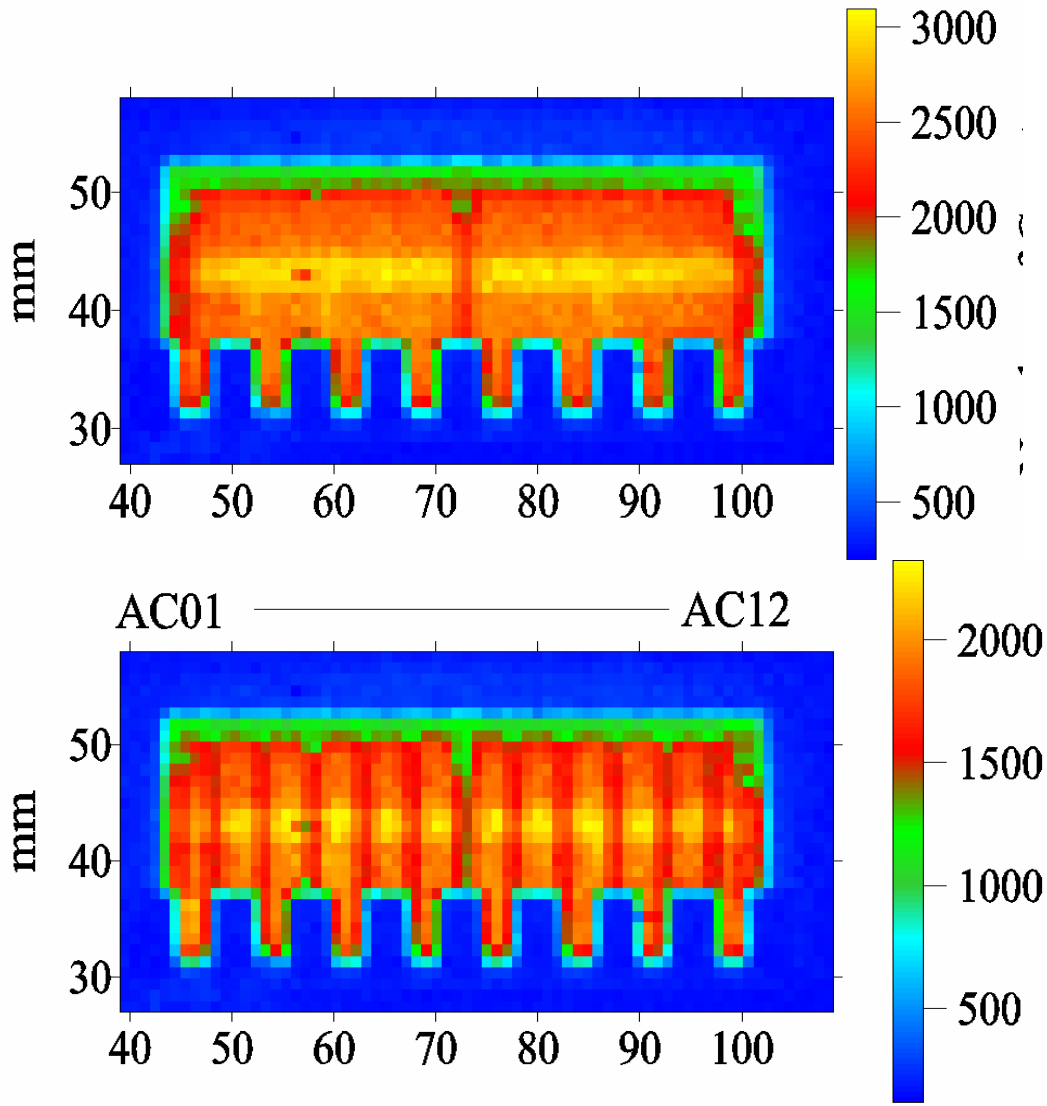
Co-57 DC x-y surface intensity distribution





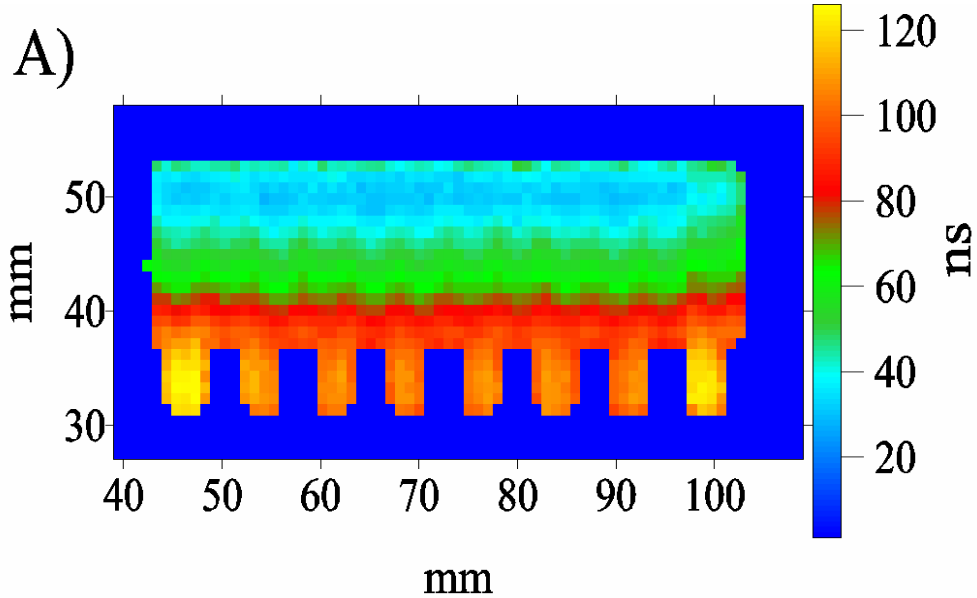
- The results are presented for 122 keV with 1 minute of data per position. Source on DC side.

Co-57 side surface intensity distribution

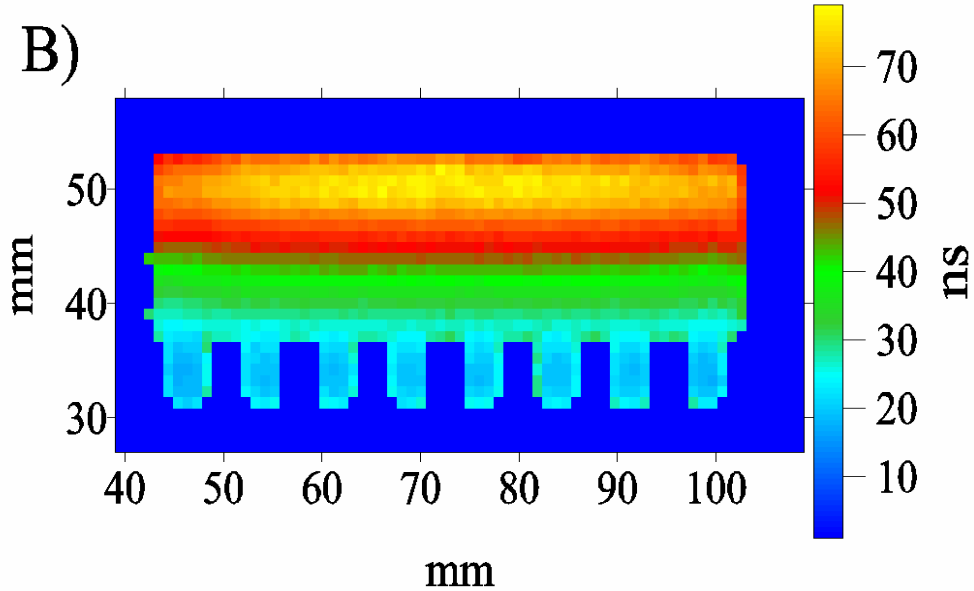


- **The results are presented for 122 keV with 1 minute of data per position.**

Co-57 side surface T30 rise time distribution



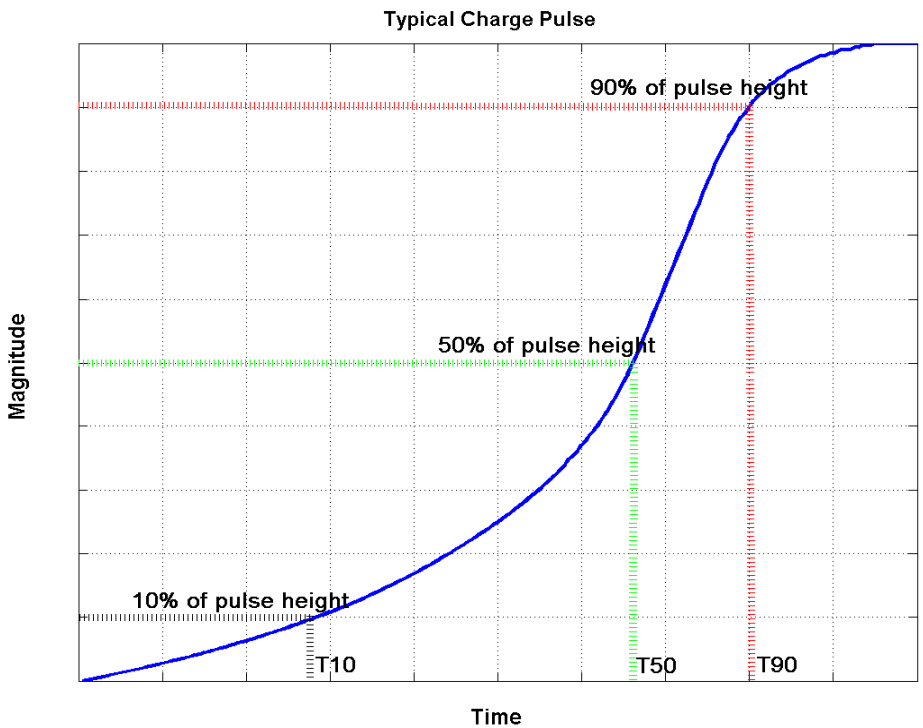
T30 AC

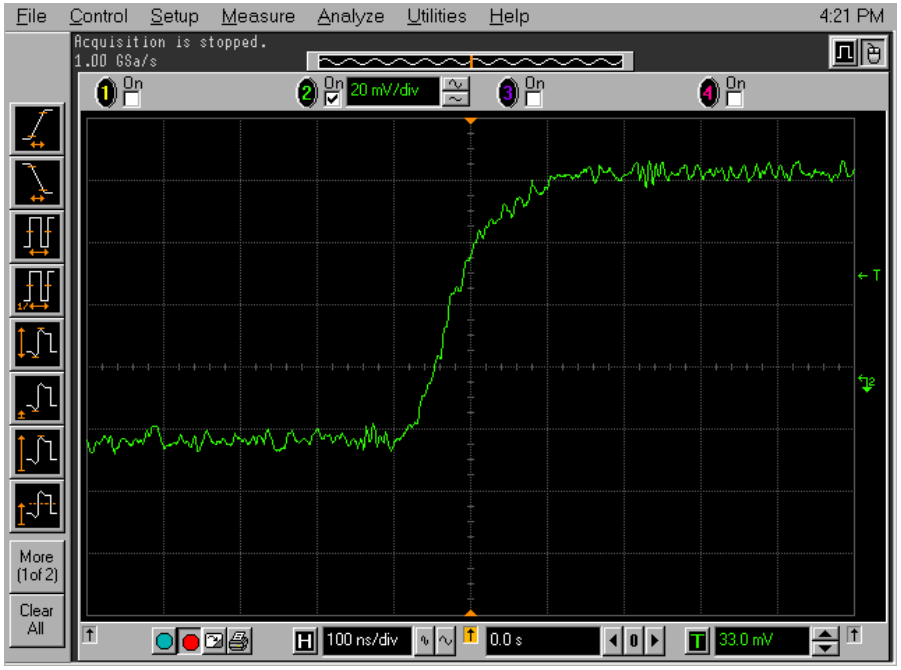


T30 DC

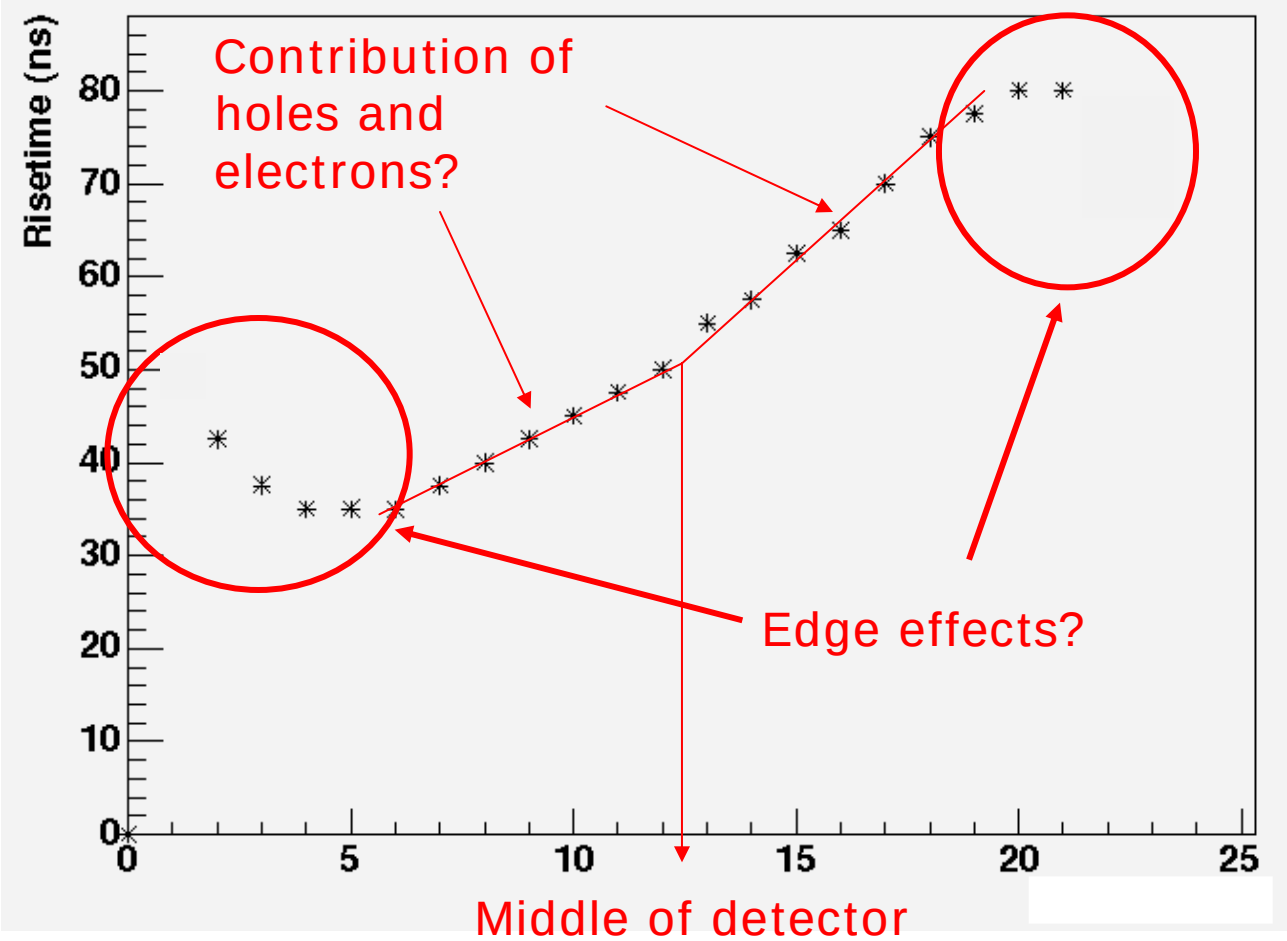
Risetime Analysis

- **Charge pulse results from γ-ray interaction**
  - Drift Velocity of e-h pairs saturated
  - Rise time varies with depth
  - Calibrate T10, T50, T90



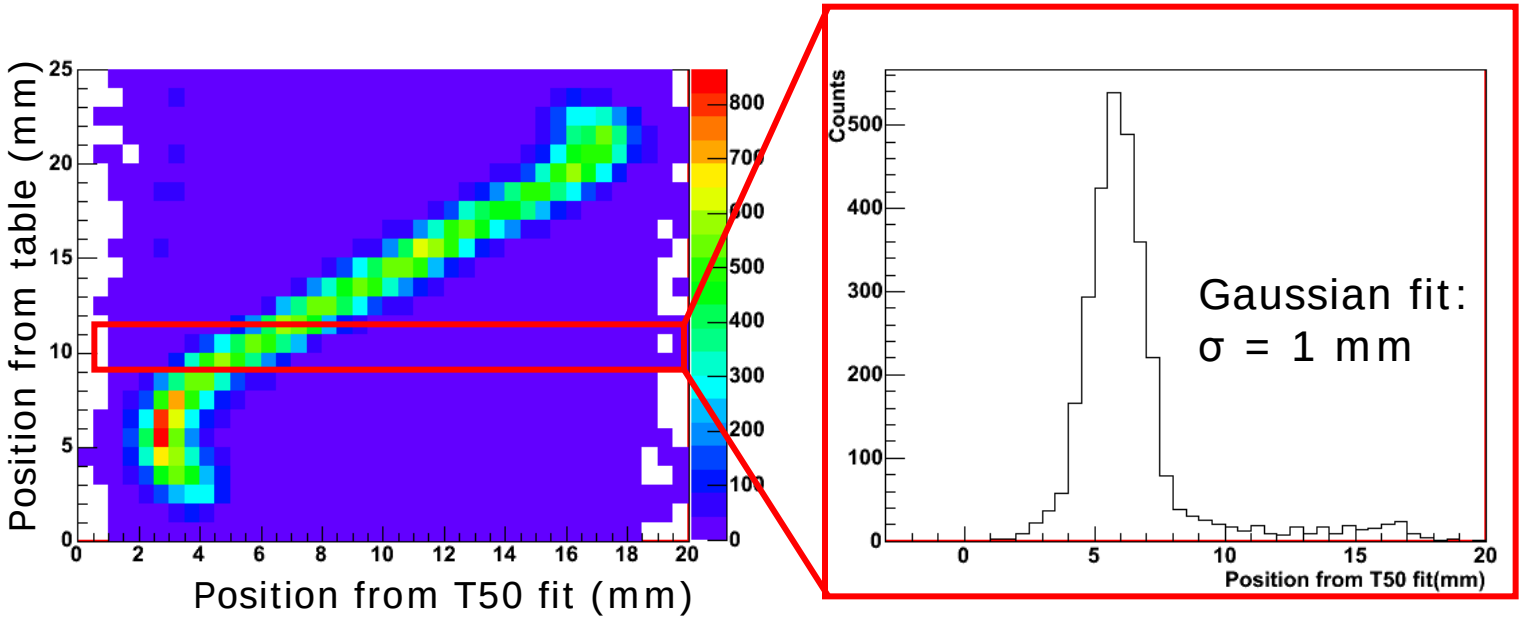


T50 response on the DC side



Distance away from contact

Recalculation of the position



- **T50 is a good measure to evaluate the depth of interaction inside the major part of the detector**

Image Charge Analysis

- **Signals induced on adjacent strips**

➢ Finite magnitude while charges are moving

➢ Relative magnitudes vary with proximity of interaction

➢ Calibration of some asymmetry parameter

$$A = \frac{Q_{left} - Q_{right}}{Q_{left} + Q_{right}}$$

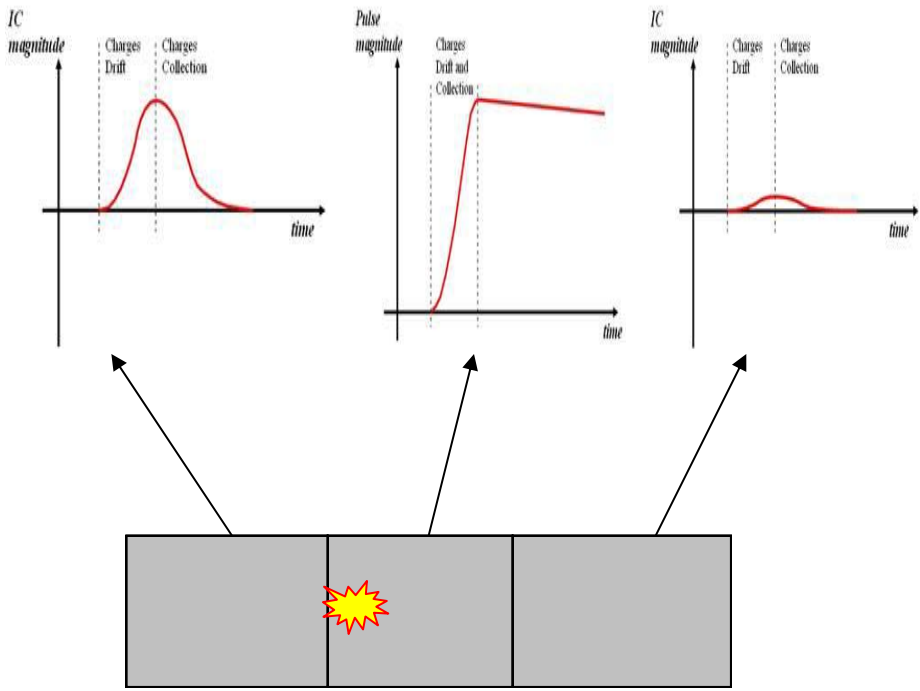


Image Charge Asymmetry

Response as a function of lateral position – Step 1

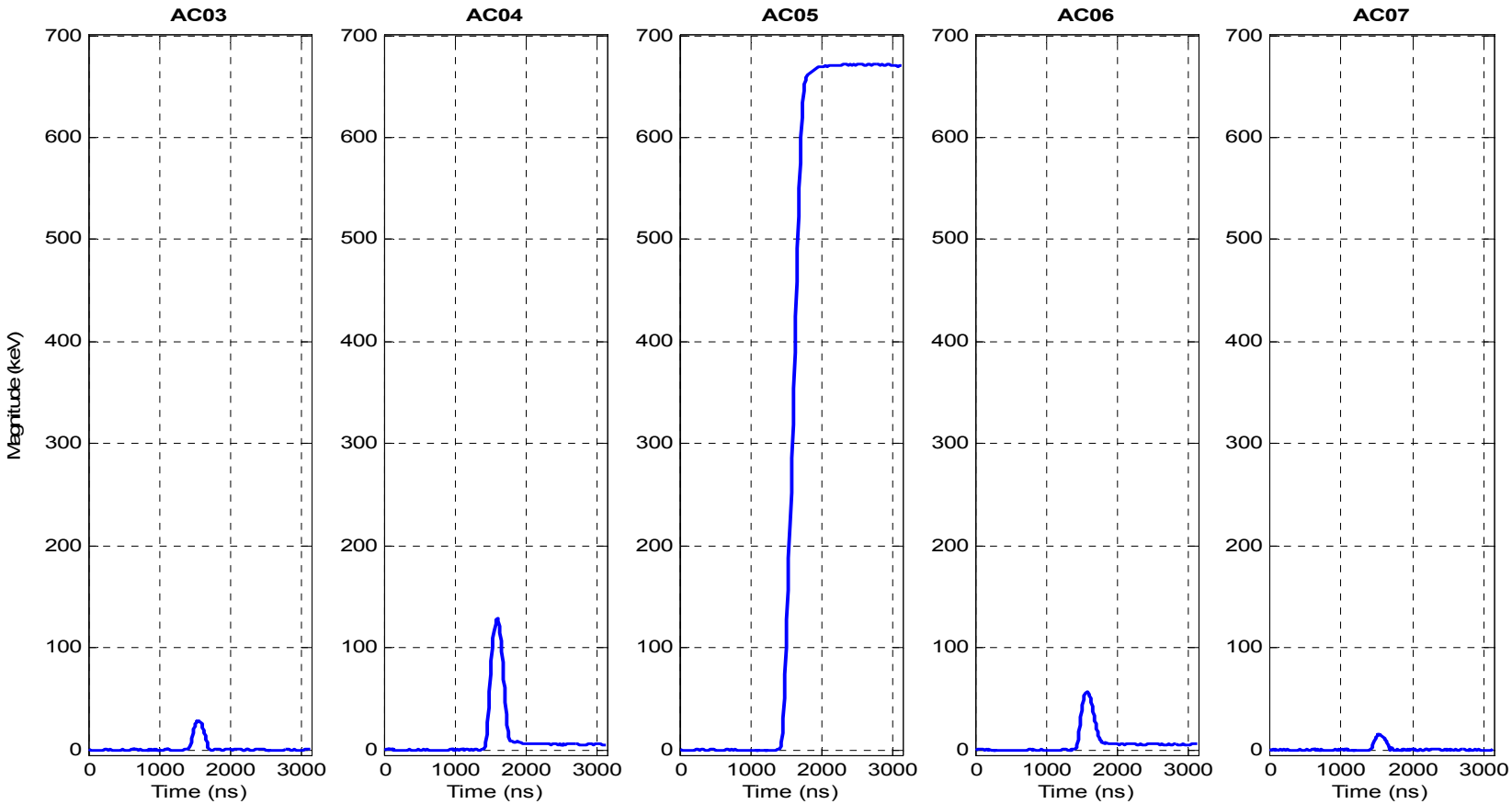
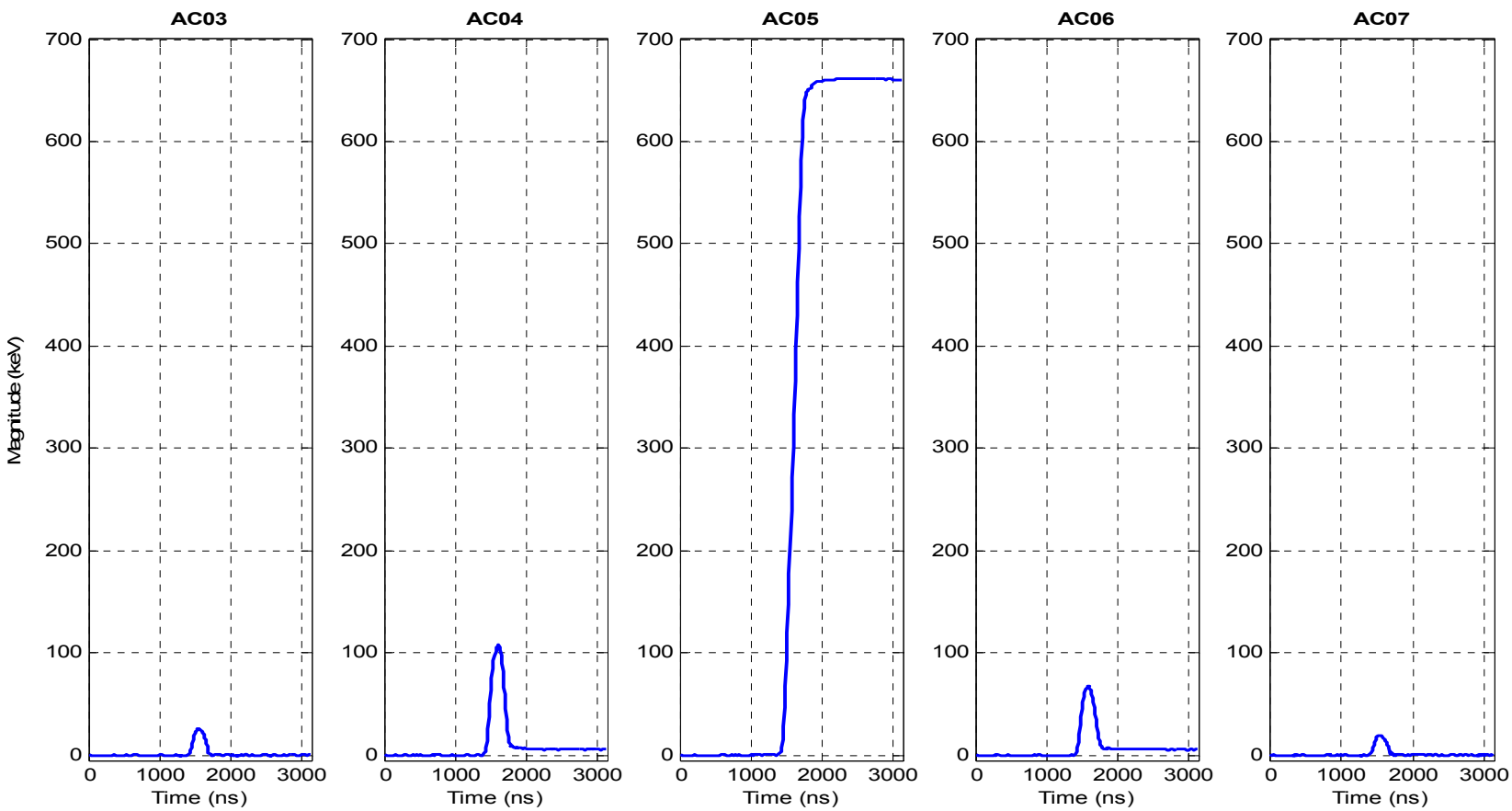


Image Charge Asymmetry

Response as a function of lateral position – Step 2



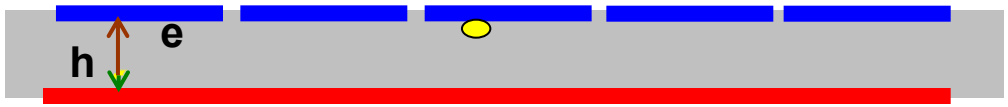
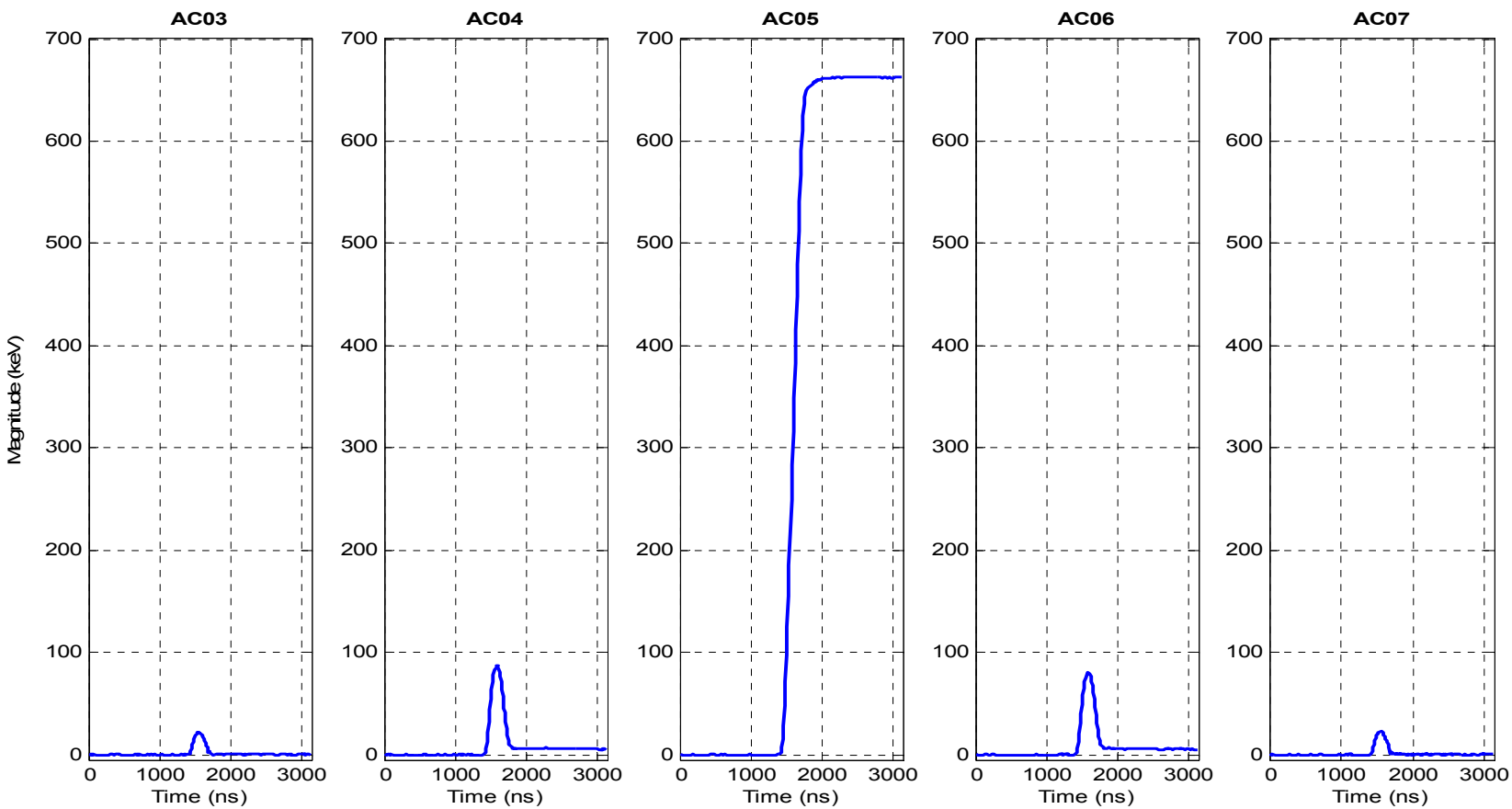


Image Charge Asymmetry

Response as a function of lateral position - Step 3



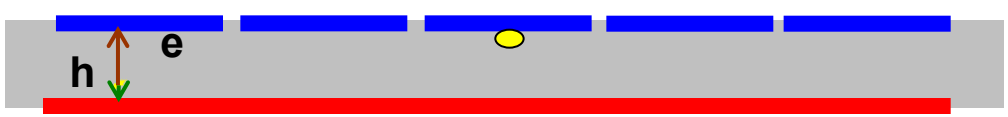
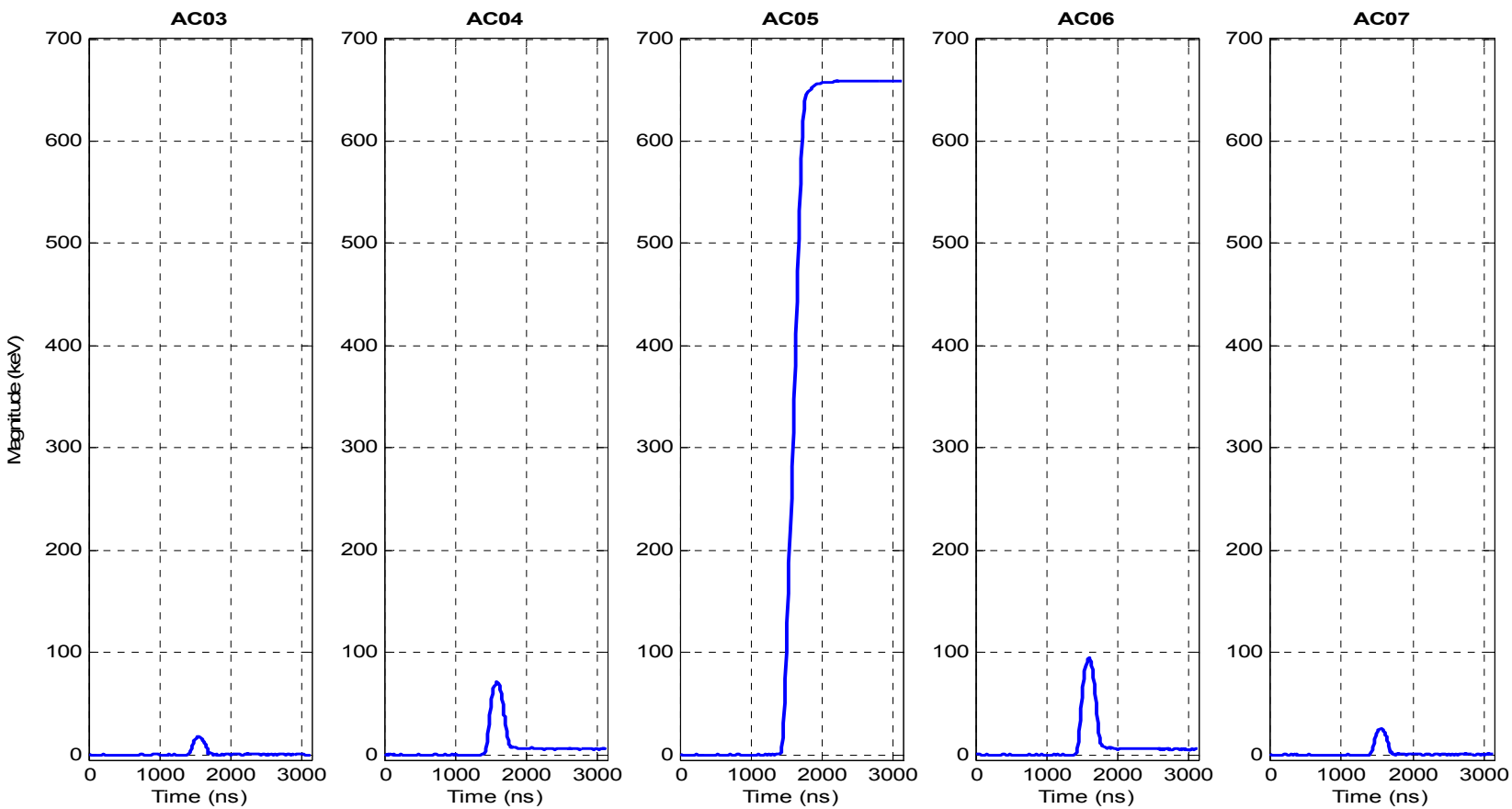


Image Charge Asymmetry

Response as a function of lateral position - Step 4



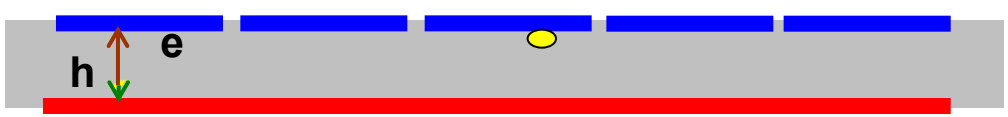
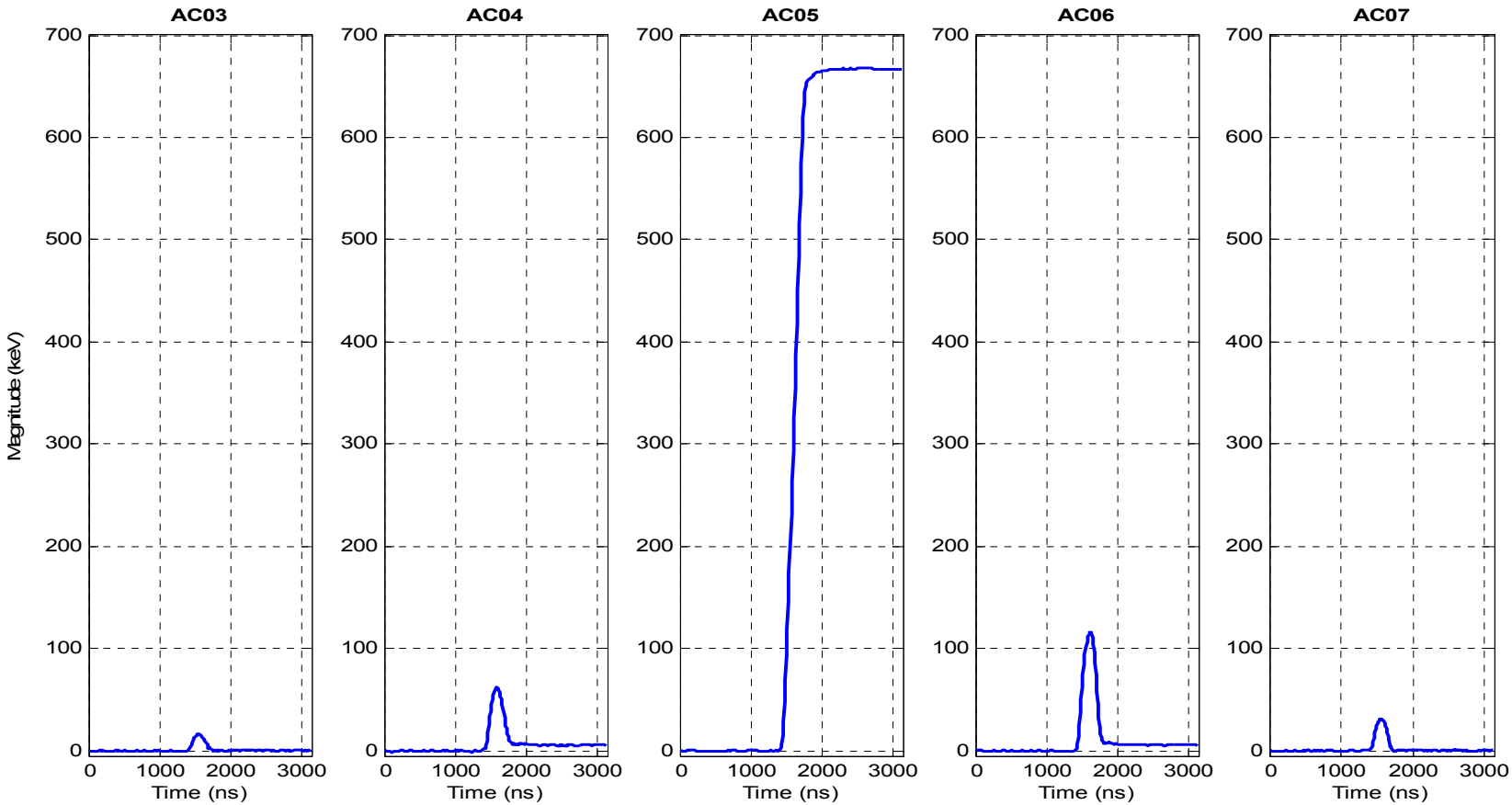


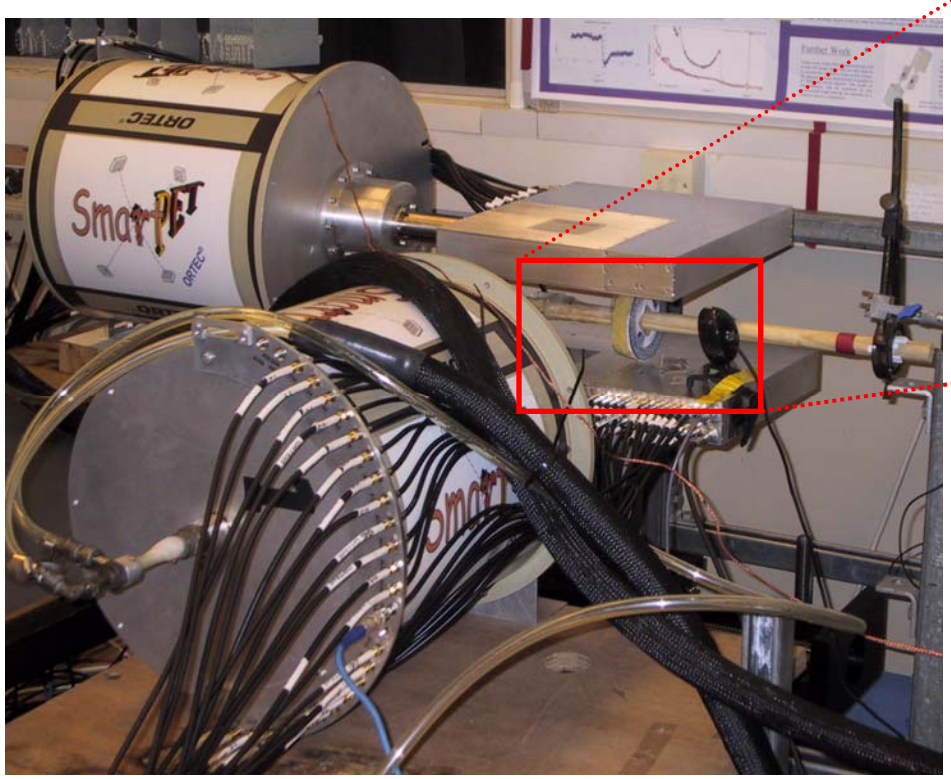
Image Charge Asymmetry

Response as a function of lateral position - Step 5



Application to PET Imaging

- One of the first demonstrations of event-by-event applied PSA
- Imaging of ^{22}Na point sources



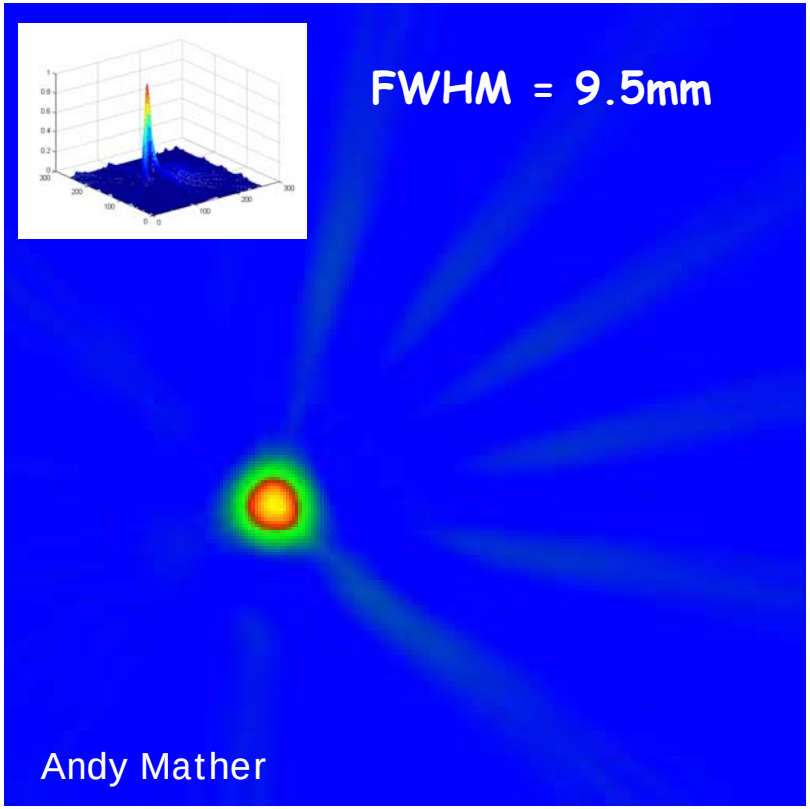
- NIM logic coincidence trigger
- Data collected every 5°
- FBP & ML-EM Reconstruction

Reconstructed Images

- Simple PSA techniques applied event-by-event
- Filtered Back Projection – ^{22}Na source

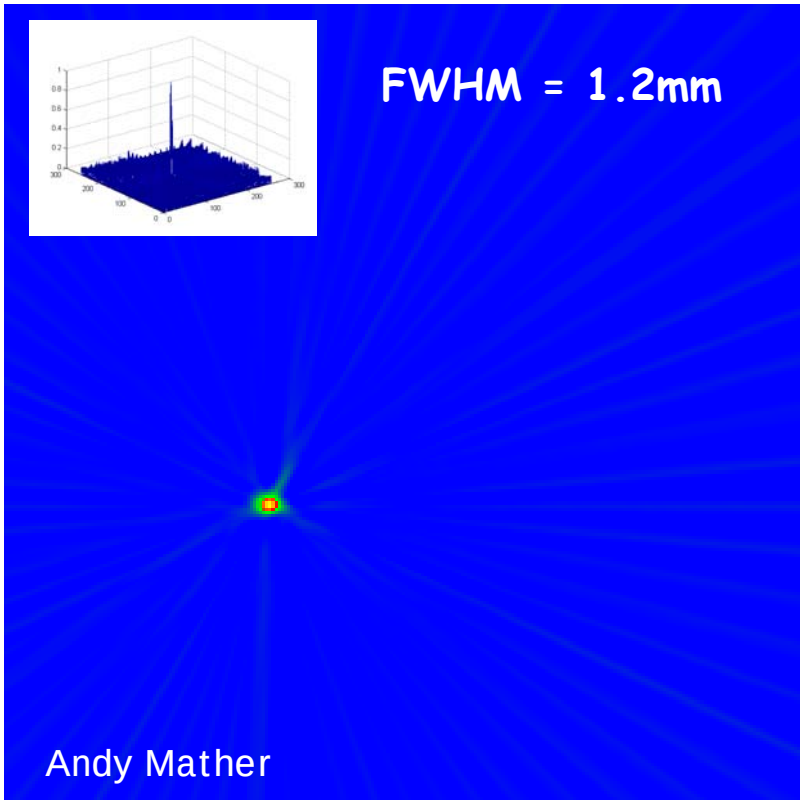
2mm depth
1mm lateral

No PSA



80mm

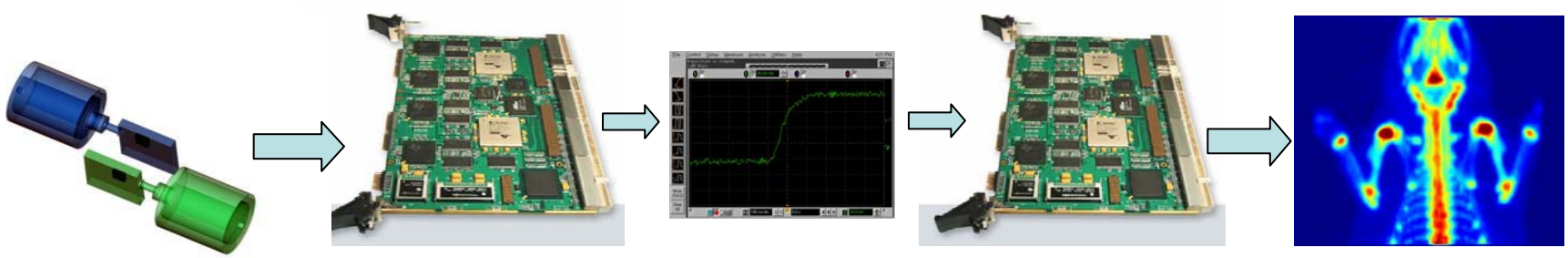
PSA

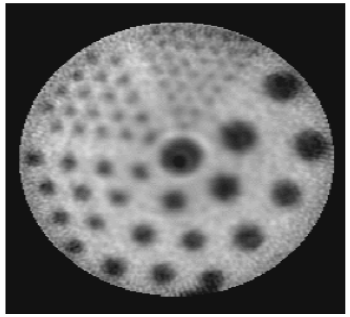


80mm

Online PSA - DAQ

- New digital DAQ commissioned – 50 – 100 kHz
- Commercial Solution from Lyrtech
  - 105MHz, 14 bit FADCs
  - FPGA & DSP – online PSA (x,y,z,t,E)
- 2 Levels of processing with global time stamping





- DAQ testing underway & algorithm development ongoing
- Phantom imaging summer 2006
- Small animal imaging

New Sources for scanner characterisation

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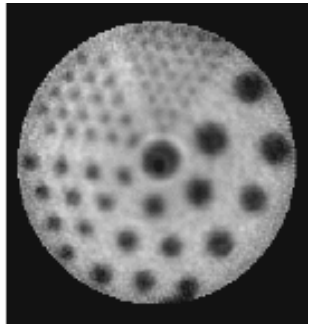
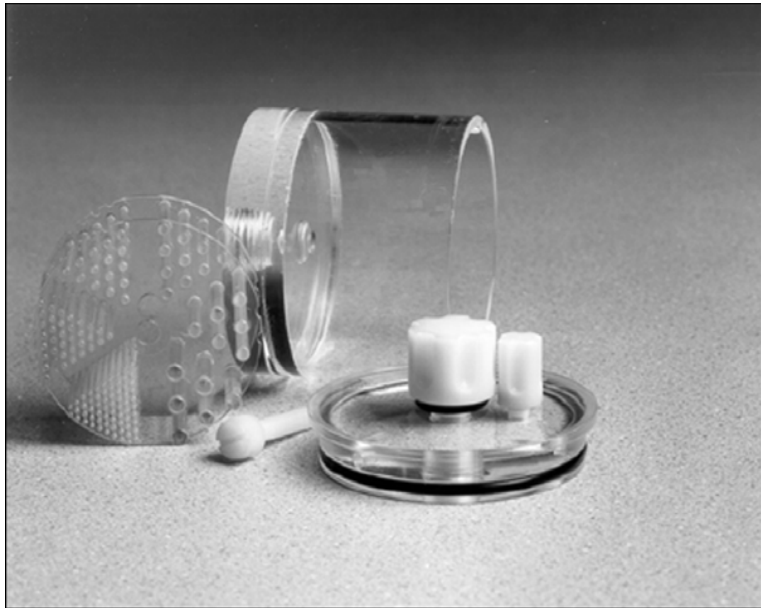
- Micro Deluxe Phantom filled with 370kBq of ^{22}Na
- **Main Applications:**
  - Small animal system evaluation (with field-of view greater than 45 mm)
  - Spatial resolution measurements
  - Evaluation of centre-of-rotation error
- **Specifications:**
  - Rod diameters: 1.2, 1.6, 2.4, 3.2, 4.0 and 4.8 mm
  - Height of rods: 3.4 cm
  - Insert diameter: 4.4 cm
  - Cylinder outside diameter: 5 cm
  - Cylinder inside diameter: 4.5 cm
  - Cylinder inside height: 3.7 cm





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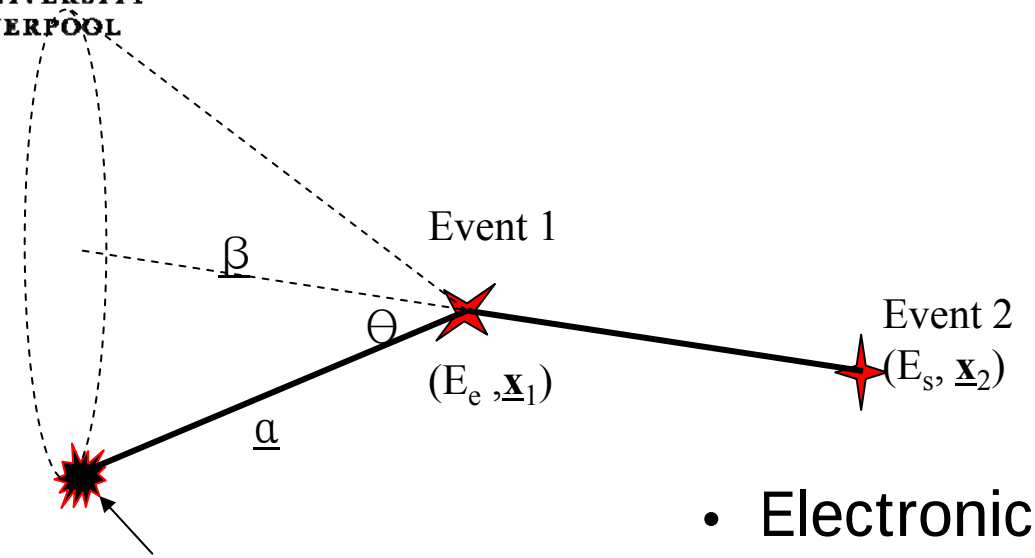
Compton Camera aspects

Compton Scattering



- Electronic collimation
- γ must have a trajectory along a cone surface, described by axis : β and θ
- Energy of incident gamma E_0 (E_e, $\underline{\mathbf{x}}1$), and location of second event

Compton Camera

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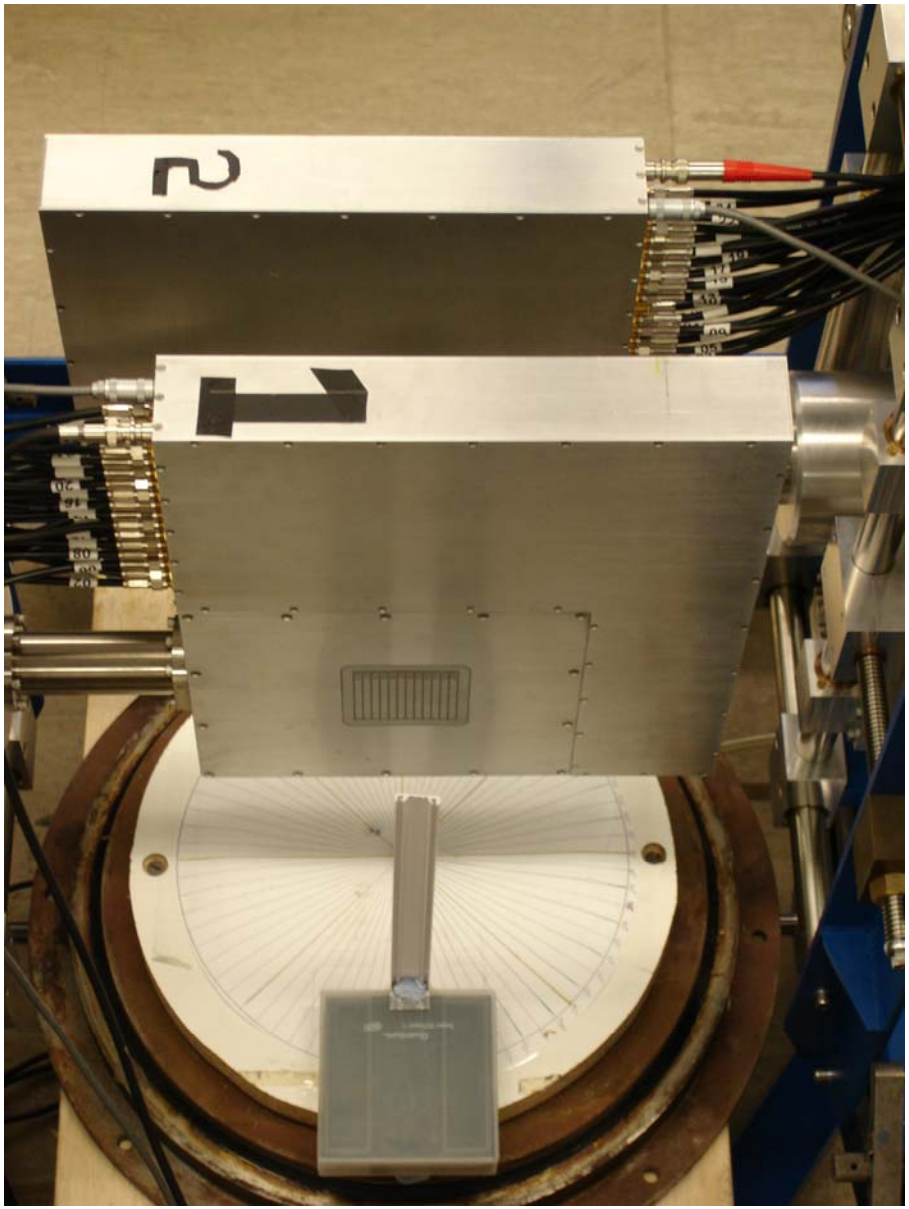
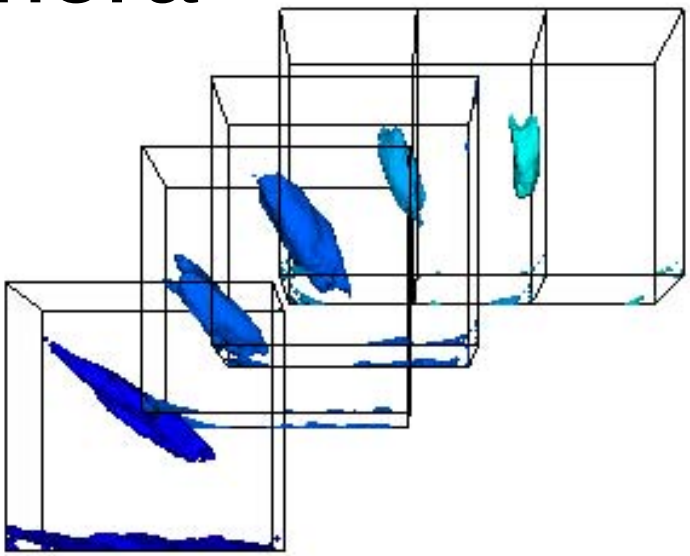
- 10μCi ^{152}Eu (370 kBq)
- 60mm from det 1
- Source rotated
  - Zero degrees in 15º steps up to 60º
- Detector separation
  - 3 – 11cm in 2cm steps
- Gates set on energies
  - 779, 1408keV



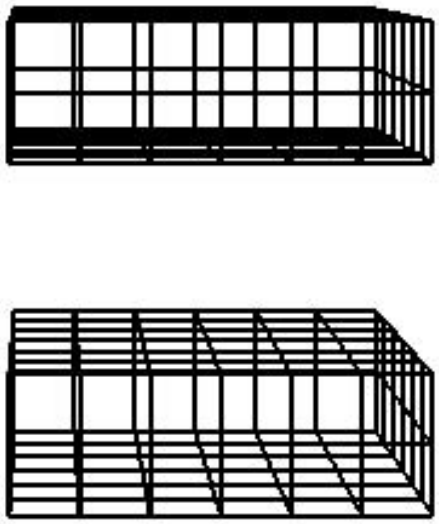
Imaging Progress : Compton Camera

- ^{152}Eu point source imaging.
- 30 keV gate on 778 keV.
- 30mm detector separation with 5mm position resolution.
- Single interactions in each detector.



Cone beam reconstruction with 10 iterations. No PSA

~6mm image resolution x-y.



Imaging Progress : Compton Camera

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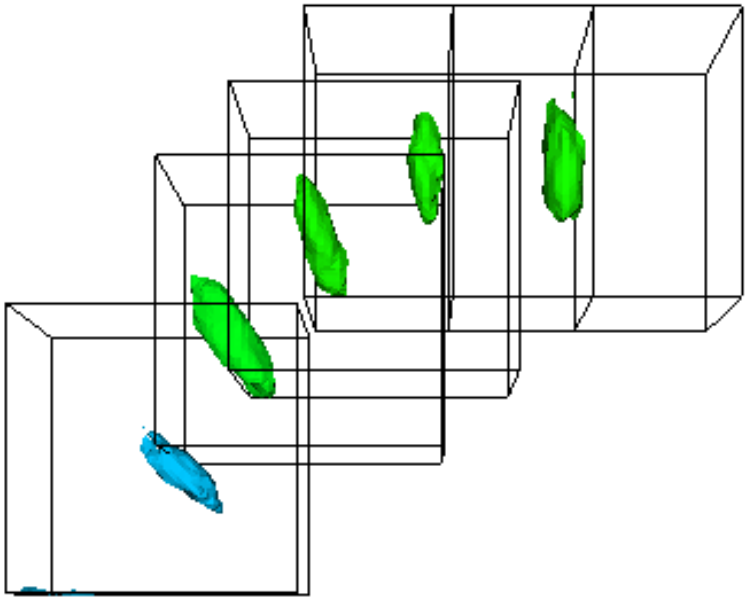
- ^{152}Eu point source imaging.
- 30 keV gate on 1408 keV.
- 30mm detector separation with 5mm position resolution.
- Single interactions in each detector.



Cone beam reconstruction with 10 iterations. No PSA

~8mm image resolution x-y.

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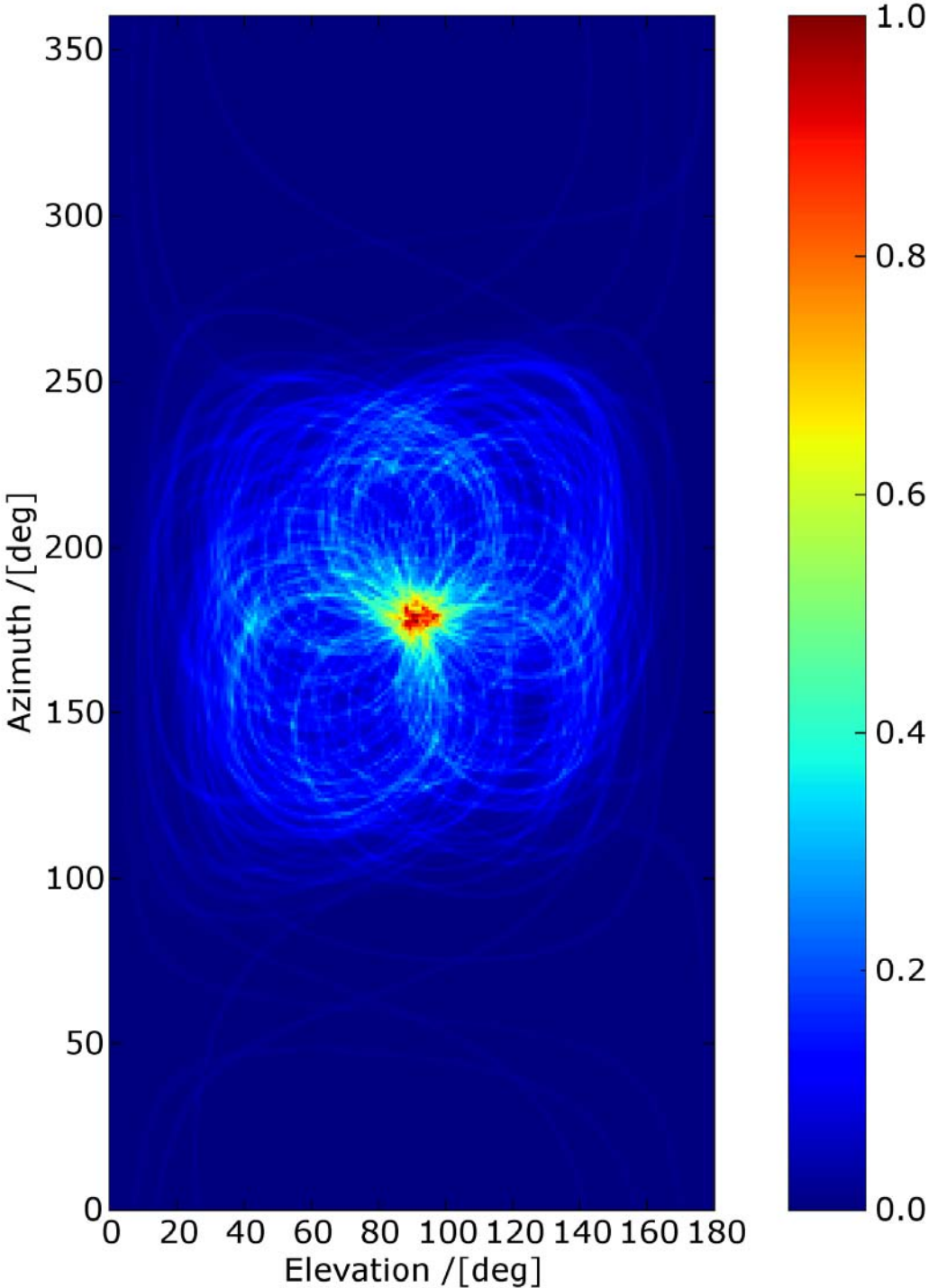
1408 keV

Cones



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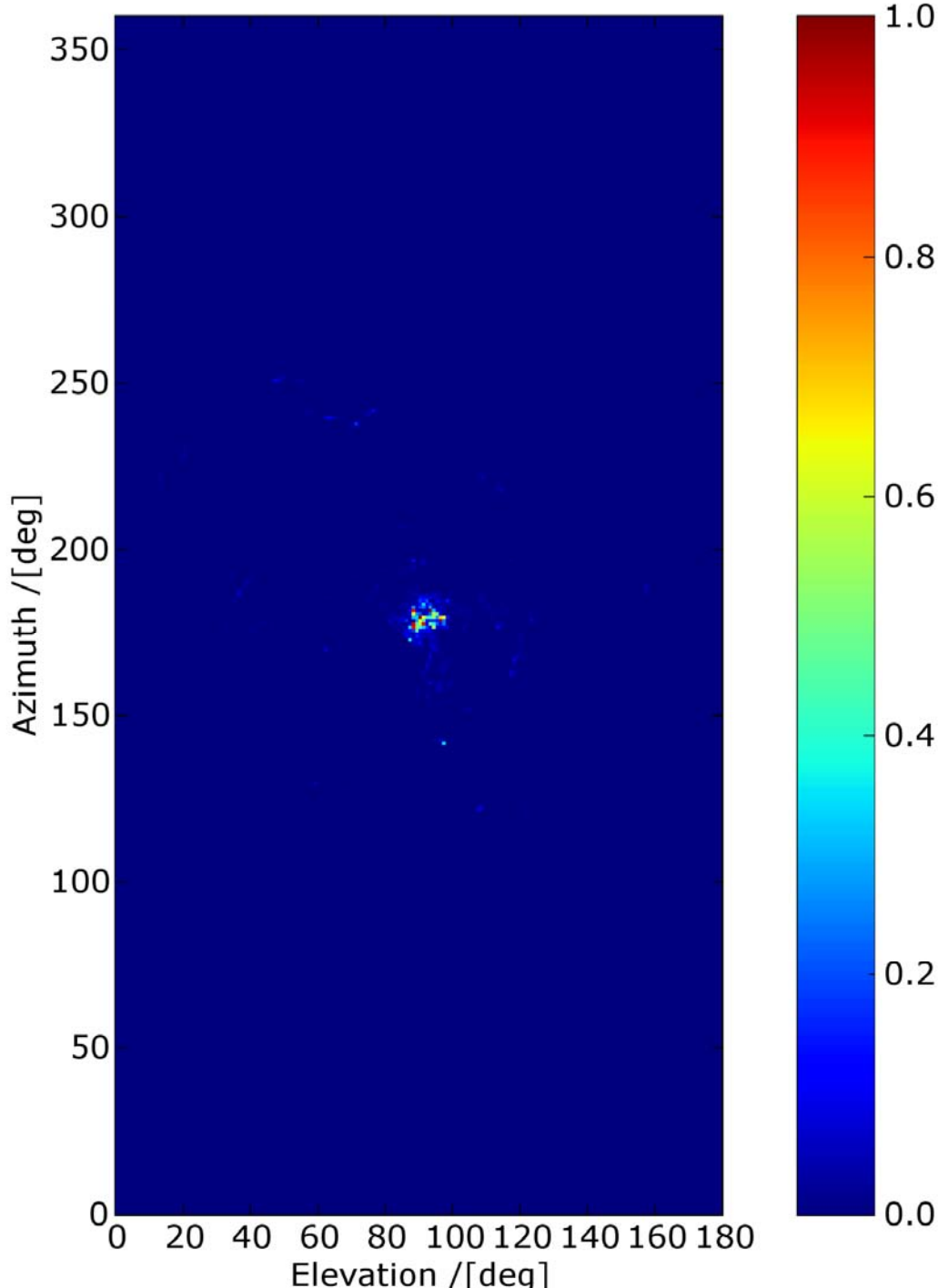
1408 keV

Image analysis



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Conclusions

Detectors work well and have been characterised

- **approx 1 x 1 x 1 mm position resolution**

Images obtained with point sources for both PET and Compton Camera

- **improve Pulse shape analysis implementation**

Next step is to use a phantom and then a realistic subject to image

- **small animal with ^{18}F**
- **extended radioactive source (waste?)**

Implement new electronics for high count rates and online analysis

R.J. Cooper [1], A.J. Boston[1], H.C Boston[1], J.R. Cresswell[1], A.N. Grint[1], A.R. Mather[1], P.J. Nolan[1], D.P. Scraggs[1], G. Turk[1], C.J. Hall[2], I. Lazarus[2], J. Simpson[2], A. Berry[3], T. Beveridge[3], J. Gillam[3], R.A. Lewis[3]

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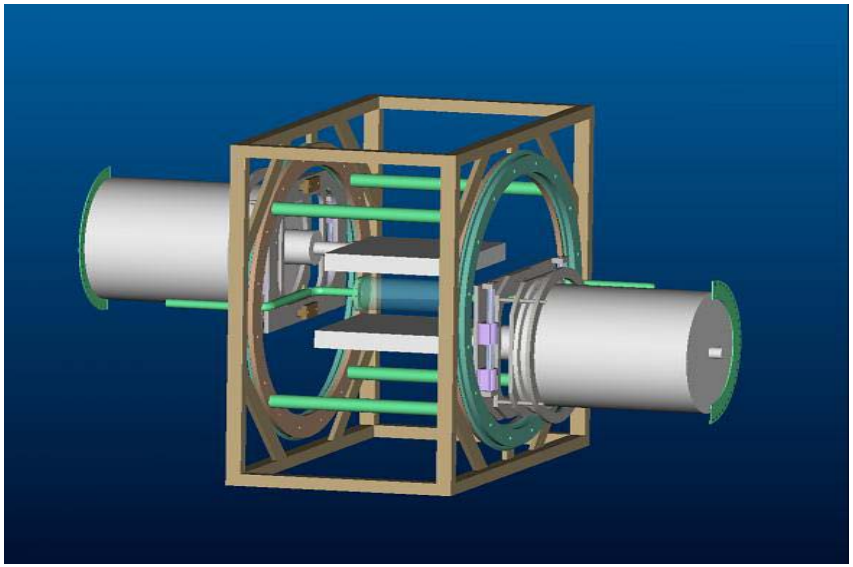
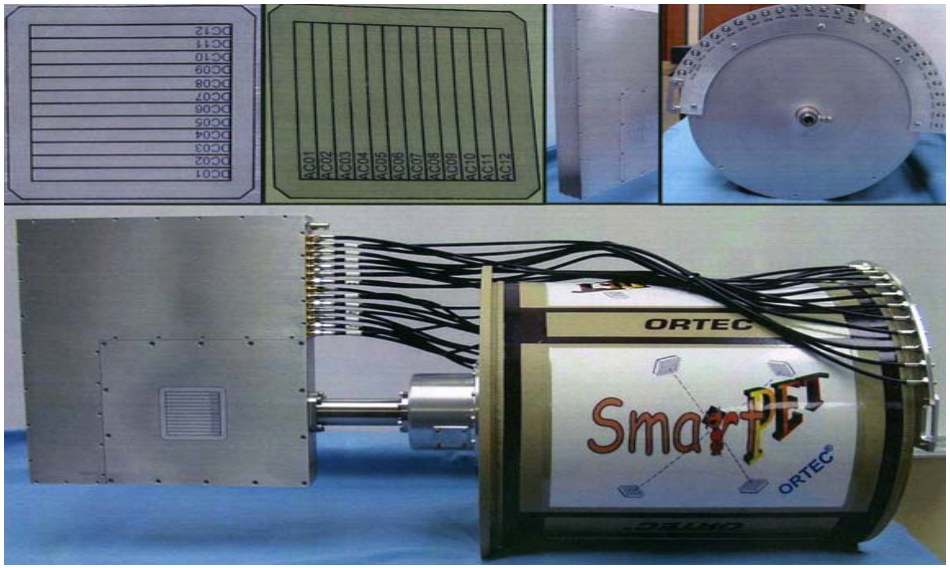
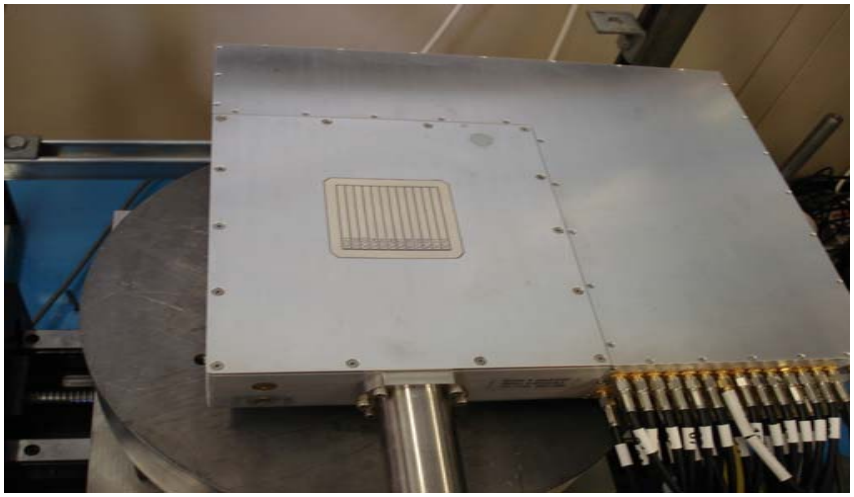
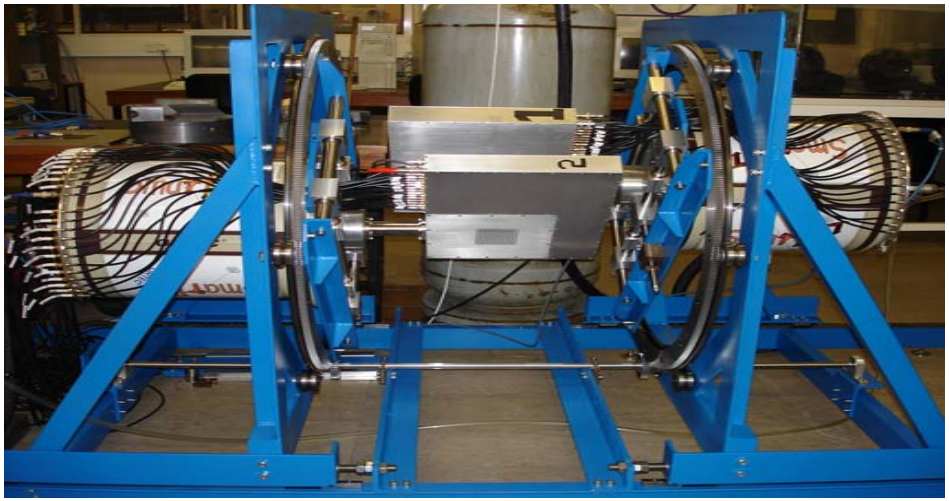






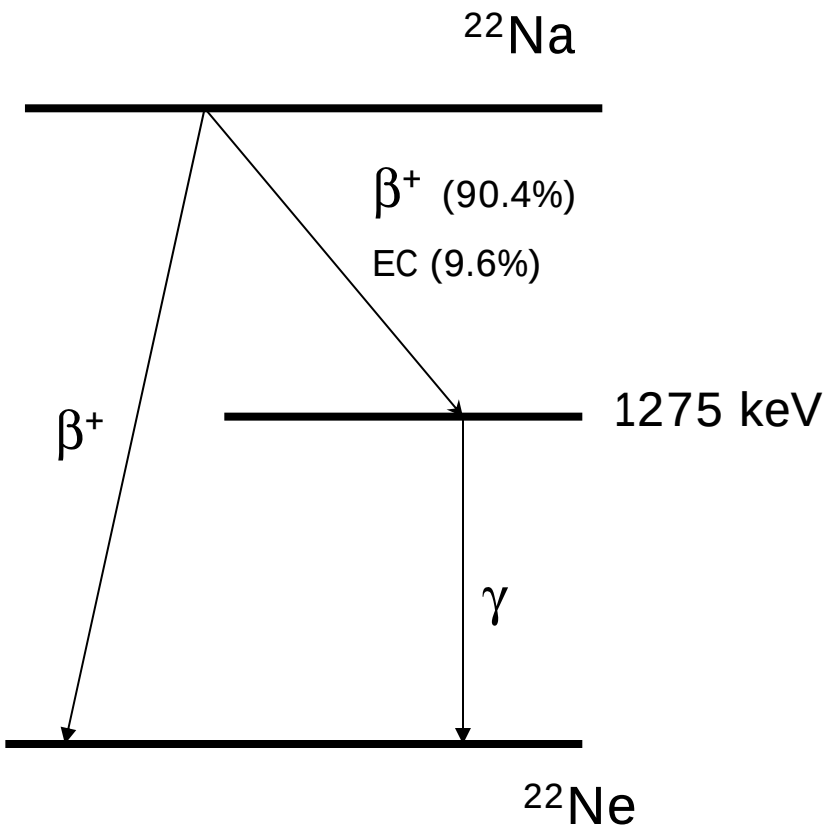


EPSRC
Engineering and Physical Sciences Research Council

MRC Medical Research Council

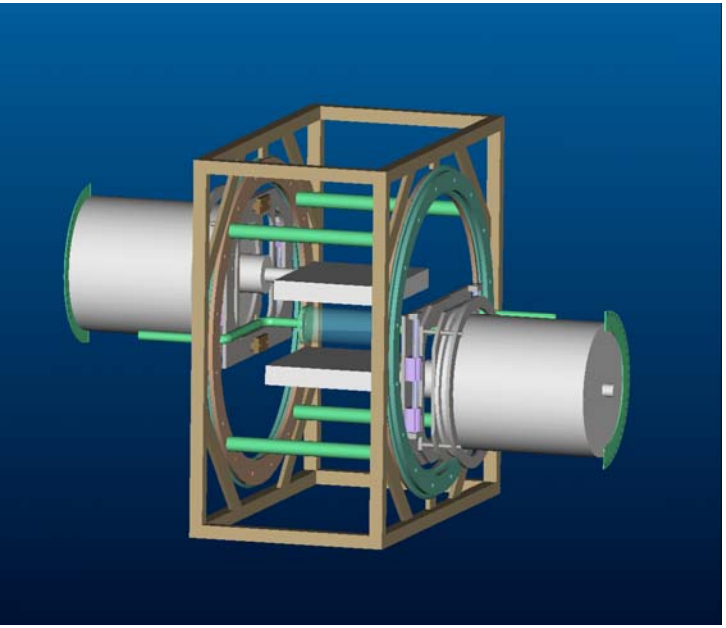
^{22}Na Decay

$t_{½}$ ~ 2.6 years



Online PSA

- Until now, all PSA has been developed/performed offline
- There is a need to demonstrate the principle online
- Calculate 3D interaction position event by event in real time
- Output list-mode data set
- Direct input to reconstruction algorithms



- Development of new digital DAQ system
- High count rate capability
  - ~50kHz – 100KHz per strip
- Real time signal processing techniques
- FPGA/DSP requirement