SmartPET: A Small Animal PET Demonstrator using HyperPure germanium Planar Detectors

HAEC OTIA FIAT LUX FOVENT STUDIA

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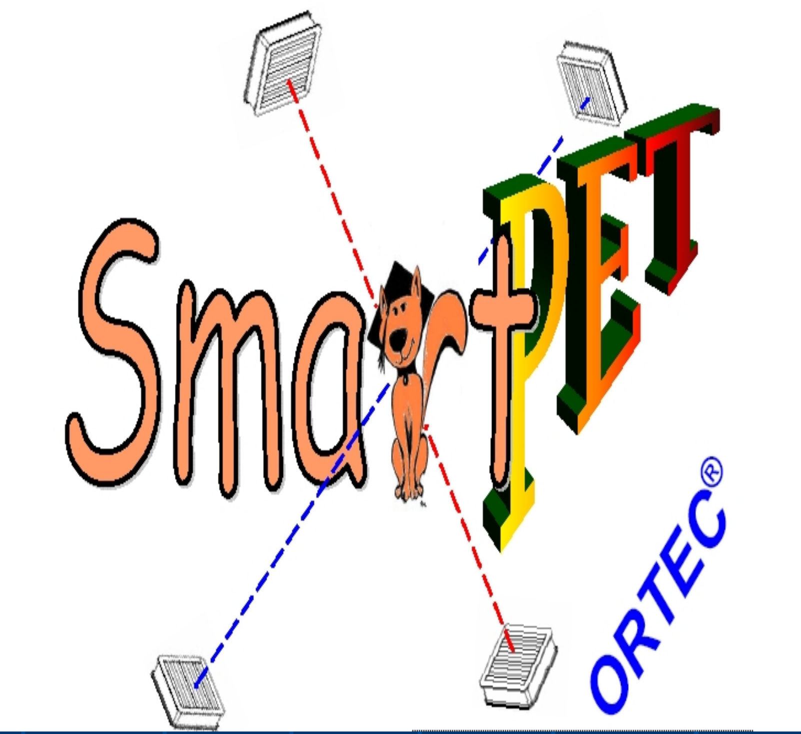
Overview

- **What is SmartPET?**
- **Key aims of the SmartPET project**
- **HPGe for medical imaging**
- **SmartPET: Instrumentation**
  - Segmented germanium Detectors
  - Digital Electronics
- **Pulse Shape Analysis (PSA)**
  - Risetime Analysis
  - Image Charge Analysis
- **Gamma Ray Tracking (GRT)**
- **Image Reconstruction**

The SmartPET Project

- Development of HPGe based PET system
- Prototype system – small animal imaging
- Segmented Ge detectors
- Digital Electronics
- Development and implementation of sophisticated data analysis techniques – PSA & GRT



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SmartPET: Key Aims

- "Proof of principle" for HPGe imaging
- Use events which Compton scatter in the detectors for image reconstruction
- Increase patient throughput and/or reduce patient dose
- Reduce uncertainty in LoR definition
- Improve diagnostic images

→ **How can Ge help us achieve these goals ?**

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HPGe for Medical Imaging

What do we need to improve?

- Identify Compton scattered events
- Reconstruct gamma ray path event by event
- Use these events to improve system efficiency
- Precise knowledge of energy, time and 3D interaction position

What does segmented germanium provide?

- Excellent energy resolution (~0.4% @511keV vs ~20% BGO)
- Ability to "Addback" events – improve Photopeak efficiency
- Fine spatial resolution – Pulse Shape Analysis
- Correlation – Gamma Ray Tracking

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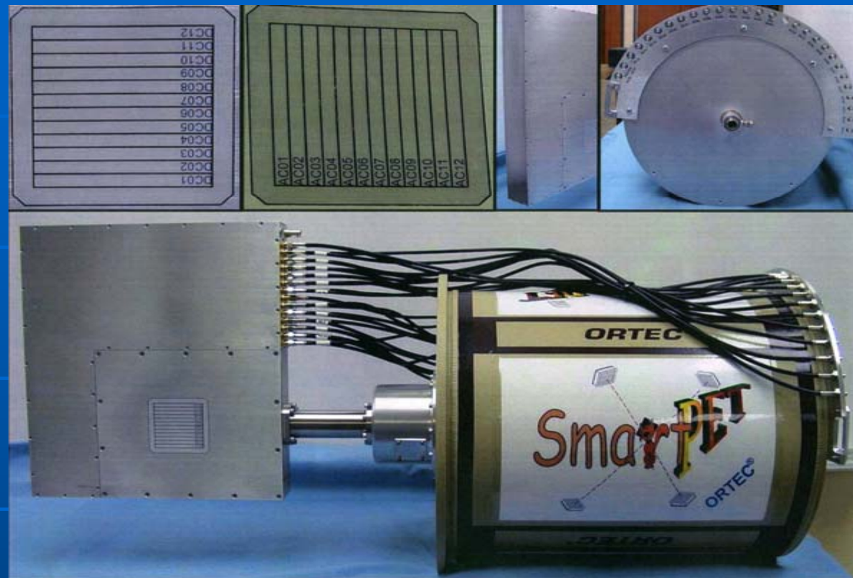
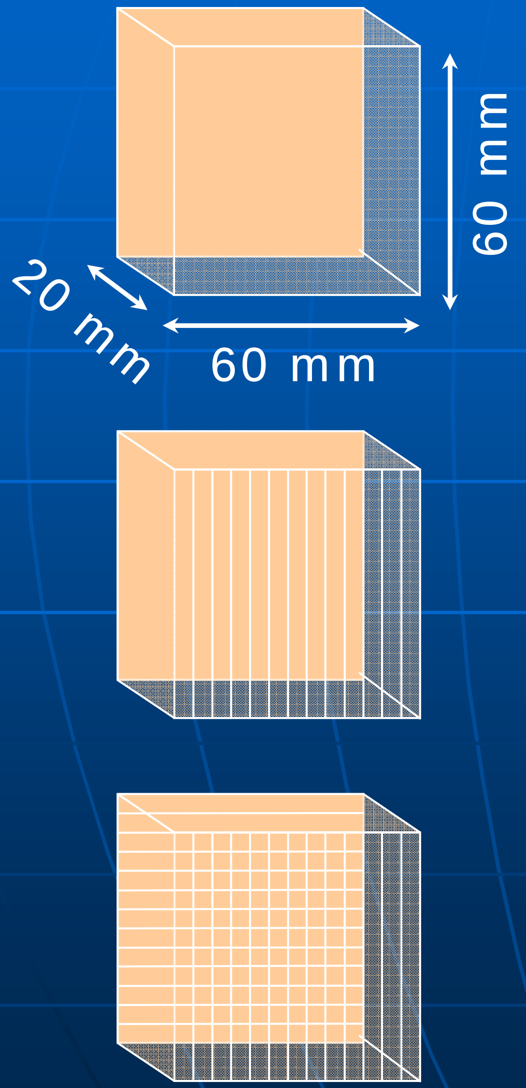
SmartPET System

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



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

Why Segment?



- No segmentation
  - Spatial Resolution 60x60x20 mm
- One electrode electrically segmented
  - Spatial Resolution now 5x60x20 mm
- Orthogonal segmentation of opposite electrode
  - Spatial Resolution 5x5x20 mm

All with no loss in efficiency
- Facilitates "Addback"

24 strips + 1 guard ring = 25 channels

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Pulse Shape Analysis

- Use charge pulse information to improve spatial resolution to $1mm^3$
- Risetime analysis identifies ***depth*** of interaction
- Image charge analysis allows determination of ***lateral*** position
- Characterisation of detector
- Calibrate experimental response as a function of position (G. Turk)
- Electric field simulation generates reference pulse shape database – online PSA

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Risetime Analysis

- Charge pulse results from γ-ray interaction
  - ➢ **Drift Velocity of e-h pairs saturated**
  - ➢ **Risetime varies with depth**
  - ➢ **Calibrate T30, T60, T90**

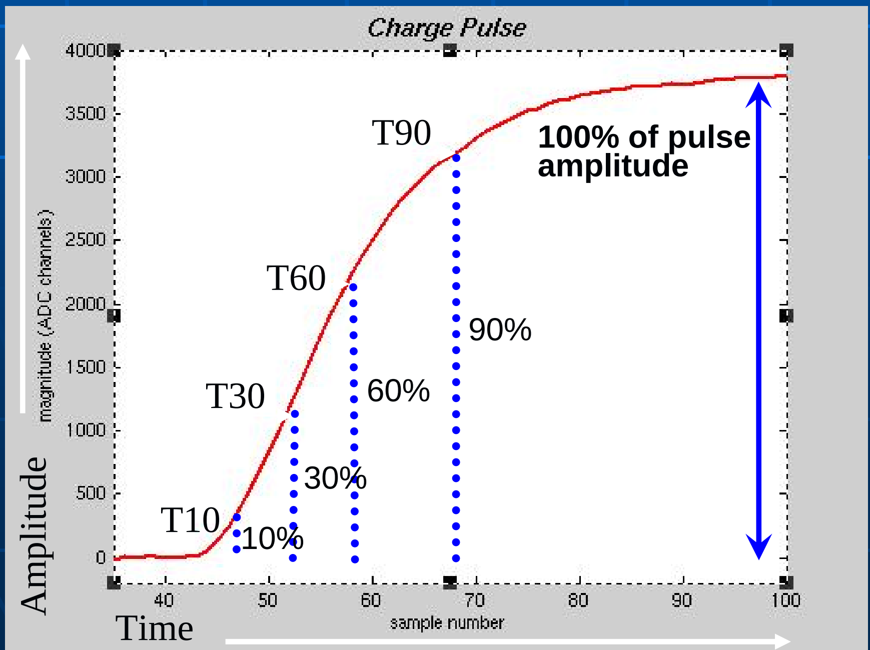

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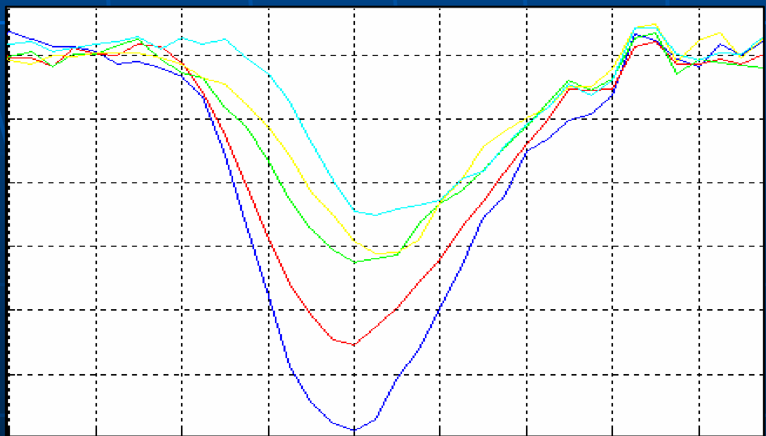
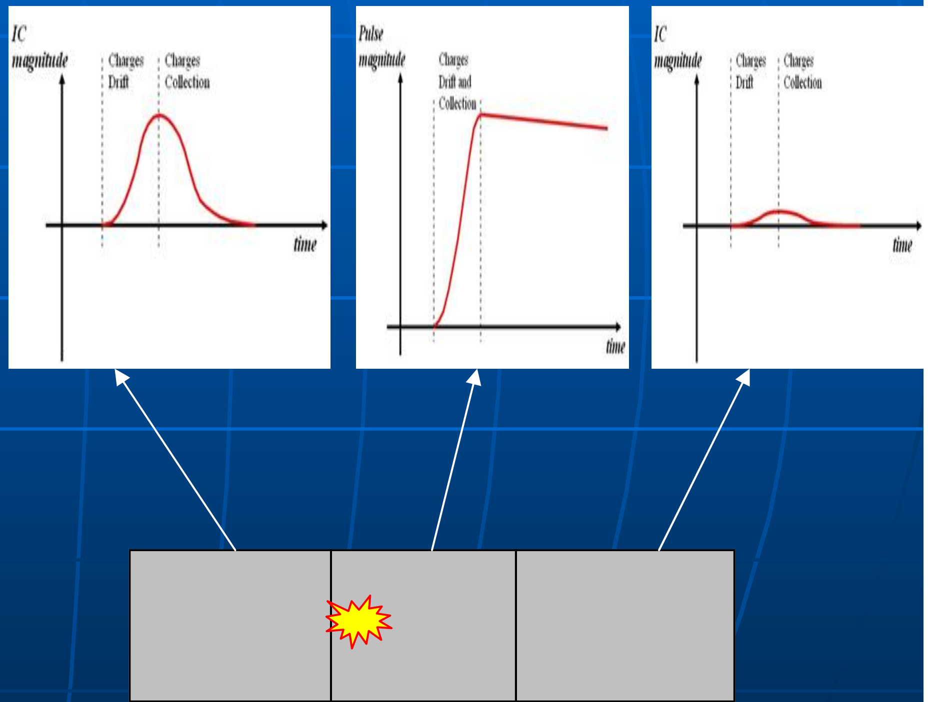
Image Charge Analysis

- Signals induced on adjacent strips
  - ➢ Finite magnitude while charges are moving
  - ➢ Relative magnitudes vary with proximity of interaction
  - ➢ Calibration of asymmetry parameter , A





Variation of Image Charge magnitude

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

Gamma Ray Tracking (GRT)

What is Gamma Ray Tracking?

- Three dimensional reconstruction of gamma-ray paths
- Correlation of scattering events – kinematics of Compton scattering
- Based on precise position, energy and time information provided by PSA

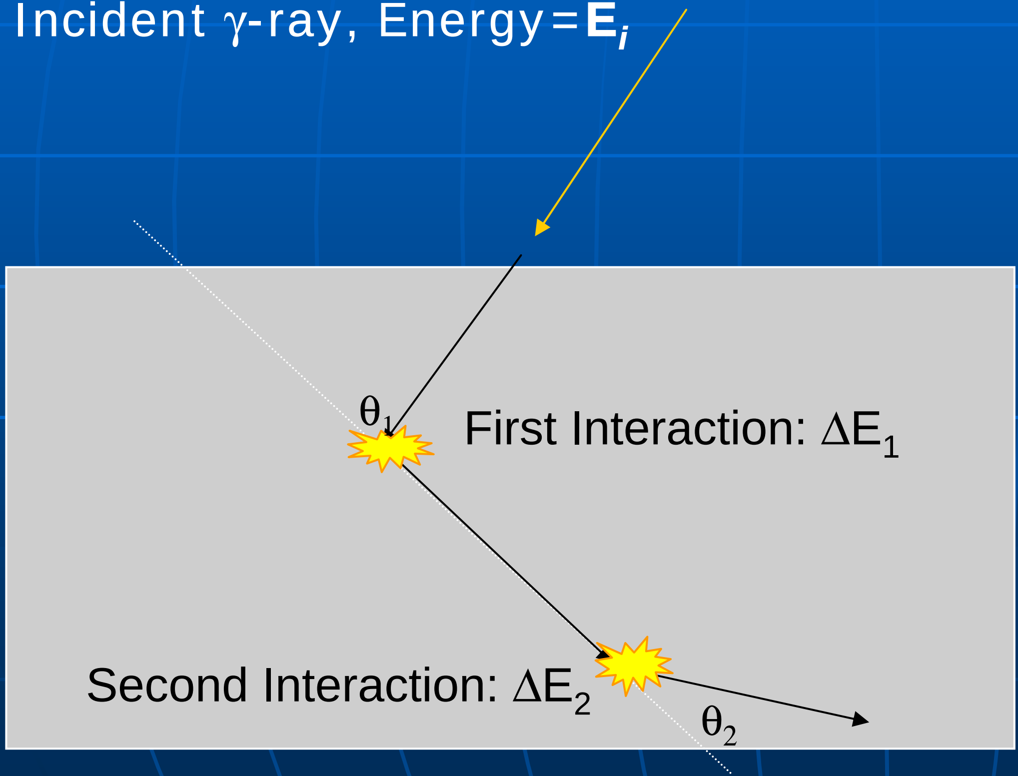
What can we achieve with GRT?

- Unprecedented efficiency for medical imaging system
- Ability to pinpoint position of first interaction
- Improved LoR definition – better images (?)

Gamma Ray Tracking (GRT)

How will it work?

Incident γ-ray, Energy=$\mathbf{E}_i$



Eq (1):

Calculate E_i from the angle between scatters and first two energy deposits

$$E_i = \Delta E_1 + \frac{\Delta E_2 + \sqrt{\Delta E_2^2 + 4\Delta E_2 m_e c^2 / (1 - \cos\theta_2)}}{2}$$

Eq (2):

Calculate incoming angle from incident energy and first energy deposit

$$\theta_1 = \cos^{-1}\left(1 - m_e c^2 \left[\frac{1}{(E_i - \Delta E_1)} - \frac{1}{E_i}\right]\right)$$

Image Reconstruction

- Parallel area of research
- Develop fast, accurate reconstruction algorithms (Poster - A. Mather)
- Analytic (FBP) and Statistical (MLEM) methods
- Cone beam reconstruction development at Monash
- Development of image quality assessment metrics/algorithms

MLEM

- Iterative
- Accurate
- Slow
- CPU intensive
- Handles low stats

FBP

- Analytic
- Fast
- Noisy
- Blurred

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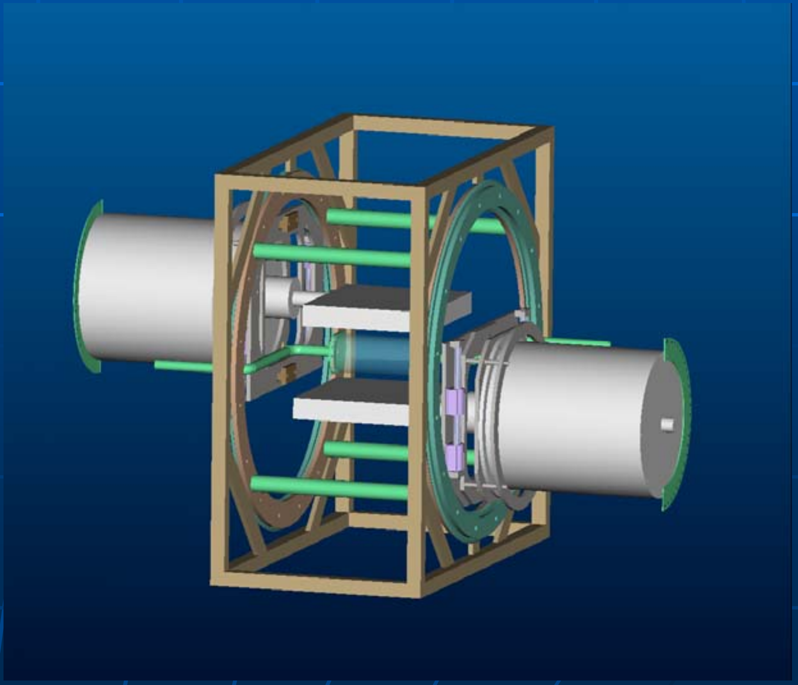
SmartPET: Progress

- 3 Years into the project
- One detector fully characterised
- Characterisation of second under way
- PSA algorithms ready for experimental validation
- GRT progress worldwide
- Reconstruction algorithms producing good results

SmartPET: The Future

- Experimental tests of coincidence system
- Full validation of reconstruction algorithms
- Online PSA & GRT
- Small animal imaging



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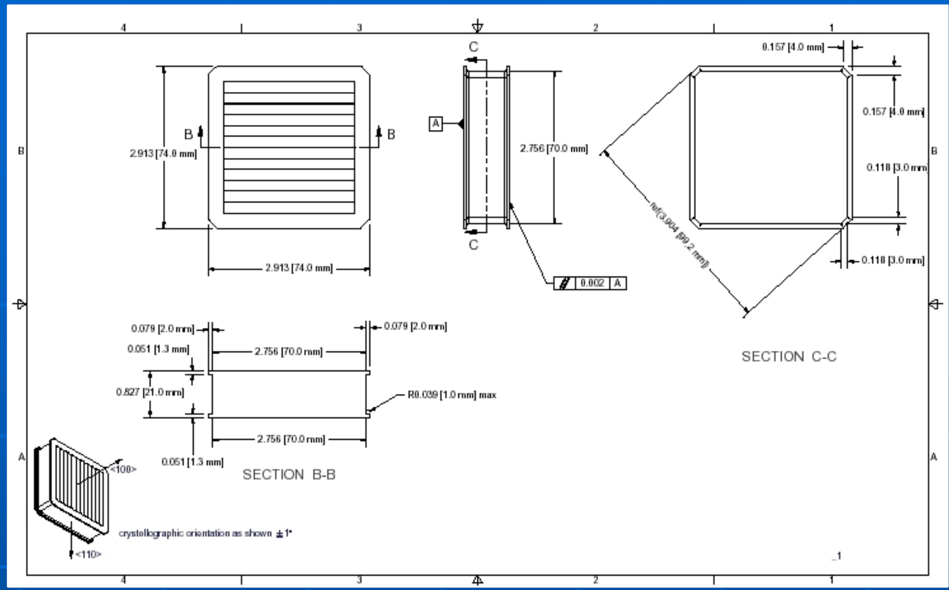

Detector Specification

- Depletion at -1300V, Operation at -1800V
- 12 x12 Segmentation, 5mm strip pitch
- AC contacts ~0.3 µm thick separated by 180µm
- DC contacts ~50µm thick separated by 300µm
- 1mm thick Aluminium entrance window
- Warm FET configuration, 300mV/MeV pre-amps
- Average energy resolution ~ 1.5keV FWHM @ 122keV
- P:T ~70% vs ~15% BGO