A modular positron camera for Positron Emission Particle Tracking in harsh environments

T. W. Leadbeater, D.J. Parker, J Gargiuli

Positron Imaging Centre,

School of Physics & Astronomy,

University of Birmingham,

UK

EPSRC

Engineering and Physical Sciences Research Council

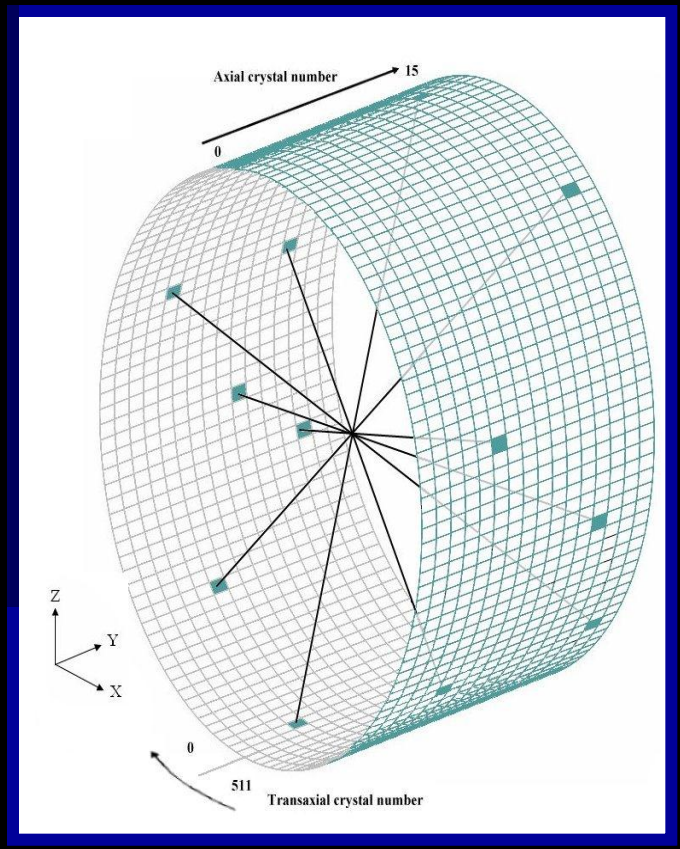
Positron Imaging

Positrons produced from β^+ decay of proton rich nuclei

Positron loses energy & annihilates

Results in 2 back-to-back 511 keV photons

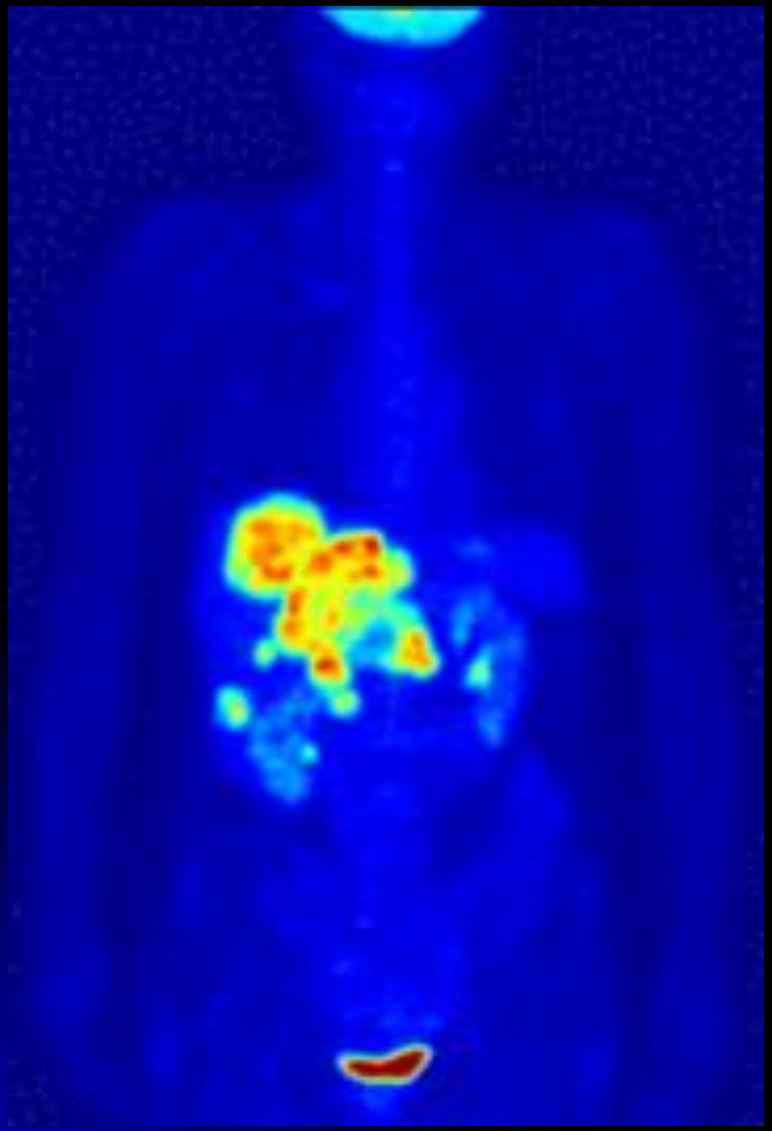
Coincident detection of both photons defines trajectory

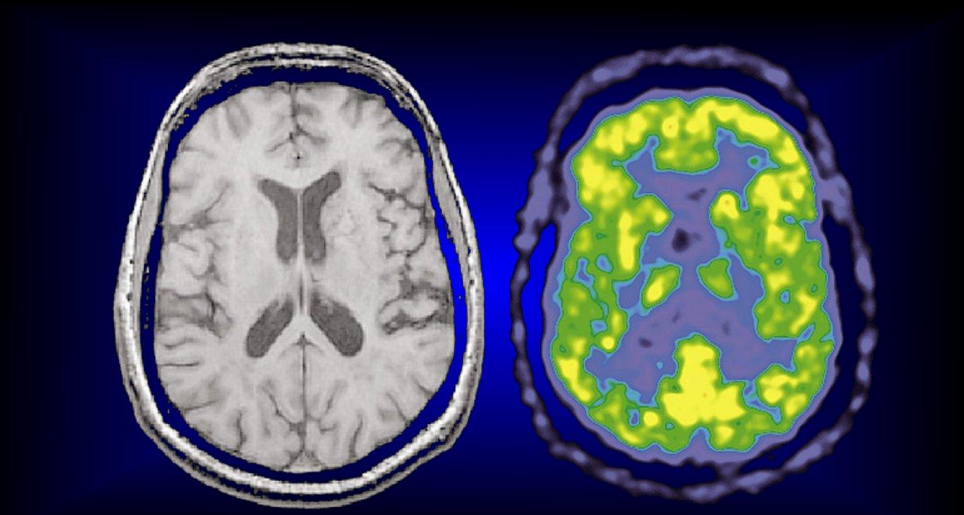


Medical imaging involves radio-labelling of glucose molecules

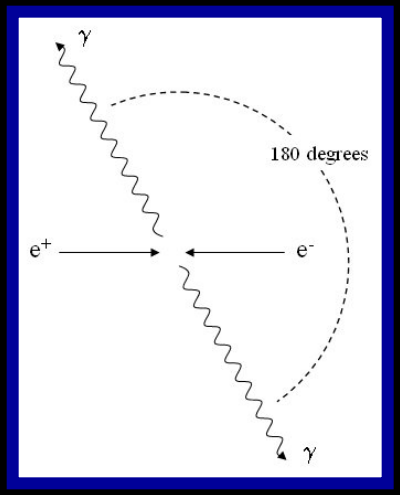
Industrial imaging involves labelling fluids or particles

Positron Emission Tomography





Comparison of MRI & PET images



Acquisition times:

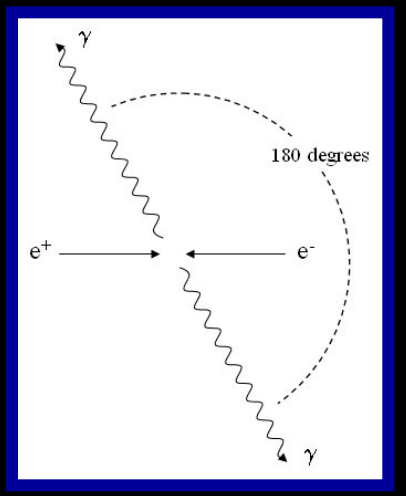
Minutes – hours

~ 10^9 events

Positron Emission Particle Tracking

Single particle loaded with radioisotope

$$^{16}0(^{3}_{2}He, p)^{18}F$$

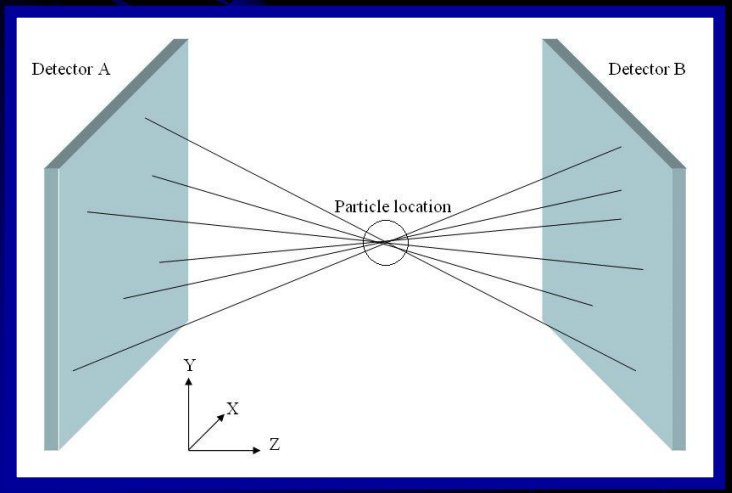


Line of Response (LOR) defined along photon trajectory

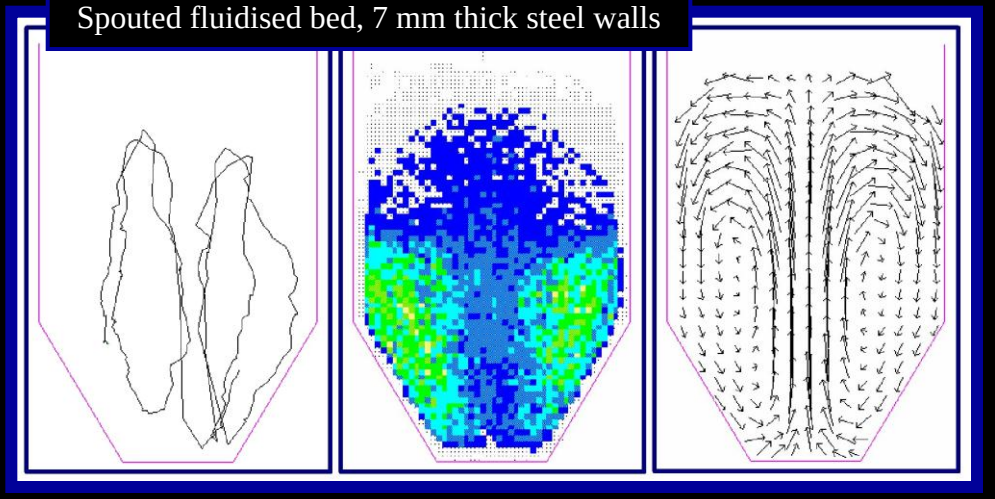
Triangulation of successive LORs gives particle location

50 – 1000 events per location

~50% of 511 keV photons are transmitted through 11 mm steel



Spouted fluidised bed, 7 mm thick steel walls



Particulate Science & Technology

Three primary phases of matter: Solids, Liquids & Gases

Particles / powders make up to 70% of matter processed by humanity:

Solid particles, bubbles, liquid drops

Particles / powders exhibit properties of all three phases:

Withstand deformation (solids)

Flow (liquids)

Can be compressed (gases)

Particulate science aims to understand relationships between micro- (particle scale) and macro- (bulk behaviour) properties

Understanding of particle – particle and particle – fluid interactions

Detector Systems

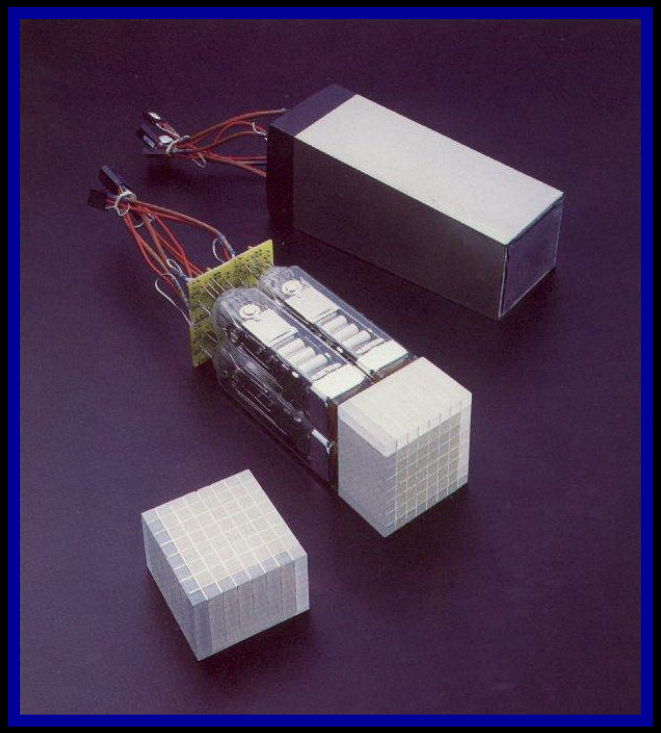
Detectors derived from redundant clinical imaging systems
(ECAT-931 Siemens medical systems)

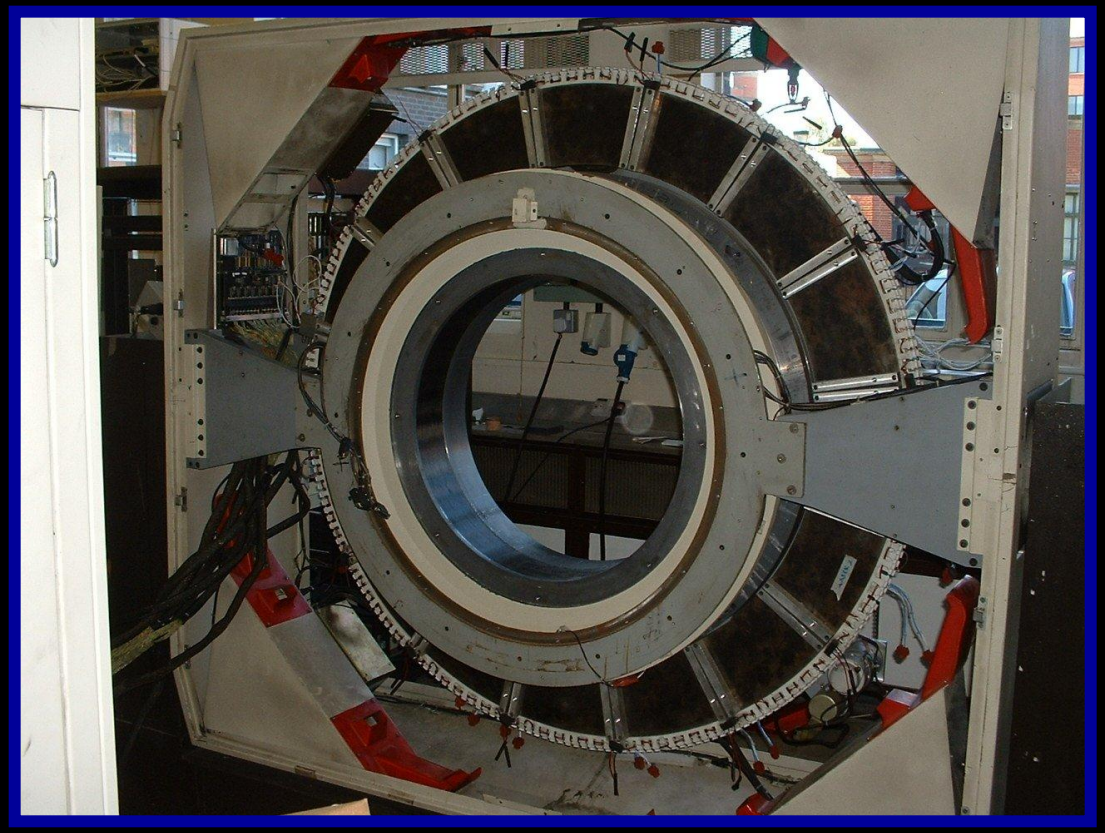
2 rings of 64 detector blocks:

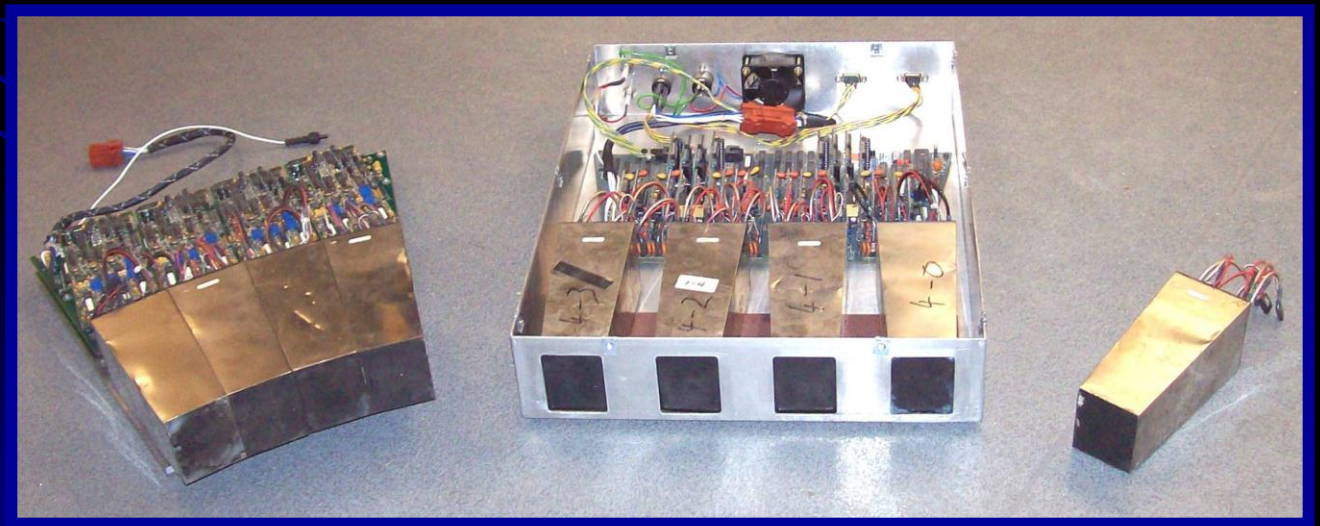
- 8 x 4 BGO crystal elements
- 6.25 x 12.5 mm^2
- 4096 detection elements

Modified for PEPT:

- Time information
- List – mode data storage







Modular Positron Camera

Modular detector units (scintillators, PMTs, support electronics etc.)
Central coincidence processing units
Data acquisition and processing system

Customisable geometry:

- Accommodate large apparatus
- Transportable

Adjustable field of view:

- Design camera geometry for application
- High sensitivity regions-of-interest
- Cover many sections of device

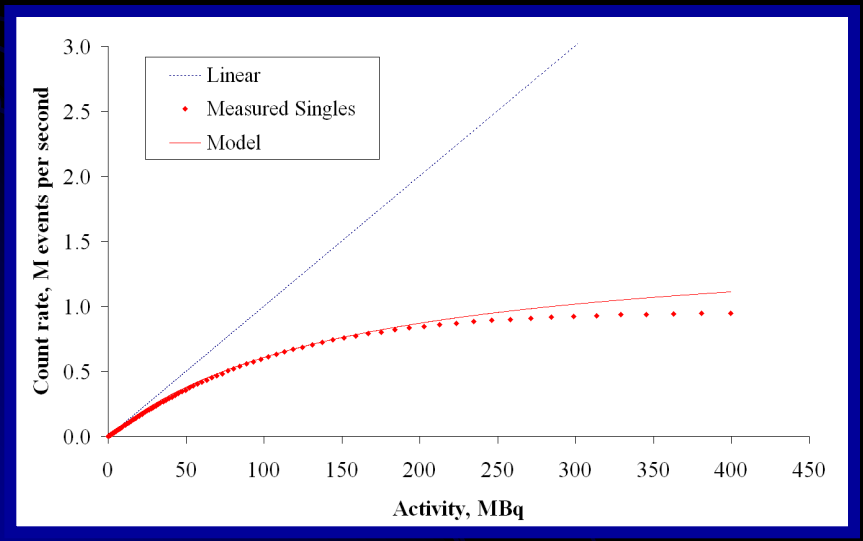
16 modules housed in sturdy boxes and PAT tested

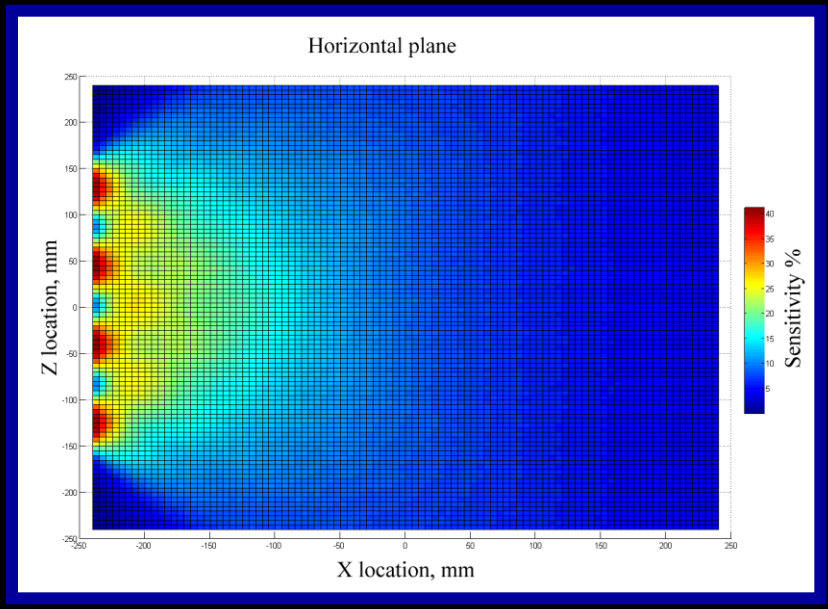
System Performance – Single gammas

Energy resolution @ 511keV (FWHM photopeak) measured to be 15% (75keV)
Energy discriminators set to 350 - 850 keV
Accepts scatters up to 55 degrees, but allows high event rate

Intrinsic peak efficiency measured to be 45%

Response linear with activity up to 500k events per second
Event rate saturation at 1M events per second
Dead time 0.65µs per module, 1.2µs per block





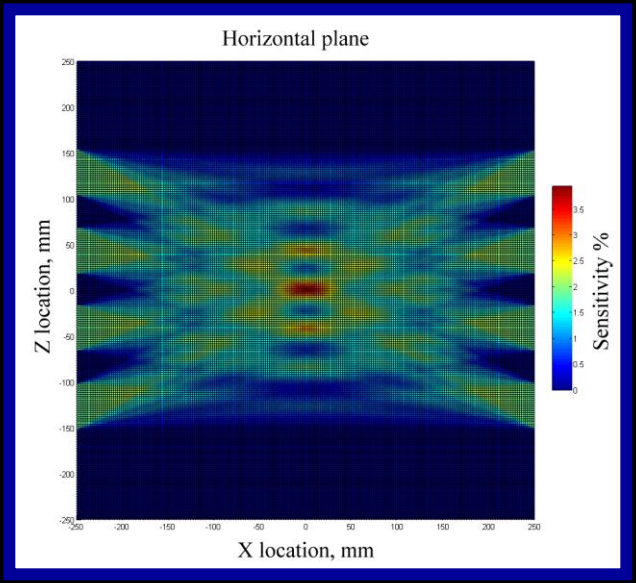
System Performance – Coincidences

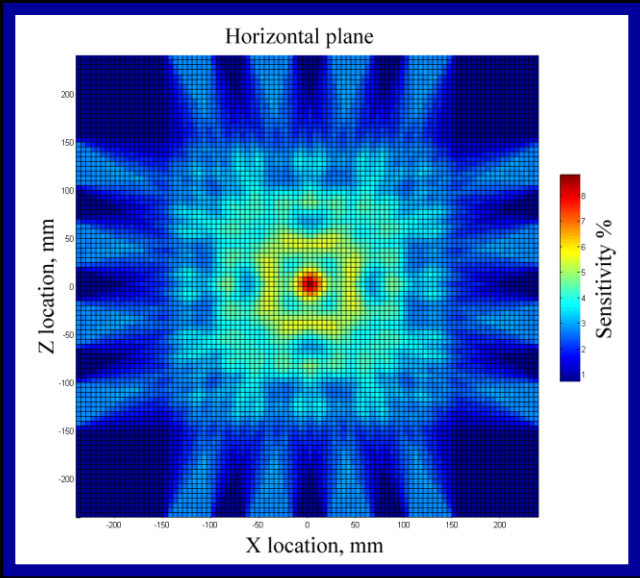
2 opposing modules separated by 250 mm

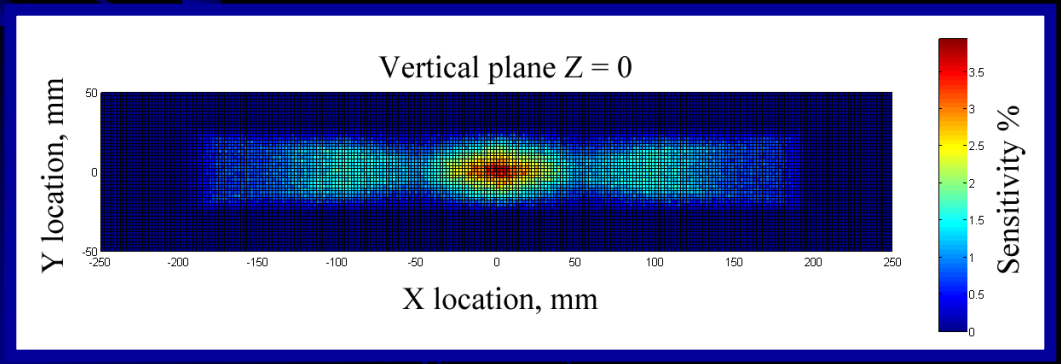
Bare tracer peak coincidence sensitivity 5% (centre)
Average sensitivity across FoV 1%

Monte Carlo sensitivity maps used to optimise camera geometry

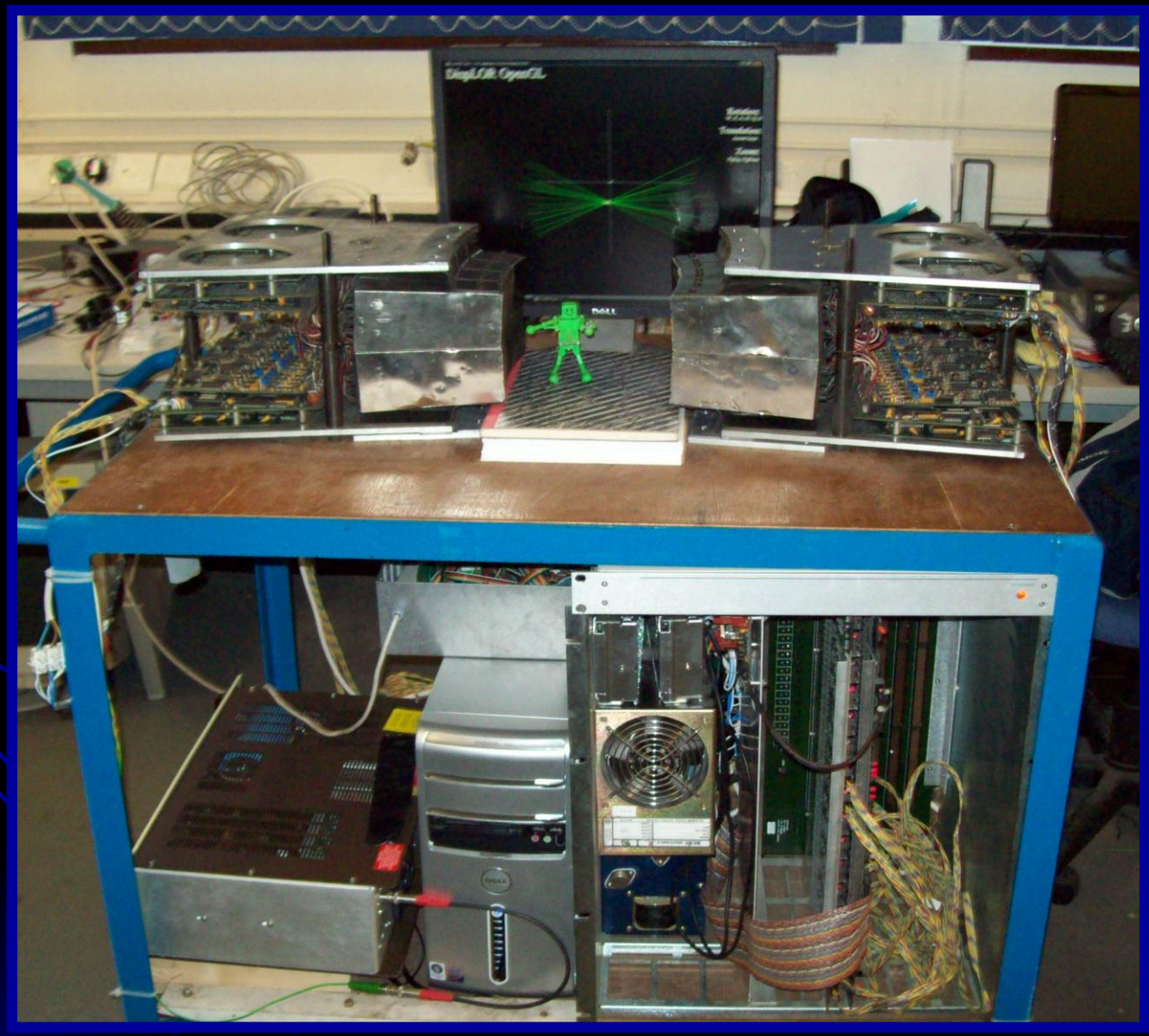
PEPT algorithm relatively insensitive to non-uniform field of view

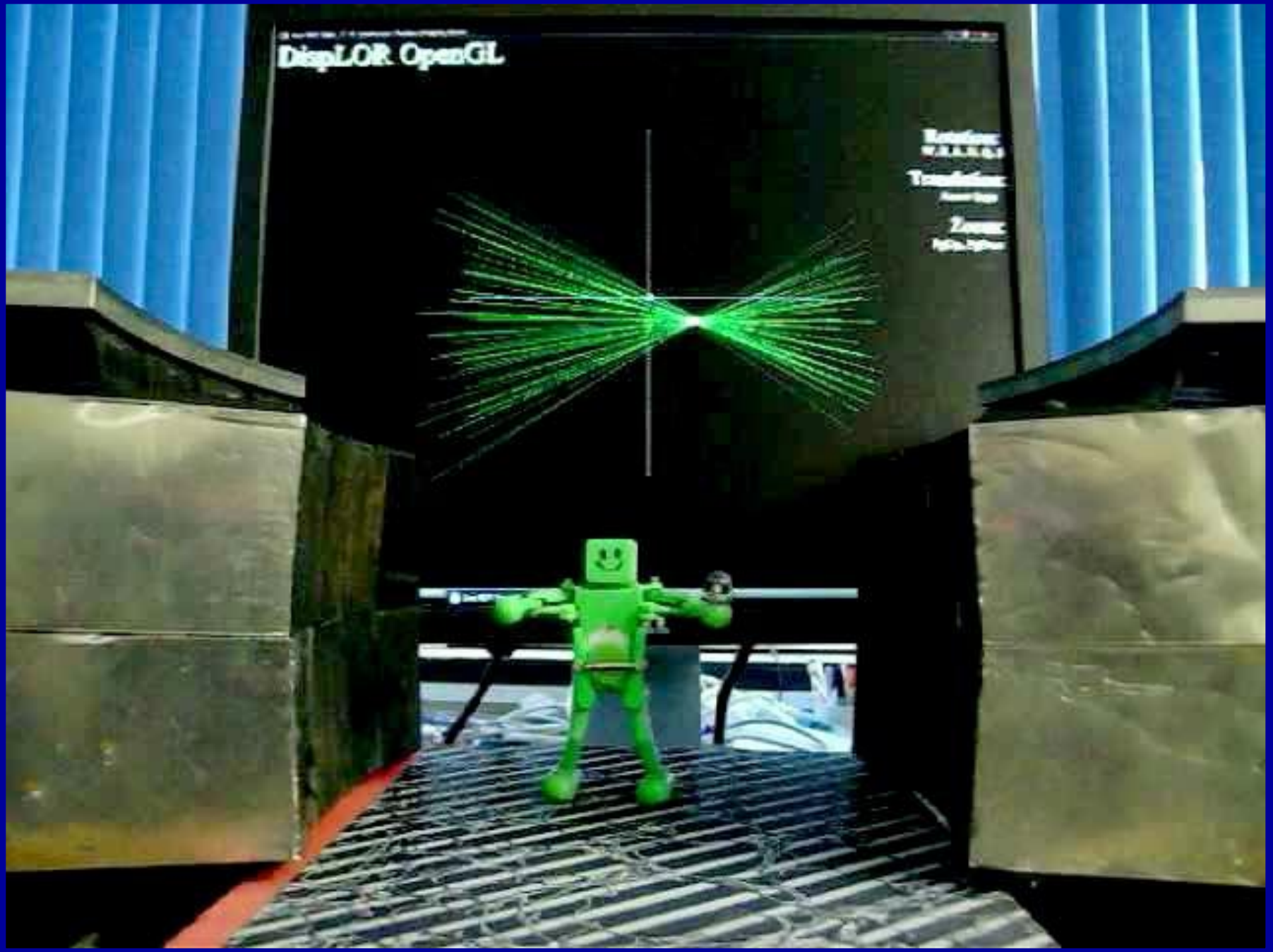






Practical Demonstration




DisplLOR OpenGL

In practice

Data rates up to 4MHz (optimum activity ~ 100MBq)
Locations on kHz basis
Precision around 1mm in 3D
Tracer moving at 1m/s moves 2mm in this time

Transmission of 511keV photons allows real systems to be studied – i.e. dense and opaque systems, steel HVL 11mm

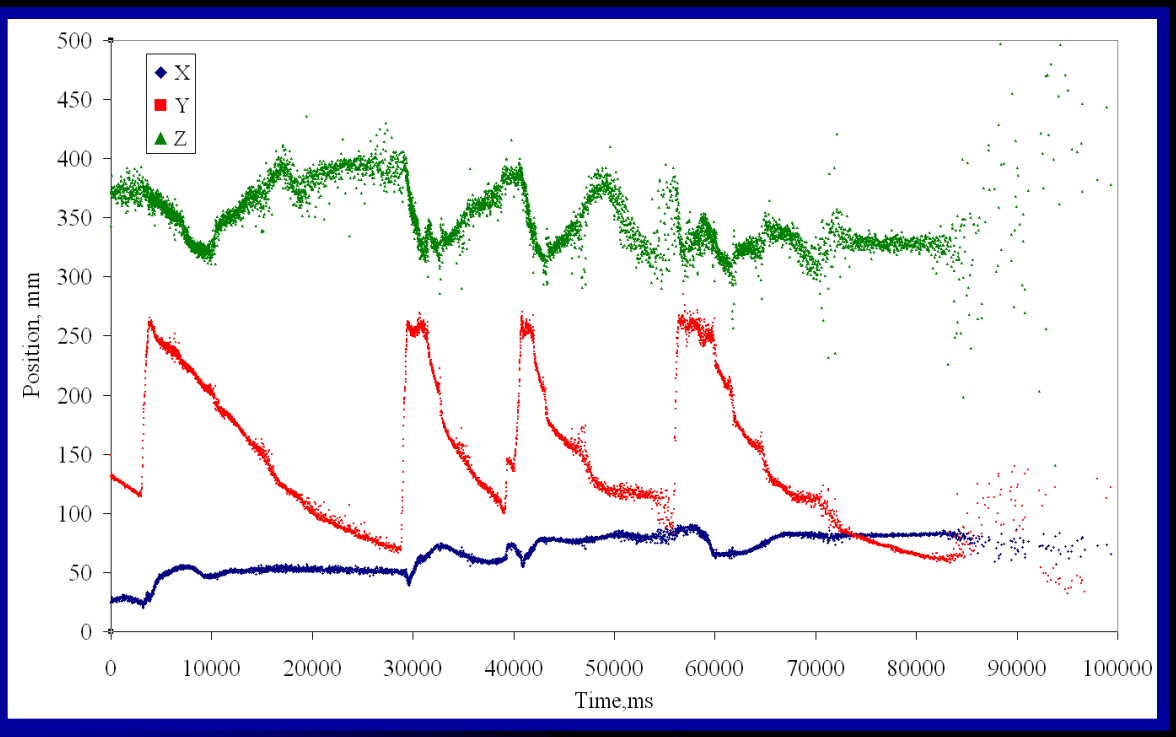
Tracers with a size range 50 μm – mm's

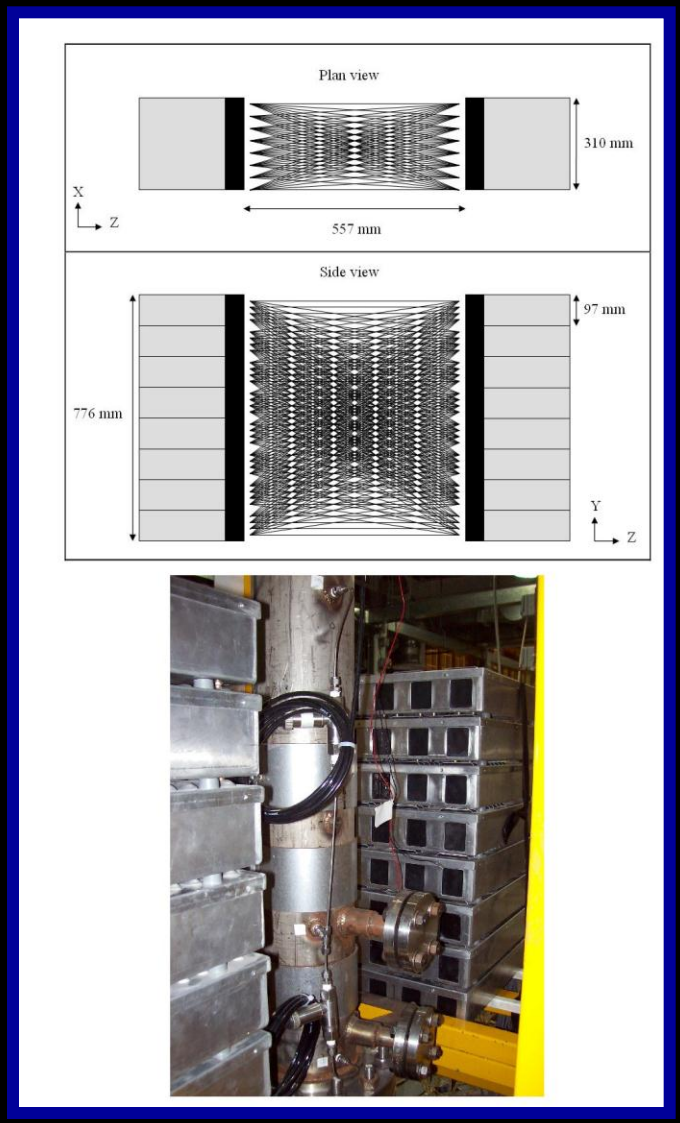
Range of materials: Glass, sand, resins, catalysts, FCC and Gamma alumina, zirconia, drugs, plant seeds, potatoes, salt, coffee …

Fluidised bed: Chemical Engineering

High pressure fluidised bed
Used for polymer processing

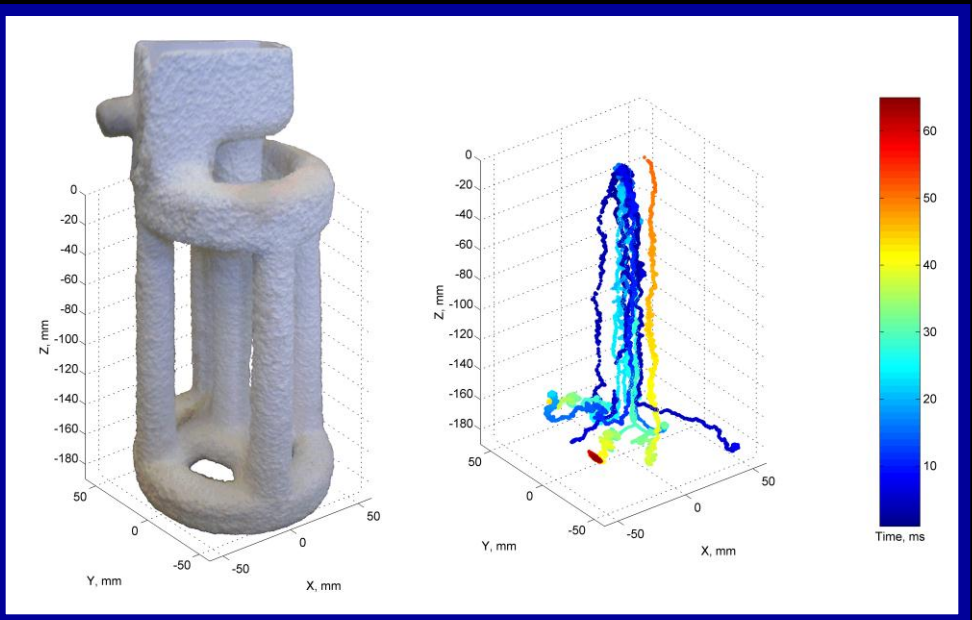
7 bar pressure, 100C





Metal casting: Metallurgy & Materials

Low temperature metals (100C)
Aluminium (660C)
Steel (2000C)



Tracer particle activity 5 – 40 MBq
Raw data rates 25-300 kHz
Particle location rate 1 - 4 kHz.
Locations accurate to:

0.5mm (stationary)

2.5mm (moving $1ms^{-1}$)

Conclusions

A modular positron camera has been developed allowing the study of a wide range of industrial systems

The flexible geometry offered by the modular camera allows:

- The field of view of the camera to be custom designed
- Transportation of the camera to study applications *in situ*.

Modular camera has been characterised

Modular camera systems used for a number of experiments:

- Various locations both on and off Birmingham campus
- Recorded data at rates up to 4 MHz
- Frequent and accurate locations

Thanks for your attention

Positron Imaging Centre,
School of Physics & Astronomy,
University of Birmingham,
UK

T. Leadbeater; t.leadbeater@bham.ac.uk

D. J. Parker, J. Gargiuli, A. Ingram, S. Bakalis,
M Barigou, J Seville.

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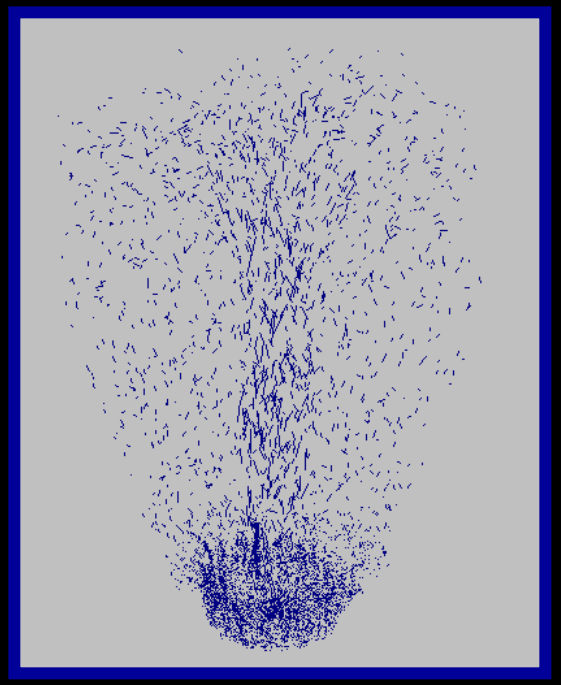
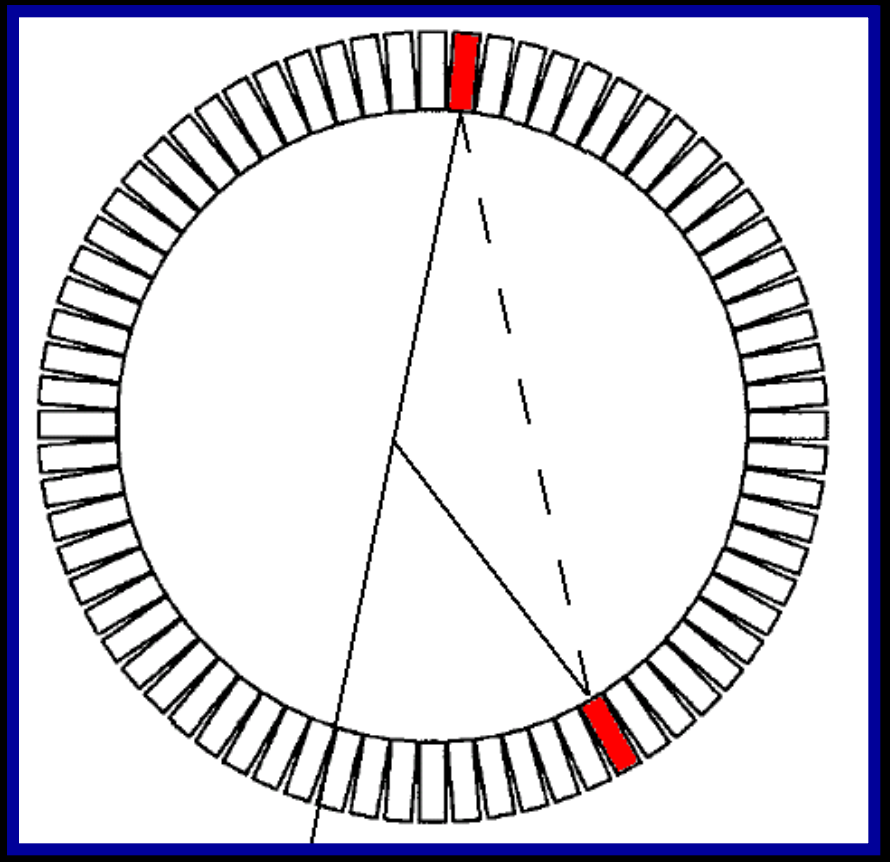


Events

- Real events
- Random coincidences
- Scattered gamma rays
- Associated gamma rays