GATE Modelling of a Novel Small Animal PET Scanner with Depth of Interaction

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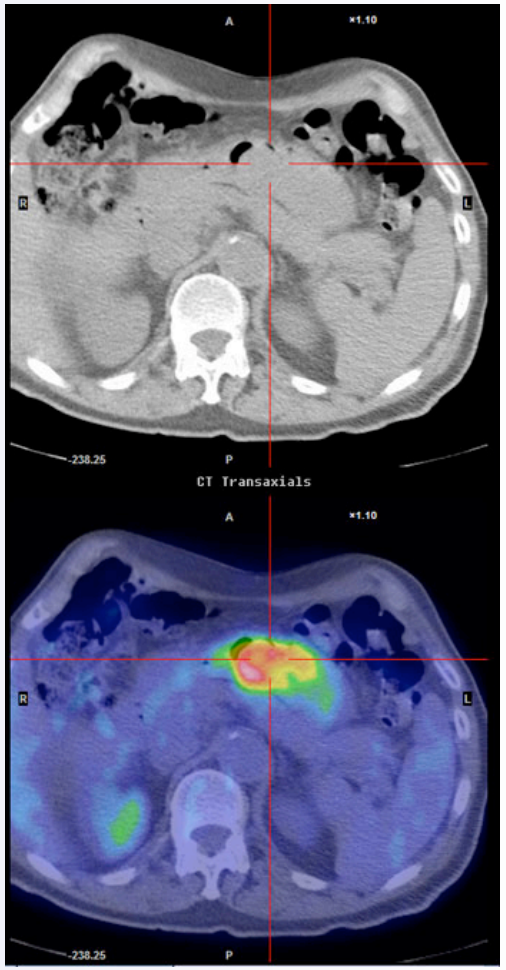
Positron Emission Tomography

PET is a functional imaging modality

- See things working!
- Latest advances include image registration between anatomical data and functional data
- Functional imaging is the only method of locating small lesions or metasteses

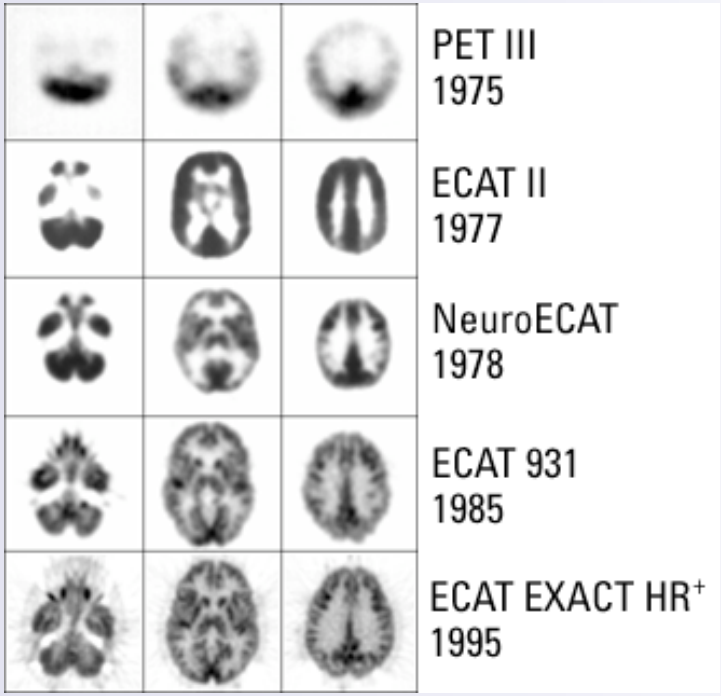


Siemens

Positron Emission Tomography

- PET has been available for nearly 30 years with significant improvements in recent years

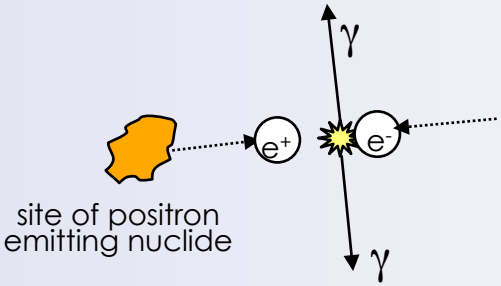
- Resolution is still relatively poor compared to anatomical modalities



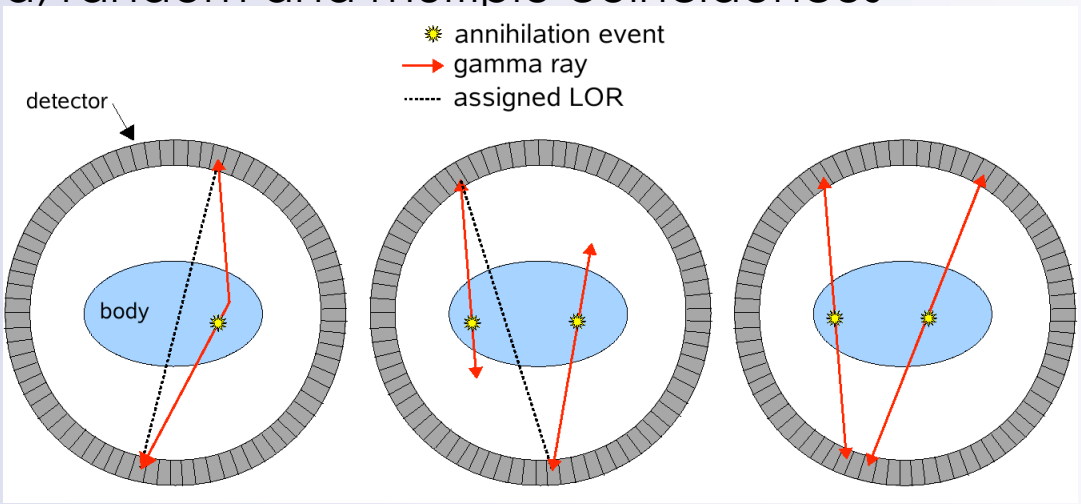
http://www.cerebromente.org.br/n01/pet/pet_hist.htm

Limitations of PET

- Inherent limitations within PET
  - positron range

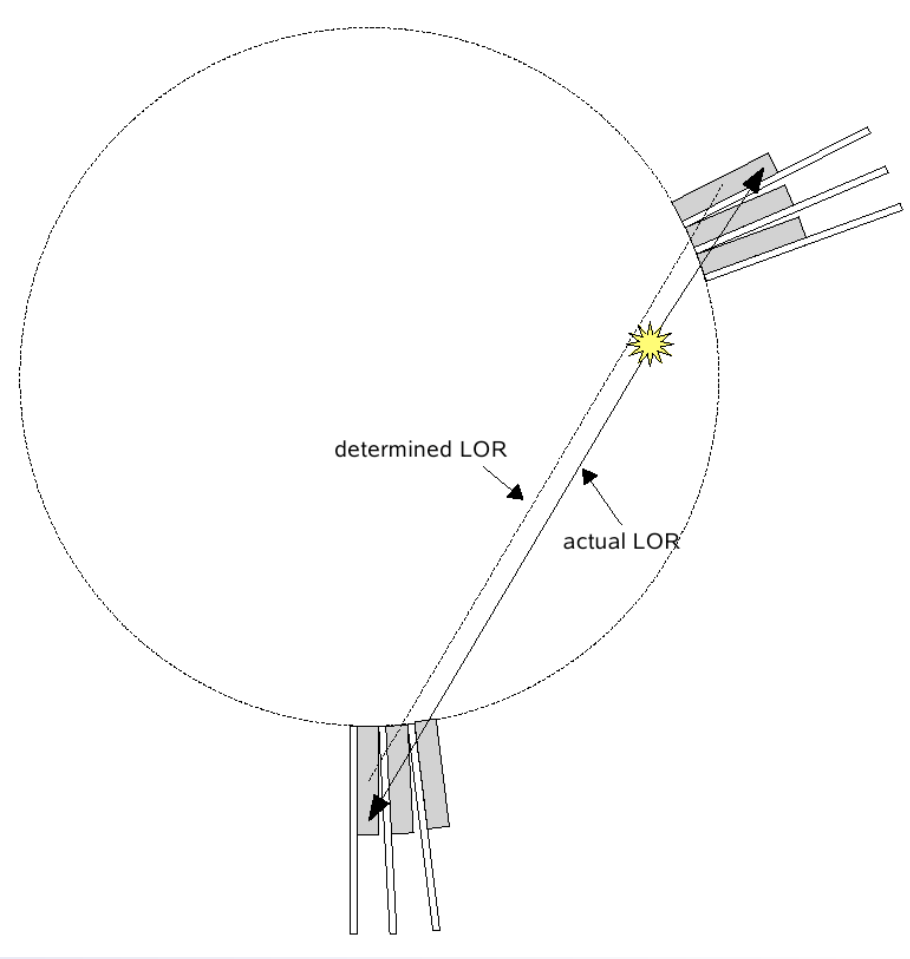


  - scattered, random and multiple coincidences



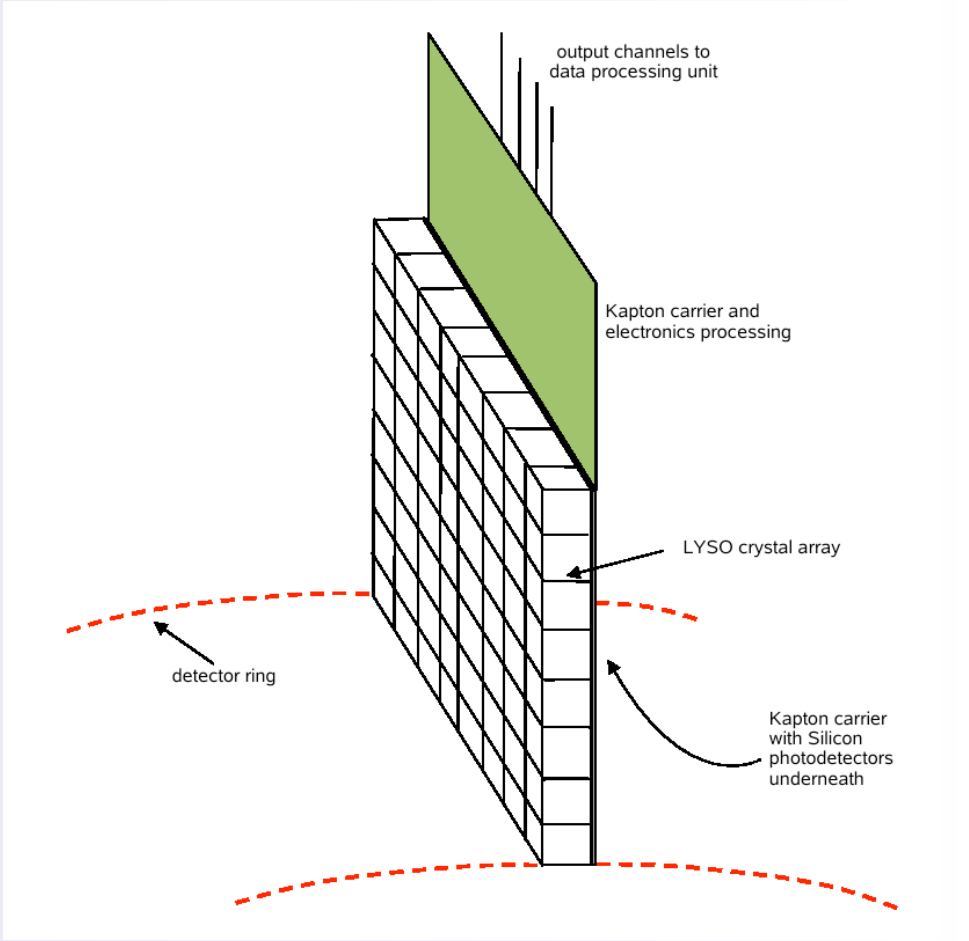
Limitations of PET

- Errors caused by the inability to determine the depth of interaction (DOI)
- All interactions in detectors are assumed to occur in a fixed arbitrary position inside the scintillator
- The CMRP is developing a detector capable of providing DOI information



Novel Detector Module

- Pixellated detector module for small animal PET
  - array of cubic LYSO crystals
  - each voxel optically connected to Si photodetector
  - photodetectors connected to electronic backend to process signals

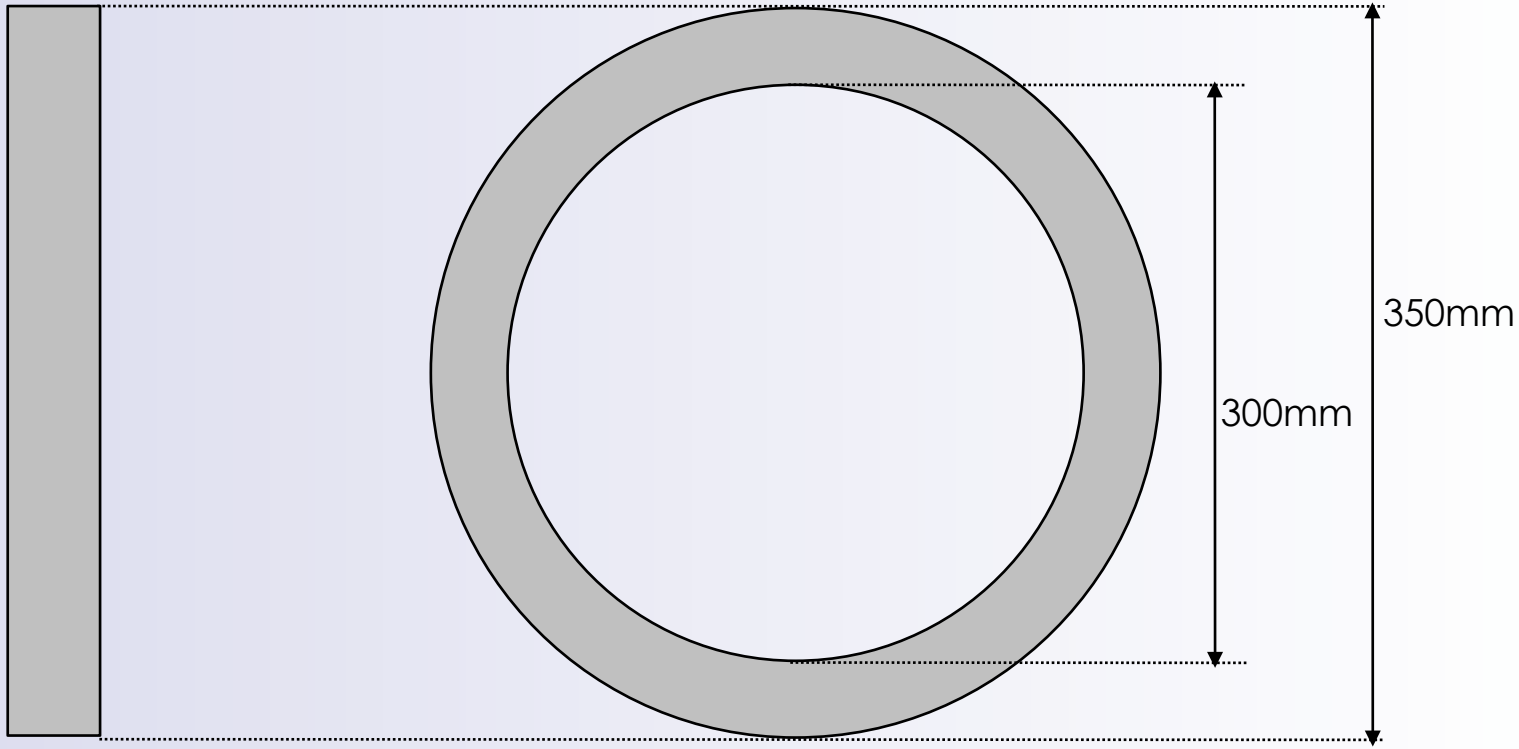


Novel Detector Module

- This detector module will improve spatial resolution by:
  - resolving more accurate DOI in crystal
  - more accurate LORs between coincident events
  - replacement of bulky PMTs with compact photodetectors

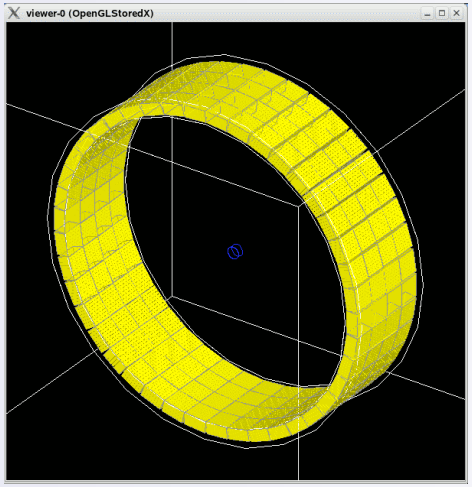
Novel Detector Module

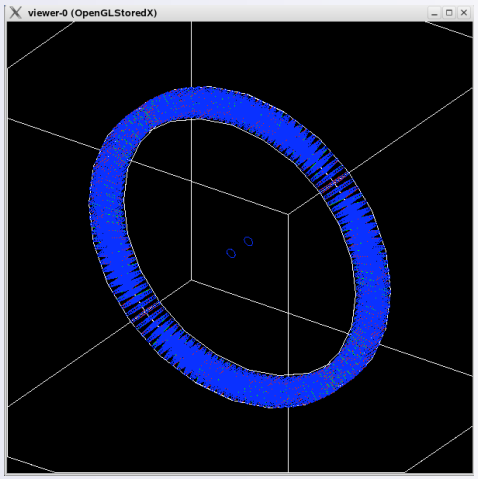
- Initial development of technology will be modelled on a single ring small animal PET scanner

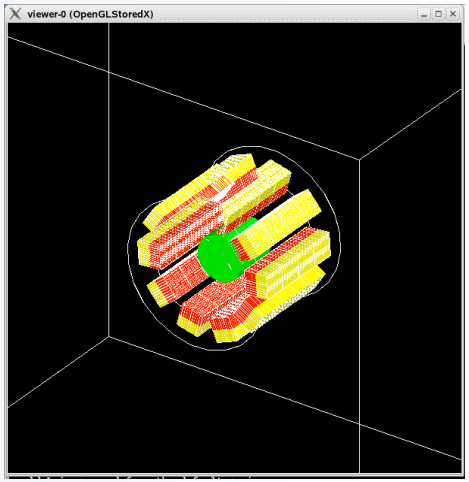


Monte Carlo Simulations using GATE

- Initial step of project is to carry out Monte Carlo simulations
- Monte Carlo simulations using GATE (GEANT Application for Tomographic Emission)
  - Macro based front end for GEANT4, specifically for PET & SPECT applications
  - Simplifies most functions used in GEANT4







GATE

- GATE is controlled by "macro files"
  - Scanner geometry
  - Sources
  - Physics Processes
  - Phantom
  - Sensitive Volumes
  - Data Acquisition and Output
  - Simulation Time

The Scanner Geometry

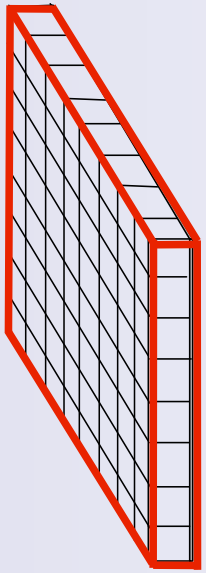
- GATE has a feature key to its operation called "scanner system"

System	attach keyword argument	Depth for readout segmentation
scanner	*"level1"*	1
	"level2"	2
	"level3"	3
	"level4"	4
	"level5"	5
CTscanner	*"block"*	1
	"pixel"	2
cylindricalPET	*"rsector"*	1
	"module"	2
	"submodule"	3
	"crystal"	4
	"layer[i], i=0,3[a]"	5
CPET	*"crystal"*	1
SPECThead	*"crystal"*	1
	"pixel"	2
ecat	*"block"*	1
	"crystal"	2
ecatAccel	*"block"*	1
	"crystal"	2
OPET	*"rsector"*	1
	"module"	2
	"submodule"	3
	"crystal"	4
	"layer[i], i=0,7[a]"	5

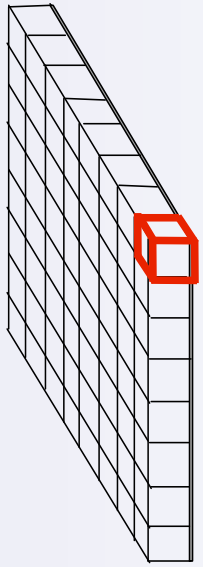
Gate v4.0 Manual

The Scanner Geometry

- cylindricalPET was the system used for this study



rsector

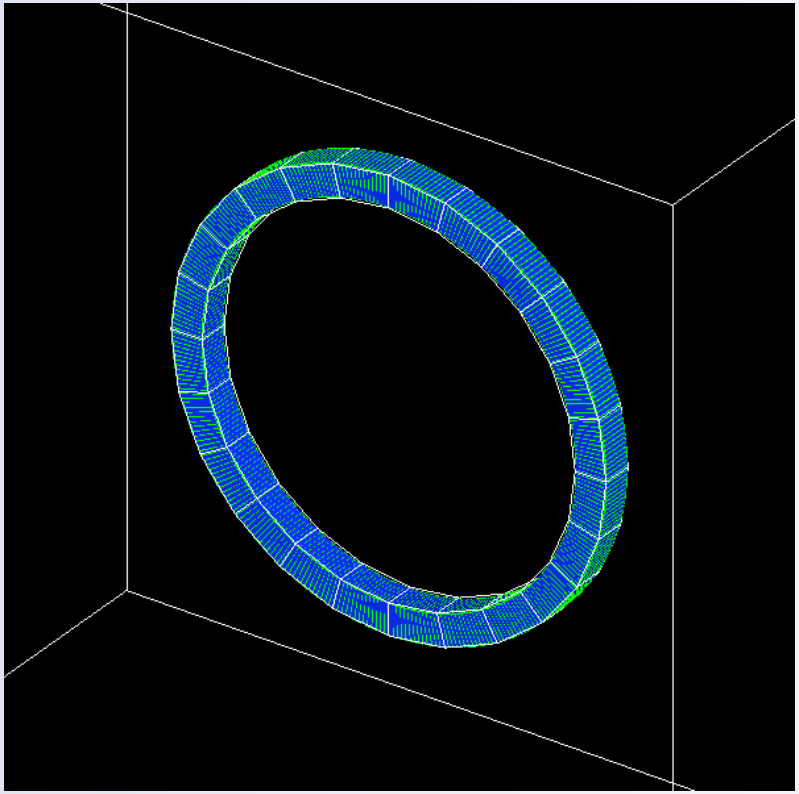


crystal

- Not all levels of the hierarchy need to be filled (ie. no module, sub-module, layer)

The Scanner Geometry

- Specify a single detector element
- Can be repeated according to how many are required
- For novel detector module, 314 modules around a ring



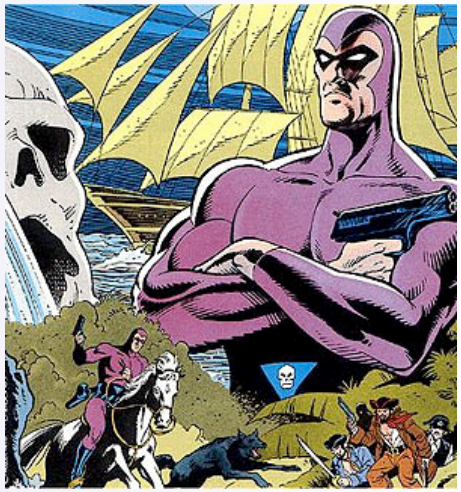
The Sources

- The sources can be specified as
  - positron emitters
  - ion emitters
  - back-to-back gamma emitters
- Other parameters
  - Activity
  - Position
  - Emission spectrum
  - Restrictions on the direction of emission
- In this study, sources are isotropic positron emitting point sources placed at centre of FOV, 10, 30, 50, 70, 90 and 110mm from centre of FOV

The Phantom

- Specify
  - Shape
  - Dimensions
  - Composition

- In this case, phantom is a simple large water cylinder

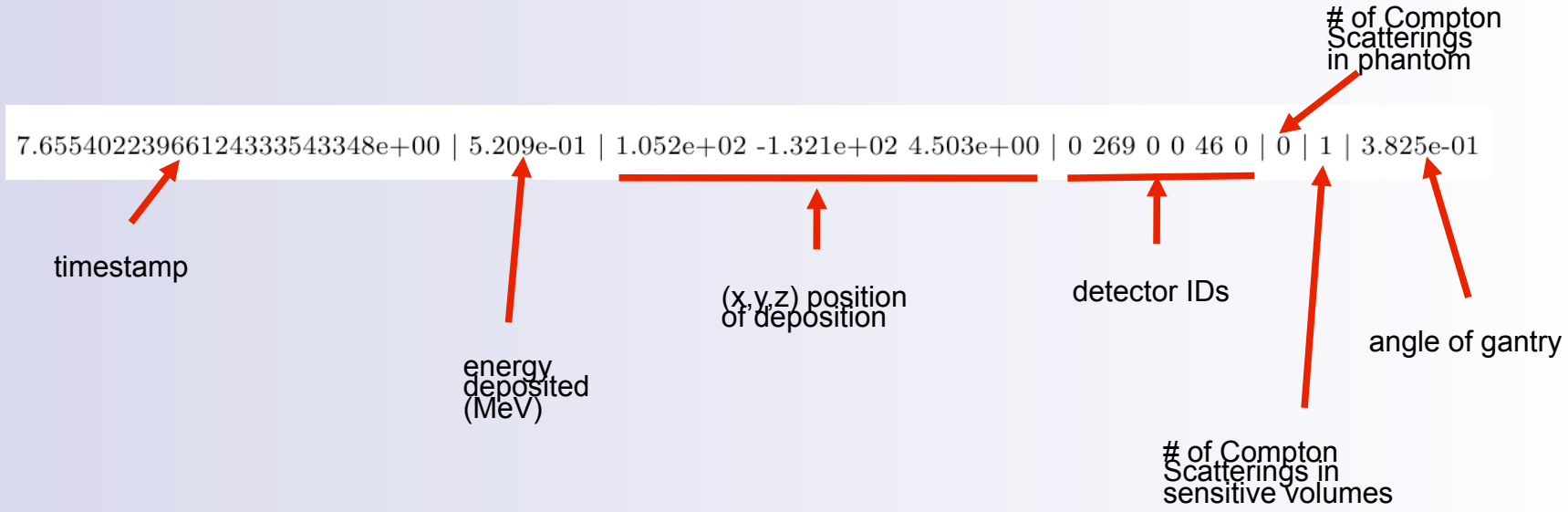


Sensitive Volumes and Data Acquisition

- In this study, sensitive volumes are the crystals and the phantom
- "Hits" are recorded for each interaction in a sensitive volume
  - the position
  - direction before/after interaction
  - type of interaction
  - energy deposited
- Data from hits is sent to the "Digitizer" module in GATE
- Digitizer recreates the pulse processing
  - Summing of separate pulses inside a given sensitive volume
  - Blurring of energy response
  - Blurring of positional information

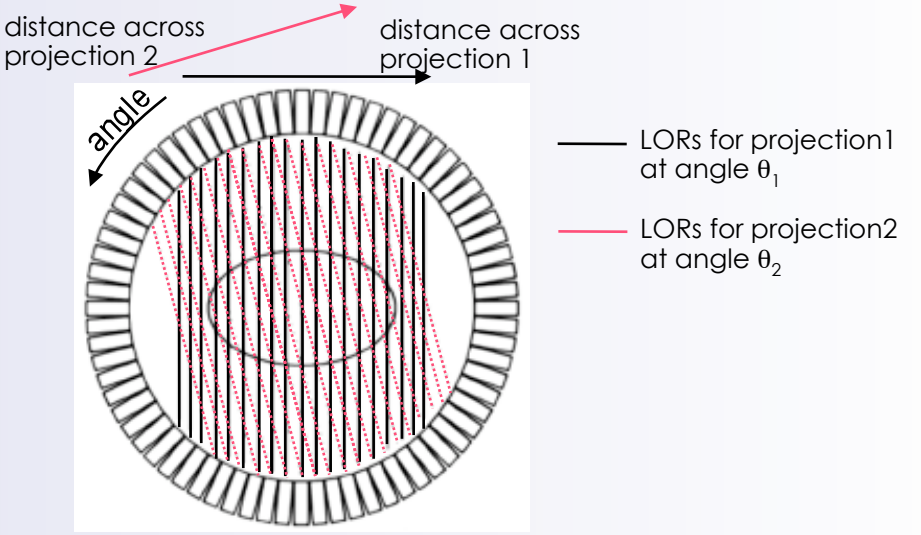
Data Output

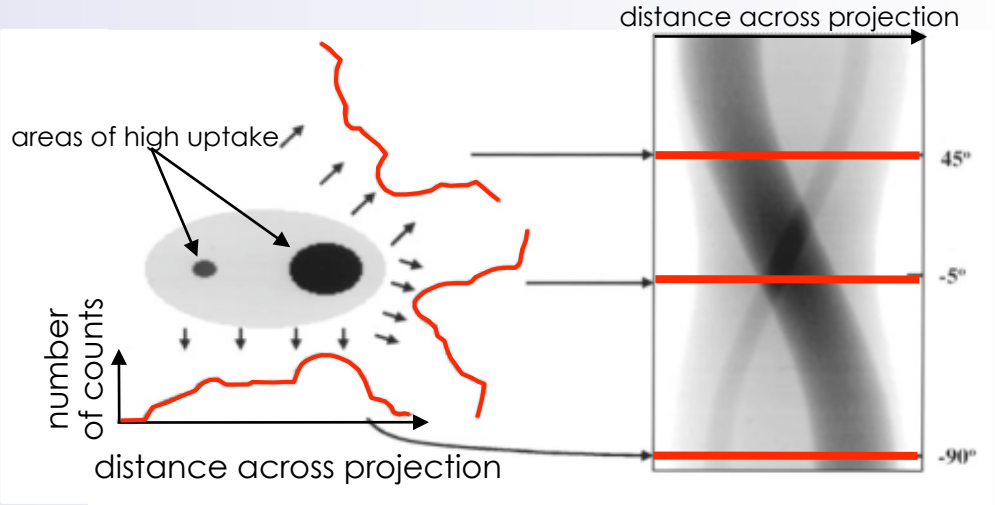
- Output of data acquisition module is almost identical to the information from a real scanner
- The method of data storage is customisable (eg. ROOT, LMF, ecat)
- ASCII data is the most flexible for this study



Sinograms

- Sinograms are an efficient method of data storage
- Moving down the sinogram, the rows show the counts across the projection as the angle of that projection is changed
- Each projection is a slice of the sinogram





Data Acquistions in PET Imaging, Frederic H. Fahey, Journal of Nuclear Medicine Technology, Vol 30 No 2, June 2002

Data Storage and Processing

- We have developed a Sinogram Binning Application for MC data
  - Flexible
  - Potential for further expansion

- This application is split into a number of modules:
  - the user input stage
  - reading in of coincidence data from the Monte Carlo output files
  - the calculation of the LOR for the sinogram
  - the data output stage

- The development of this code has been the main focus of my PhD

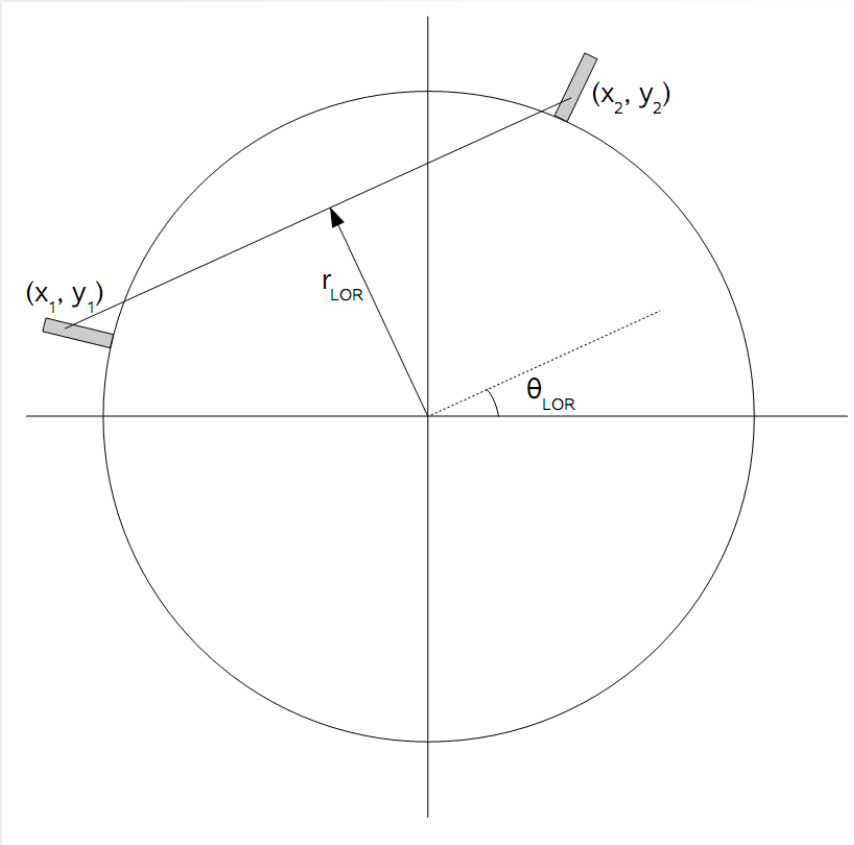
User Input

- In order for the data to be processed correctly, a number of parameters must be known including:
  - ring size
  - number of detector modules around the ring
  - size of each crystal element
  - total thickness of crystal
  - number of DOI layers of crystal
  - number of crystals in the axial, radial and tangential directions
  - energy windows

- These variables are used to correctly calculate the positions of each coincidence after the data is read in from the MC data files

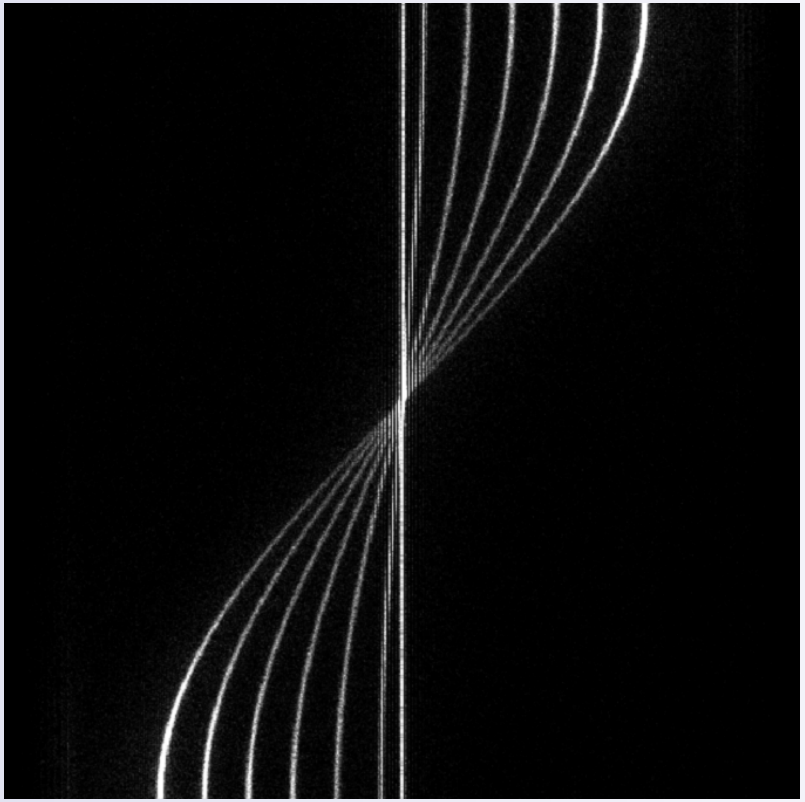
Position Calculation

- By knowing the coordinates of each interaction position, the radial distance of the LOR from the centre of the FOV and the angle of the LOR with respect to a fixed reference can be determined
- The hard part is calculating the position!
- Each detector volume is given a unique ID. Knowing the ID of a volume, and how many volumes exist allow determination of the position using simple 3D coordinate geometry



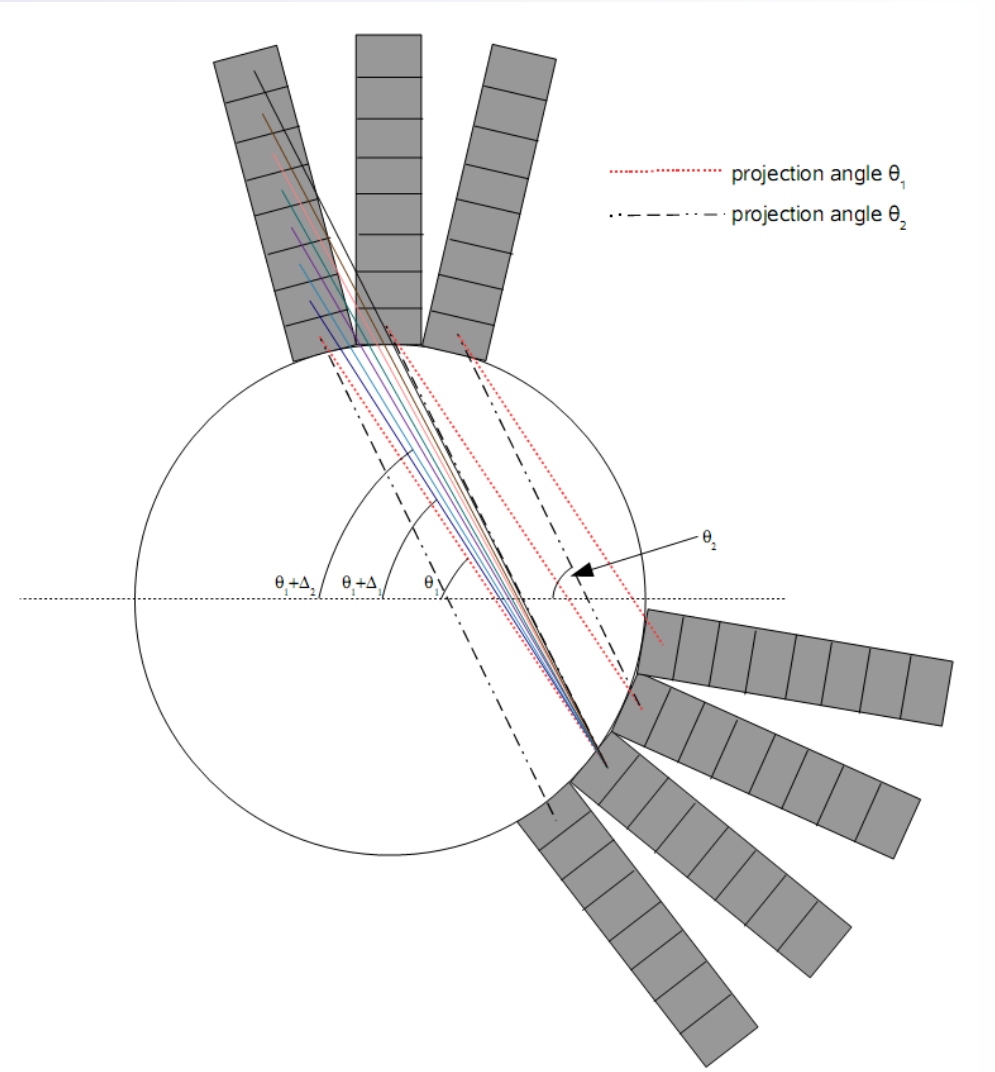
Sinogram Binning

- Using the radial distance and angle of the LOR, the required element of the sinogram is incremented
- Final result is an number of text files containing a large array representing the sinograms from different slices



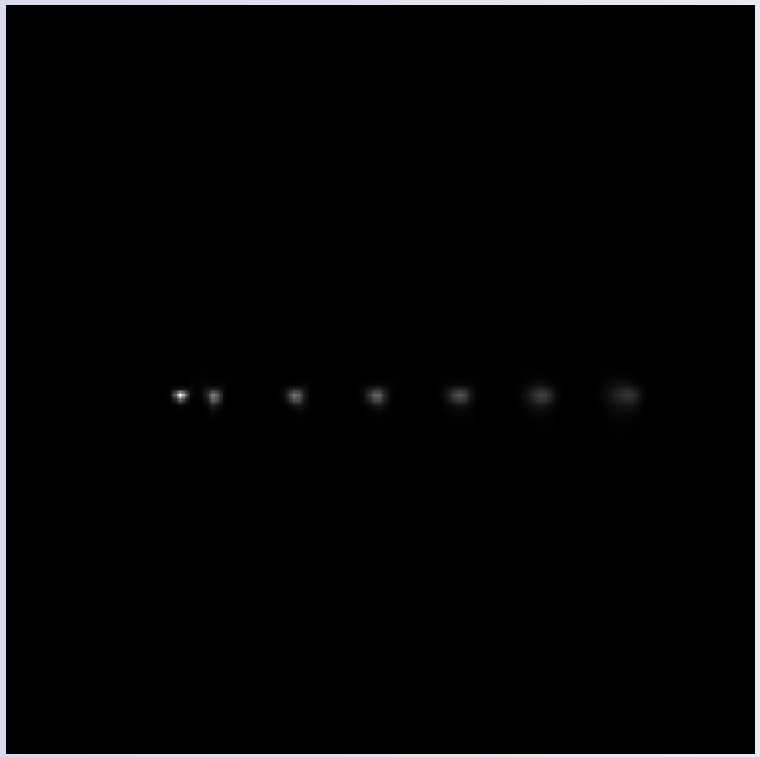
Sinogram Upsampling

- One of the major features of the novel detector module and the sinogram binning application is the ability to upsample data
- Added LORs between traditional LORs are possible
- Added spatial resolution at the edge of the FOV
  - Specifically a reduction in the radial elongation artefact

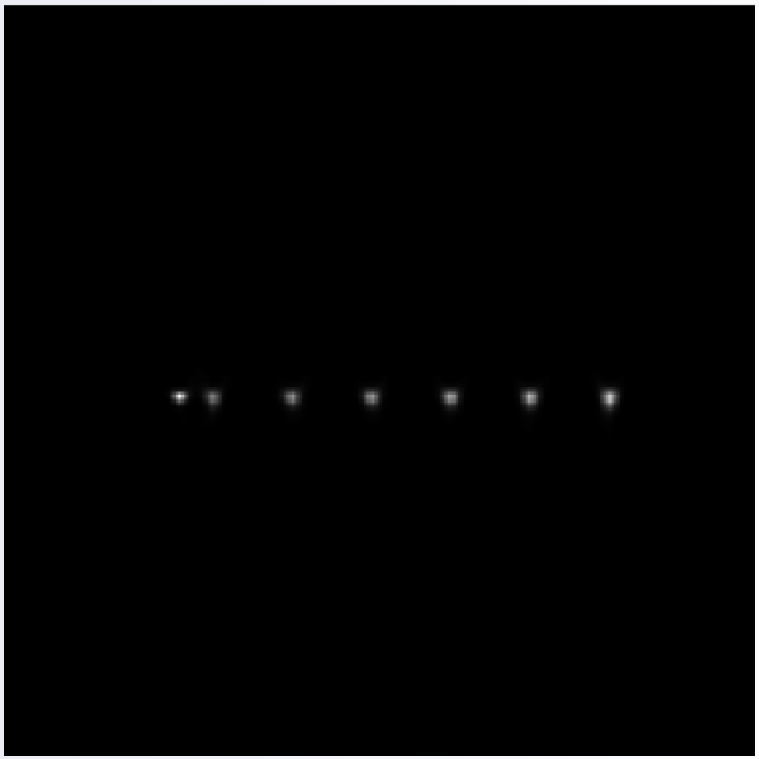


Reduction in Radial Elongation Artefact

- Using 8 layers of DOI significantly reduces radial elongation artefact



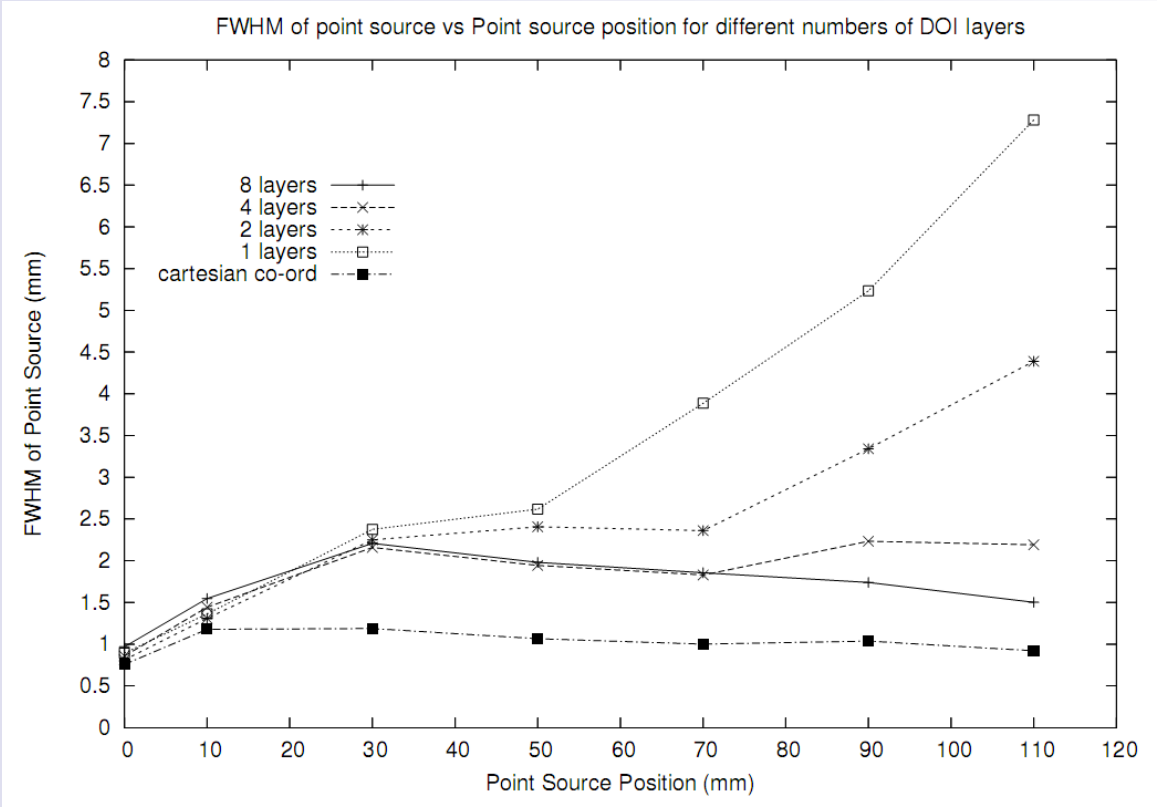
monolithic crystal block



8 layers of crystal

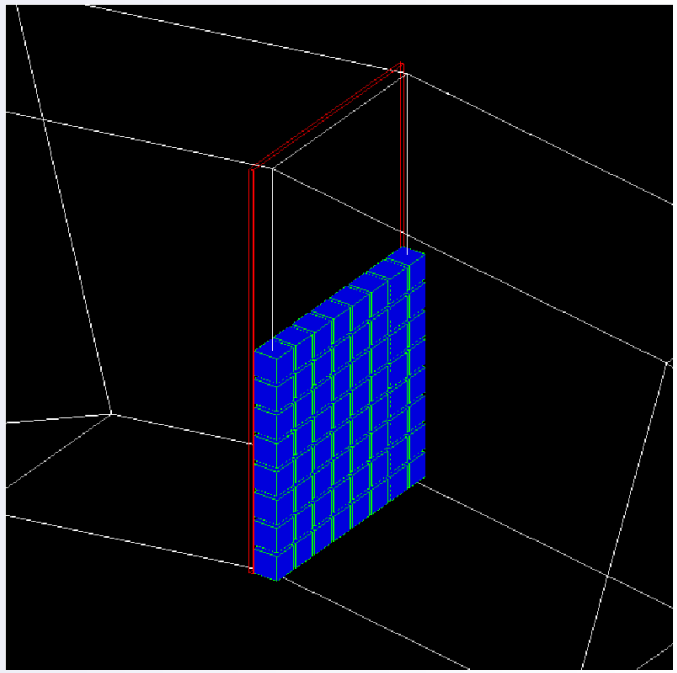
Phoswich Detectors

- The sinogram binning code can rebin the data according to how many layers of crystals
- Electronic complexity can be reduced for some studies



Other Studies

- Numerous other studies characterising and optimising the detector module have been undertaken
  - Optimal crystal size
  - Crystal arrangement
  - Effect of phantoms and positron range
  - Sensitivity
- A realistic detector module has also been investigated
- Experimental verification of sinogram binning application conducted using MicroPET Focus 220 scanner at the Brain and Mind Research Institute



Simulation Platform

- All MC simulations at the CMRP are performed on a 50 node cluster
- Students have access to 8 nodes at a time and queuing times are minimal.
- GATE simulations take a LOOOOOOONG time.

Conclusions

- Optimisation of detector using Monte Carlo studies has been undertaken
- Sinogram binning application can be used by future researchers to further investigate other aspects of the scanner
- Preliminary spatial resolution measurements indicate a resolution of less than 2mm for the entire FOV, improving to 1.6mm at the edge of FOV
- Experimental verification of sinogram code appears likely