Towards a continuous crystal APD-based PET detector design

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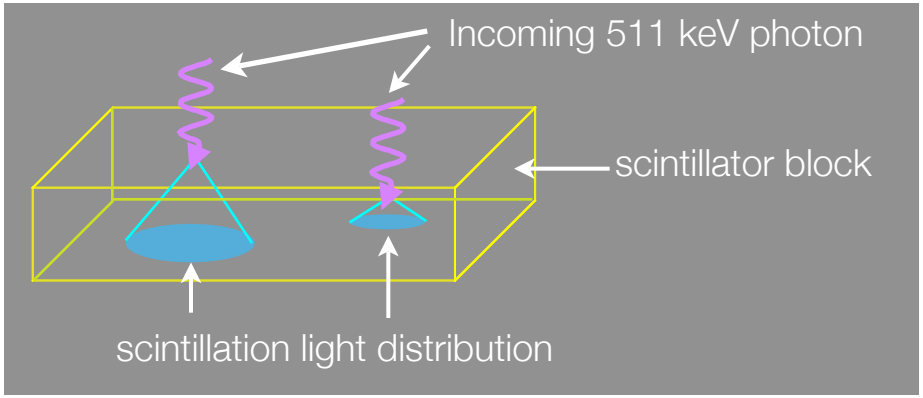
Improving sensitivity in small diameter systems

- Image variance is determined by number of coincidences measured.
- This can be achieved by
  - Scanning longer
  - Injecting higher tracer dose
  - Time of Flight (Whole body PET)
  - Increasing the scanner sensitivity
    - Thicker scintillators
    - Eliminate dead spaces (Inter-crystal, photo detector packaging, Inter-detector)

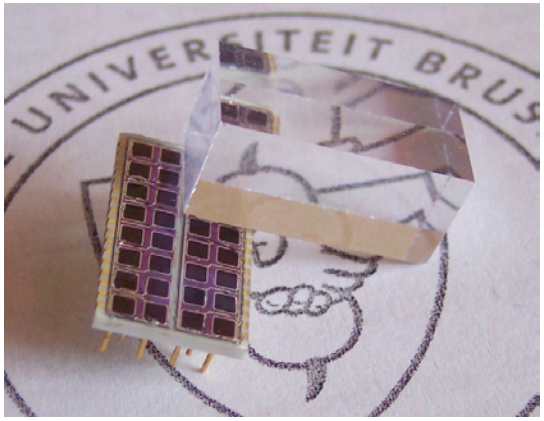
Monolithic Scintillator + PS PD

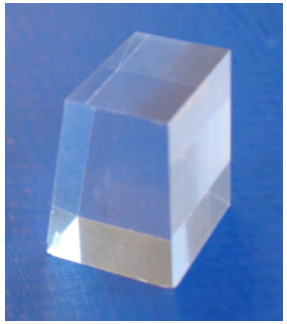
- Position and DOI information is embedded in the light distribution measured by a position sensitive photo detector
- Exit surface can be larger than the sensitive photo detector area
- Improved sensitivity
- Other advantages are
  - Continuous coordinates
  - Better energy resolution
  - Easier and cheaper to produce and assemble
- Drawback : needs more electronic channels

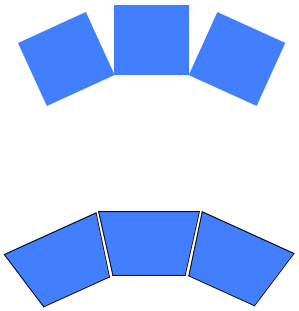


Detector components

- LSO scintillator block
  - 20x10x10 mm
  - 20x10x20 mm
  - 20x10(14)x20 mm (Trapezoidal)





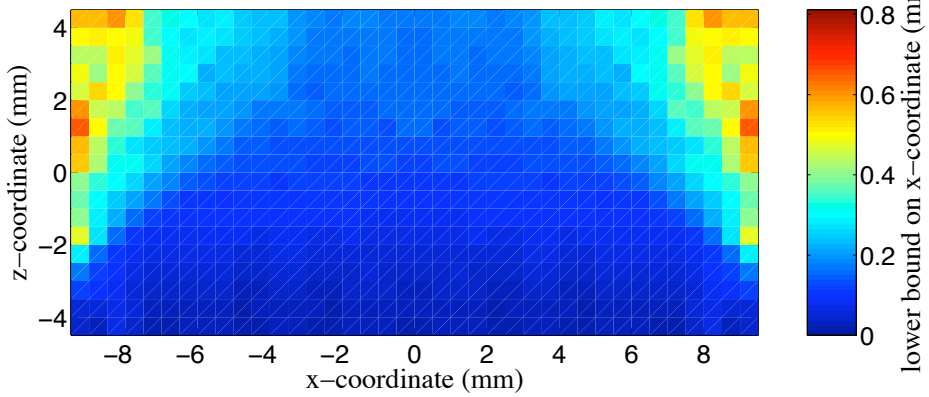


- Hamamatsu S8550 APD array :
  - 4 x 8 pixels
  - Pixel size : 1.6 x 1.6 mm
  - Pixel pitch : 2.3 mm pitch
  - Gain : ~ 50 - 100x
  - Pro : MRI compatible
  - Con: needs good pre-amp

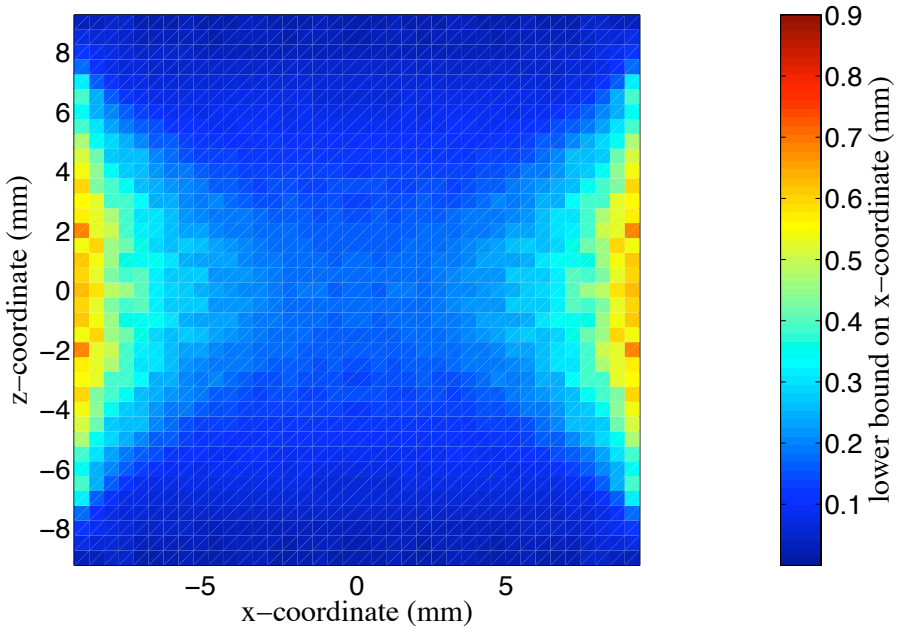
Cramer-Rao Lower variance bounds

- Simulation (Geant4) of scintillation point sources in LSO block

20x10x10 mm^3 LSO
Bottom APD



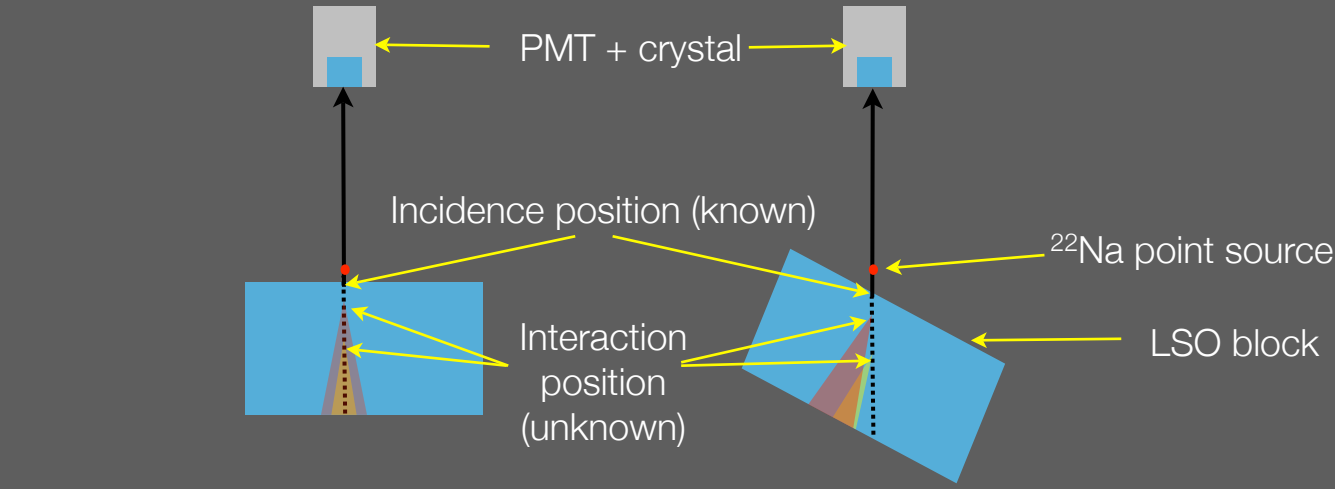
20x10x20 mm^3 LSO
Bottom and top APD



Finding the photon position

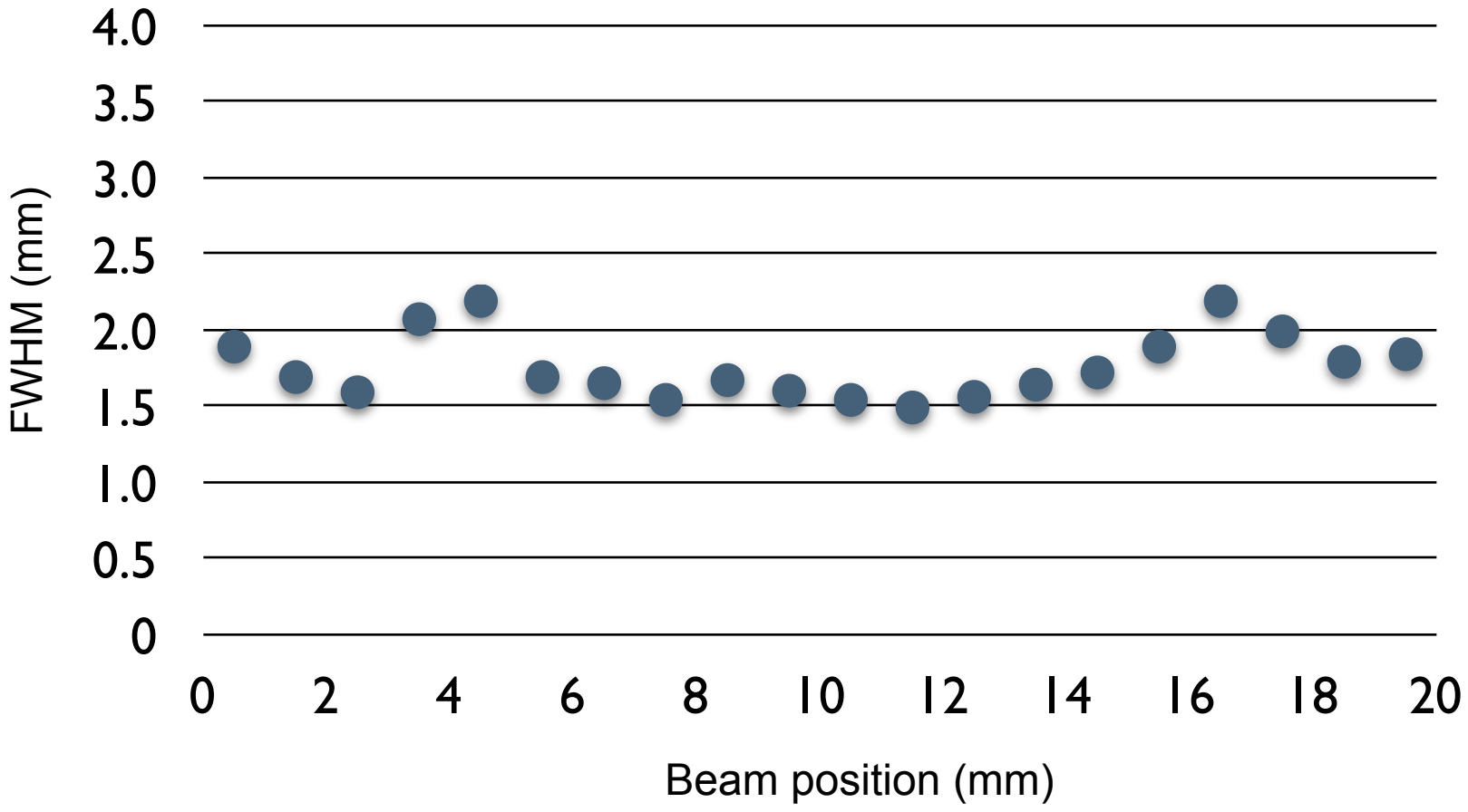
- Train position algorithm by collecting reference data :
  - Put a narrow 511 keV photon beam at various positions on the surface of the block
  - Register the 32/64 APD pixel values with the known position
- Extracting position information of an unknown photon by
  - Comparing the 32/64 APD pixel values with events in the reference set and find the most likely position
  - Use the 32/64 APD pixel values as the input to a neural networks which was trained using the reference data

What do we train ?

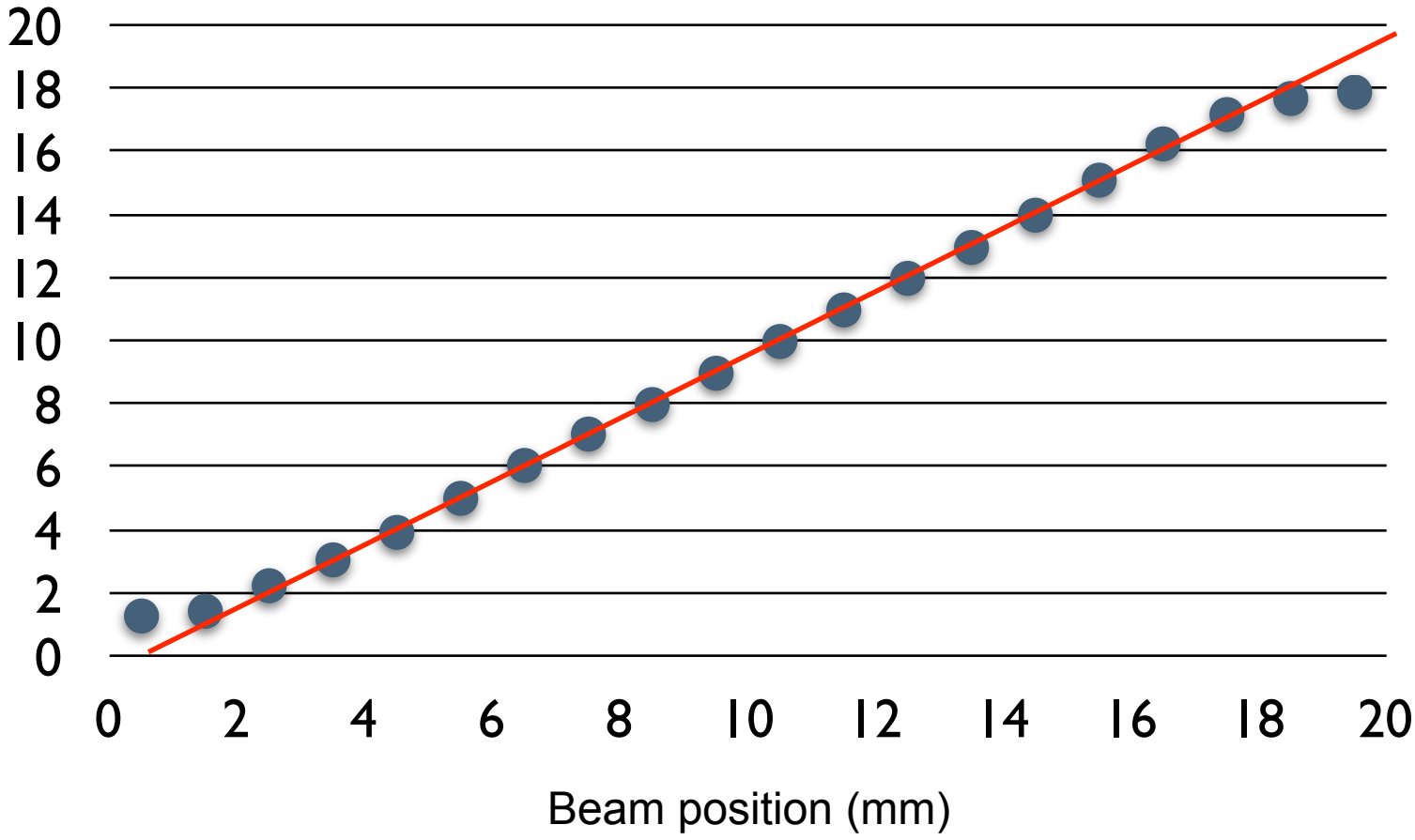


- ☑ We train algorithms to compute the incidence position
- ☑ Incidence position has no parallax error
- ☑ Relation between measured scintillation light distribution and incidence position depends on incidence angle

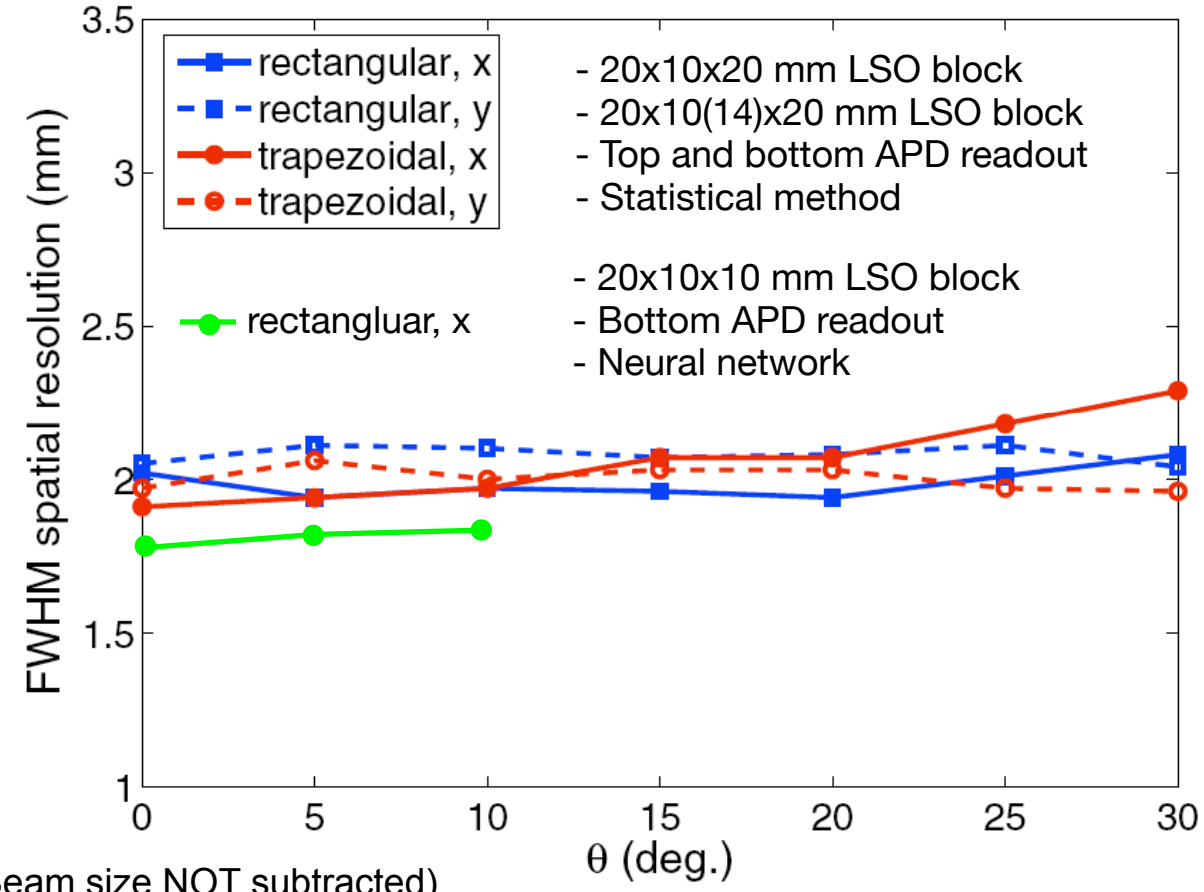
Local spatial resolution using neural networks



Coordinate linearity using neural networks

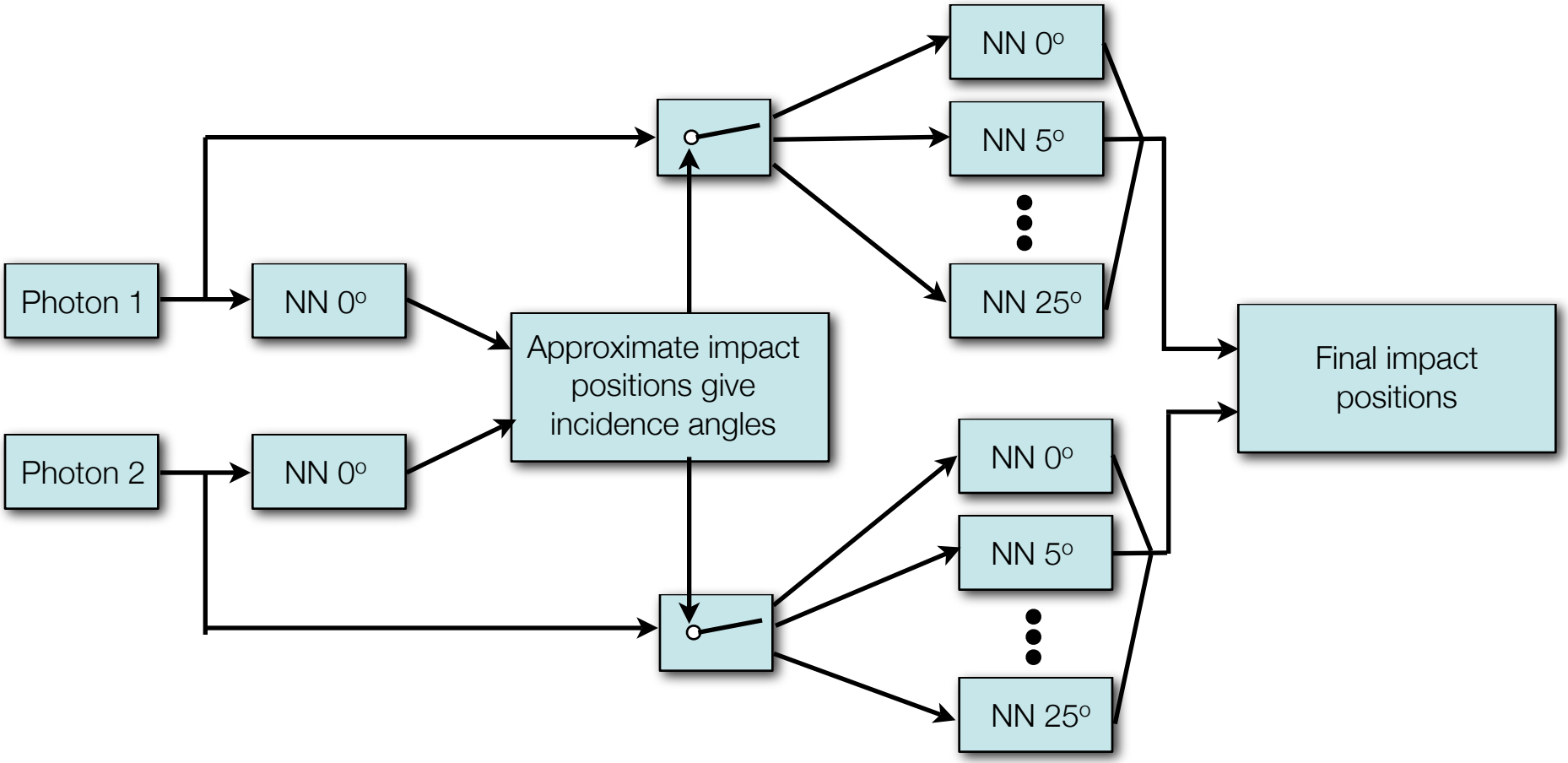


Detector resolution vs incidence angle

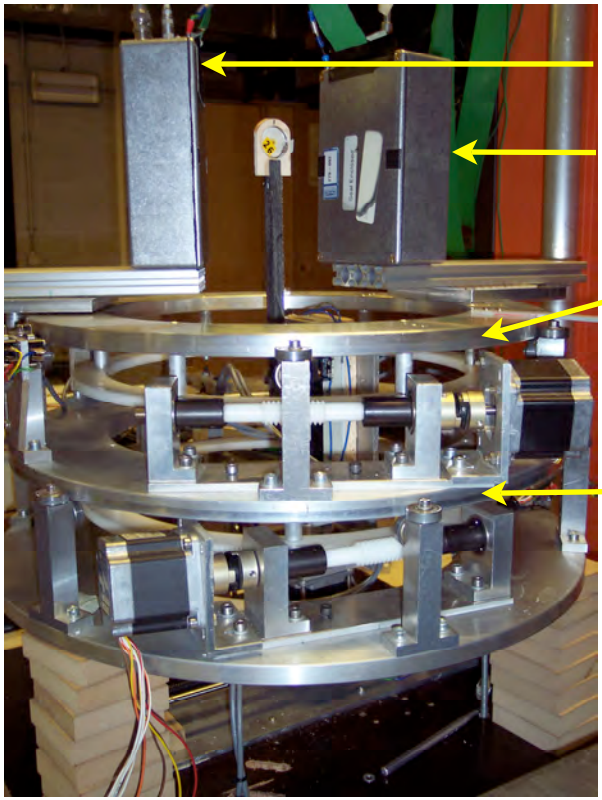


(~ 1 mm FWHM Beam size NOT subtracted)

Implementation in PET



Simulator set-up

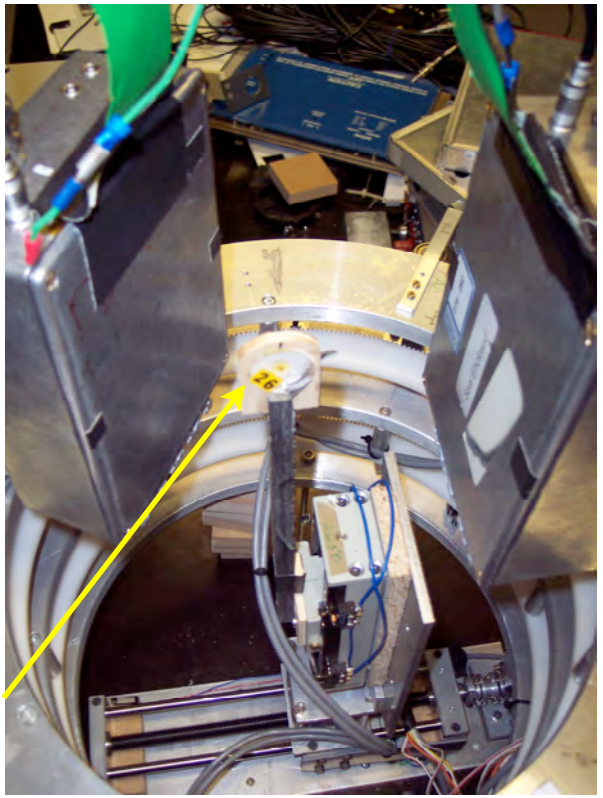


Detector box 1 (20x10x10 mm LSO - APD - 32 ch. Preamp)

Detector box 2

Rotate detector 2
relative to detector 1

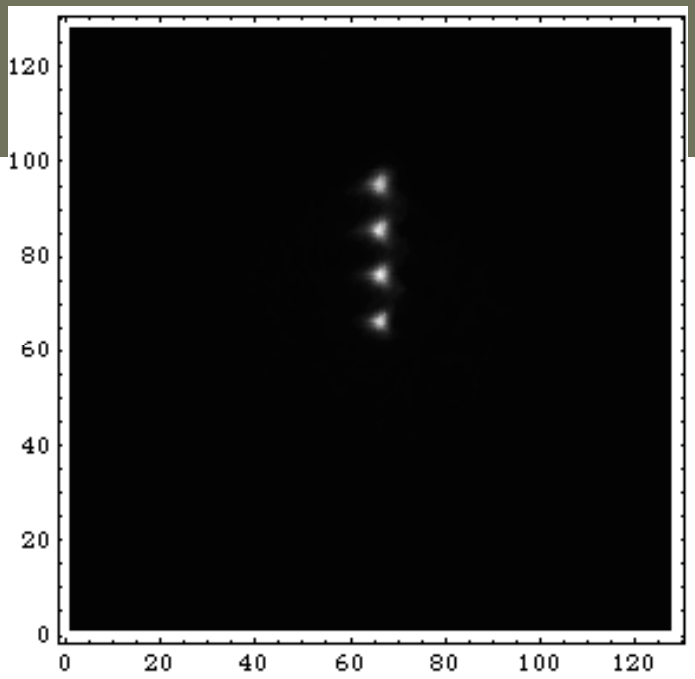
Rotate detector 1
and 2 over 360°

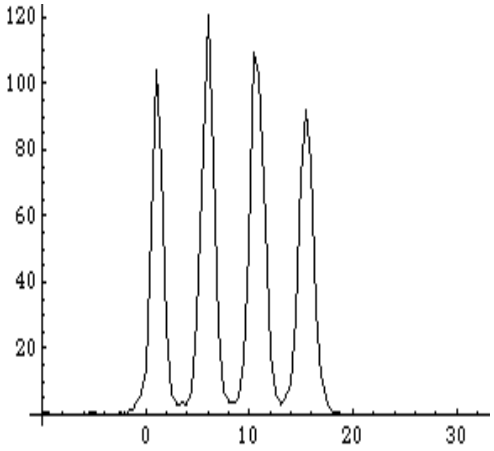


3.7 MBq ^{22}Na source with 250 µm diameter.

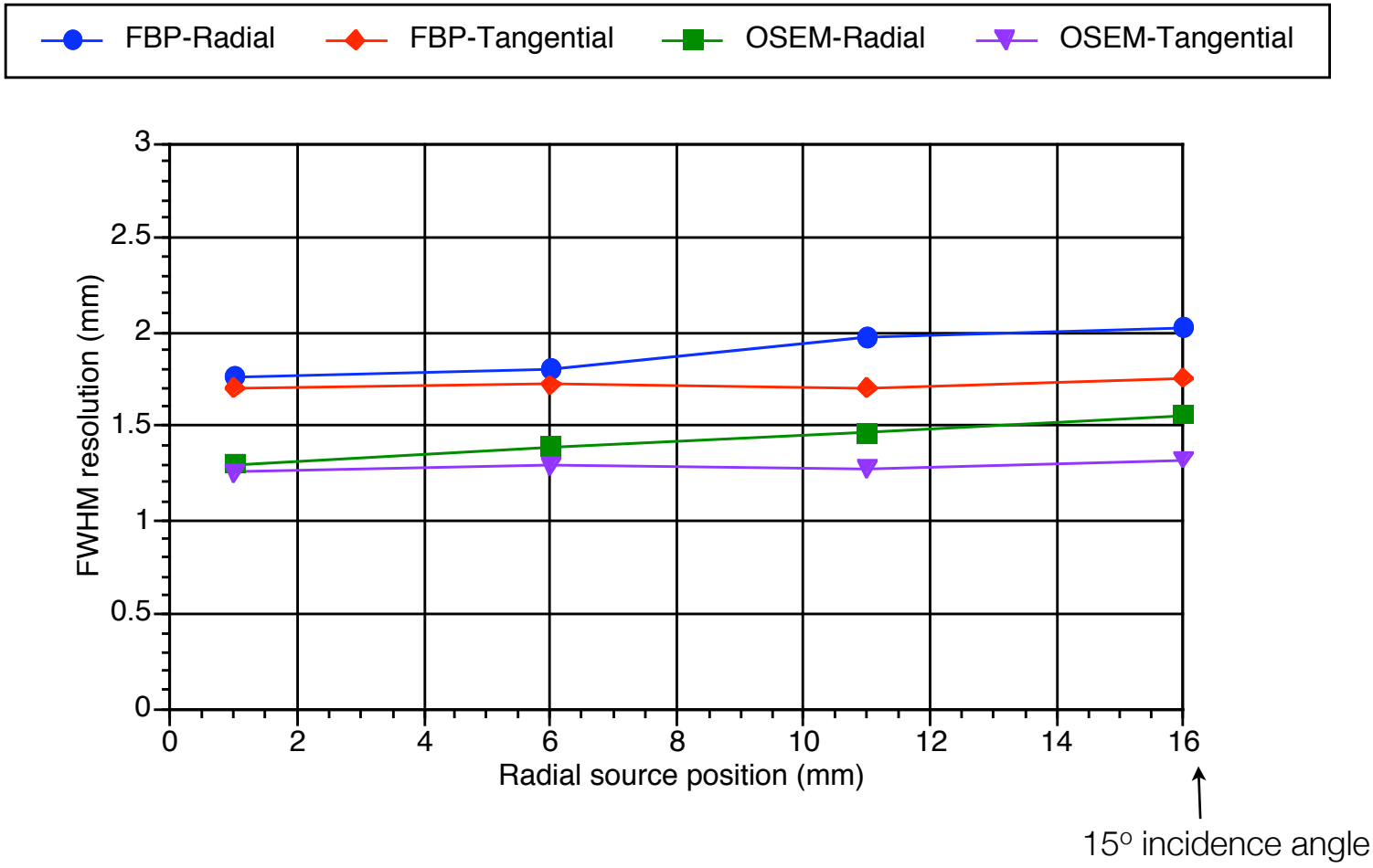
Point source images

- 5 mm separation
- Only 0° NN used
- FBP reconstruction
  - 128x128 image matrix
  - 0.5 mm pixel size
- 1.8 mm FWHM @ 1 mm from center
- 3.5 mm FWTM @ 1 mm from center

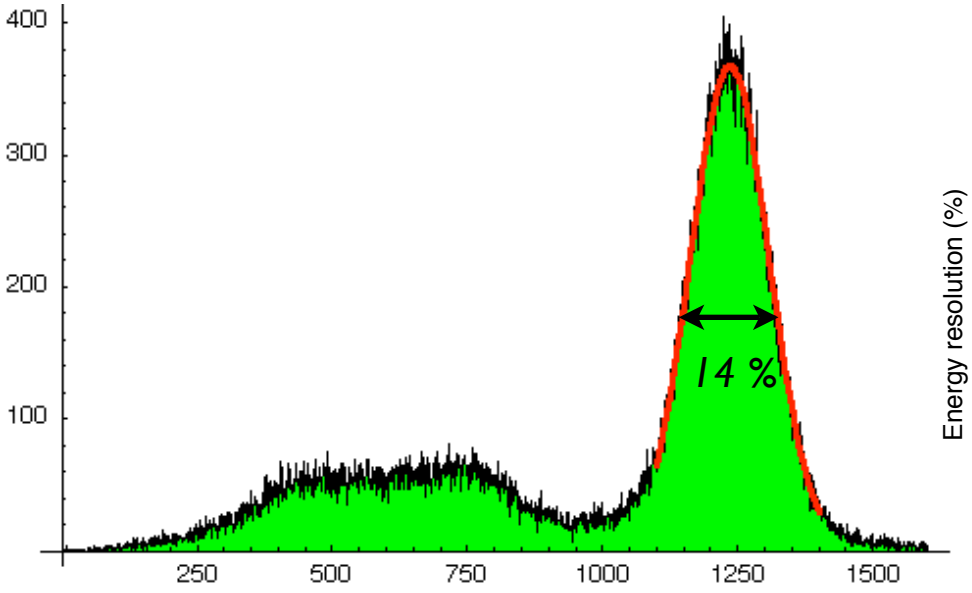


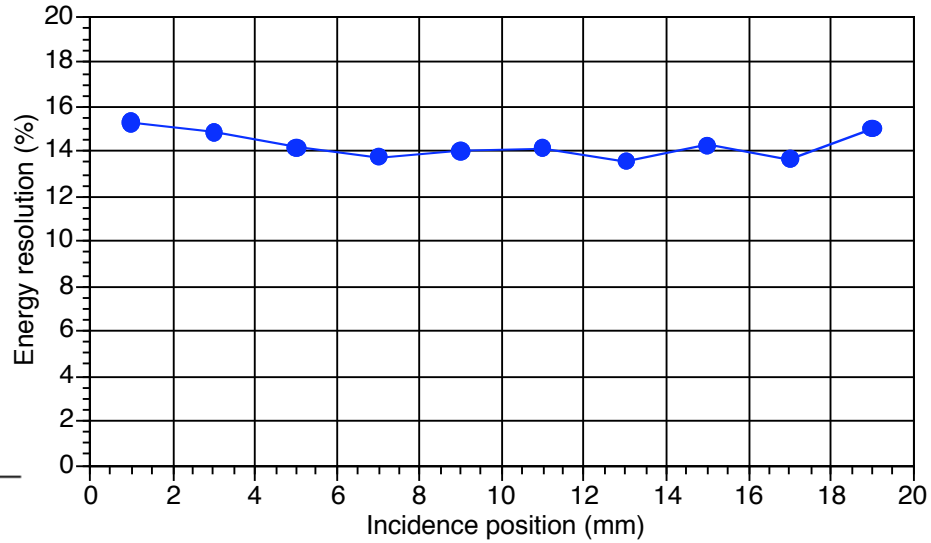


Transaxial resolution



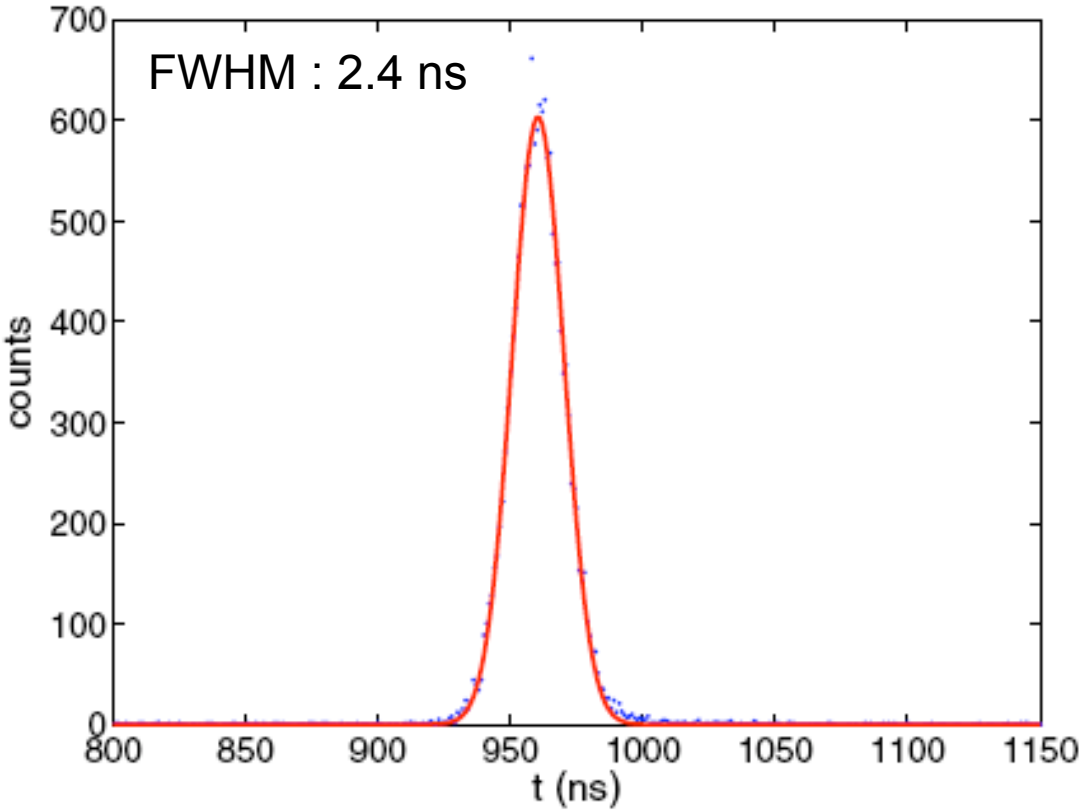
Energy resolution





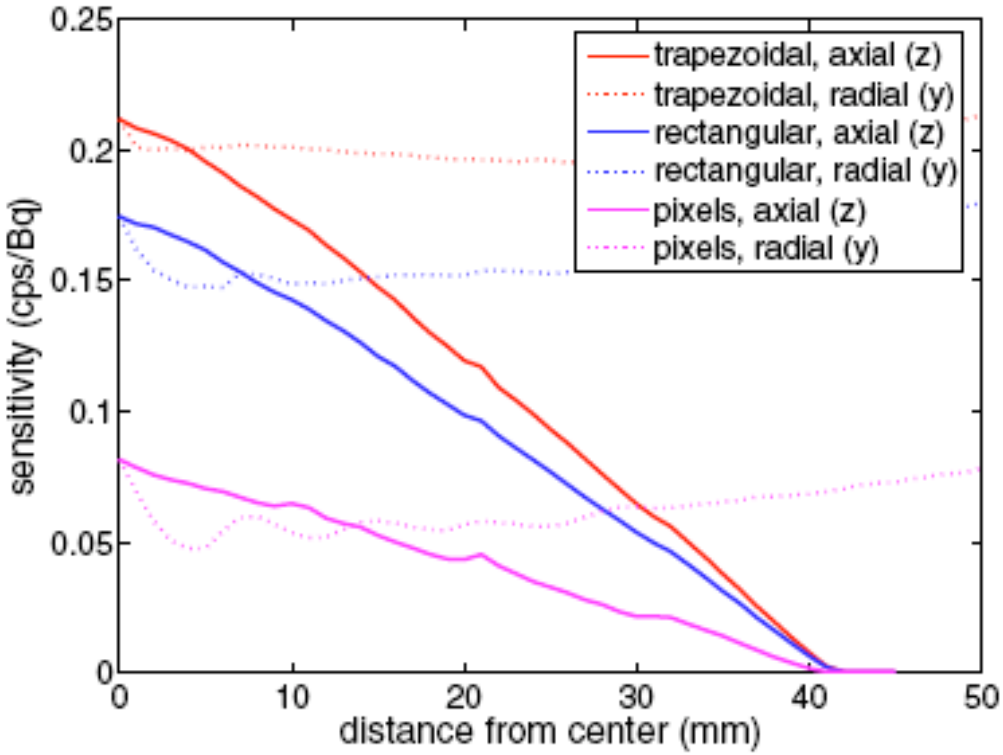
Detector time resolution

Time spectrum against BaF_2 crystal + PMT



Sensitivity

- GATE simulation
- 4 ring (ø=12.4 cm, H= 8 cm)
- 32 APDs/ring
  - 4x8 matrix of 2x2x20 mm pixels, 2.3 mm pitch
  - 20x11.5x20 mm block
  - 20x11.5(15.4)x20 mm block
- 250 - 750 keV energy window
- 5 ns time window



Conclusions

- Double readout required for thick (> 10 mm) scintillator blocks
- Spatial resolution better than 2 mm and constant over a large range of incidence angles. Image resolution of 1.5 mm should be possible.
- Energy resolution : ~ 14 %
- Detector time resolution : 2.5 ns (3.4 ns coincidence time resolution)
- Sensitivity can be greatly enhanced
- Developed and tested an in-situ detector position calibration method (see poster Cedric Lemaitre)