AX-PET : A novel PET concept with G-APD readout

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On behalf of the AX-PET collaboration

https://twiki.cern.ch/twiki/bin/view/AXIALPET

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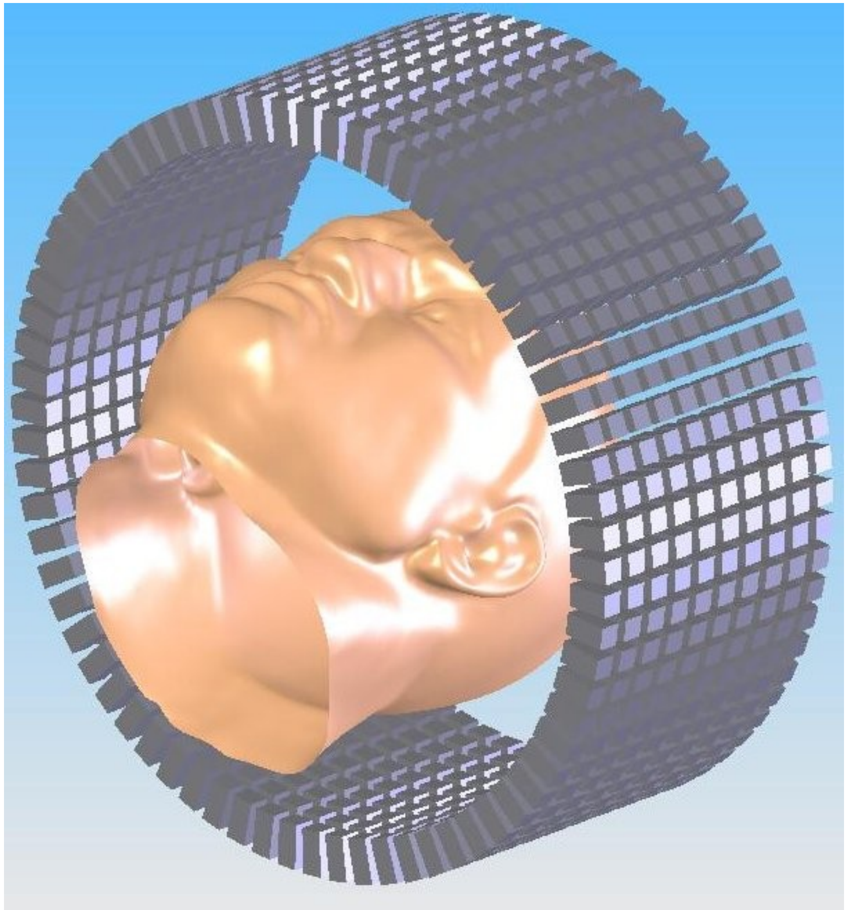
Outline

- The AX-PET concept
- Detector components
- Module characterisation
  - Energy resolution
  - Spatial resolution
  - Sensitivity
- Simulation validation
- Results of tomographic reconstructions

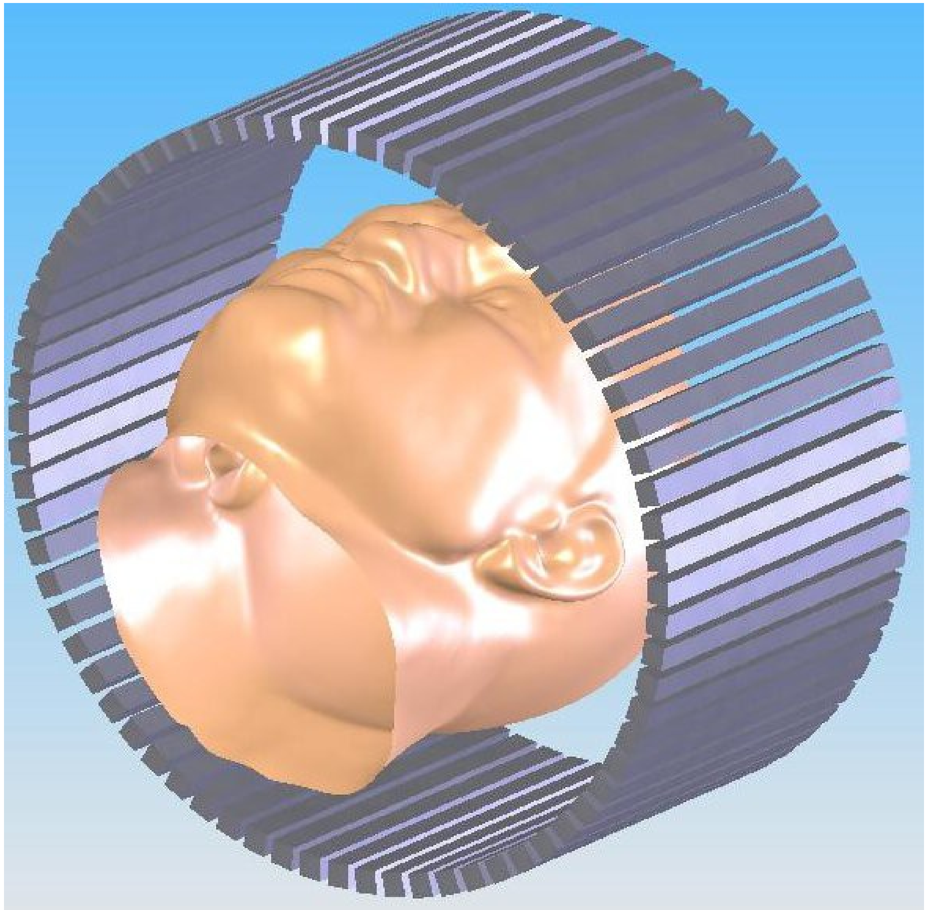
The AX-PET concept

Standard PET scanners



Short crystals radially oriented
Block readout

AX-PET geometry proposal



Long crystals axially oriented
Single crystal readout

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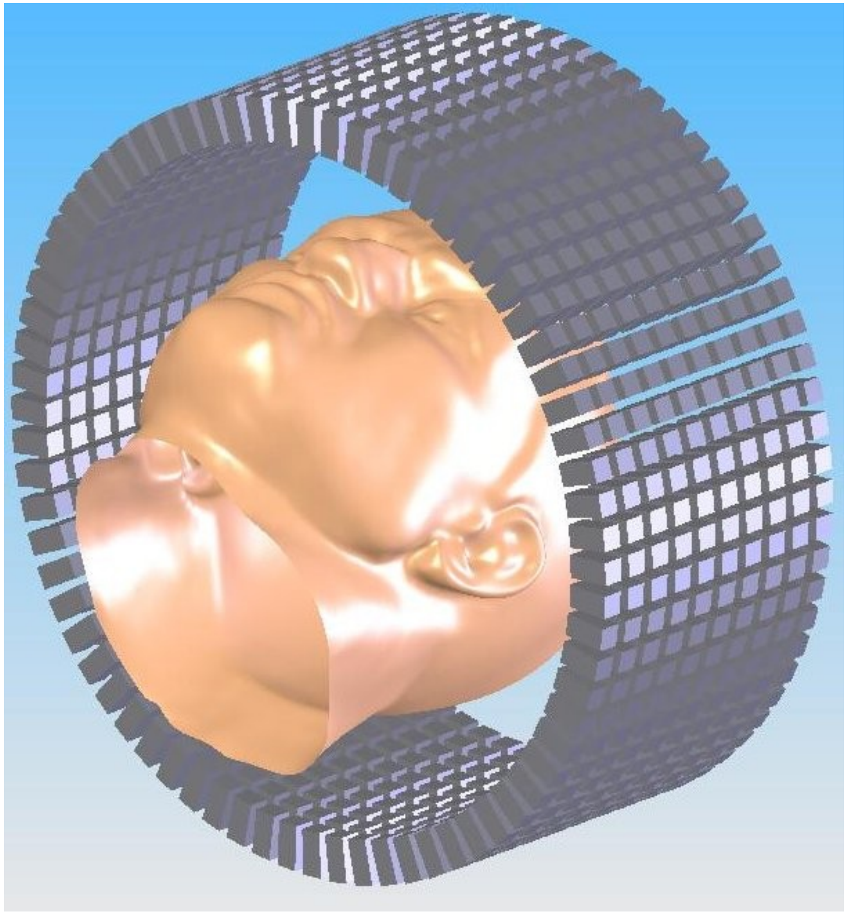

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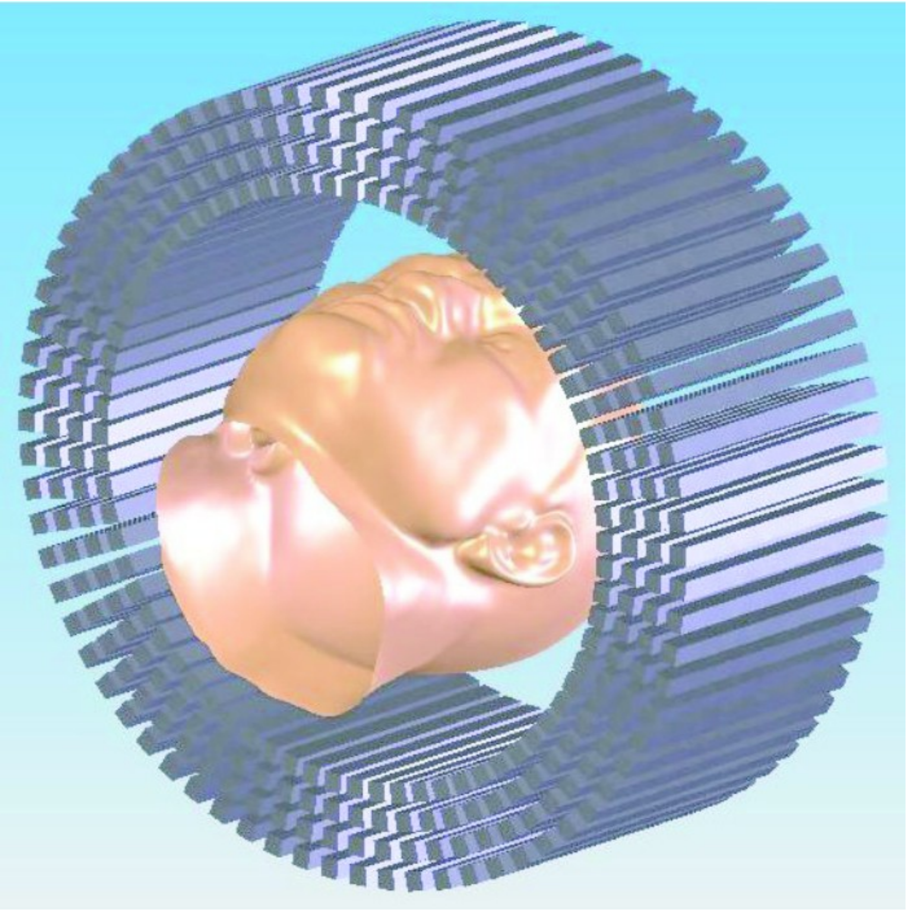

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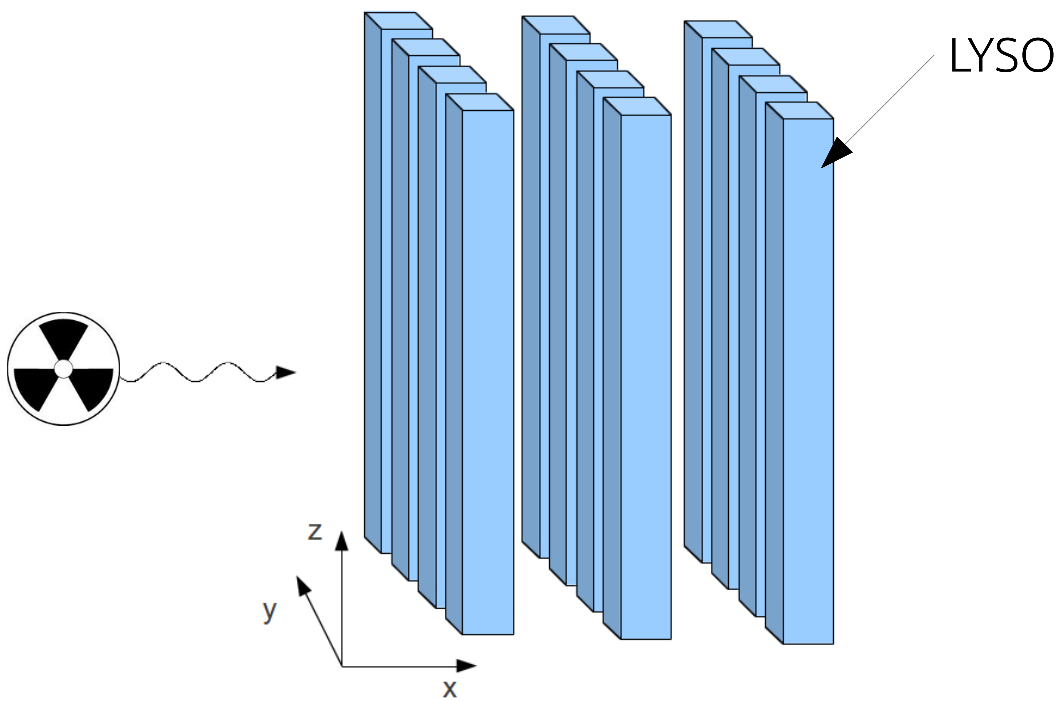
The AX-PET concept

3D measurement of the photon interaction point

- Transaxial coordinate and energy measurement with thin elongated scintillator LYSO crystals
  - The hit crystals gives the transaxial coordinate (x, y)



The AX-PET concept

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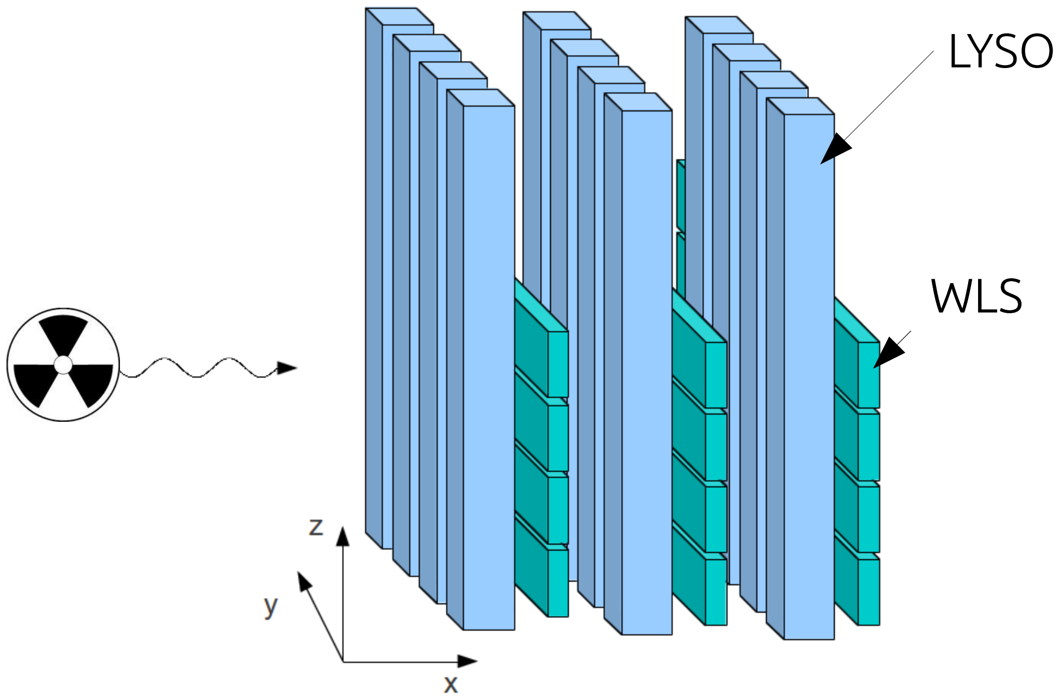

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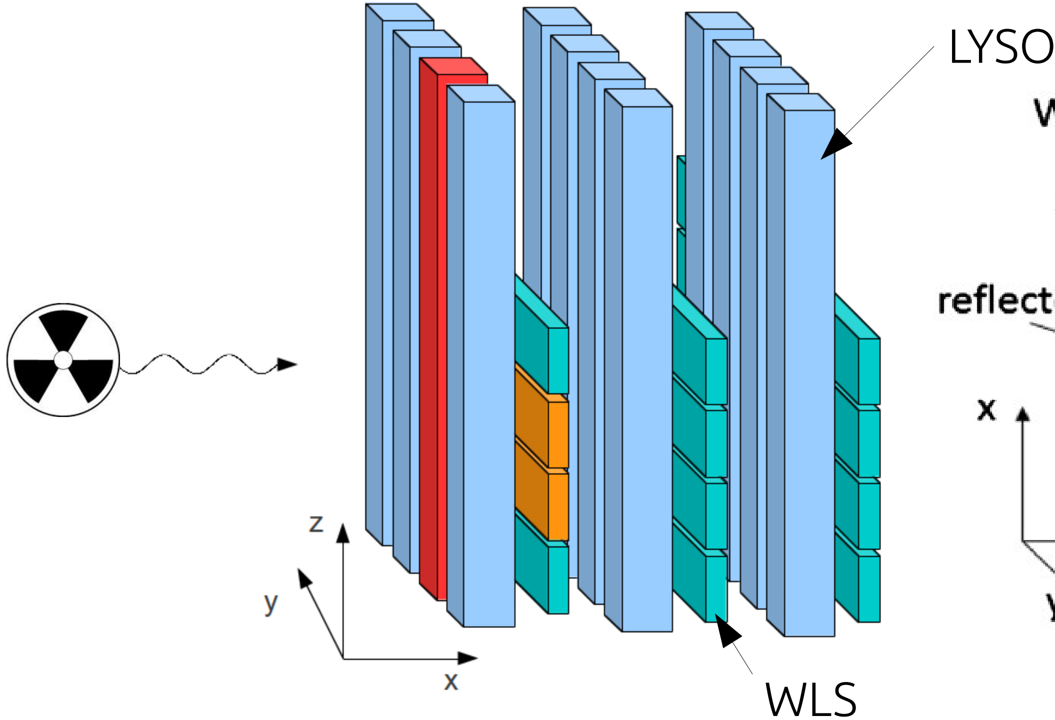
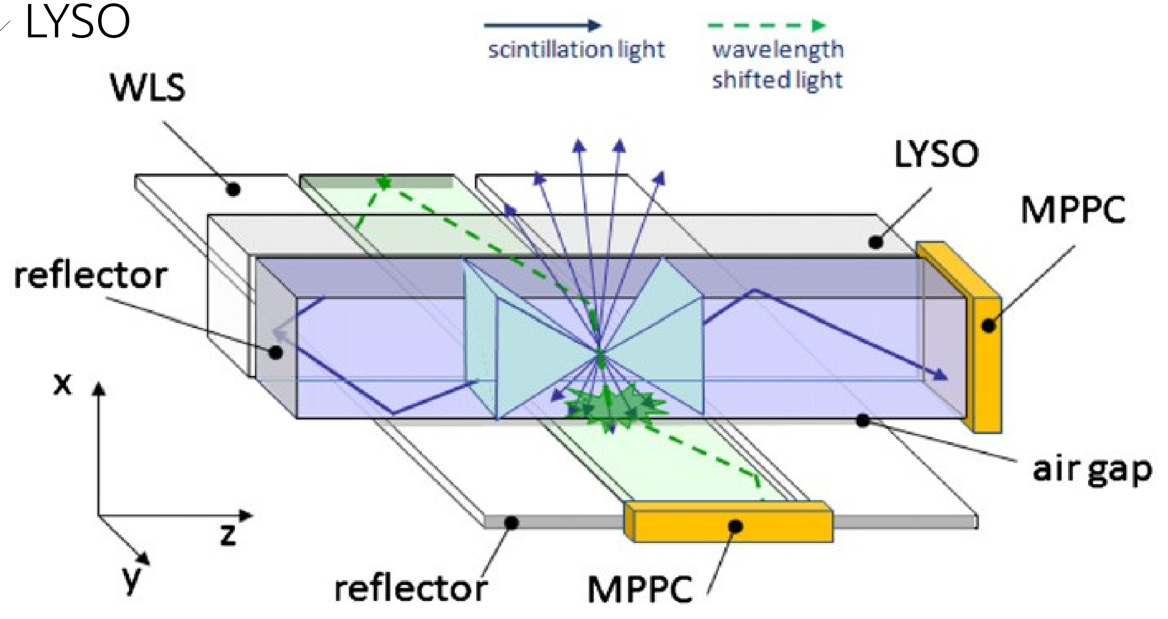
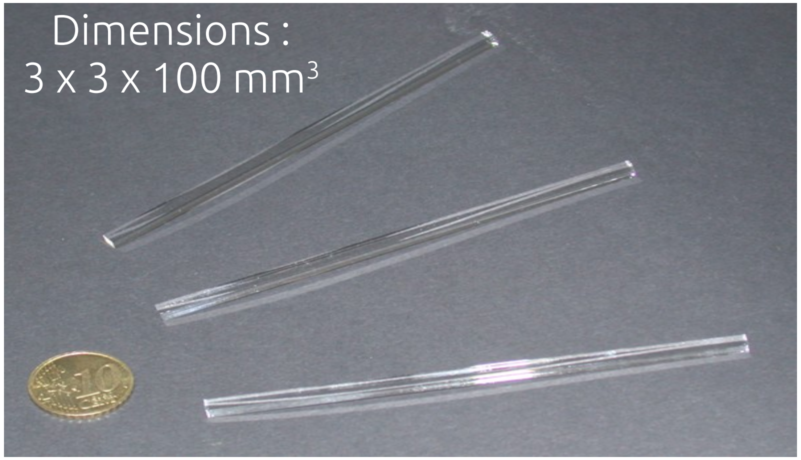




Detector components

Scintillator crystals and WLS strips

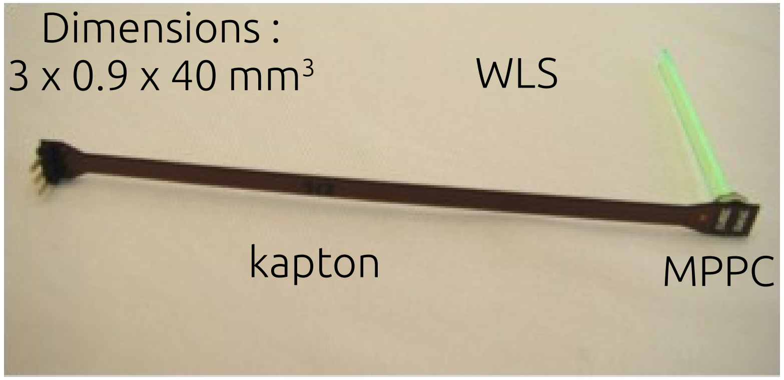
- LYSO ($Lu_{1.8}Y_{0.2}SiO_5$:Ce), Prelude 420 from Saint Gobain



From Saint Gobain :
- Light Yield LY=32 photons/keV
- Attenuation length (at 511keV) λ_{511}=12 mm

Measured parameters :
- Effective optical absorption length : λ_{opt} = (412 ± 31) mm
- Intrinsic energy resolution : $(\Delta E/E)_{intr}$ = (8.3 ± 0.5)% (FWHM) at 511 keV

- WLS strips, Type EJ-280-10x, from Eljen Technologies



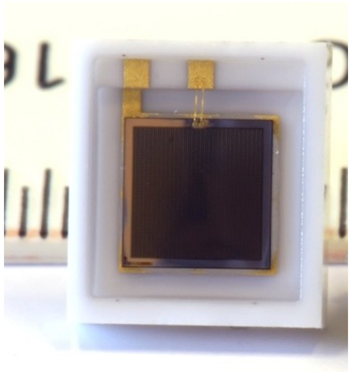
From Eljen :
- Absorption length 0,4 mm for blue light
- QE (fluorescent material): 0.86%

Measured parameters
- λ_{opt} = (188 ± 36) mm

Detector components

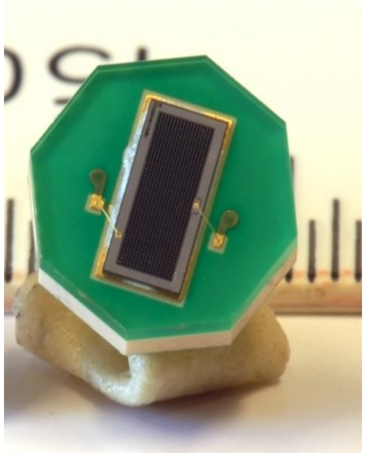
Photodectors : G-APD arrays

- LYSO readout : MPPC – Hamamatsu Type S10362-33-050C



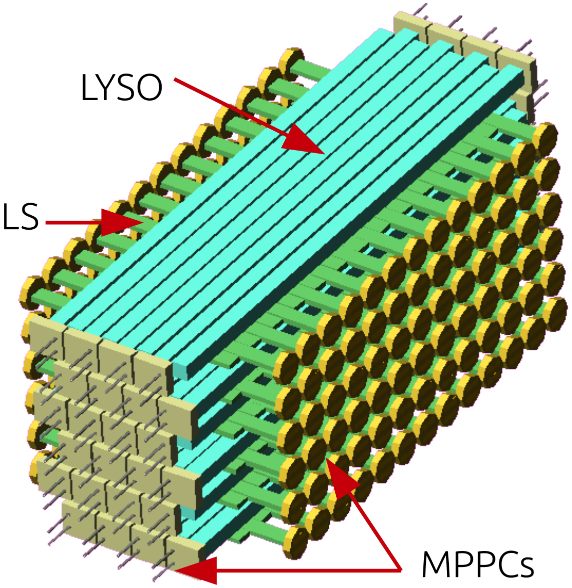
- 3 x 3 mm^2 area, 3600 cells 50 x 50 um^2
- PDE ~ 40%
- Gain : 5.7 10^5
- Bias voltage ~ 70 V

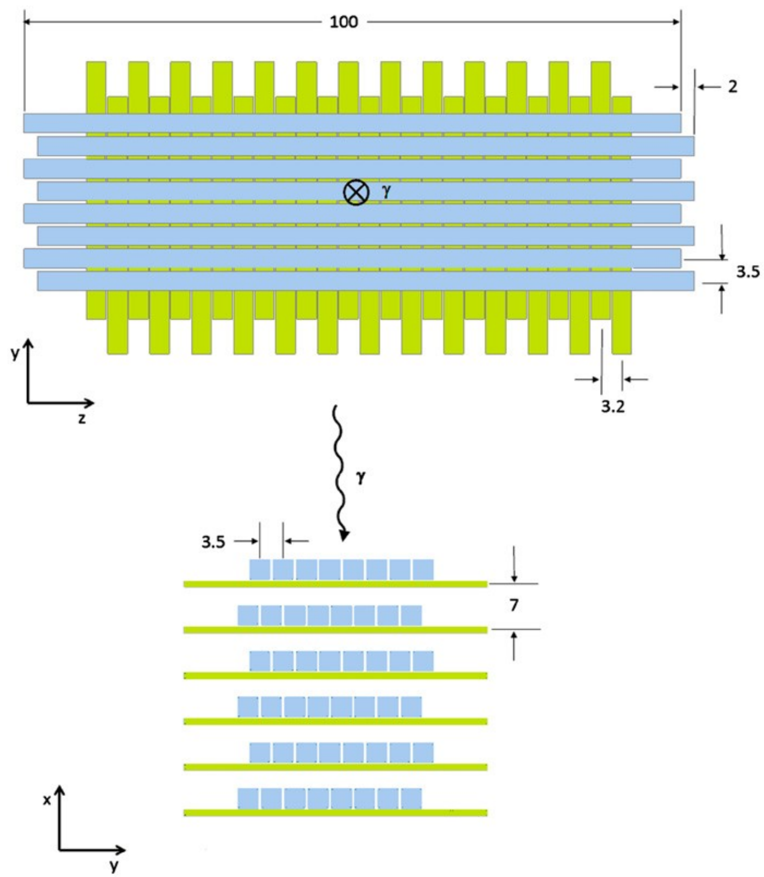
- WLS strips readout : MPPC – Hamamatsu OCTAGON-SMD custom made

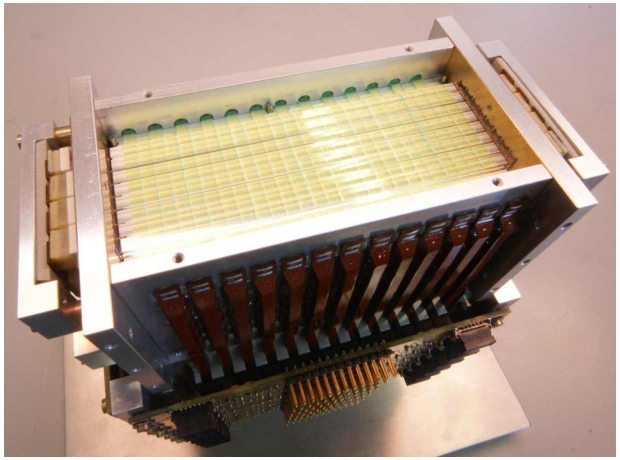


- 3. 22 x 1.19 mm^2 area, 782 cells of 70 x 70 um^2
- PDE ~ 40%
- Gain : 4 10^5
- Bias voltage ~ 70 V

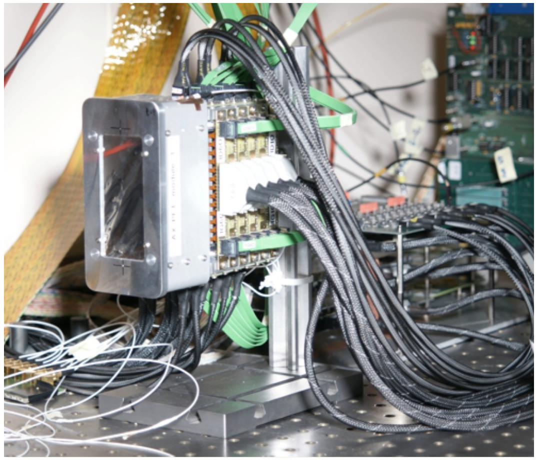
Module assembly







Assembled module

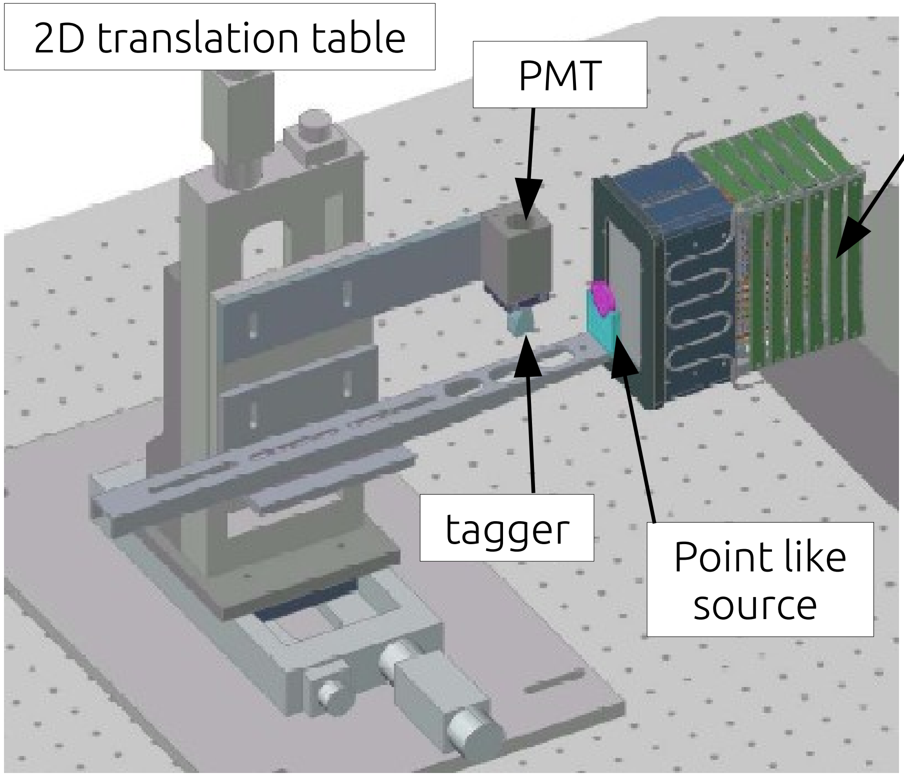


Module housing and services

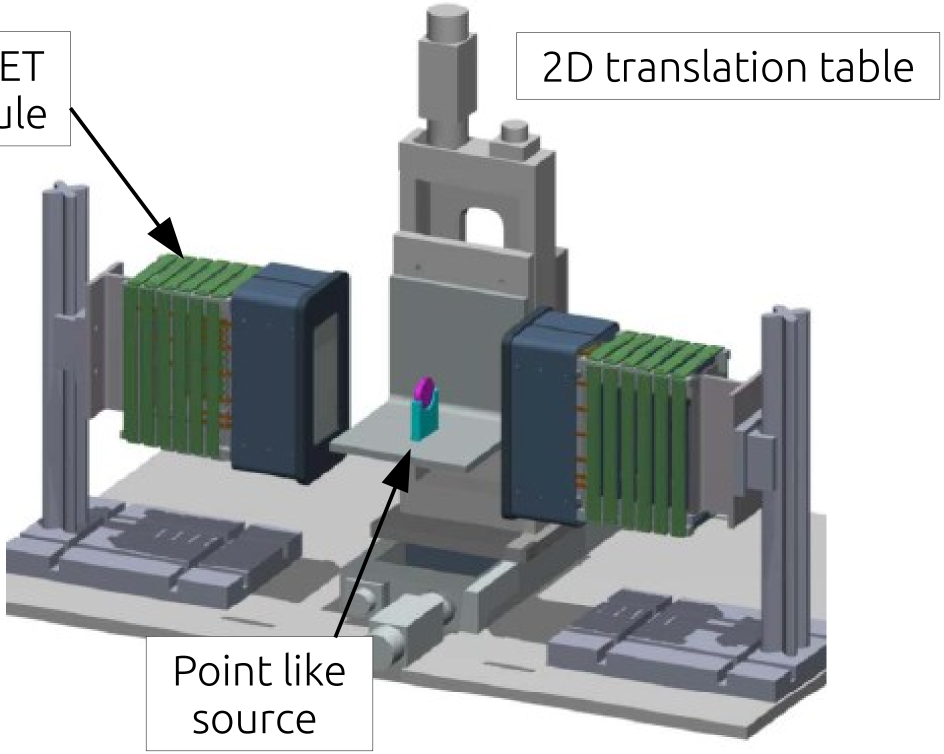
- Each module is composed by six layers
- Each layer is made of 8 LYSOs and 26 WLS both staggered to enable the readout
  - → 204 channels per module
- All layers are optically decoupled

Module characterisation

Single module characterisation



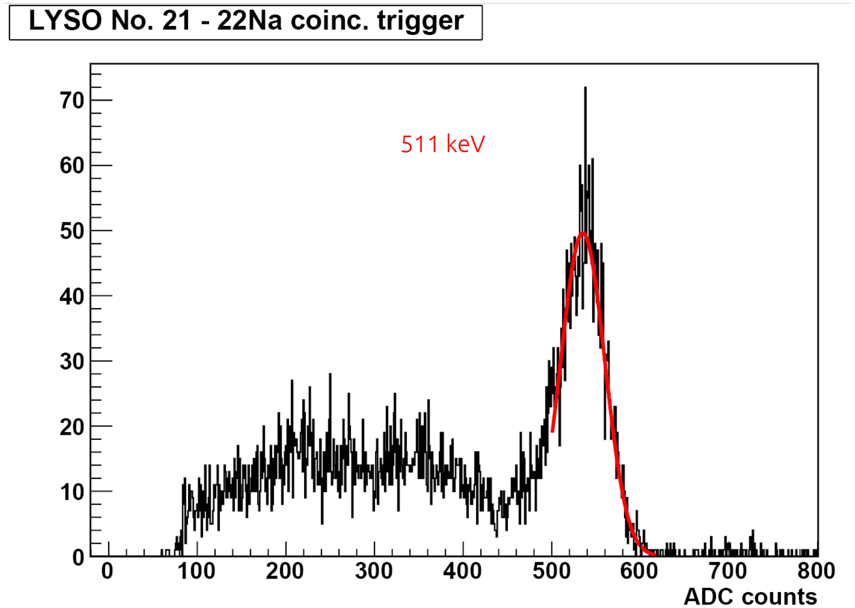
Characterisation of modules in coincidence

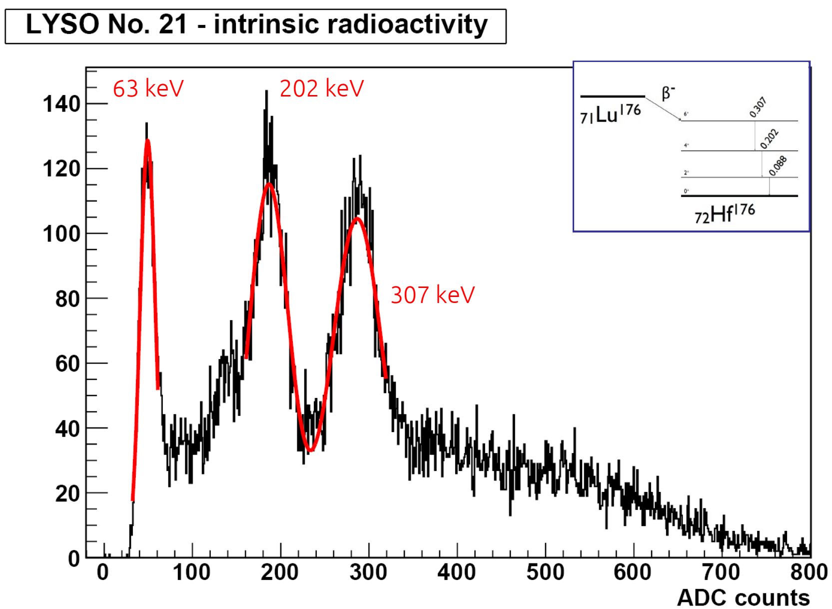


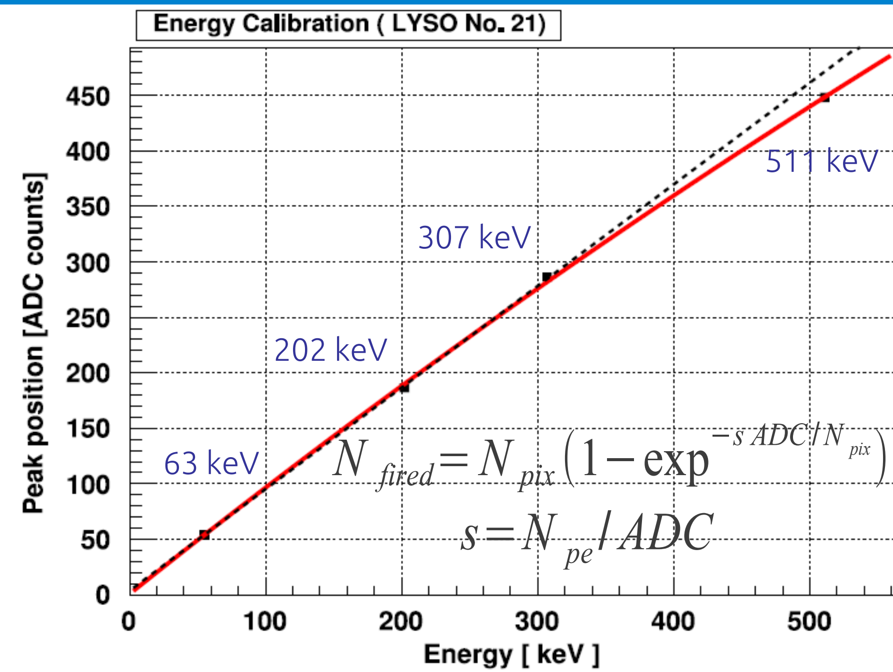
Point-like source : Na^{22} (Ø0.25 mm, A~900 kBq)

doi:10.1016/j.nima.2011.06.059

MPPC saturation correction and Energy calibration







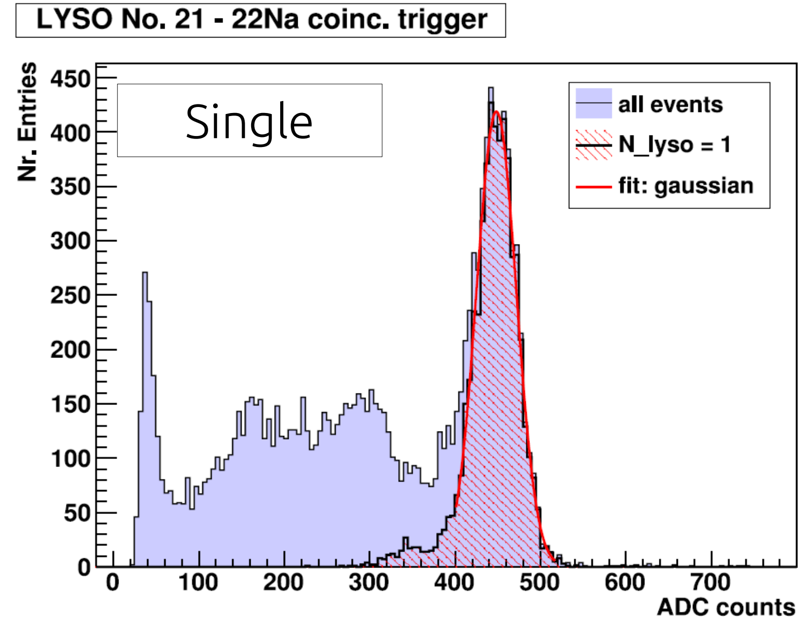
- In order to correct the MPPC saturation, two calibration sets are needed :
  - Photoelectric peak at 511 keV, acquired with the ^{22}Na source
  - "Integrated calibration source" : Two of the peaks of the ^{176}Lu decay spectrum at 202 and 307 keV (natural radioactivity of LYSO) and the Lutetium K_α escape line at 63 keV

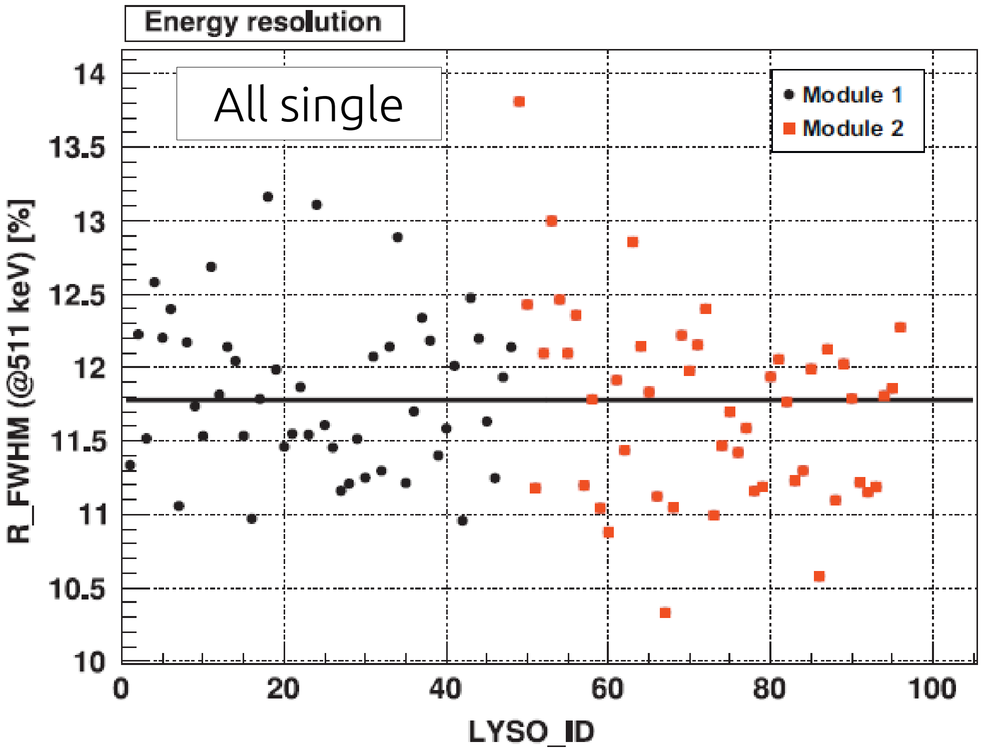
- The four data points are fitted to take into account the saturation effect in the MPPCs

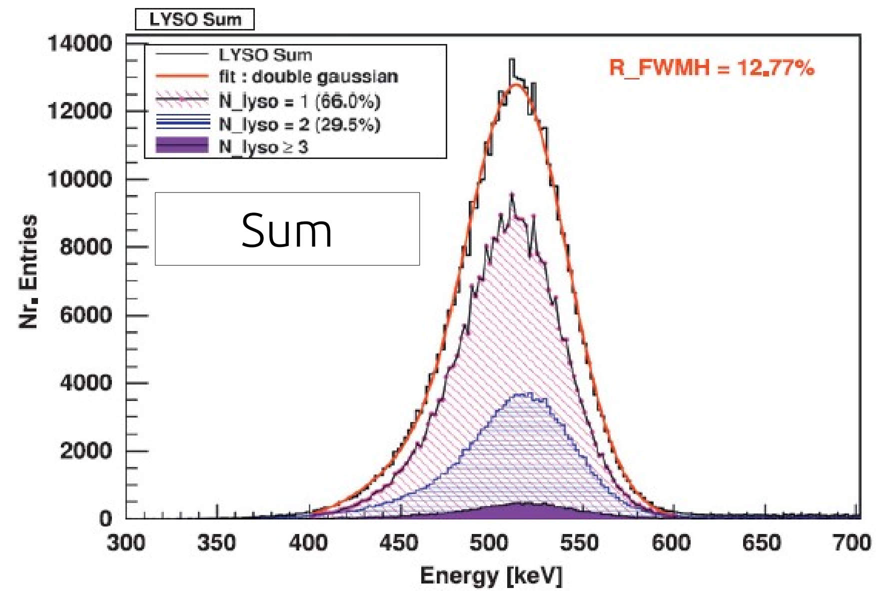
Energy Resolution

- The average value of the energy resolution of all the LYSO crystals for both modules is 11.8% FWHM at 511 keV

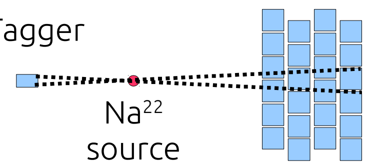
- The resolution obtained for sum of the energy in all LYSO is about 12.8% FWHM at 511 keV







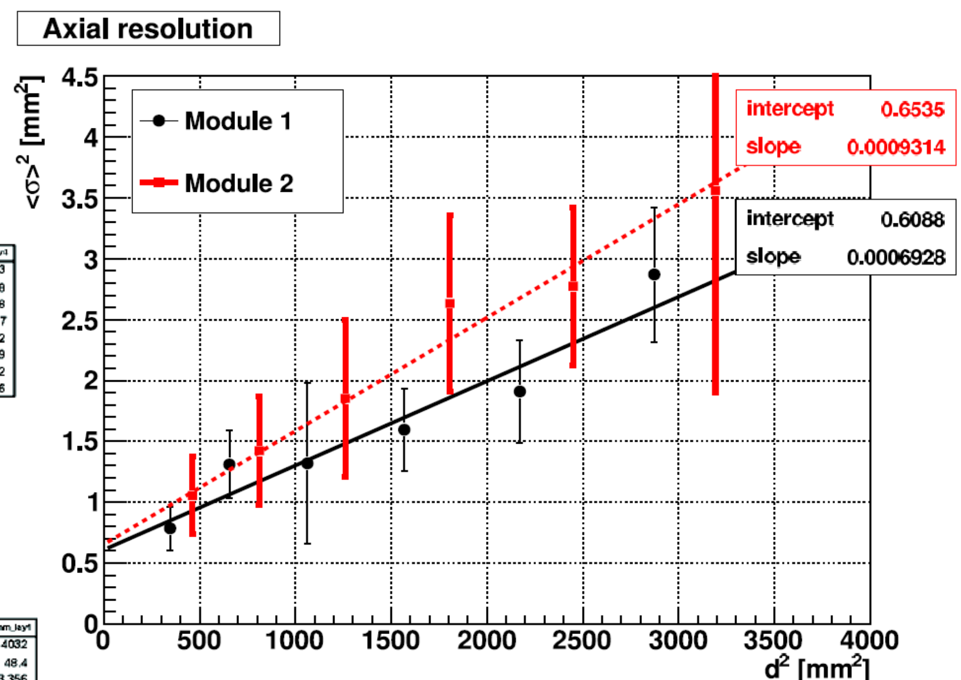
Spatial resolution with point-like source

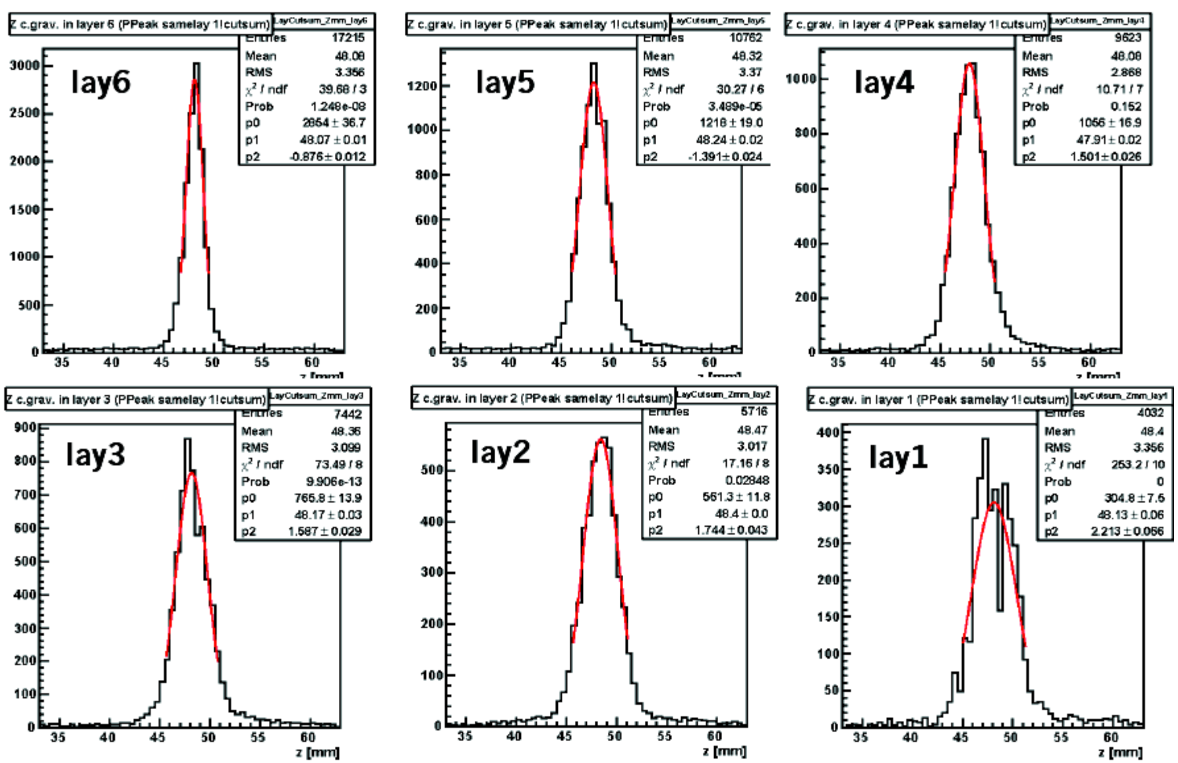


Collimated beam for precision scan

<u>Taken into account :</u>

- positron range : ρ ~ 0.54mm
- non-collinearity : ~ 0.0022 x D ~ 0.33mm
- source dimensions : ø=250µm
- Beam divergence



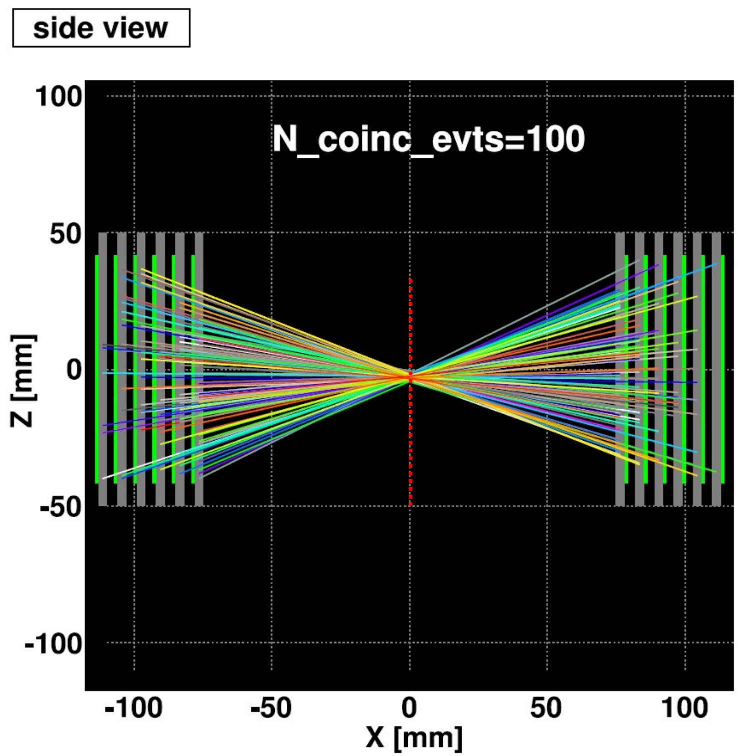


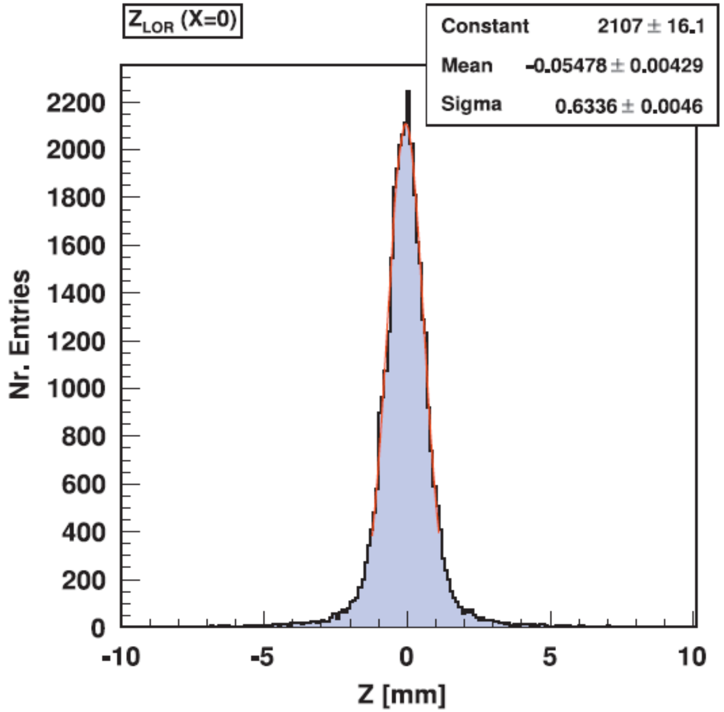
<u>Results:</u>

Axial resolutions

- Module 1 : 1.75 mm FWHM
- Module 2 : 1.83 mm FWHM

Spatial resolution with point-like source



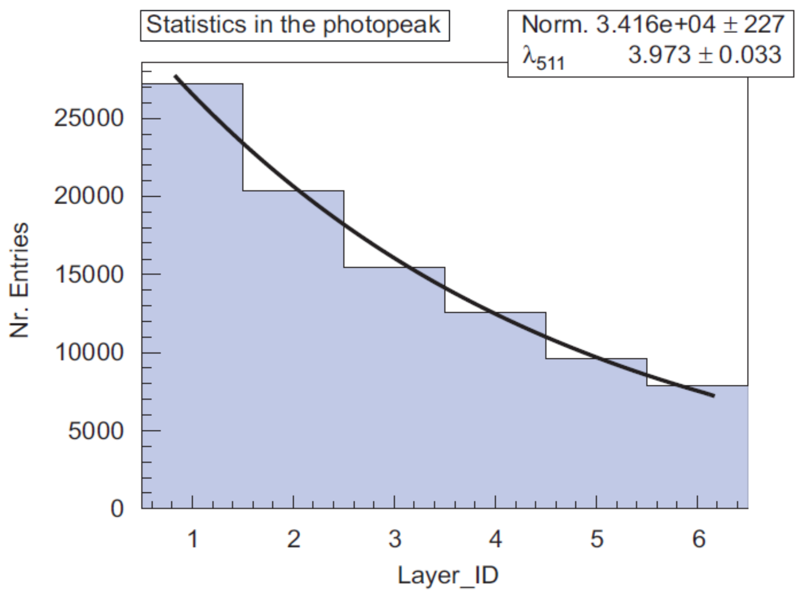


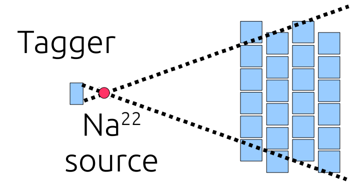
RESULT

Axial resolution

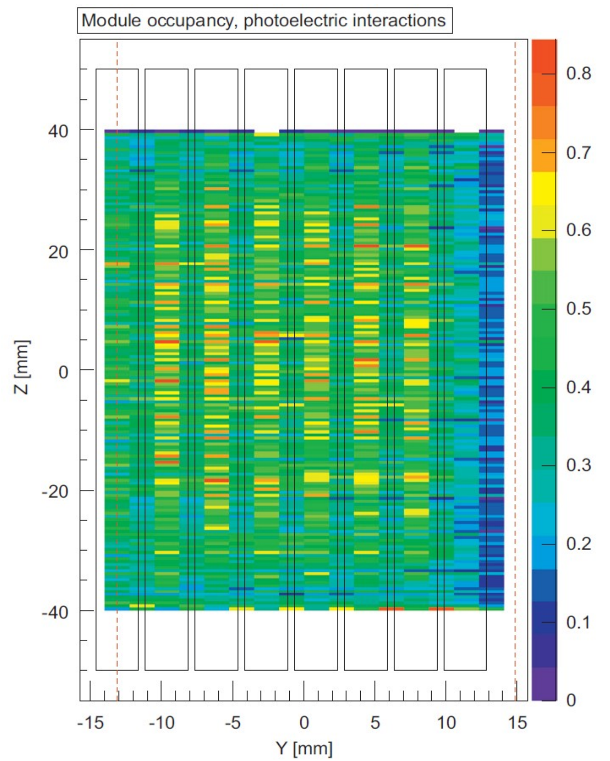
- LOR of 100 coincidences in the axial plane. Intersection with plane x=0 gives R = 1.35 mm FWHM
- Consistant √2 factor between single module resolution and modules in coincidence

Detection efficiency, sensitivity

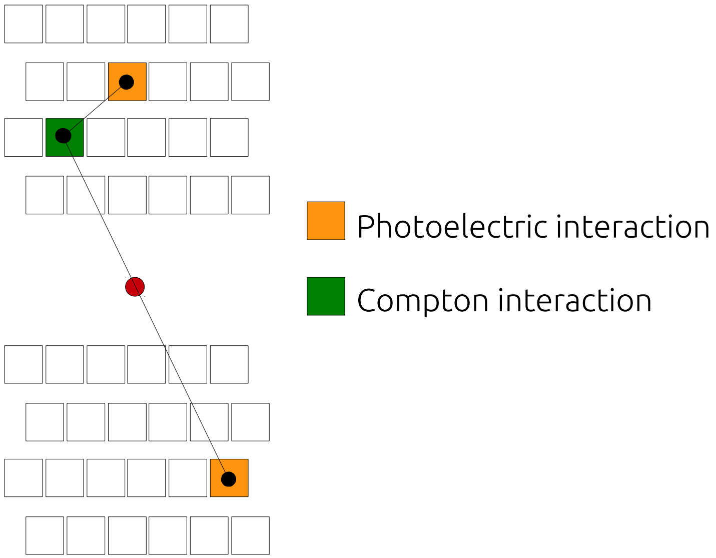




wide beam for global scan



- Photoelectric interaction detection efficiency with six layers : 77%
- Good homogeneity of the module occupancy for photoelectric interactions

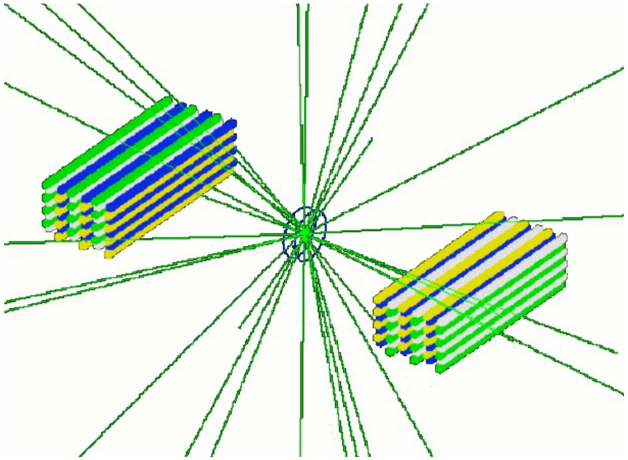


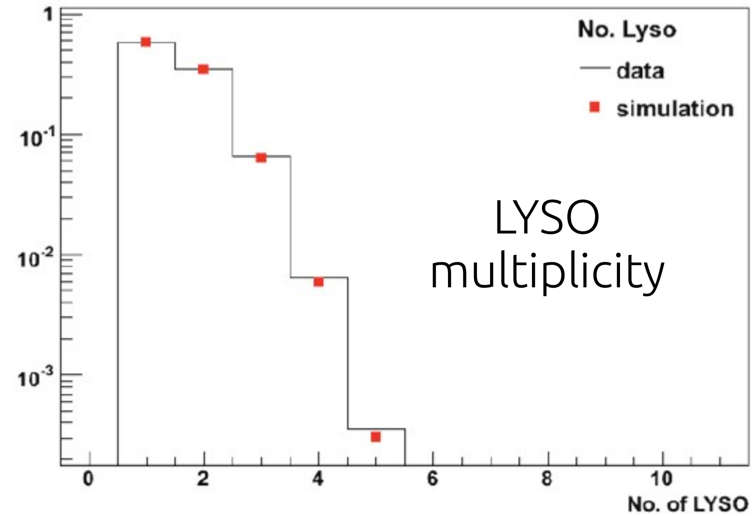
- The hability for Inter-Crystal Scattering identification is enhanced by the geometry and granularity of the detector
- Several identification algorithms has been used in the simulation and show in average an efficiency ~60 %

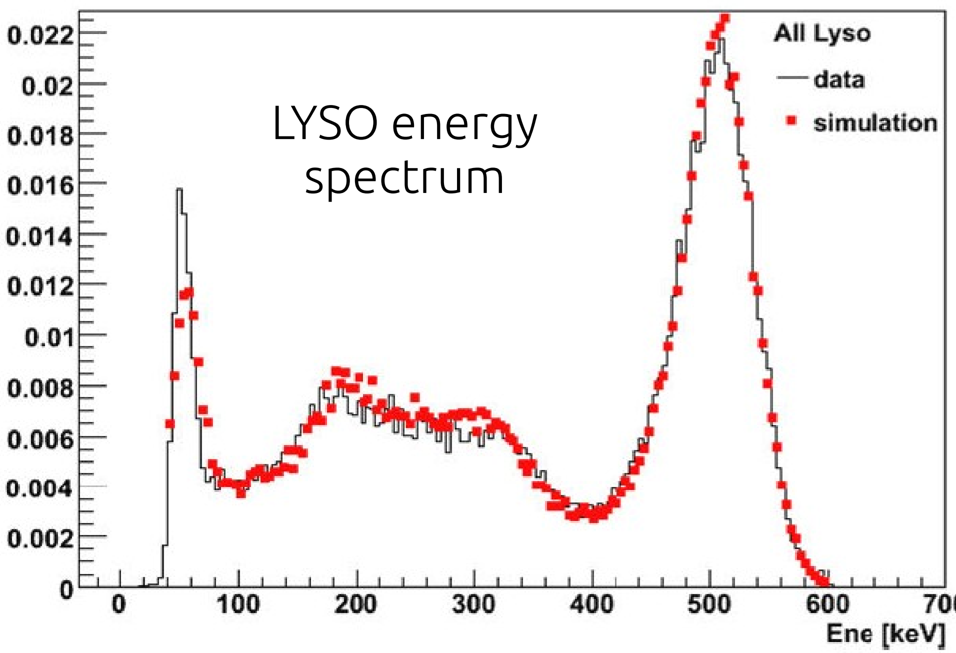
Simulation validation

Dedicated simulation developed :

- Geant4, GATE based
- Modification of some Geant4 classes to include the WLS parametrization





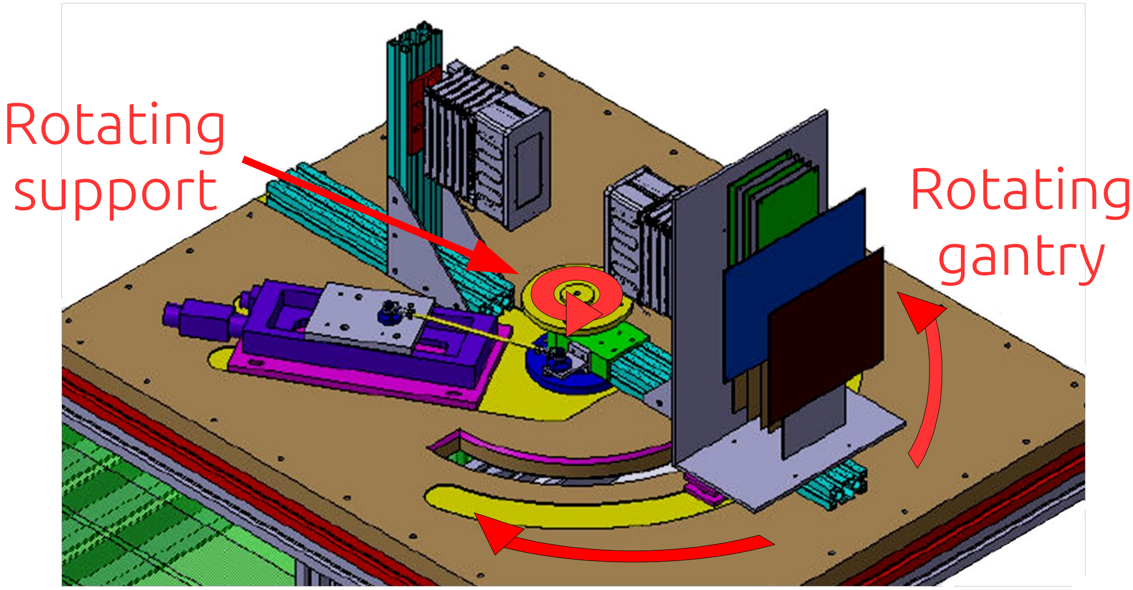


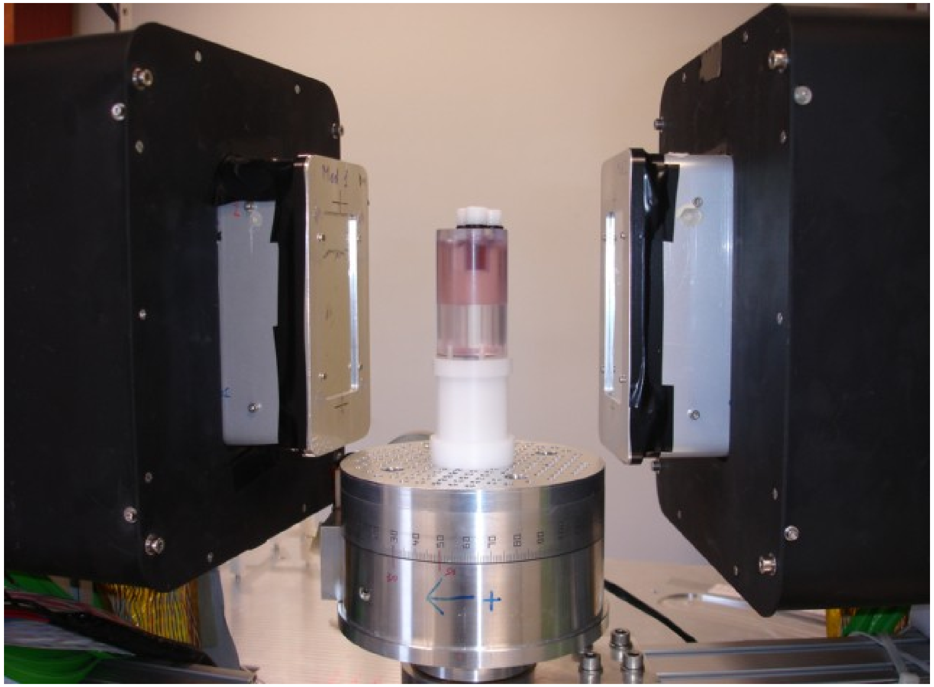
Simulation was used in oder to :

- Better understanding of the device behavior
- Support image reconstruction algorithm development
- Improve reconstructed imaged
- Generate synthetic data sets to train the Compton reconstruction algorithm

Test bench for tomographic reconstruction

- The two modules are mounted on top of a portable platform, which houses also the electronics, power supply, etc...
- A rotating motor can move the source or phantom positioned in the field of view
- One of the modules can rotate wrt 180° position by ±60°





Measurement with phantoms

How to mimic a full ring scanner ?

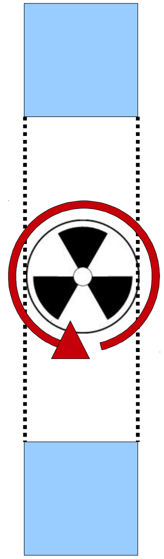
➡ It depends on the Field Of View (FOV)

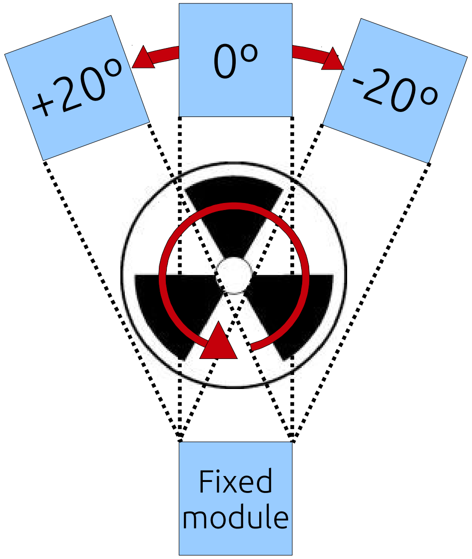
Standard FOV :

- Distance between modules 15 cm
- Modules both fixed : source rotates by 360°
- First measurement campaign with phantoms performed at ETH-Zurich in April 2010

Extended FOV :

- One module fixed
- The other rotates by ±20°
- The source rotates by 360° (20° steps)
- Second measurement campaign with phantoms AAA-St Genis Pouilly in July 2010





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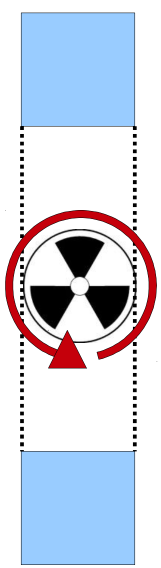
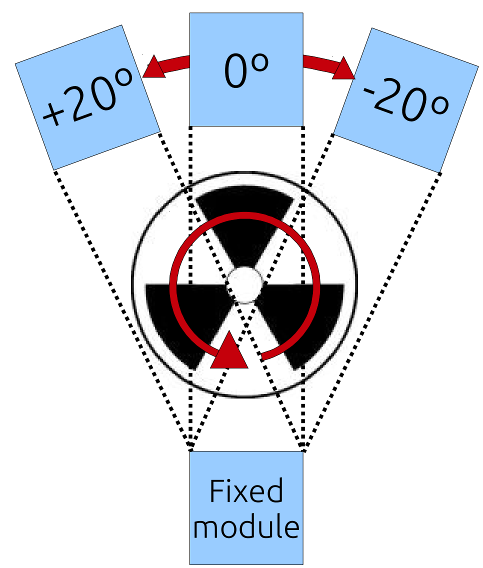


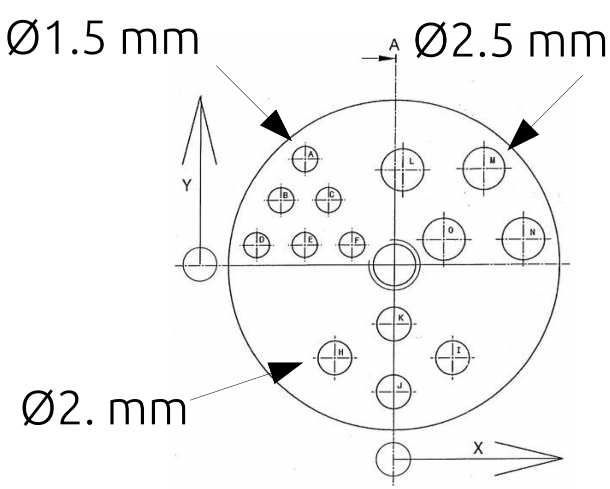
Dedicated reconstruction code based on MLEM (Maximum-Likelihood Expectation-Maximization)

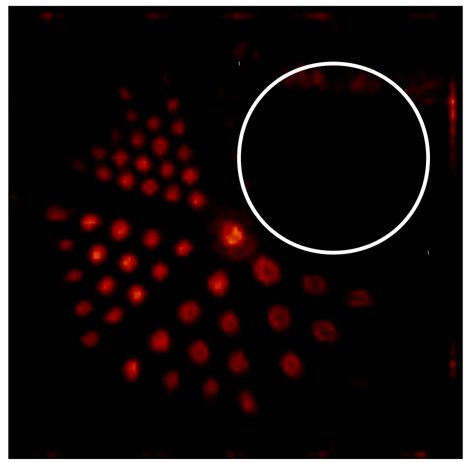
Geometrical component of the System Matrix computed using Siddon's ray-tracing technique



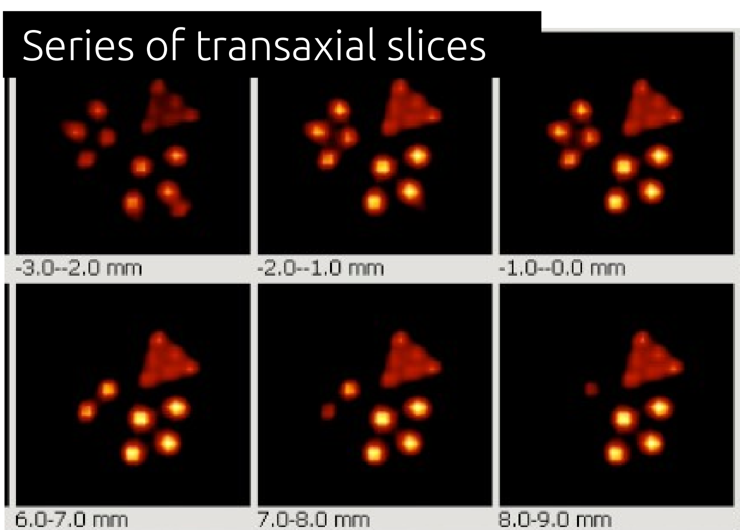
Results from tomographic reconstruction

Derenzo

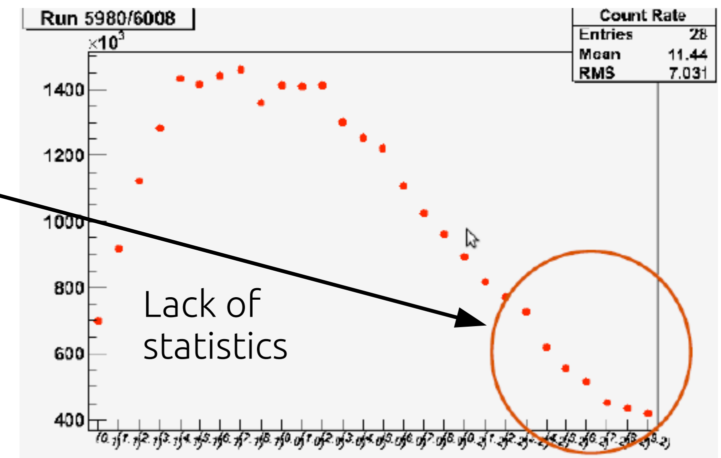




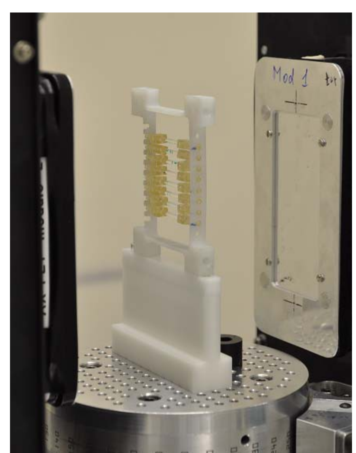
Ø1.5 mm capillaries resolved

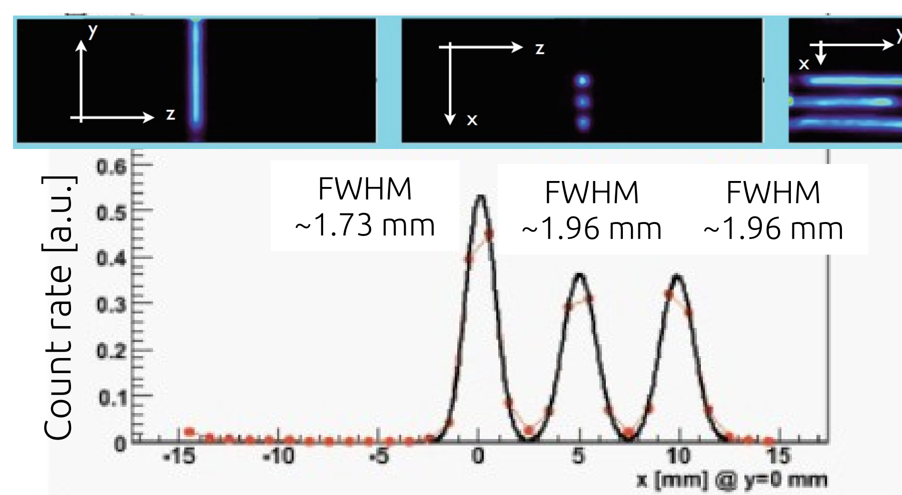


Mini Deluxe



Capillaries (Ø1.4 mm)

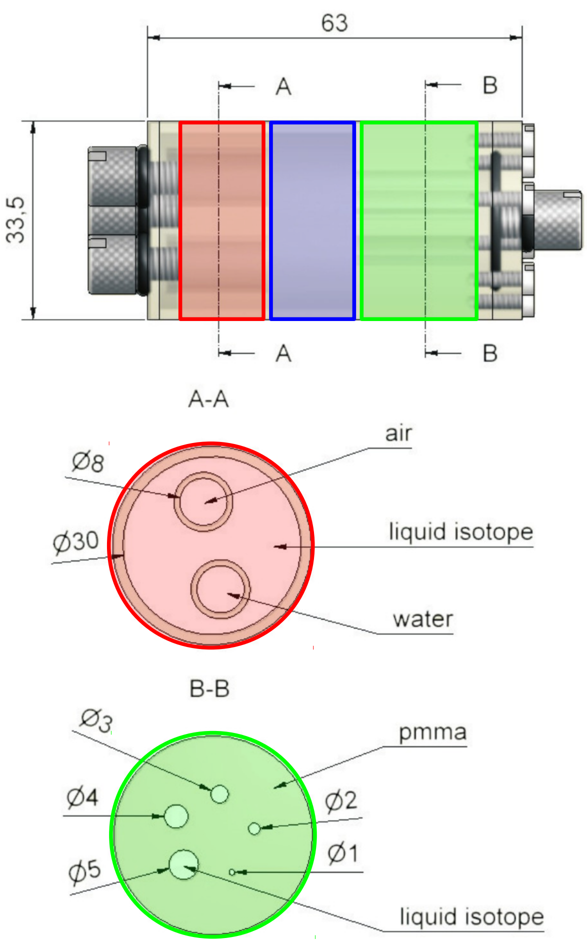


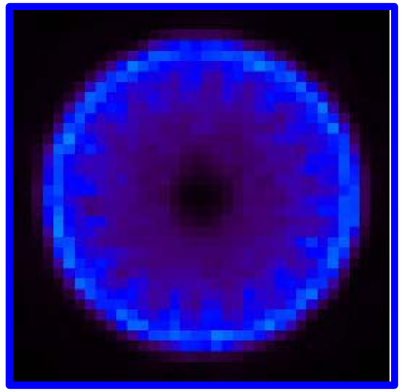


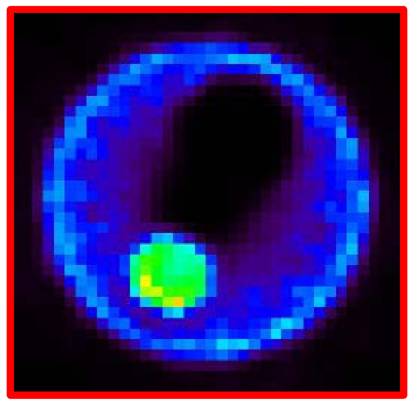
Results from tomographic reconstruction

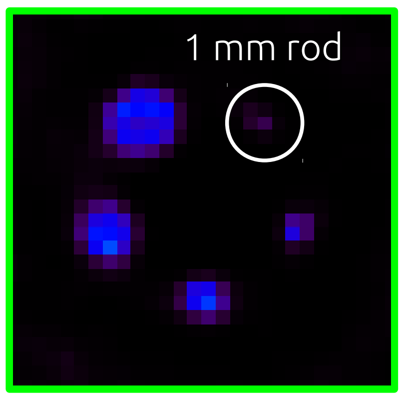
NEMA NU4

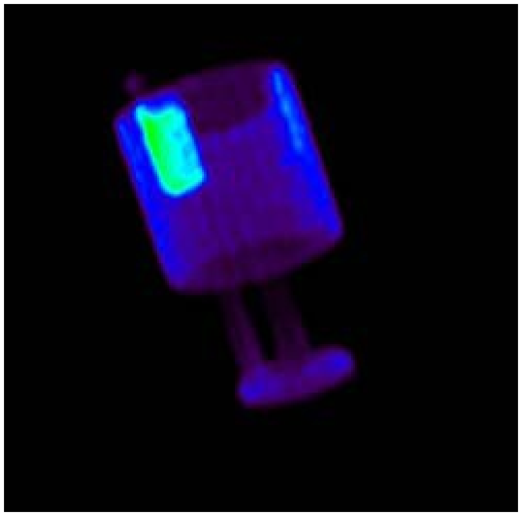
Image Quality
Mouse Phantom

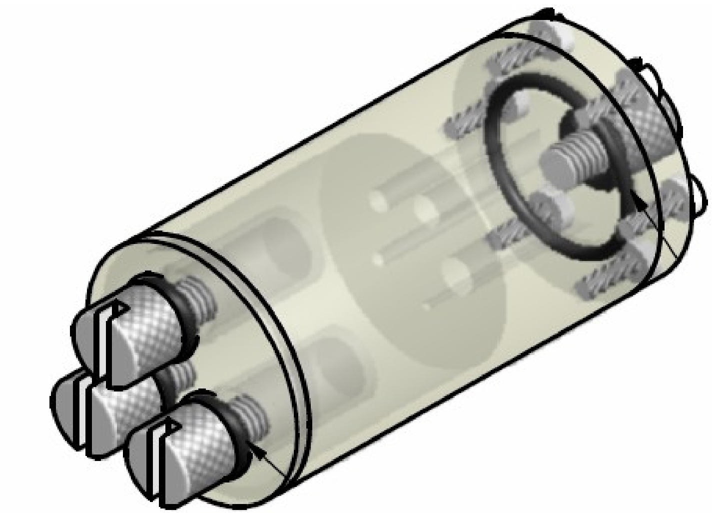












- Reconstruction problems mainly come from statistics or missing coverage
- Can still be improved refining the voxel size

Results from tomographic reconstruction

NEMA NU4

Image Quality
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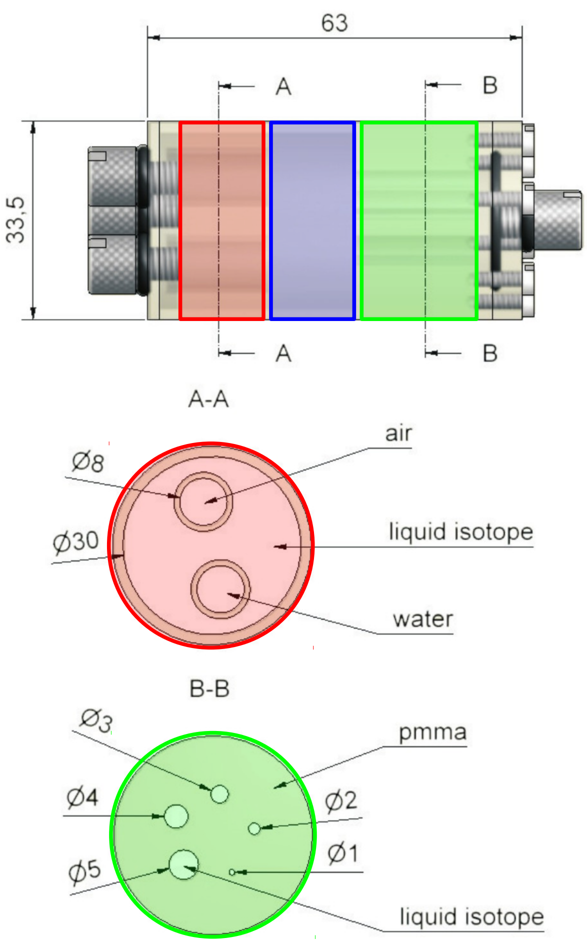

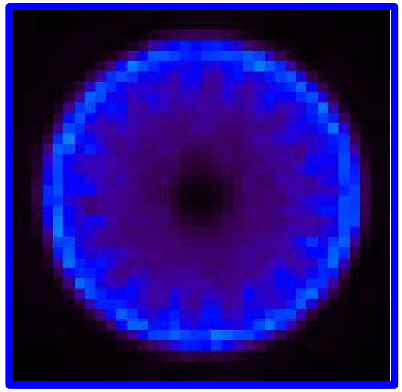

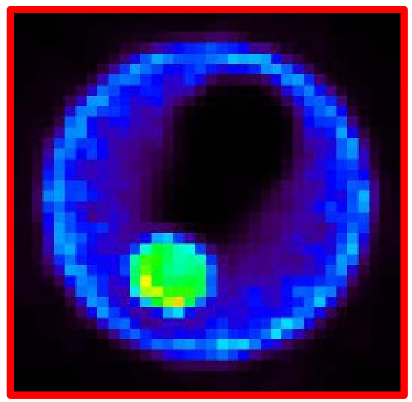

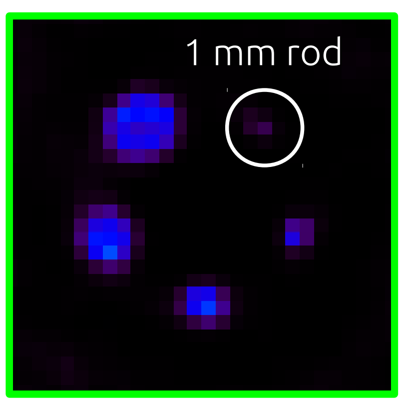

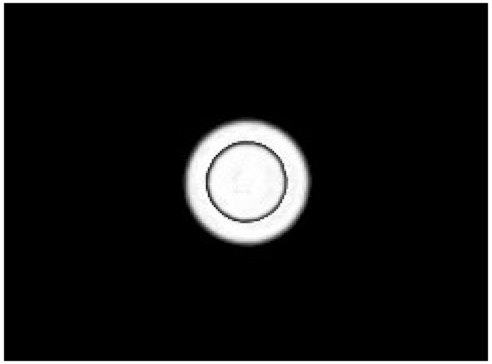

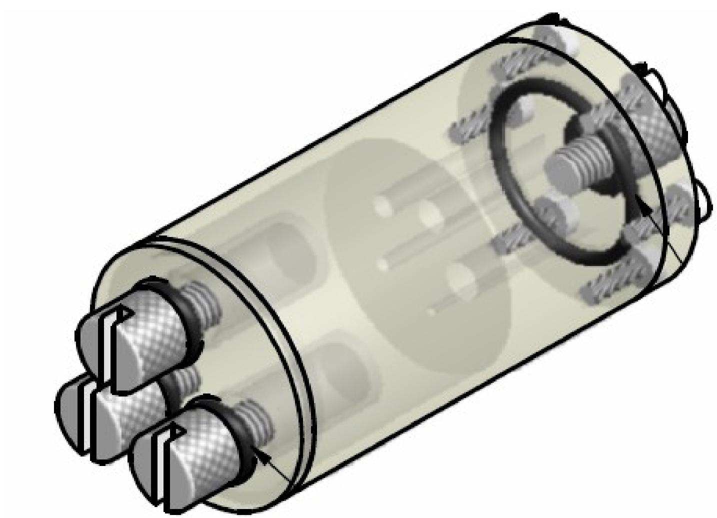

- Reconstruction problems mainly come from statistics or missing coverage
- Can still be improved refining the voxel size

Conclusions

- Modules fully characterized individually and in coincidence
  - Energy resolution single crystal 11.6% FWHM @ 511 keV
  - Axial resolution ~1.35 mm FWHM in coincidence
- Tuned simulation, very useful for reconstruction
- Reconstruction of point like source and phantoms with great precision
- Next steps :
  - Next campaign of measurements with phantoms to increase statistics (AAA, St Genis) and improve reconstruction images
  - Include Compton scattered events in the reconstruction
  - Simulate a full ring using the same concept

Thanks for your attention
The AX-PET collaboration

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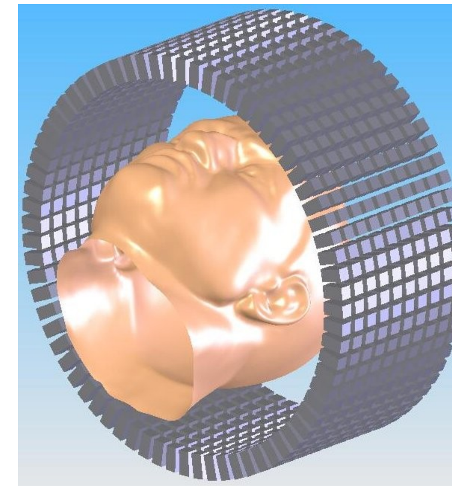
BACKUP SLIDES

The AX-PET concept

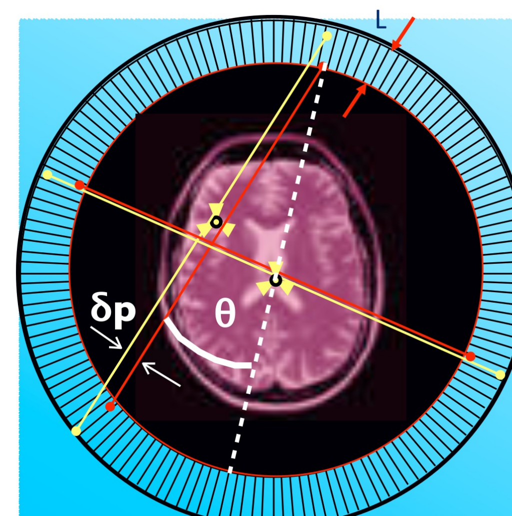
Conventional PET devices

Radial arrangement of scintillating crystals



Limitations :

- Cannot optimize spatial resolution **R** and efficiency **ε** at the same time, a compromise is needed :
  - No information about depth of interaction (DOI)
    - ➔ Parallax errors, $\delta p = L \sin\theta$ => short crystals to improve **R**
  - ε related to absorption lenght ,
    - – $\varepsilon = 1 - e^{-L/\lambda}$ => Long cristals to improve **ε**

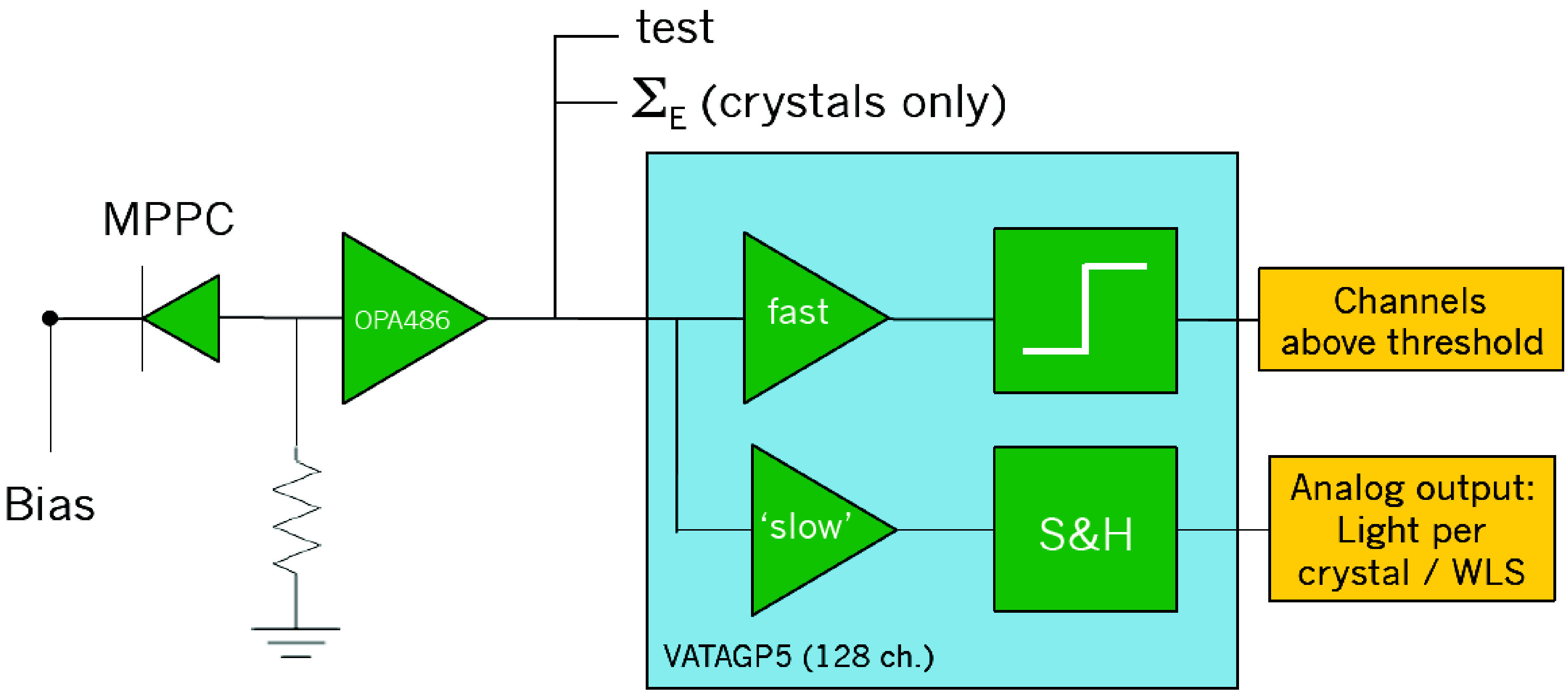


Conclusion :

→ Long radial crystals : high **ε** but poor **R**

→ Short radial crystals : high **R** but poor **ε**

Front end electronics and trigger

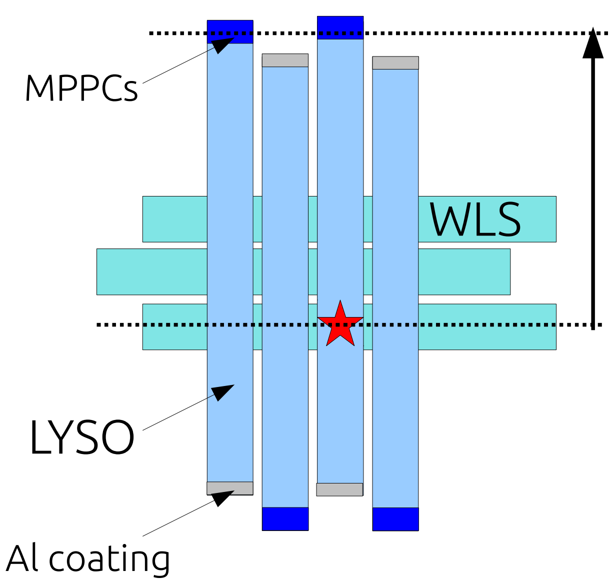


- Analog readout of crystals and WLS strips
- Sequential or sparse (only channels above threshold)
- Fast energy sum of all crystals of 1 module
- Trigger on 2 x 511 keV deposition in 2 modules

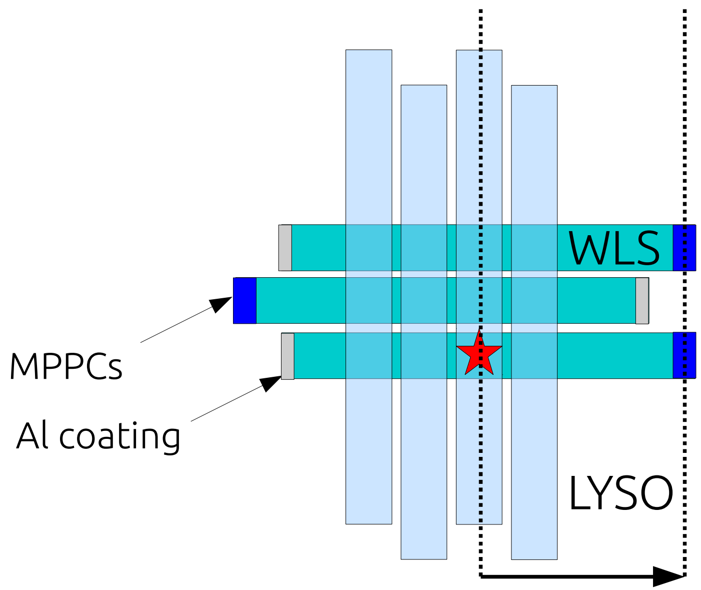
Measurement corrections

- The variation of the MPPC gain with the temperature is corrected to uniformize the response of all the LYSO and WLS
- WLS and LYSO are read out on one side, the other extremity being covered with a Al coating. Thus the light collected by the MPPCs depends on the position of the photoelectric interaction : Attenuation and reflexions
- This can be corrected using the spatial information from the WLS and LYSO

LYSO corrections

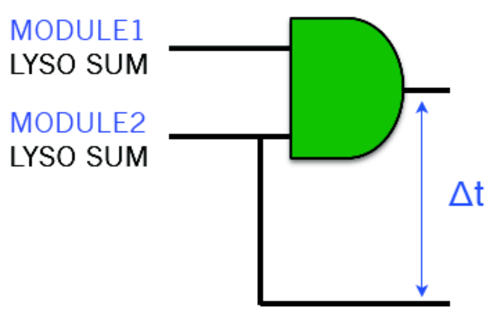


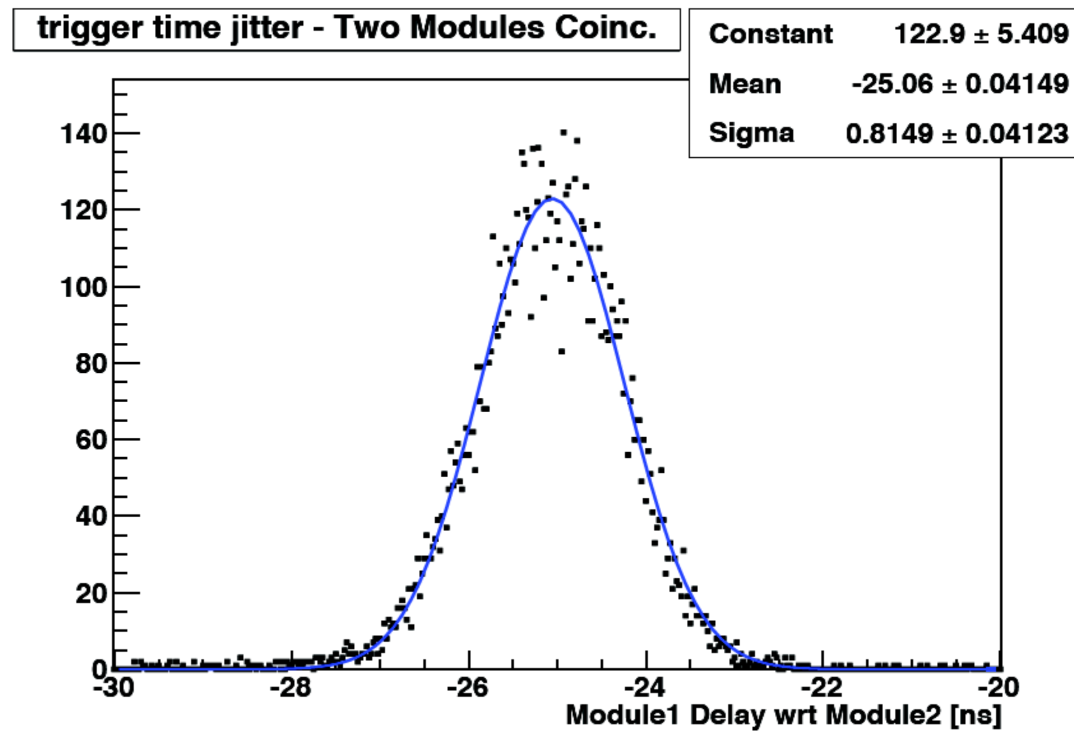
WLS corrections



Time resolution

- measure delay of coincidence wrt Mod2
- measurement from the scope [Lecroy Waverunner LT584 L 1GHz]





Measured time resolution : FWHM ~1.9 ns