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

Demonstration of an Axial PET concept for Brain and Small Animal Imaging

Christian Joram, CERN PH/DT

- The AXIAL PET concept
- Design of the Demonstrator (2 modules)
- Characterization
- Simulation and Reconstruction
- Next steps / near future plans

The AX-PET collaboration

Istituto Nazionale di Fisica Nucleare Bari (INFN)

Ohio State University (OSU)

European Organization for Nuclear Research (CERN)

University of Michigan

University of Rome Sapienza (INFN)

Instituto de Fisica Corpuscular (IFIC)

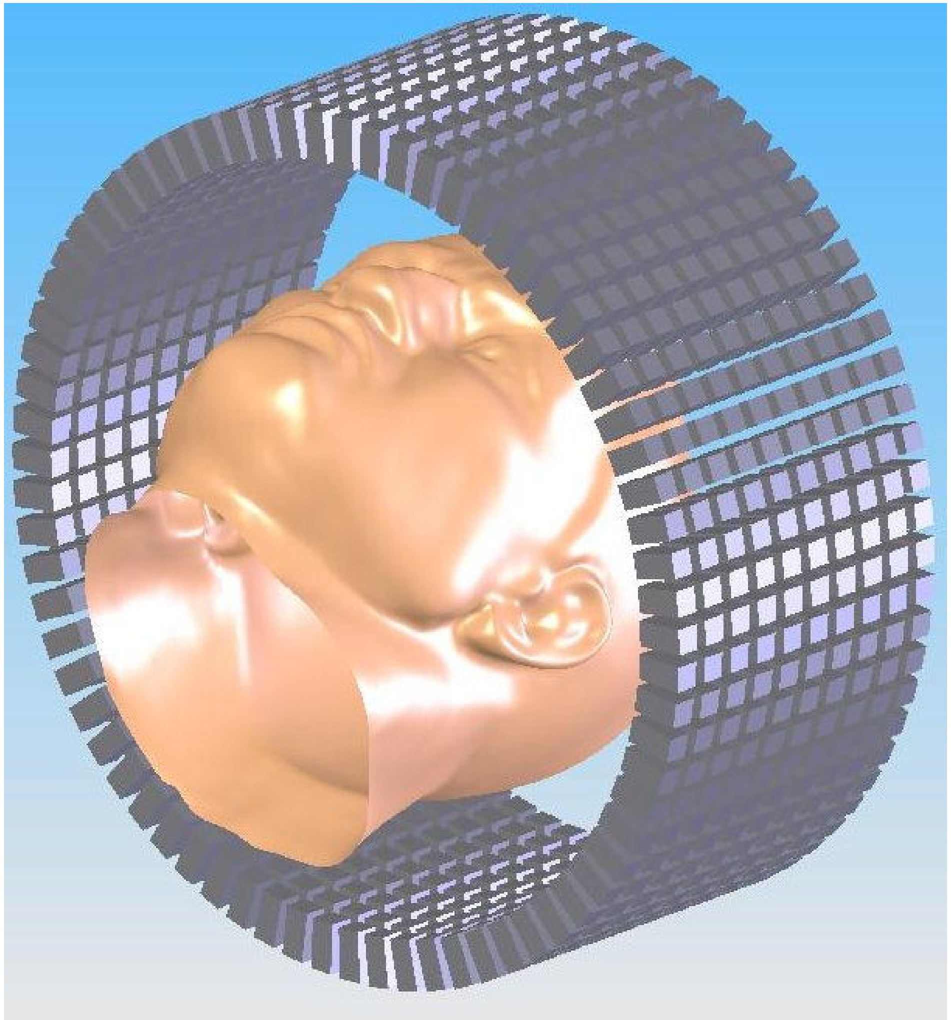
Paul Scherrer Institute (PSI)

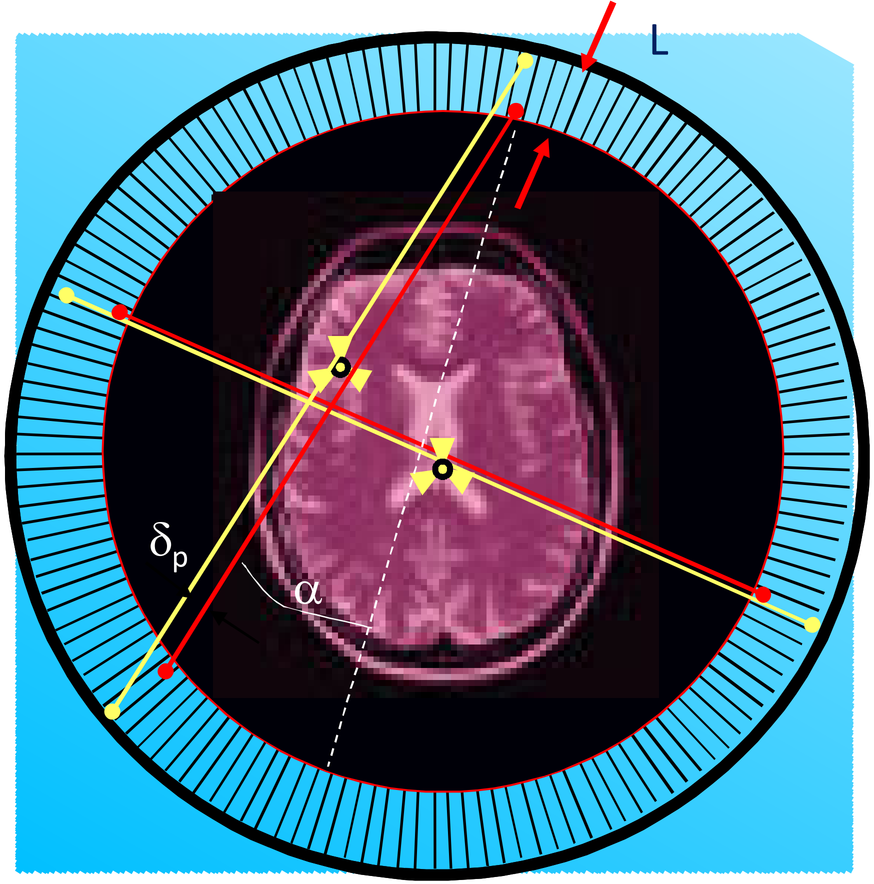
Eidgenössische Technische Hochschule (ETH)

P. Beltrame, A. Braem, V. Fanti, C. Joram, T. Schneider, J. Séguinot, C. Casella, G. Dissertori, L. Djambazov, W. Lustermann, F. Nessi-Tedaldi, F. Pauss, D. Schinzel, P. Solevi, J. F. Oliver, M. Rafecas, R. De Leo, E. Nappi, E. Chesi, H. Kagan, A. Rudge, P. Weilhammer, D. Renker, N. Clinthorne, E. Bolle, S. Stapnes , F. Meddi

WHY AX-PET ?

Standard PET today





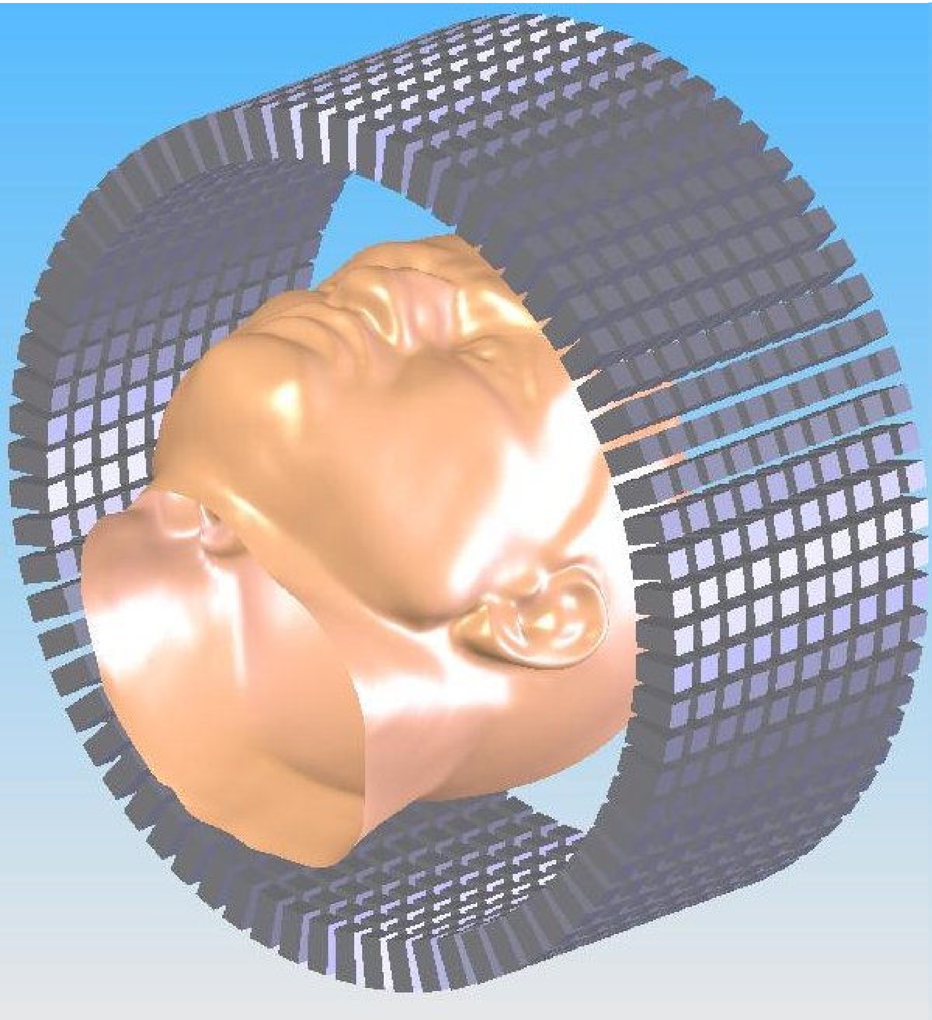
No DOI → Parallax error $\delta_p = L \cdot \sin \alpha$

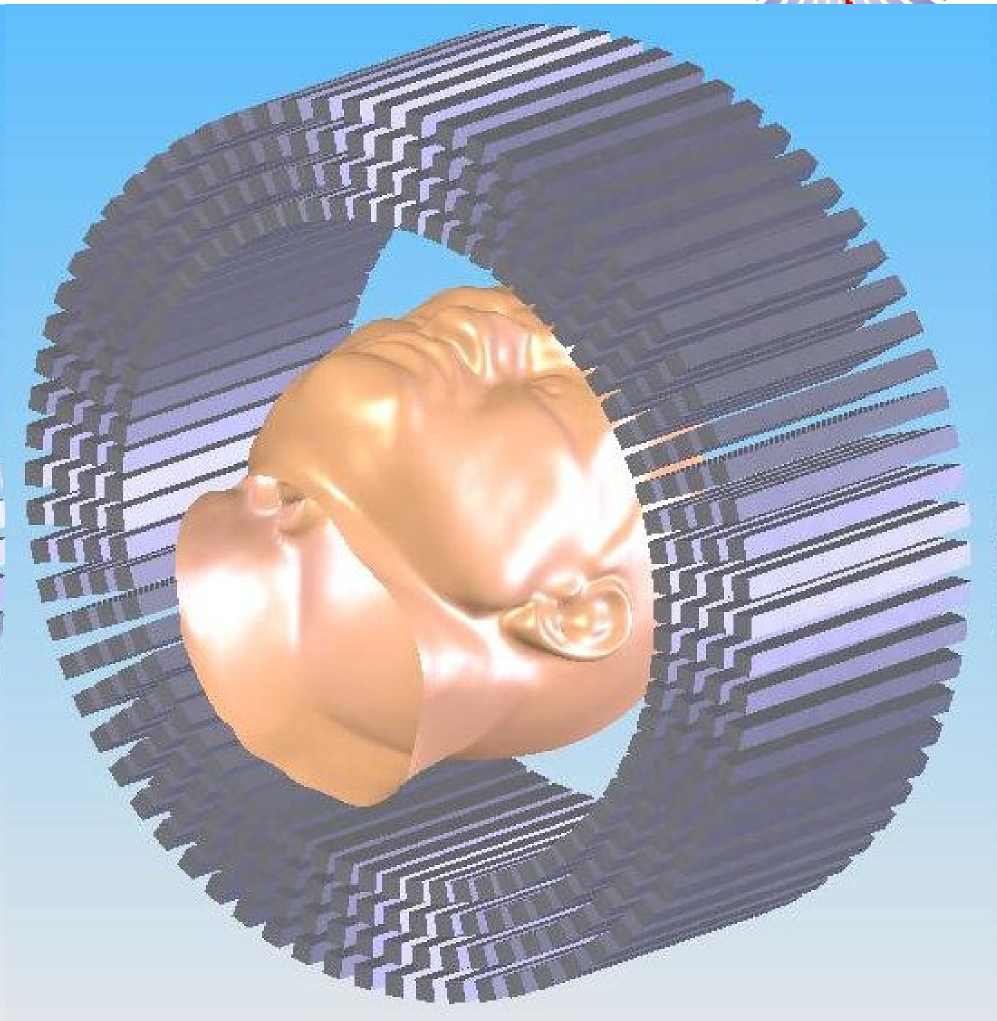
Detection efficiency $\varepsilon_2 = \left(1 - e^{-L/\lambda_a}\right)^2$

- Short, radially oriented crystals
- readout in blocks by PMTs
- Anger logic decoding
- no depth of interaction (some exceptions)

→ Find compromise between resolution and sensitivity

The AX-PET concept



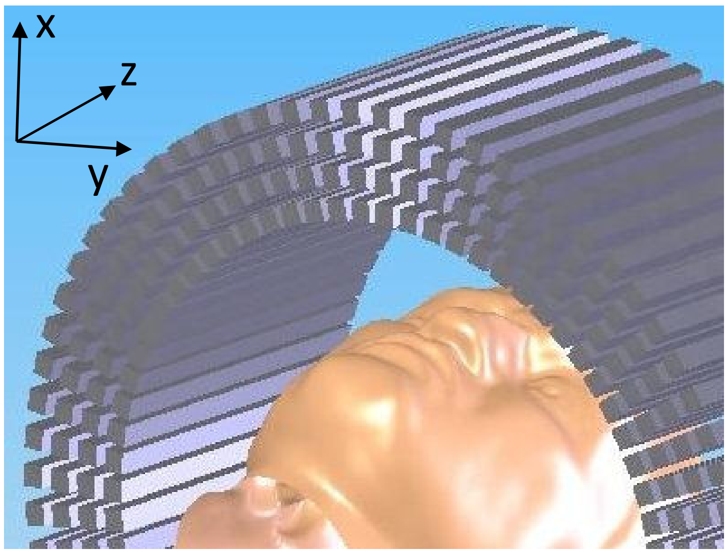


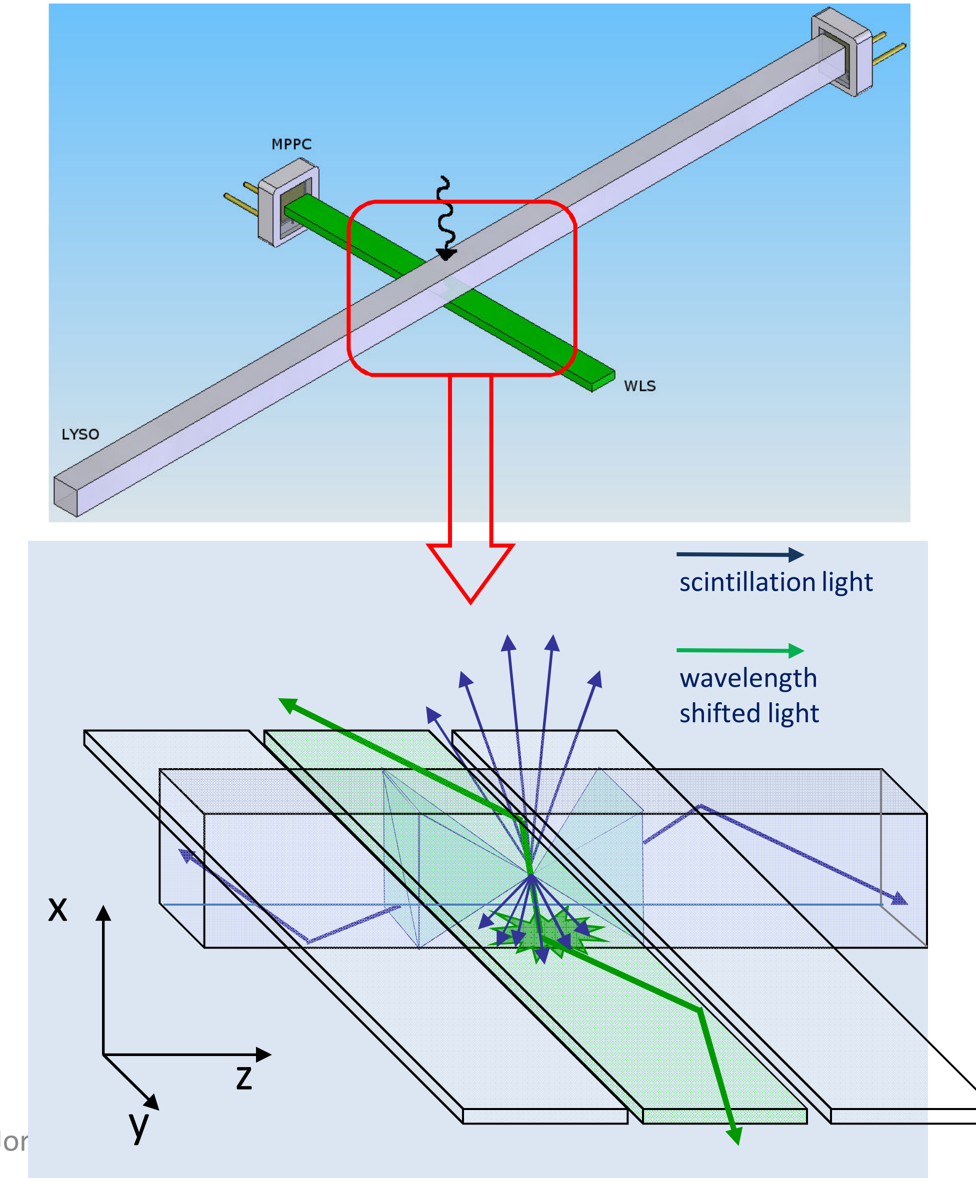
From short radially oriented, block readout crystals …

… to long, axially oriented, individually readout crystals

Our implementation of the AX-PET concept

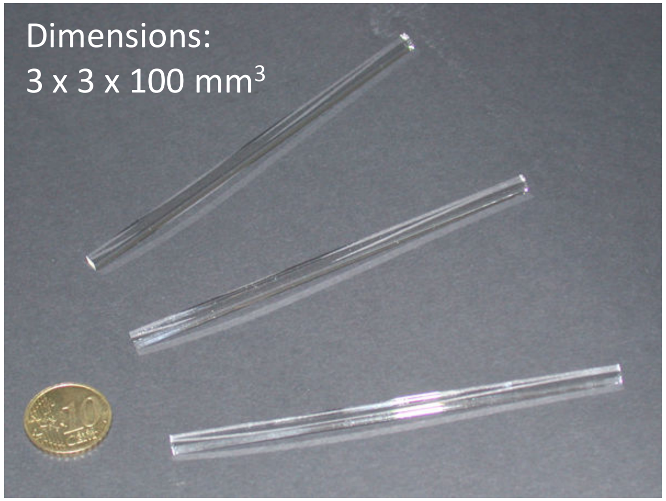
- How to read crystals ?
- How to measure axial coordinate ?



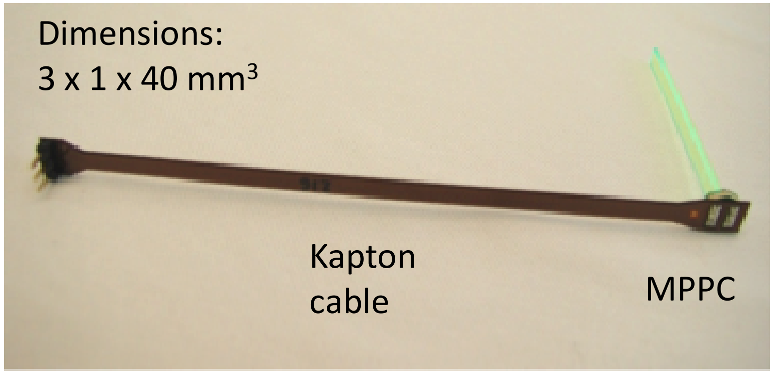


AX-PET components

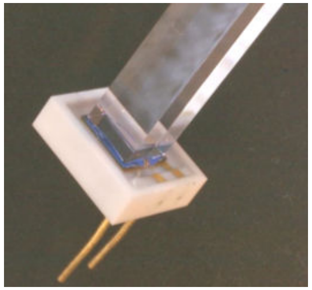
The **scintillator crystals** are Ce doped LYSO ($Lu_{1.8}Y_{.2}SiO_5$:Ce)

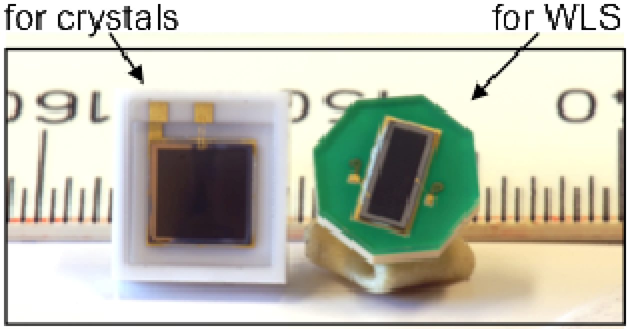


The **WLS strips** are of type EJ-280-10x from Eljen Technologies



The **photodetectors** are Geiger mode Avalanche Photodiodes (G-APD = SiPM) of type MPPC from Hamamatsu.



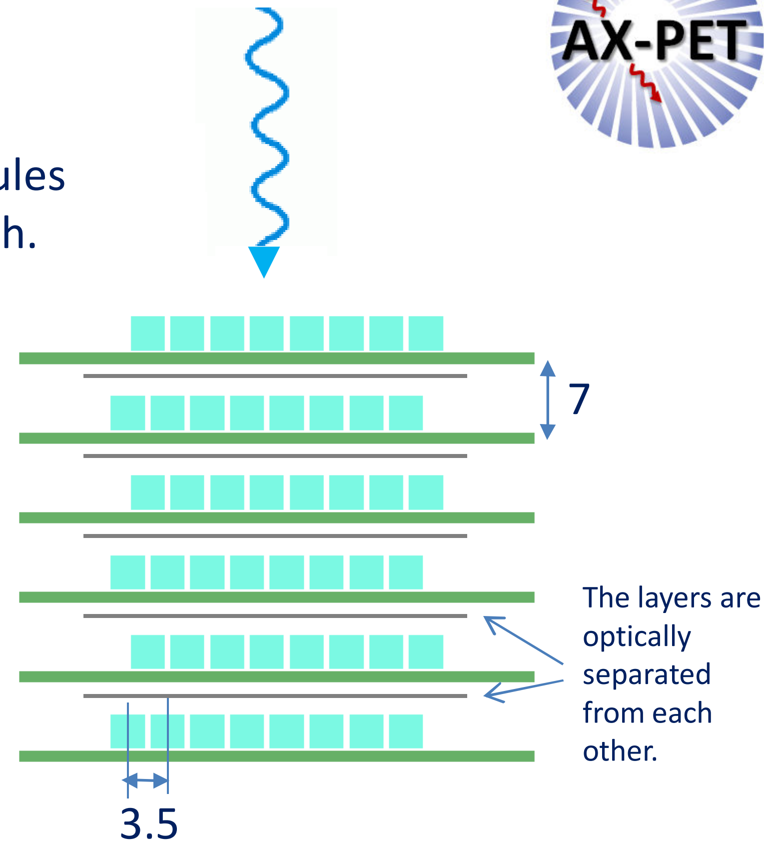


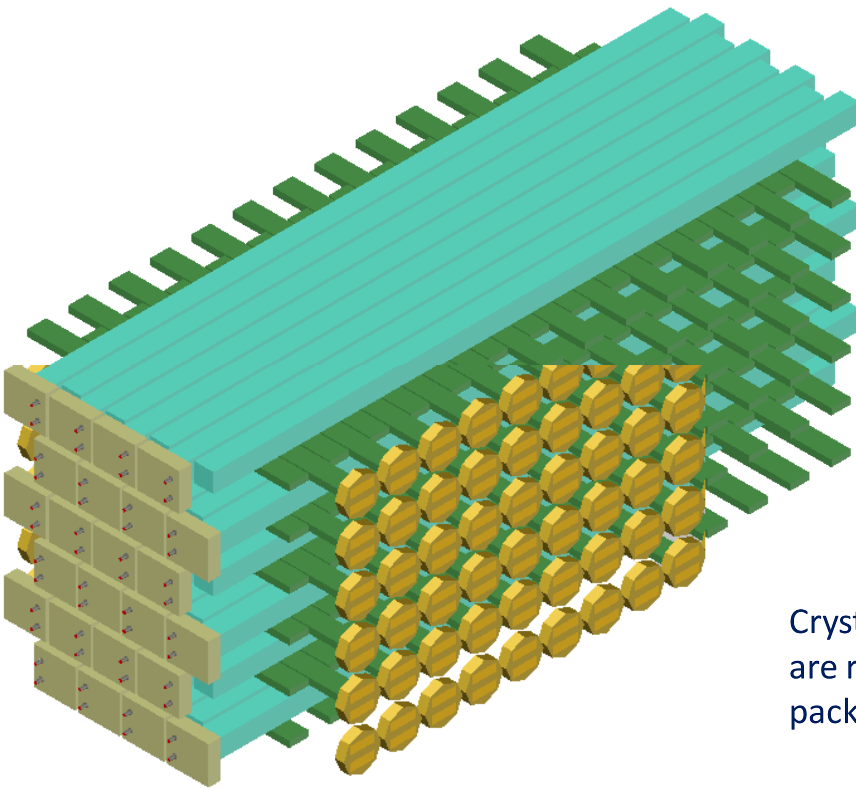
MPPC S10362-33-050C **MPPC 3.22×1.19OCTAGON-SMD**

AX-PET module geometry

- 48 crystals (6 layers x 8 crystals)
- 156 WLS strips (6 layers x 26 strips)

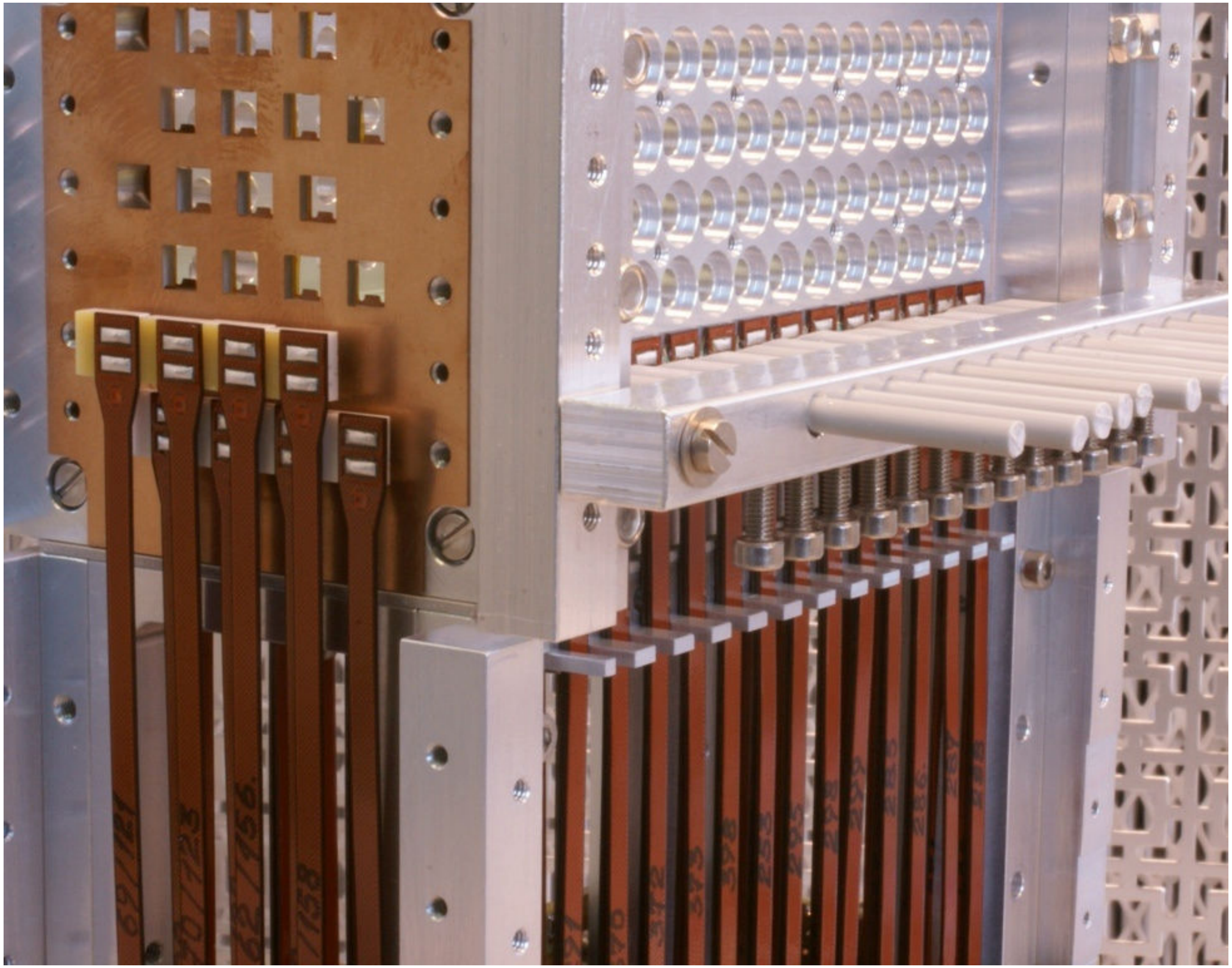
2 modules
= 408 ch.



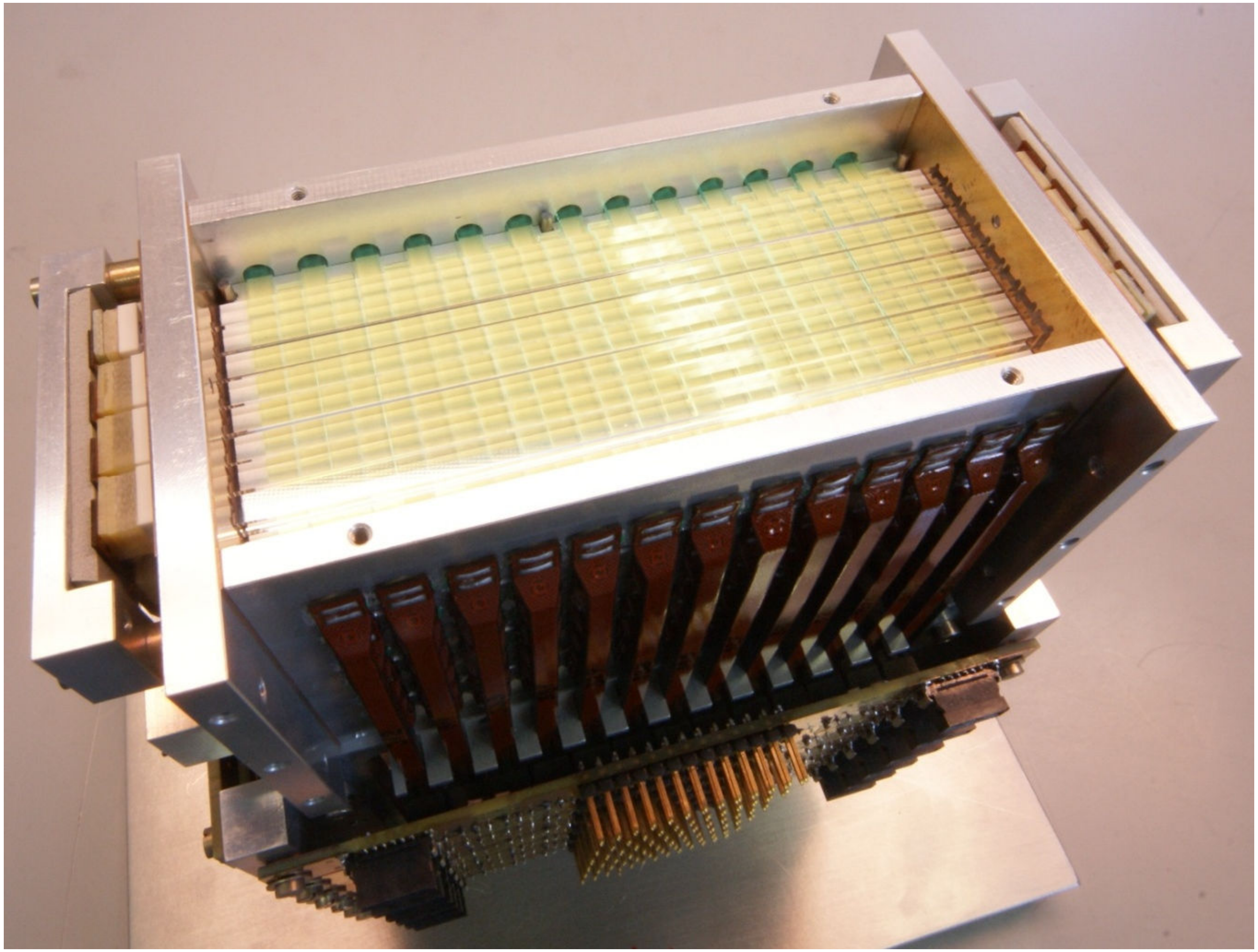


Crystals are staggered by 2 mm. Crystals and WLS strips are read out on alternate sides to allow maximum packing density.

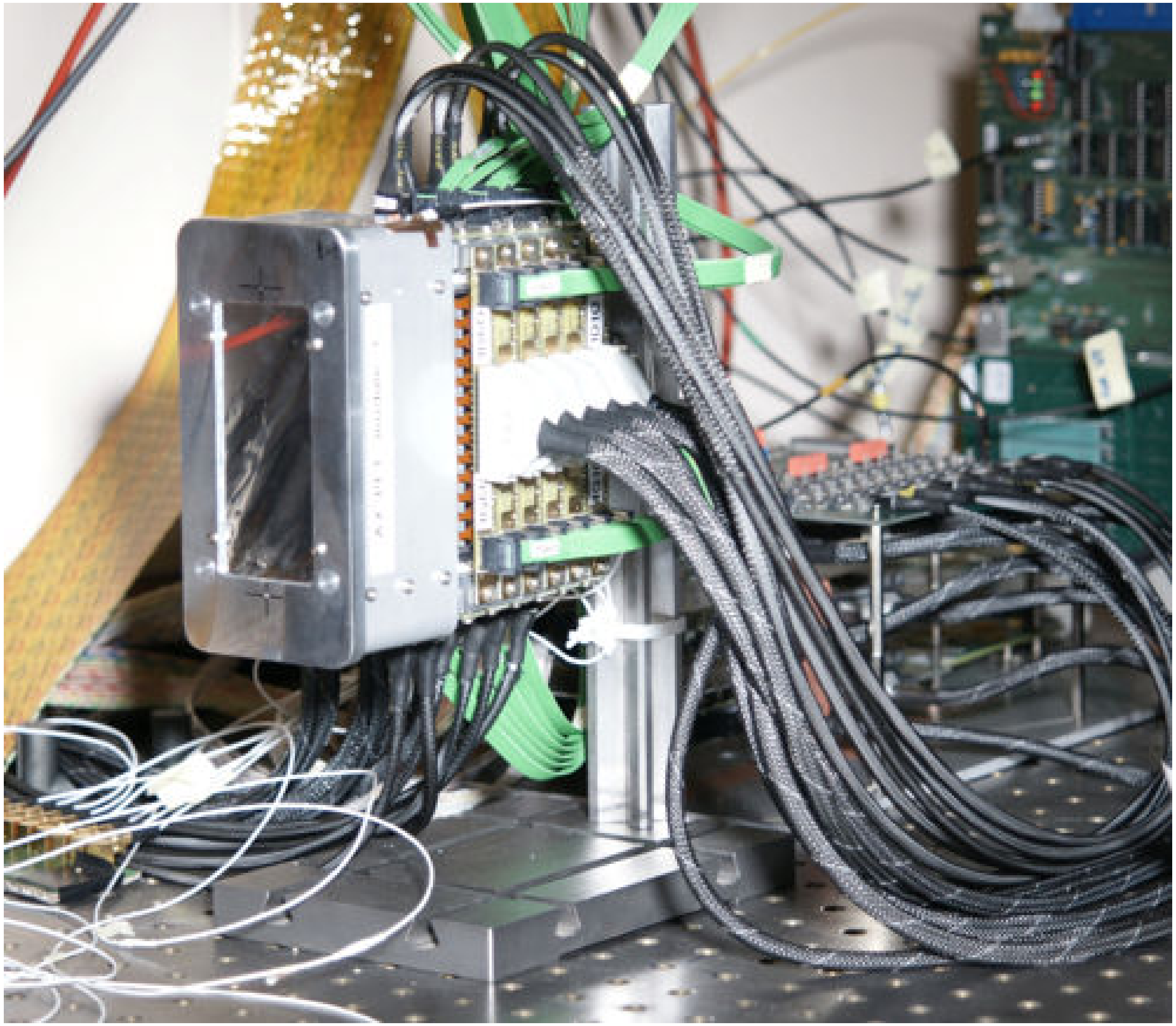
Putting everything together….



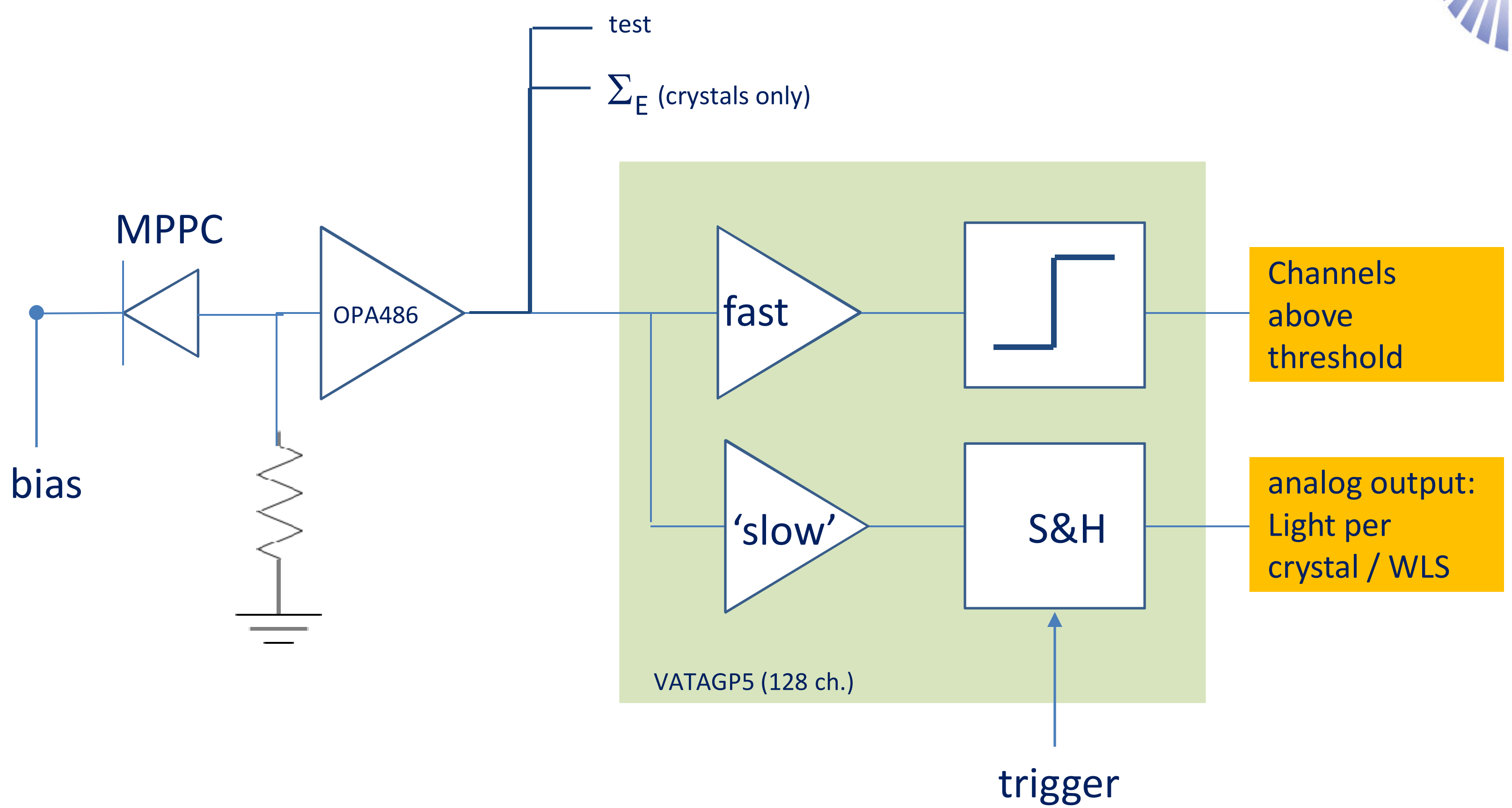
Fully assembled module (48 crystals, 156 WLS stips)



… adding light protection cover and cables



AX-PET Frontend Electronics (1 channel, simplified)

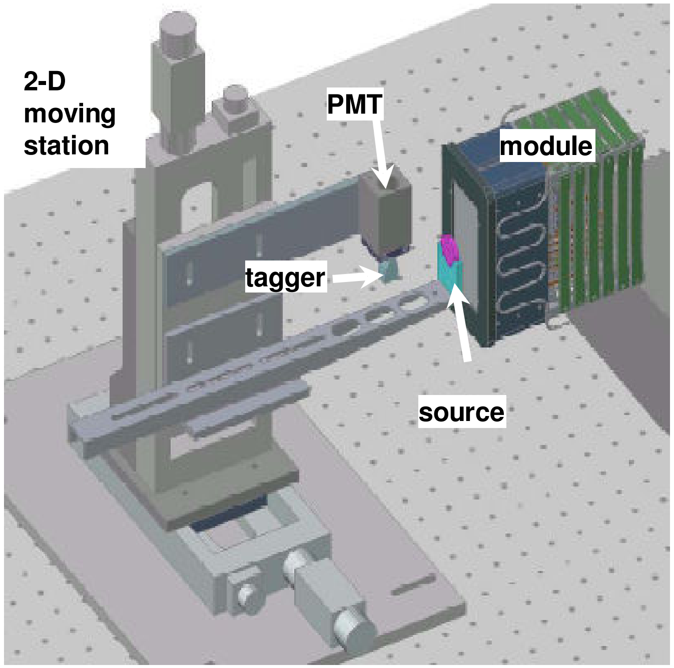


- **Analog readout** of crystals and WLS strips
- Sequential or sparse (only channels above threshold)
- **Fast energy sum** of all crystals of 1 module
- Trigger on 2 x 511 keV deposition in 2 modules

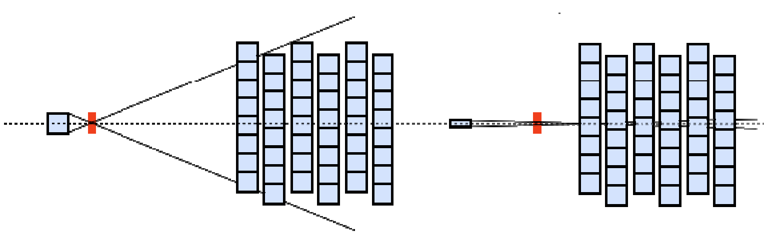
Test set-ups

^{22}Na source (ø=250μm; A~900 kBq)

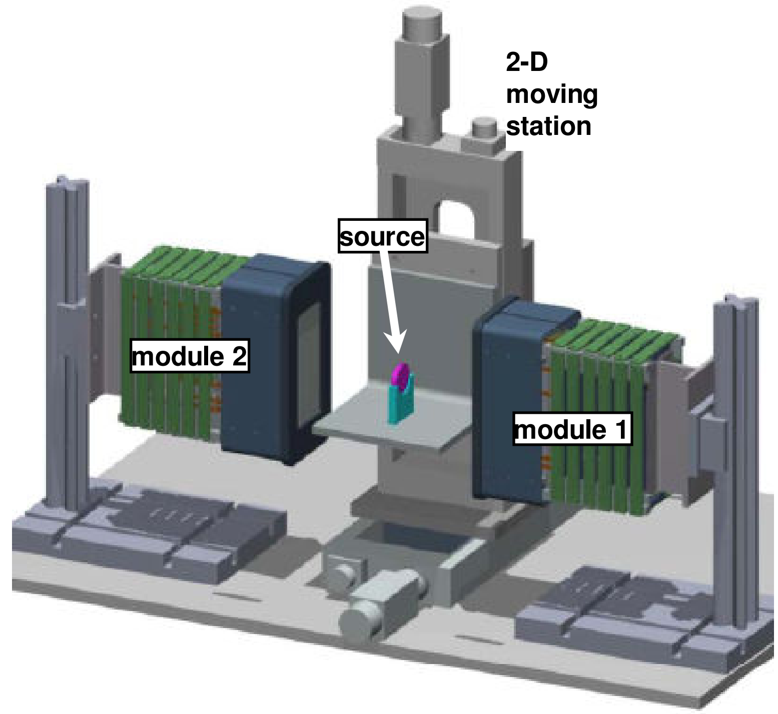
single module characterization



- Module in coincidence with a tagging scintillator
- Use of different tagging crystals



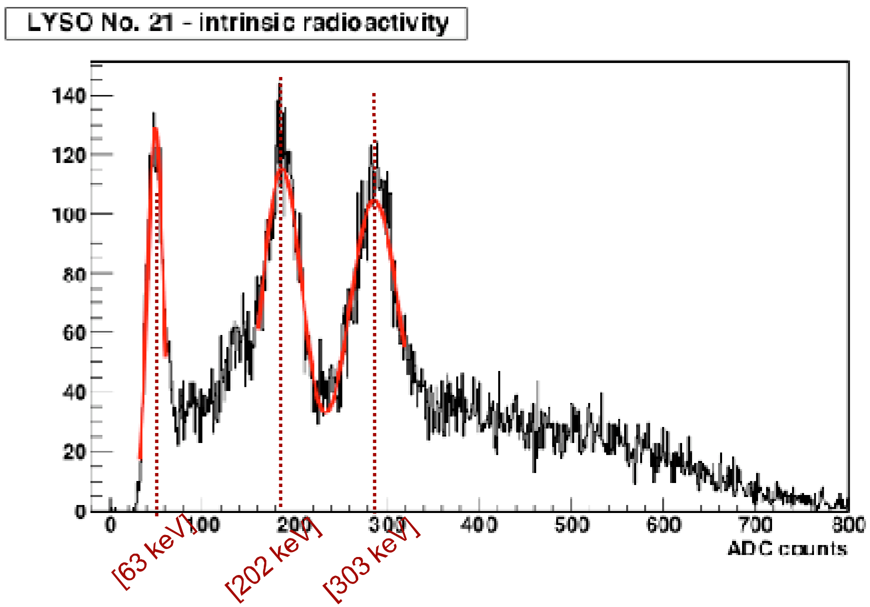
2 modules in coincidence

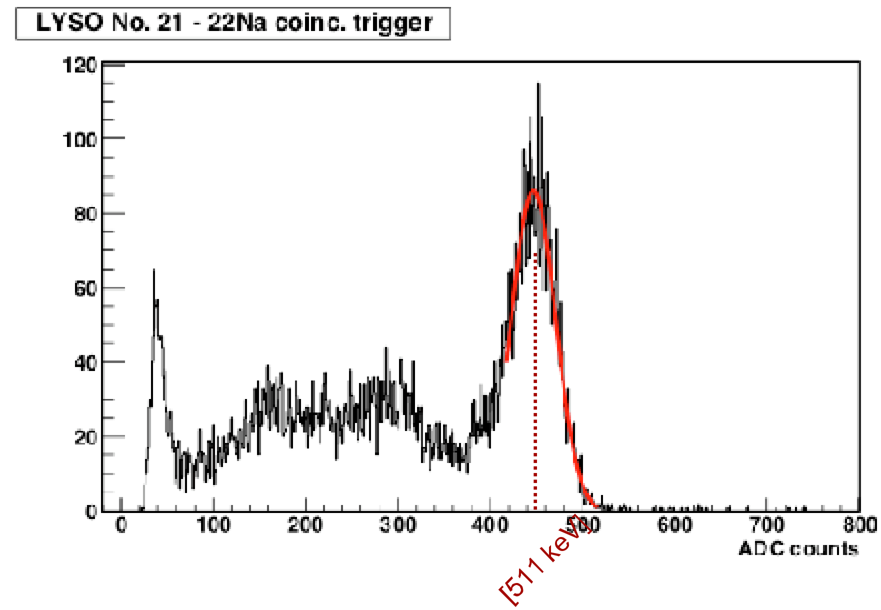


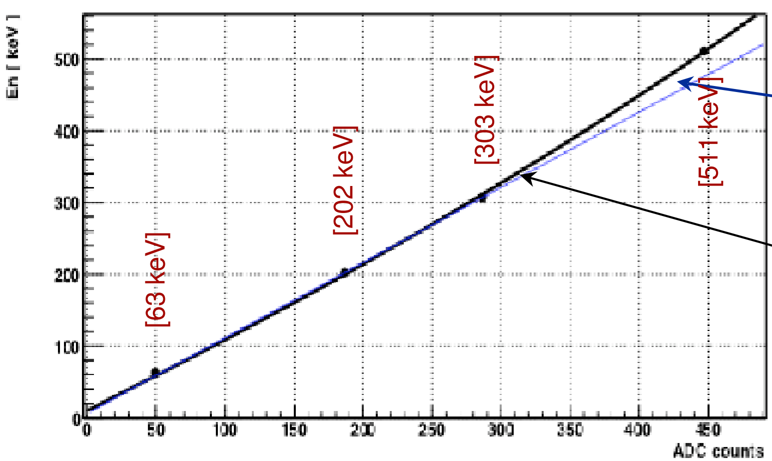
- Distance between modules = 15 cm

Energy calibration

Use intrinsic Lu radioactivity + Photopeak → self-calibrating” device



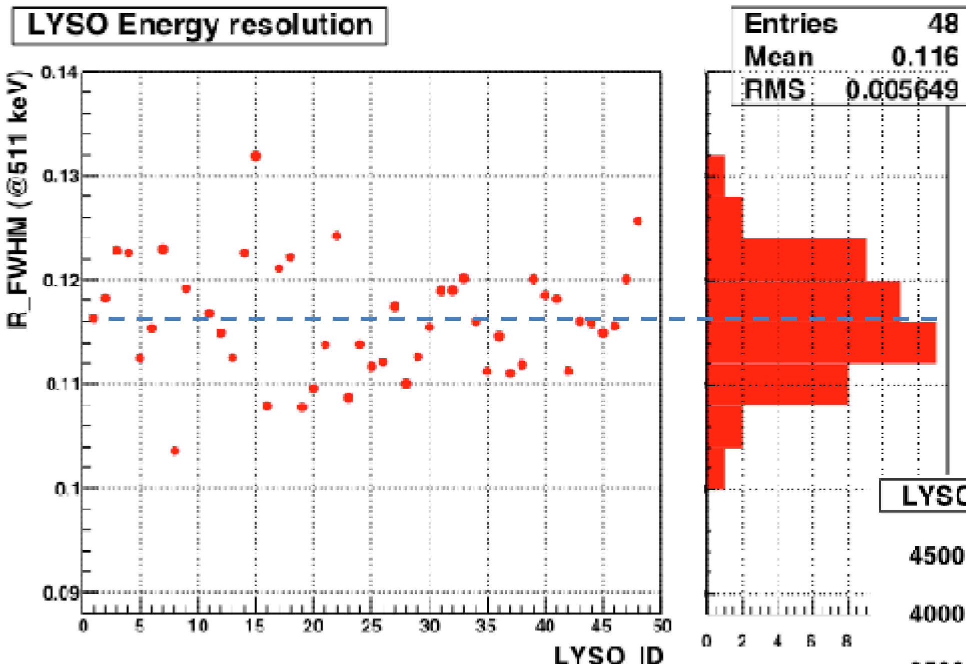




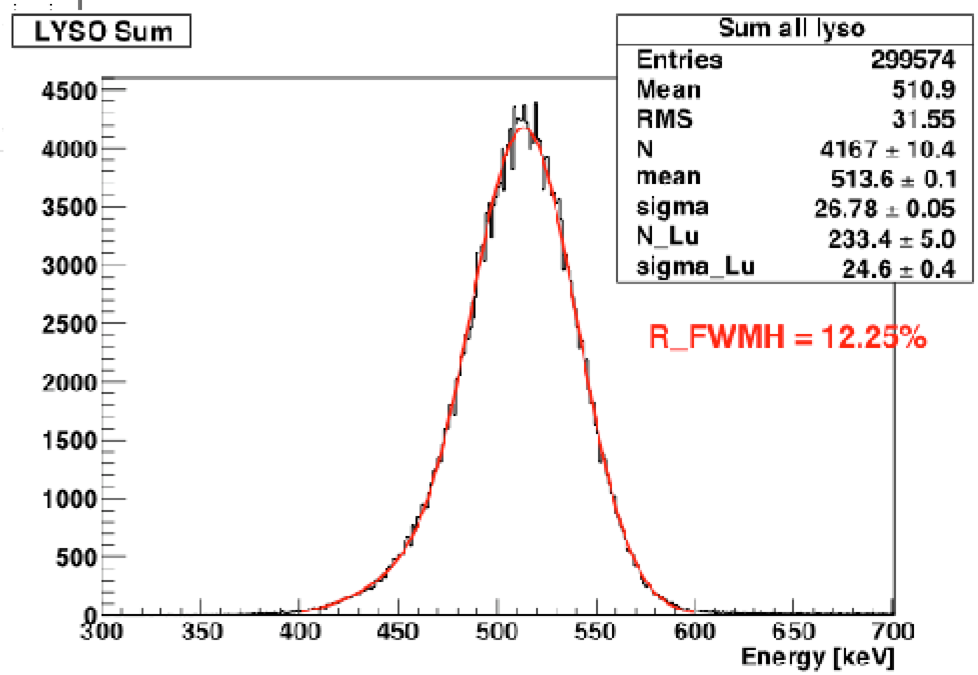
- deviation from linearity due to MPPC saturation (3600 pixels), ~ 5% effect
- parameterization: logarithmic function.

$$En(ADC) - E_0 - a \times ln\left(1 - \frac{ADC}{b}\right)$$

Energy resolution



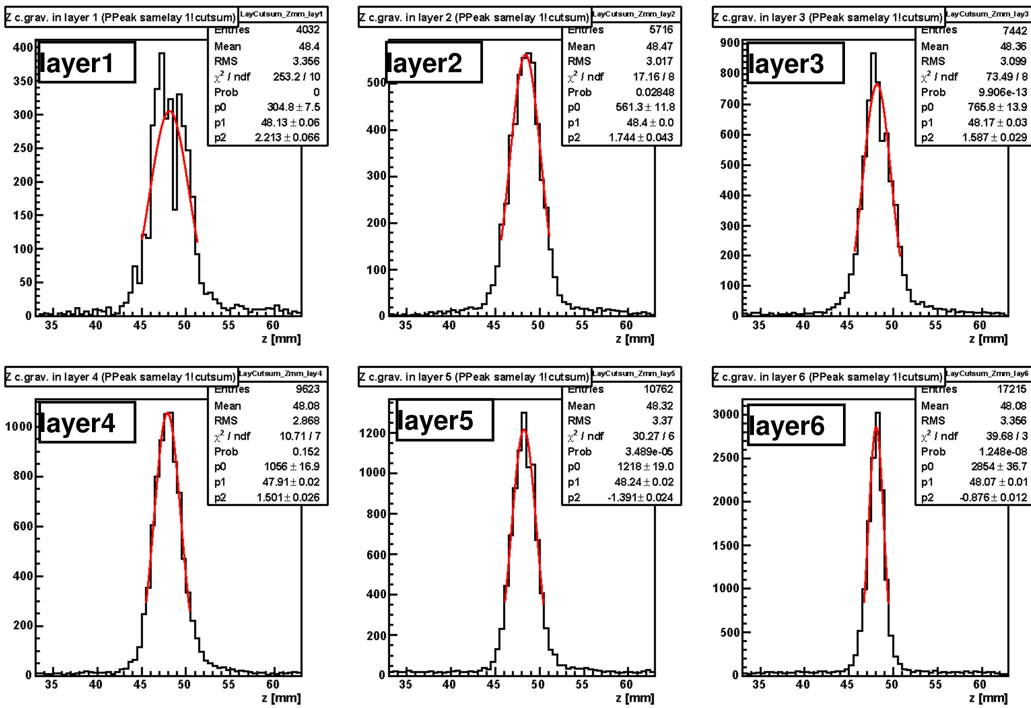
Individual crystals:
< R_FWHM > ~ 11.6% @511 keV
(averaged on all crystals)

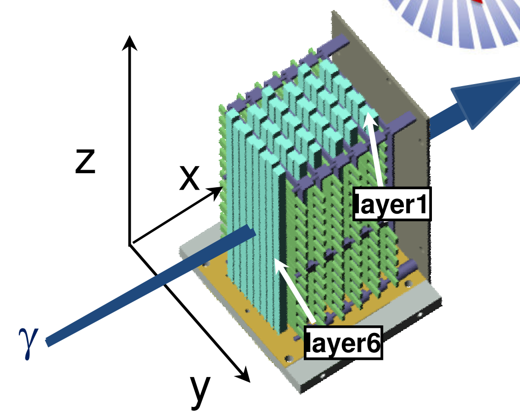


Sum signal (48 crystals)
R_FWHM_Sum ~ 12.25% at 511 keV
(on the summed distribution)

Axial (z) resolution

z coordinate = COG of hit WLS strips (typically 2-4)



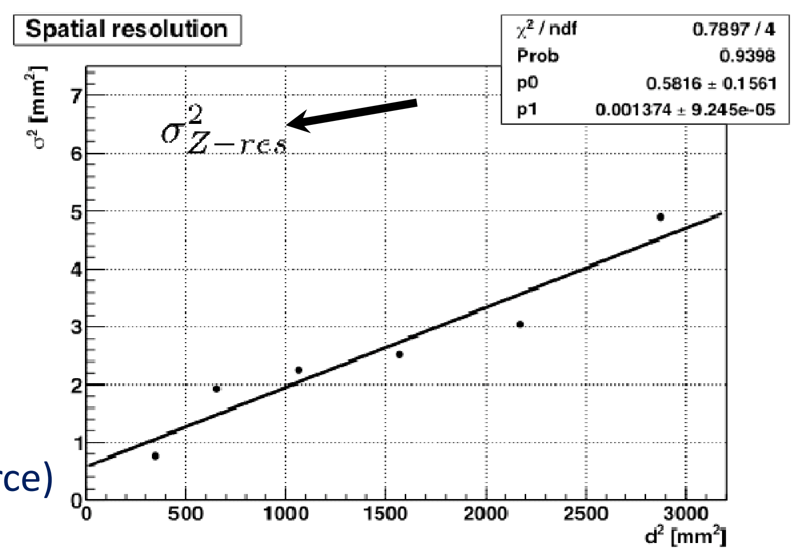


σ_i [i=1,6] include:

- intrinsic spatial resolution
- beam spot size on each layer

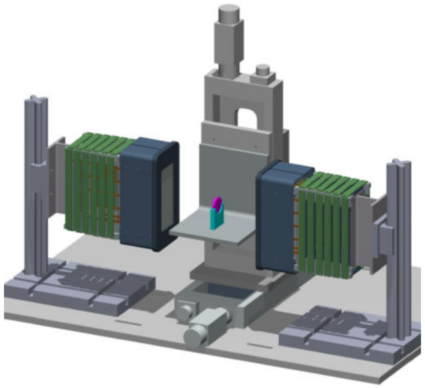
$$\sigma_i^2 = \sigma_{i\_beam}^2 + \sigma_{Z-res}^2$$

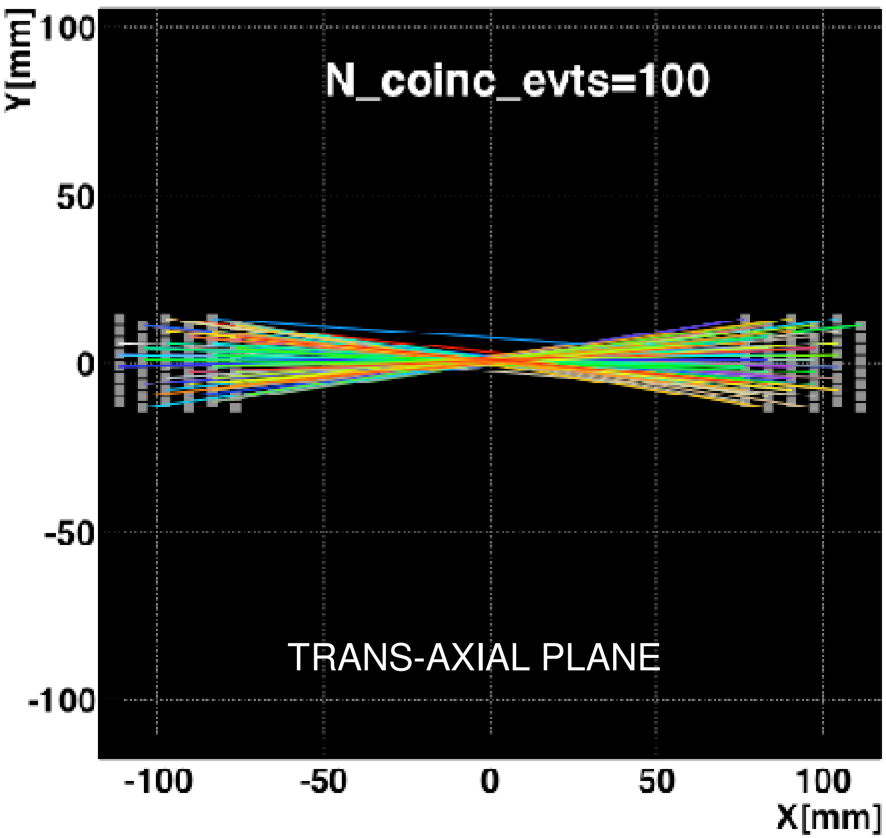
σ(d=0) ~ 0.76 mm
FWHM ~ 1.8 mm
(still includes size of source)

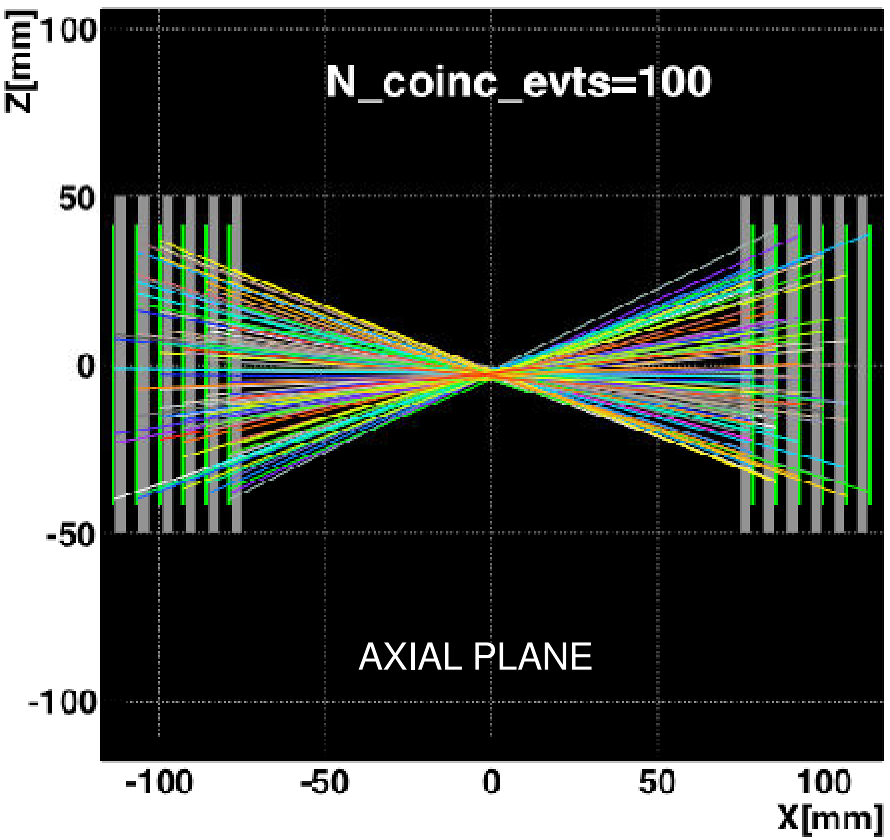


First coincidence measurements

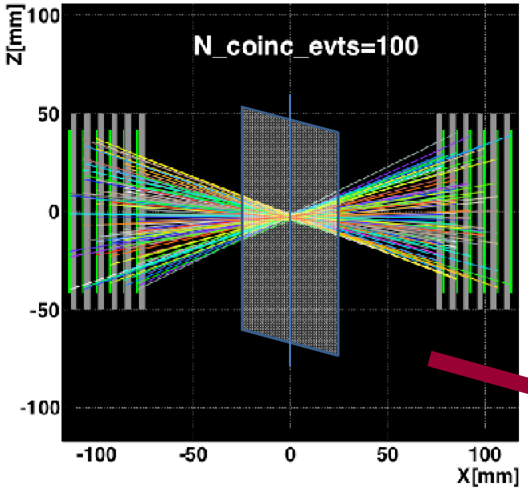
- Photoelectric events only (1 hit crystal per module)
- Draw “LOR” (pure geometrical, no tomographic reconstruction)



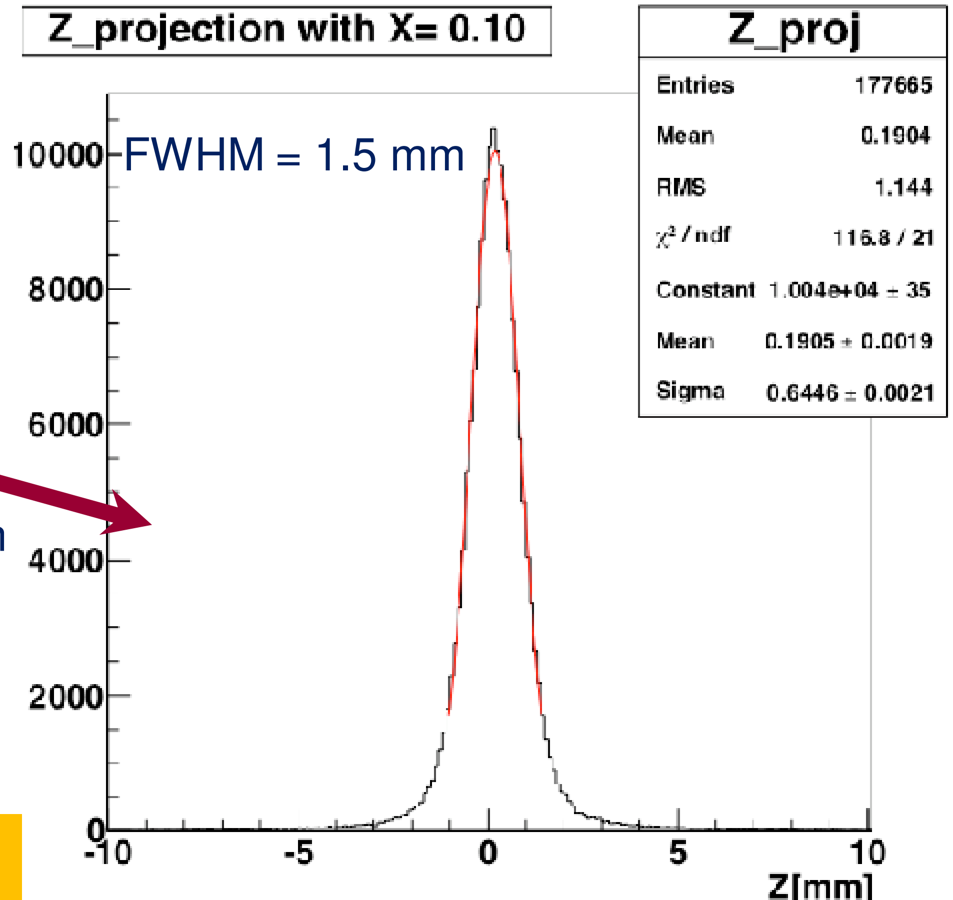




Estimate of Axial resolution



intersection with plane (x=0)

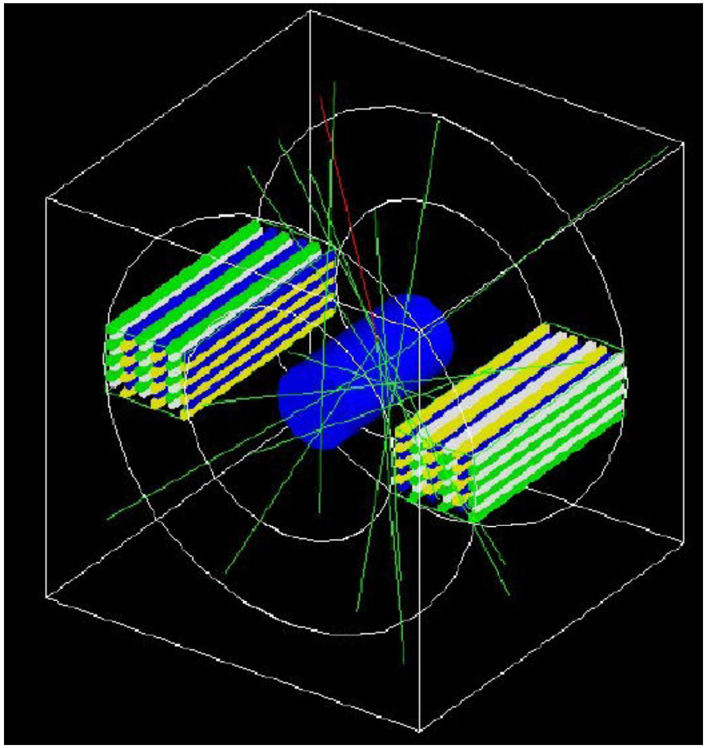


First tomographic reconstruction of point source data has been achieved last weekend. Will be discussed in AX-PET meeting tomorrow!

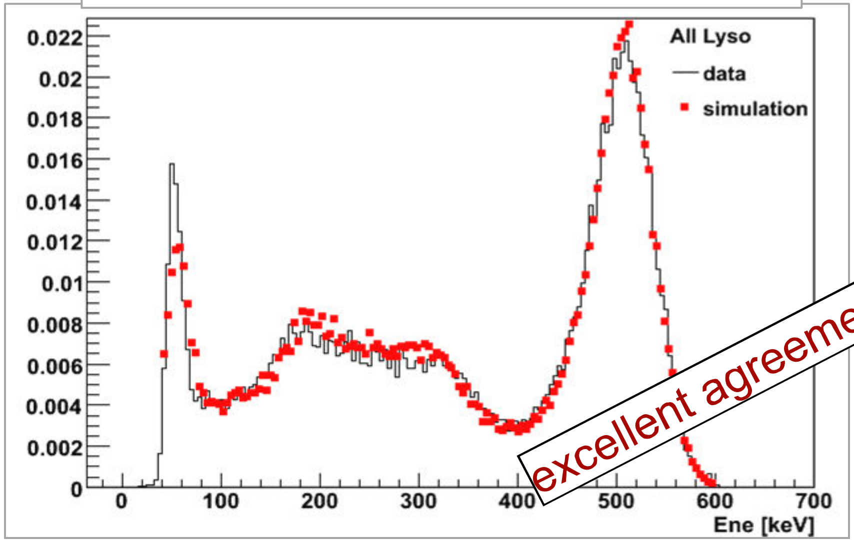
Resolution still includes size of source. Finite positron range! (in water: <range> = 0.6 mm)

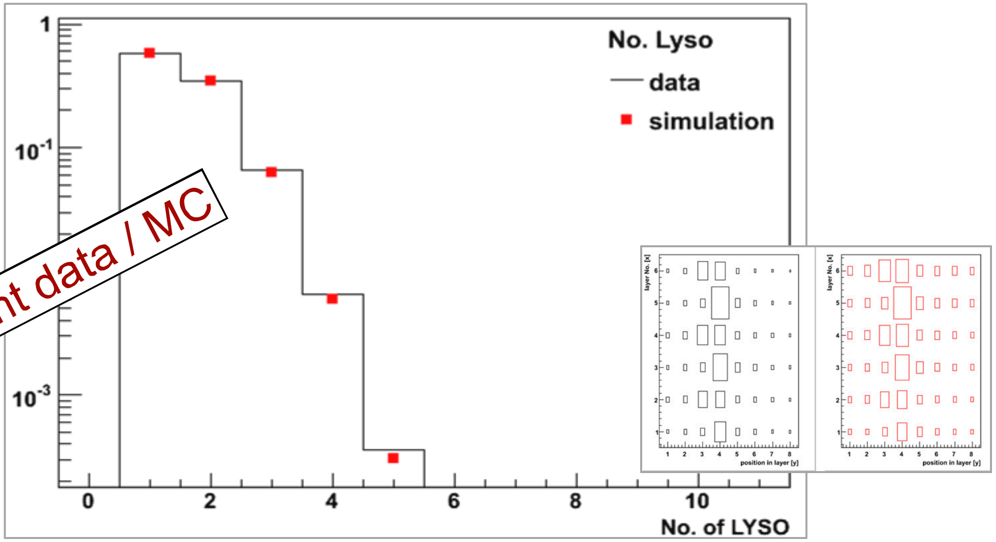
AX-PET simulation

- **Geant4** (multi-purpose Monte Carlo tool, optical transport, dedicated geometry)
- **GATE** (PET dedicated MC, including time dependent phenomena, scanner rotation, source/phantoms...)



Energy - E_{LOW}=40 keV, E_{SUM}=[400,600] keV





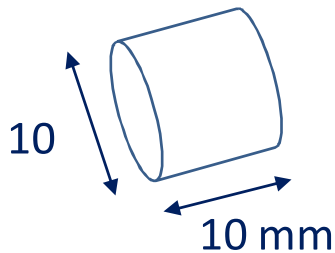
excellent agreement data / MC

AX-PET reconstruction

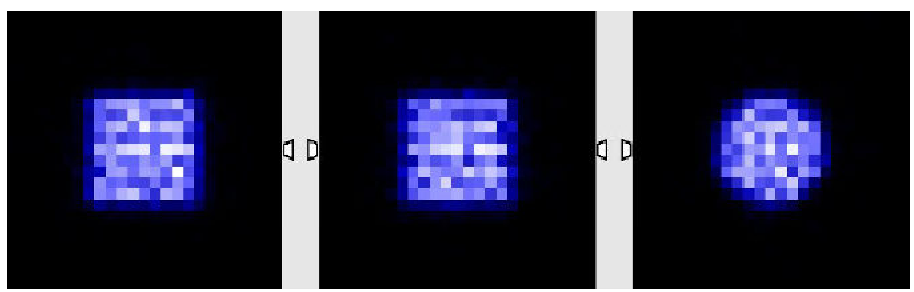
A dedicated reconstruction code, based on MLEM (Maximum Likelihood Expectation Maximization) has been developed.
The geometrical component of the system matrix has been computed using Siddon's ray-tracing technique. Takes also account for crystal attenuation and penetration effects.

Monte-Carlo data for a cylindrical source:
D = 10 mm, h = 10 mm

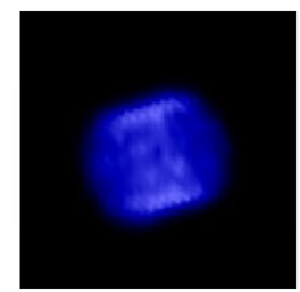
- FOV: 25x25x25 mm^3
- Voxel: 25x25x25 vox^3
- #steps = 6
- Distance = 10 cm



Reconstruction of real data very soon!



Projections (x, y, z)

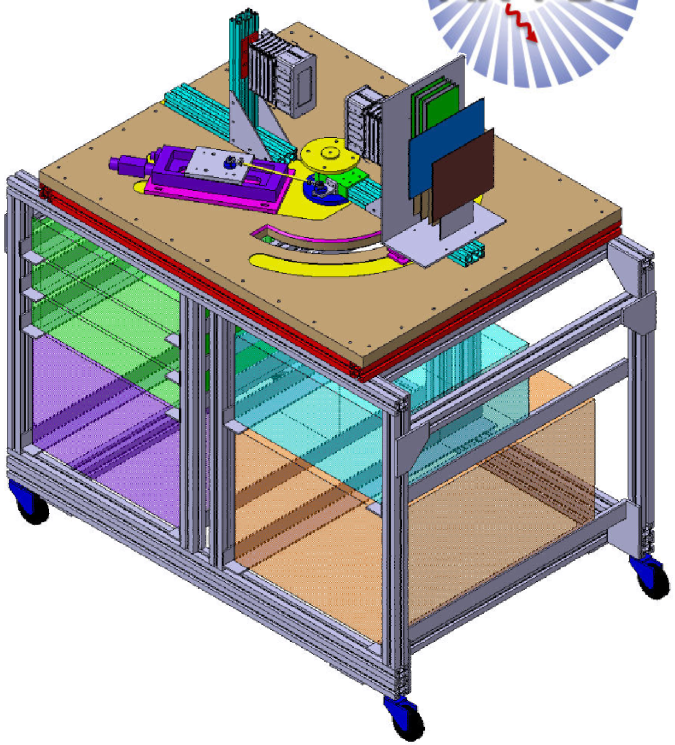


3D image

AX-PET main features

- parallax-free 3D localization of photons.
- Spatial resolution (crystal and WLS strip dimensions) and sensitivity (additional layers) can be optimized independently. Physical limits in reach.
- The 3D capability should allow to identify a significant fraction of Compton interactions (Inter Crystal Scatter).
  ICS events can either be discarded (resolution fully maintained) or reconstructed (increased sensitivity).
- AX-PET concept can be scaled in size and number of layers to match specific needs.
  → small animal PET
  → brain PET
  → full body PET
  → PEM (mammography)
- Concept and components are in principle MRI compatible and TOF extendable.

What’s next ?



- Mount set-up on a horizontal gantry
  (rotating source + 1 module rotation +/- 60°).

At ETH Zurich, in cooperation with Center for radio-pharmaceutical Science (Prof. A. Schubiger), as of ~April 2010:

- Tomographic reconstruction of small animal phantoms (FDG)
- Optimization of M.C. and reconstruction code

Time scale 1 year

- Performance extrapolation (M.C.) to full scanner and specific geometries.
- … towards commercialization (contacts with Finnish PET teams and companies)

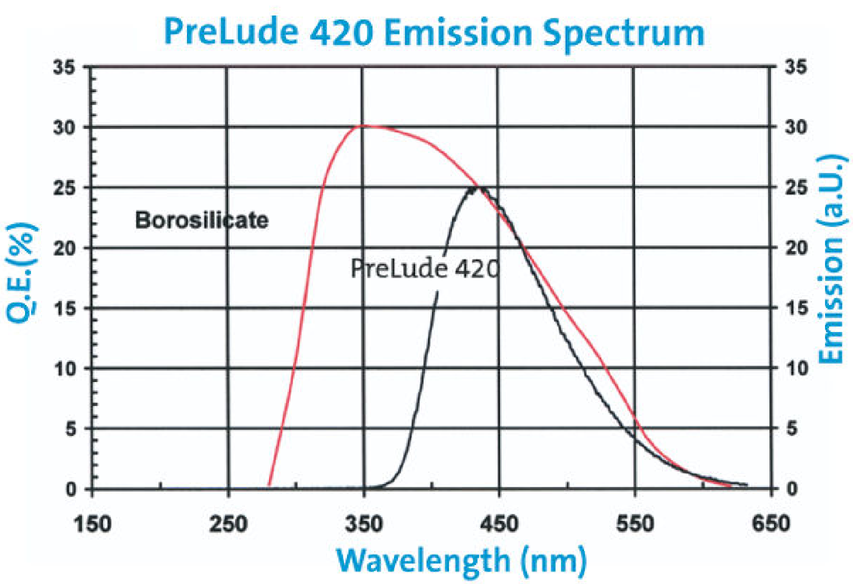
BACK-UP

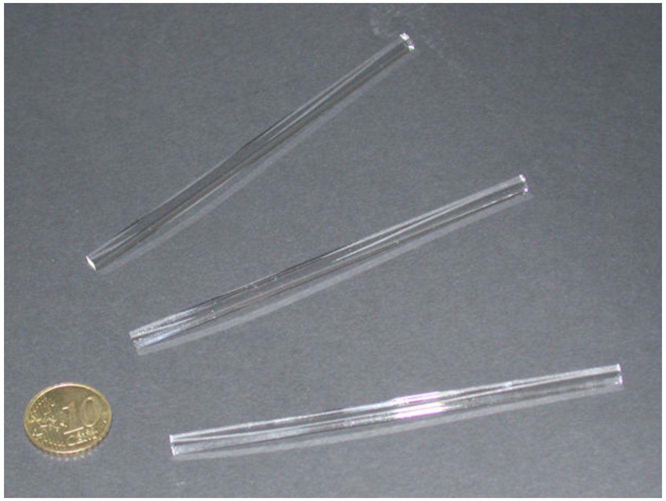
AX-PET components

The **scintillator crystals** are Ce doped LYSO ($Lu_{1.8}Y_{.2}SiO_5$:Ce) single crystals, fabricated by Saint Gobain and commercialized under the trade name PreLude 420.

The main characteristics are:

Density [g/cm3]	7.1
Attenuation length for 511 keV [cm]	1.2
Wavelength of maximum emission [nm]	420
Refractive index at W.L. of max. emission	1.81
Light yield [photons/keV]	32
Average temperature coefficient [%/K]	-0.28
Decay time [ns]	41
Intrinsic energy resolution [%, FWHM]	~8
Natural radioactivity [Bq/cm^3]	~300
Effective optical absorption length [mm]	~ 420





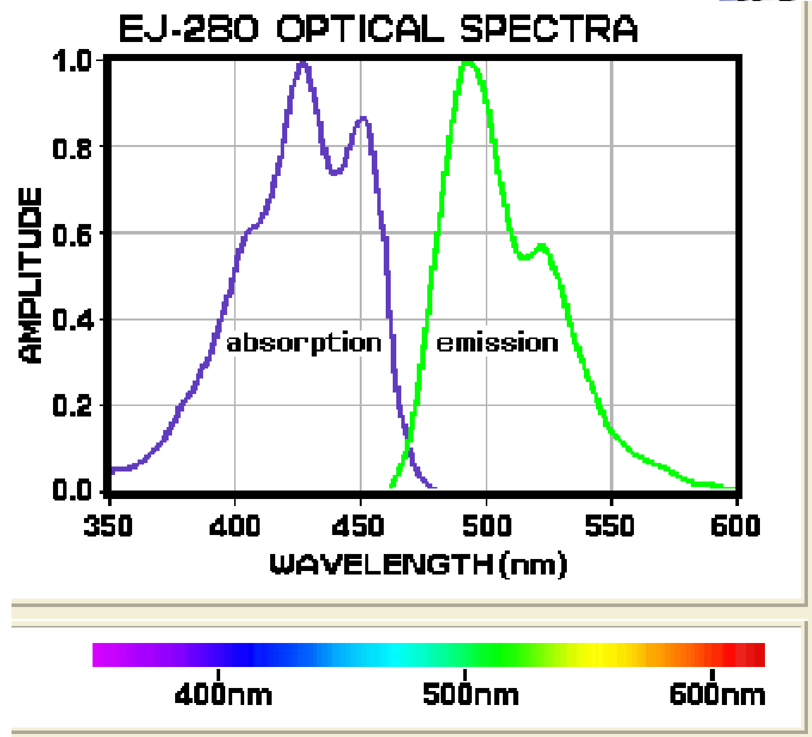
Dimensions: 3 x 3 x 100 mm^3

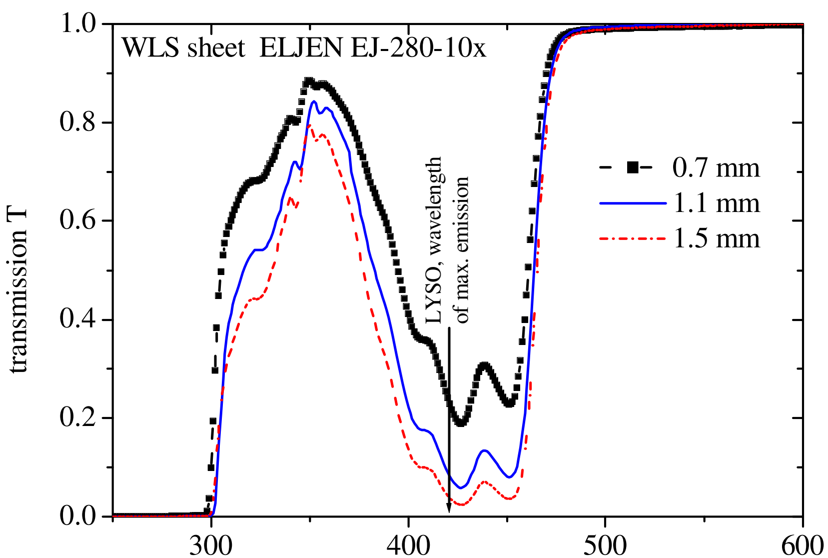
One end is read out, the other end is mirror-coated (evaporated Al-film).

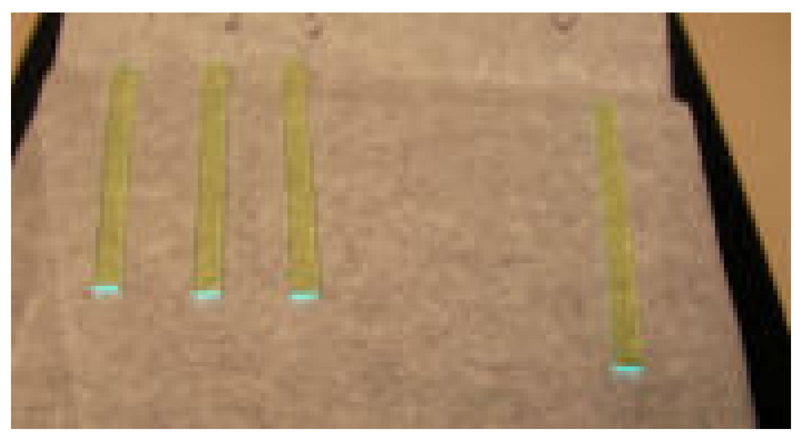
The **WLS strips** are of type EJ-280-10x from Eljen Technologies

- Shift light from blue to green
- Density: 1.023 g/cm3
- Absorption length for blue light: 0.4mm (10 x standard concentration)
- Index of reflection: 1.58
- Decay time: 8.5ns
- Size: 0.9×3×40mm^3

One end is read out, the other end is mirror-coated (evaporated Al-film).

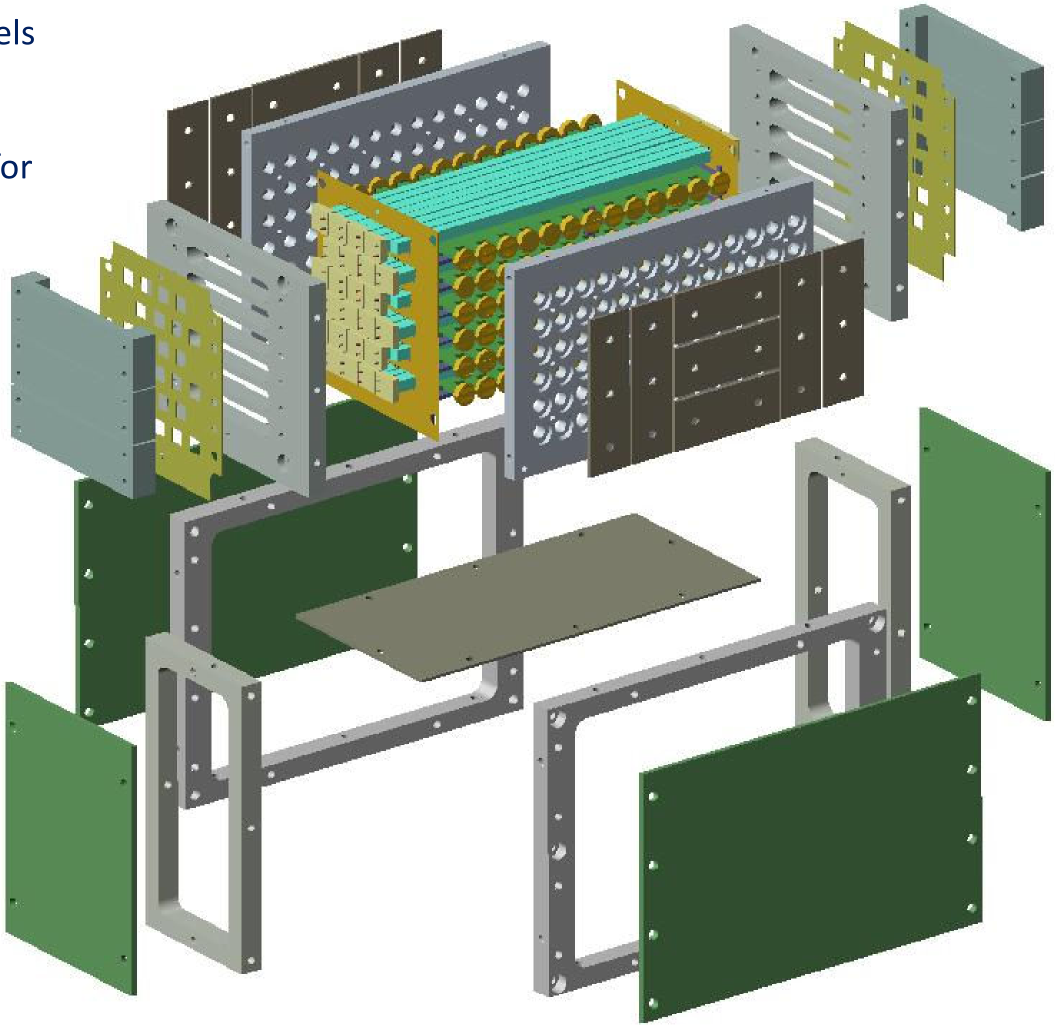






AX-PET Mechanics

- holds crystals, WLS strips, and MPPCs in place.
- carries Kapton cables and mini patch panels
- shields against ambient light
- Made from relatively light materials (Al)
- relatively complex because it's designed for full de-mountability



AX-PET Frontend / Readout / Bias (for 1 module)

FEX48
- Amplifiers for crystals
- ∑48 Xtals
- 48 differential output buffers

Demonstrator Module:
48 Xtals (crystals)
156 WLS strip

FEZ52 Amplifiers for WLS strips

FEZ52 Amplifiers for WLS strips

FEZ52 Amplifiers for WLS strips

G-APD Bias Supply (256 ch.)

Trigger System

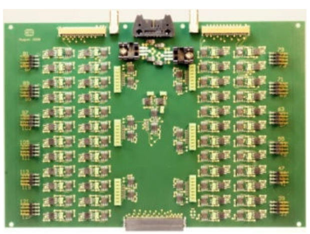
VATA card

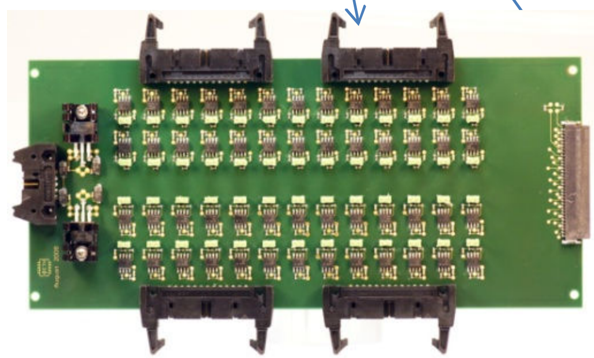
VATA card

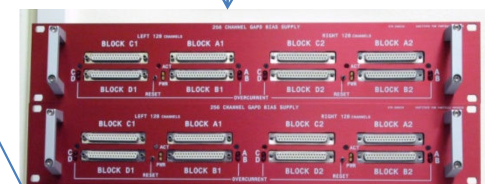
VATA card

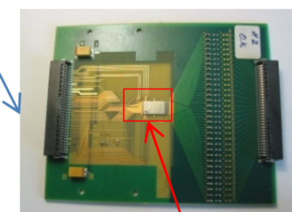
VATA card

VATA Control Card connecting to VME

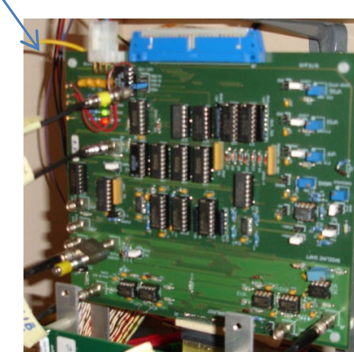


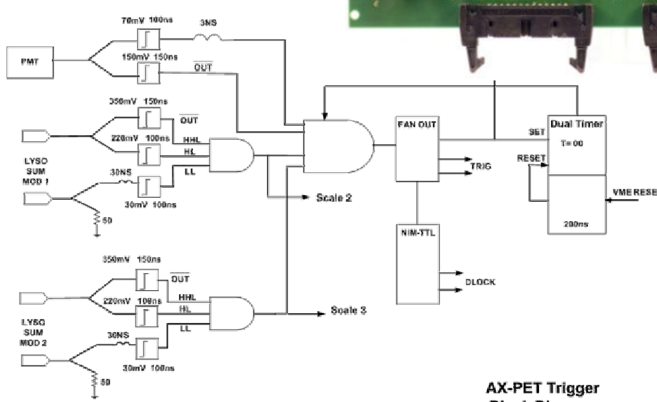






VATAGP5 ASIC



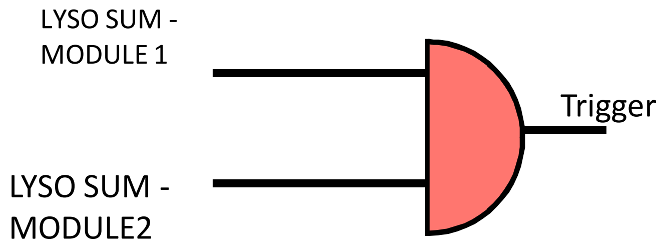


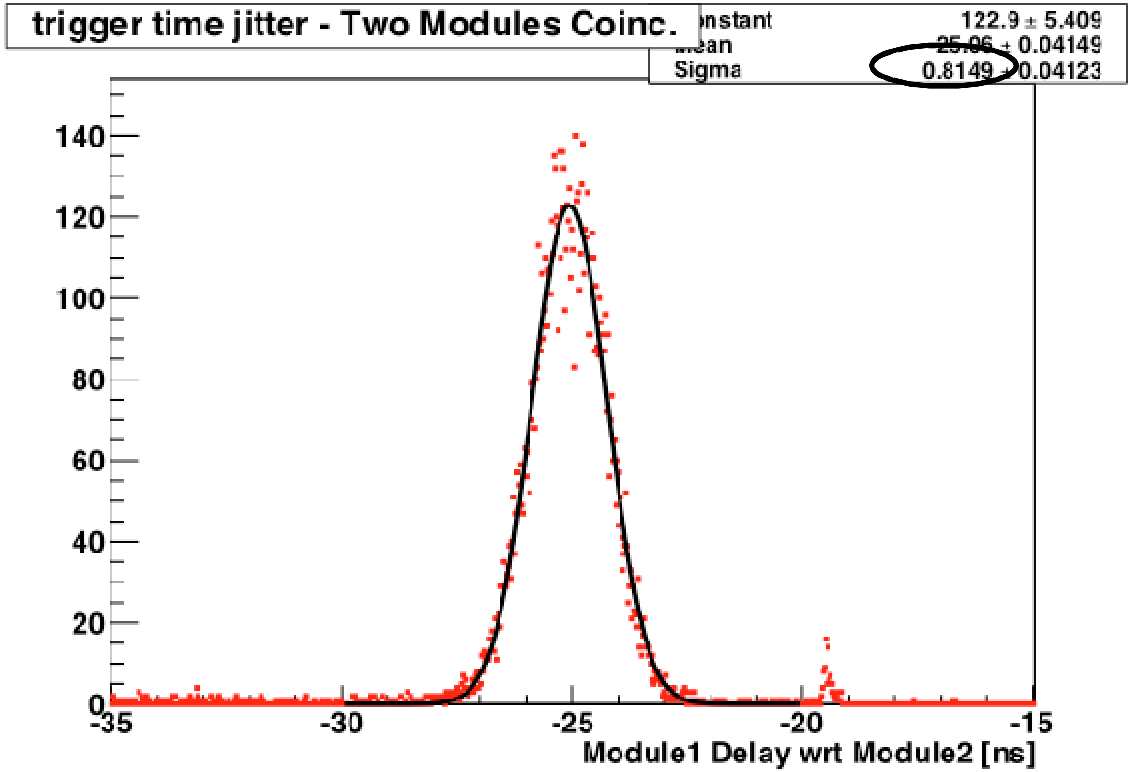
AX-PET Trigger Block Diagram

based on NIM modules

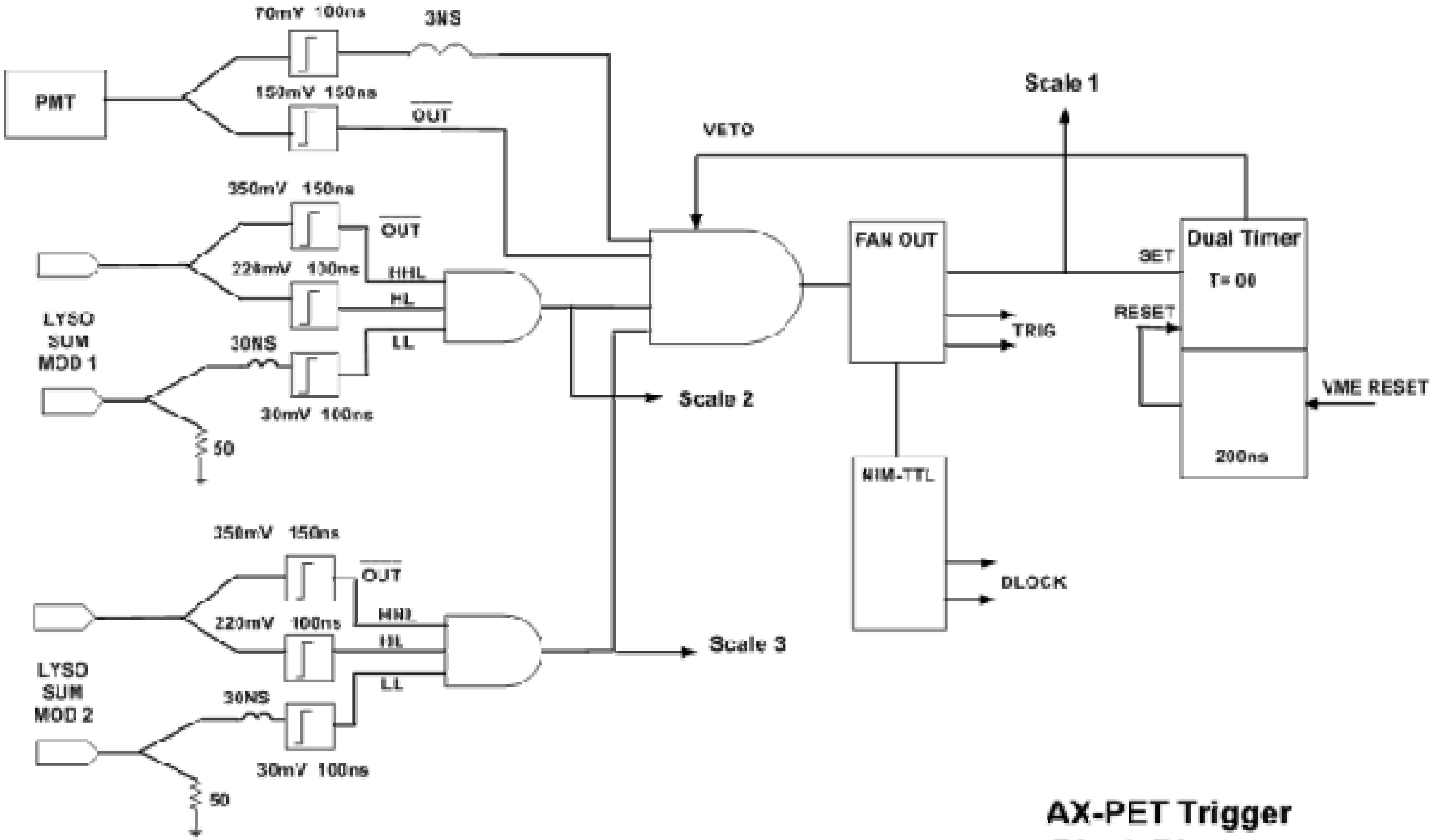
First estimate of the time resolution :

- measure delay of coincidence wrt Module2
- measurement from the scope [Lecroy Waverunner LT584 L 1GHz]





time resolution : σ ~ 800 ps



AX-PET Trigger Block Diagram