AX-PET Demonstrator

CHIPP Plenary Meeting

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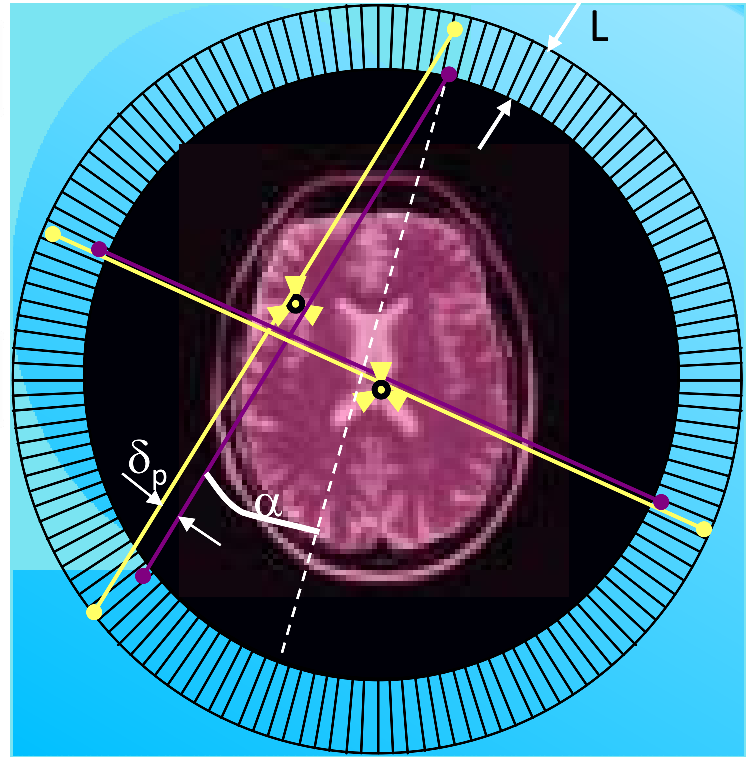
- Introduction
- AX-PET Concept
- Crystals
- Wave length shifting strips
- Photo detectors
- Mechanics
- Electronics
- Test setup

Introduction

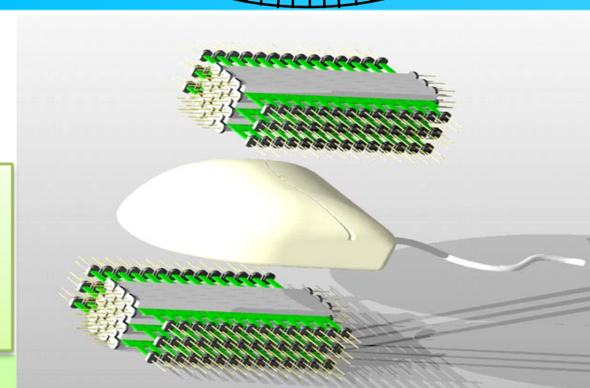
PET…Positron Emission Tomography

- Is recognized as the least invasive nuclear imaging technique
- It provides information about metabolic processes
- While other techniques like MRI or CT provide morphologic information



How does it work

- A metabolic active molecule is marked with a radioactive isotope (β^+ emitter)
- Example: FDG…fluorodesoxyglucose with ^{18}F
- The substance is enriched in metabolic active regions like cancer tissues
- Each emitted positron annihilates with an electron in the tissue, resulting in two back to back 511 keV γ's
- The photon pairs are detected in coincidence
- Using the positions of the photon pairs and the fact that they are back to back the intensity of the source is reconstructed



Typical implementations are full body scanners, brain PET scanners (with important applications in neurology) and small animal PET scanners used in cancer research

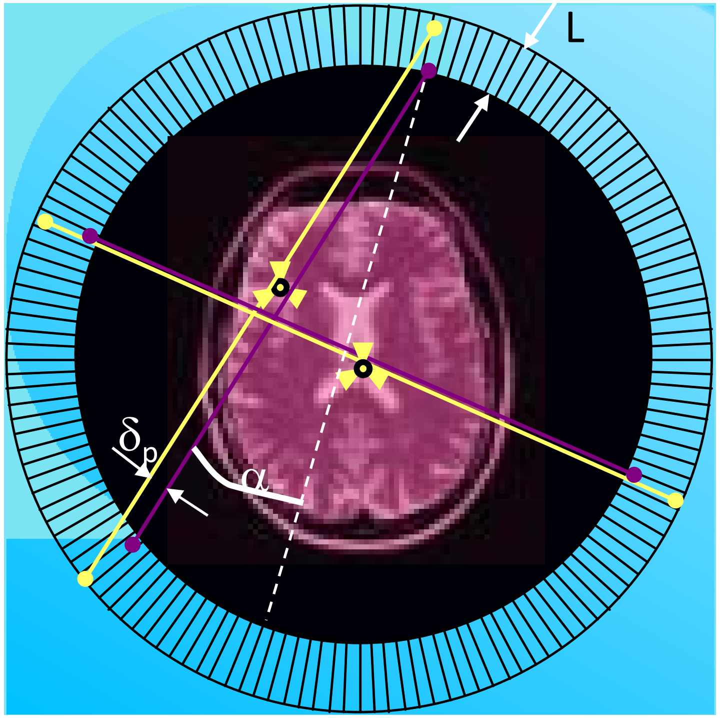
Introduction

Measured Parameters (Photon pair)

- Location: x_1, y_1, z_1 and x_2, y_2, z_2
- Energy: E_1 and E_2
- Time: t_1 and t_2 or $\Delta t = t_1 - t_2$

Energy and time are required for photon pair selection and background reduction

Pet with radial oriented crystals
x ,y resolution given by crystals cross section
z resolution depends on crystal length L



Photon pair detection efficiency

very important, in particular in clinical applications

- length of the crystals: L
- Attenuation length of the crystals: λ_a

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

LYSO: λ_a = 1.2 cm
L = λ_a → ε_2 ~40%
L = 2 * λ_a → ε_2 ~75%

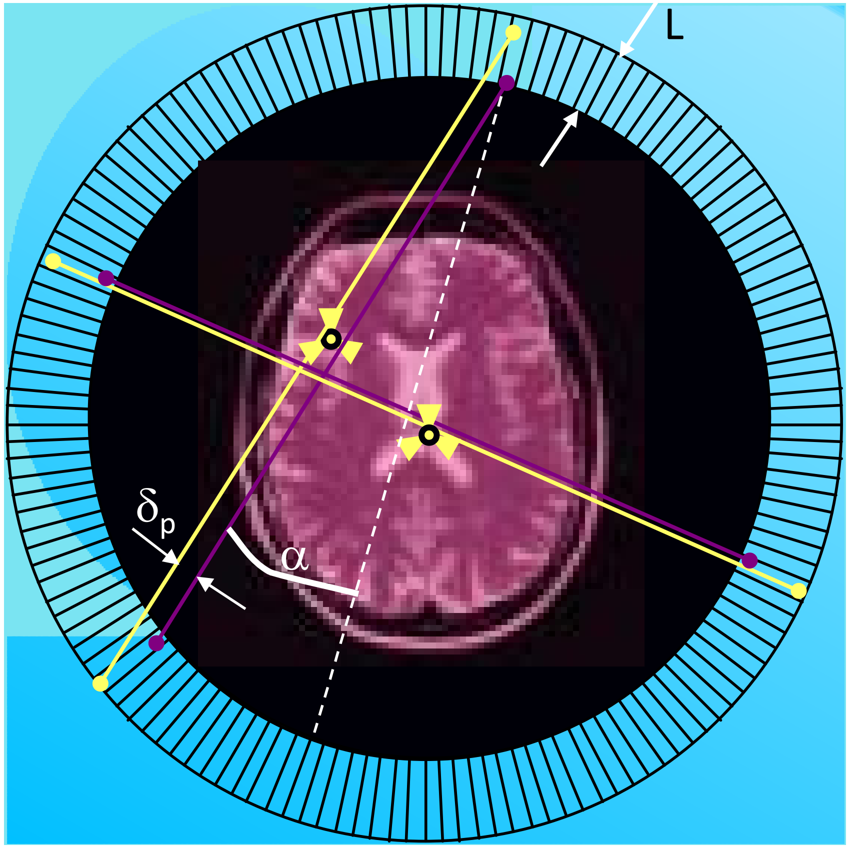
Photon pair detection efficiency → ← **Z-resolution (DOI)**

AXIAL PET Concept

Depth of interaction (DOI)

- is not measured
- Introduces a parallax error
- The resolution in the off-center region degrades significantly

$$\delta_p = L \cdot \sin \alpha$$



Solution: Measure DOI

How: Change the geometry

- use long crystals oriented parallel to the scanner axe
- Use wave length shifting strips (WLS) to read the third coordinate

AXIAL PET

Crystal + WLS

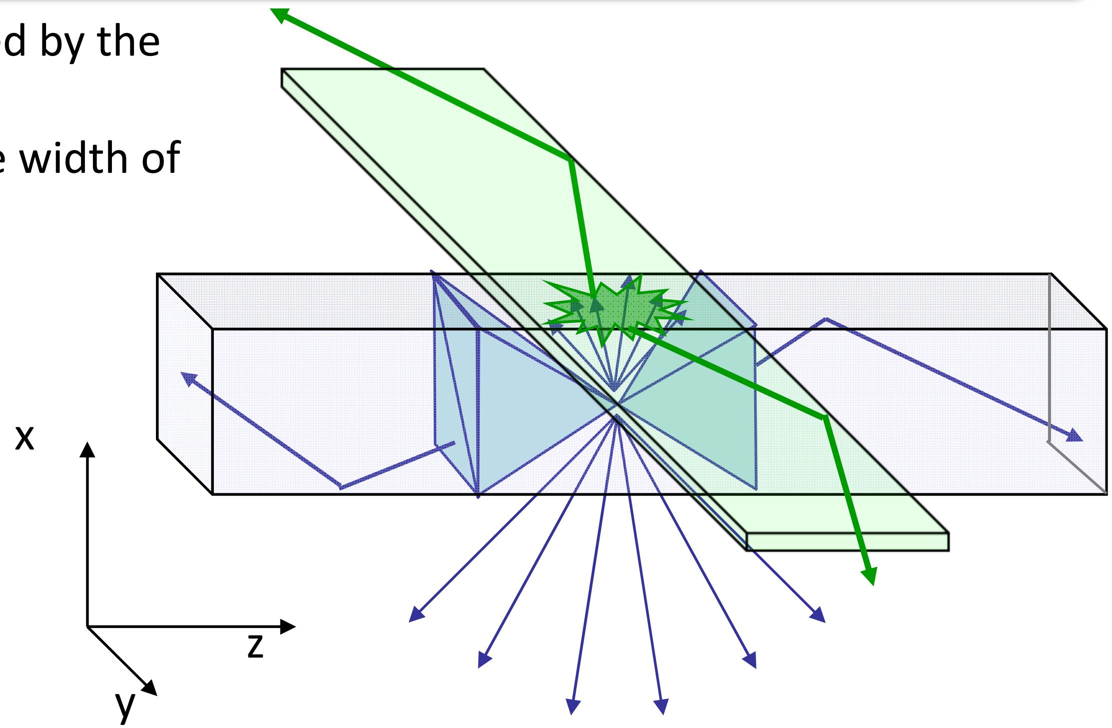
Details of scintillation and fluorescence light trapping

- X and Y coordinate are defined by the crystal dimensions
- Z coordinate is defined by the width of the WLS strip

Light detection by novel photo detectors

G-APDs = MPPC

- High PDE ~35%
- Very fast (~5ns peaking time)
- Immune to B-field (MRI, CT)



Resolution in all three coordinates can be chosen, without compromising on the photon pair detections efficiency

Detection of compton cascades is possible ➔ Increase efficiency and resolution

Proof of Principle

Measurements were carried out and the results were published

- A. Braem et. Al, “High Precision Axial Coordinate Readout for an Axial 3-D PET Detector Module using a Wave Length Shifter Strip Matrix”, NIM A 580(2007), 1513-1521
- A. Braem et. Al, “Wave Length Shifter Strips and G-APD Arrays for the Read-Out of the z-Coordinate in Axial PET Modules”, NIM A 586 (2008), 300-308

WLS results

- WLS photoelectrons yield: ~80 for (511 keV photon absorbed)
- Axial coordinate resolution (digital): 2.8 mm (FWHM) using 3 mm wide WLS strips

LYSO energy resolution

- 11.5% FWHM using G-APDs and 511 keV equivalent X-rays

Project Objective

AX-PET Demonstrator

Module 1		Module 2	
Crystals	WLS	Crystals	WLS
6 layers of **8** crystals	**6** layers of **26** strips	**6** layers of **8** crystals	**6** layers of **26** strips
48 readout channels	**156** readout channels	**48** readout channels	**156** readout channels

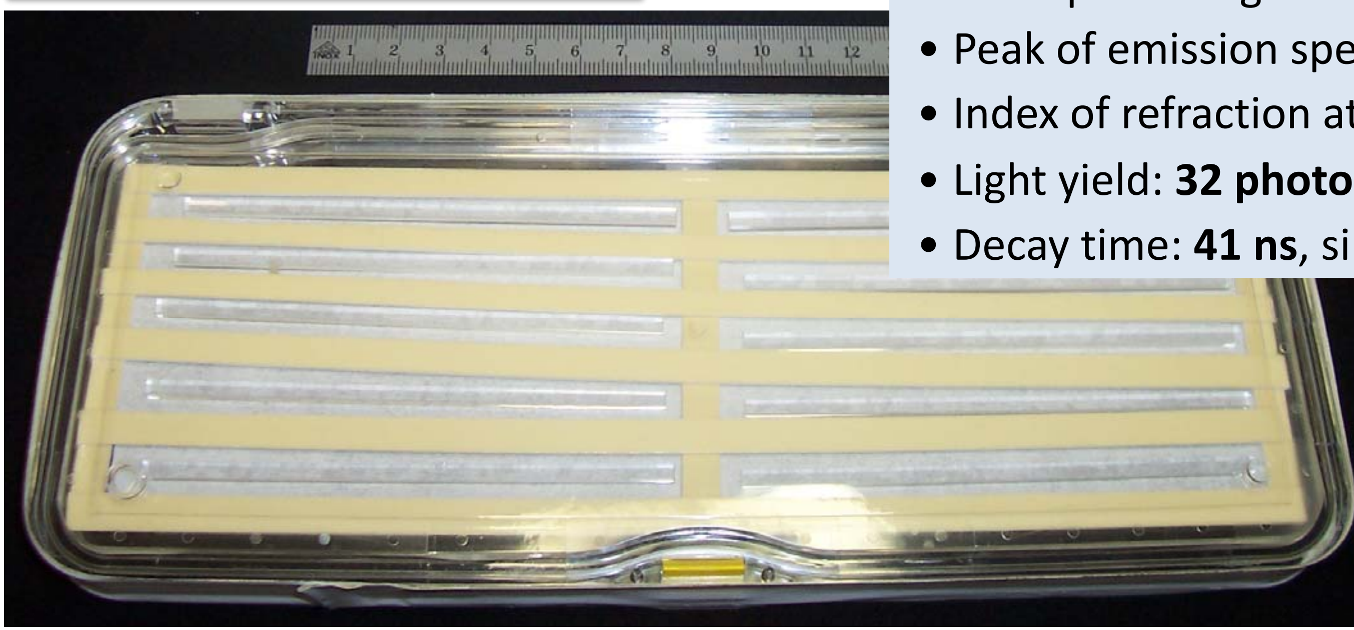
Develop simulation and reconstruction software and perform measurements with the demonstrator

- **"The results from demonstrator will be used to validate a mathematical model of the scanner, which is developed in parallel. Based on the evaluated mathematical model we will be able to predict the expected performance obtainable in various scanner applications."**

Crystals

Crystal material: LYSO
Manufacturer: Saint-Gobain
Dimensions: 3 x 3 x 100 mm^3

All (116) crystals are delivered



Prelude 420™

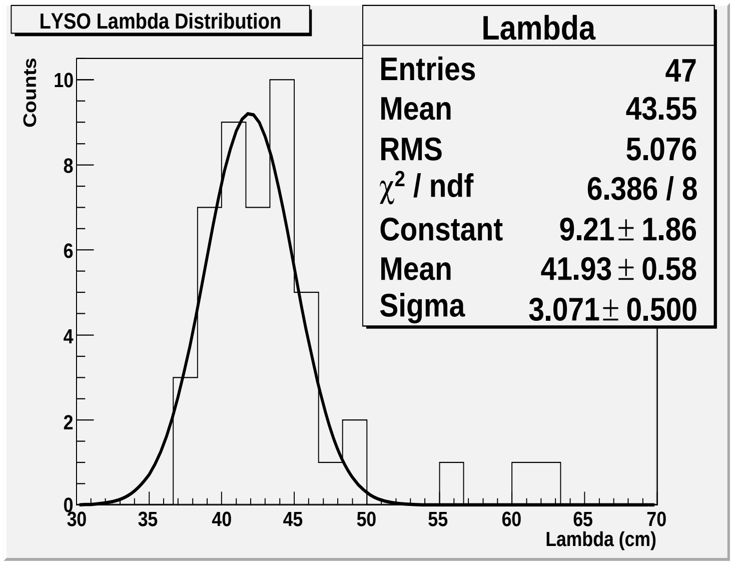
- Chemical composition: $\mathbf{Lu_9YSiO_{25}}$
- **non hygroscopic**
- Density: **7.1 g / cm^3**
- Absorption length: **1.2 cm**
- Peak of emission spectrum: **420 nm**
- Index of refraction at 420 nm: **1.81**
- Light yield: **32 photons / keV** γ
- Decay time: **41 ns**, single exponential

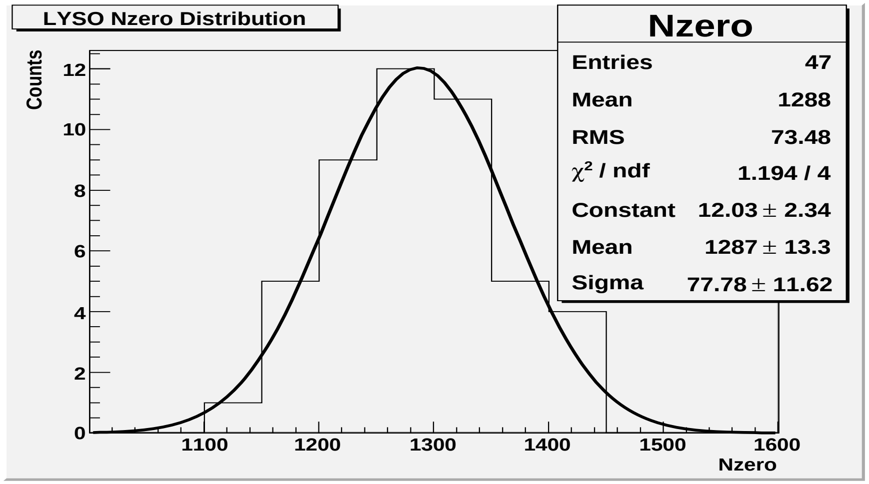
Crystals

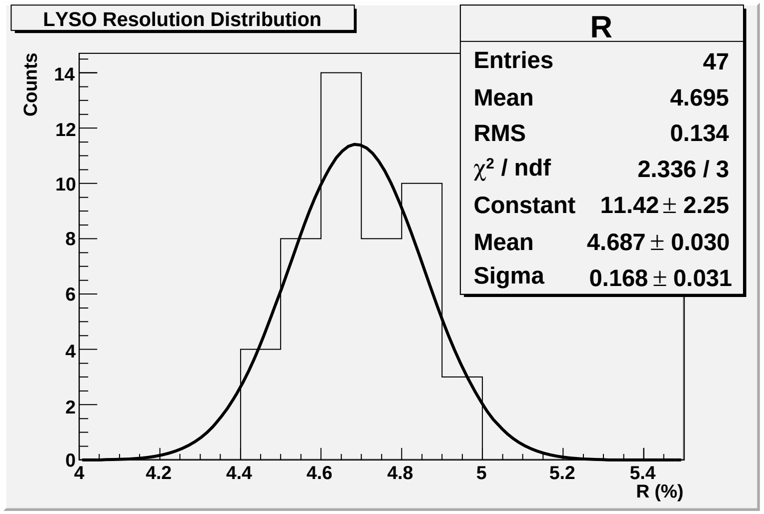
Results for 47 measured crystals

Two PMT Burle 8850 (2 inch)
Measure 511 keV γ's from a Na22 source

Attenuation length of scintillation light	• $\lambda = (41.9 \pm 0.6)$ cm
Number of p.e.	• $N_{pe} = 1287 \pm 13$
Energy resolution (FWHM)	• $\delta/E = (11.0 \pm 0.4)$ %

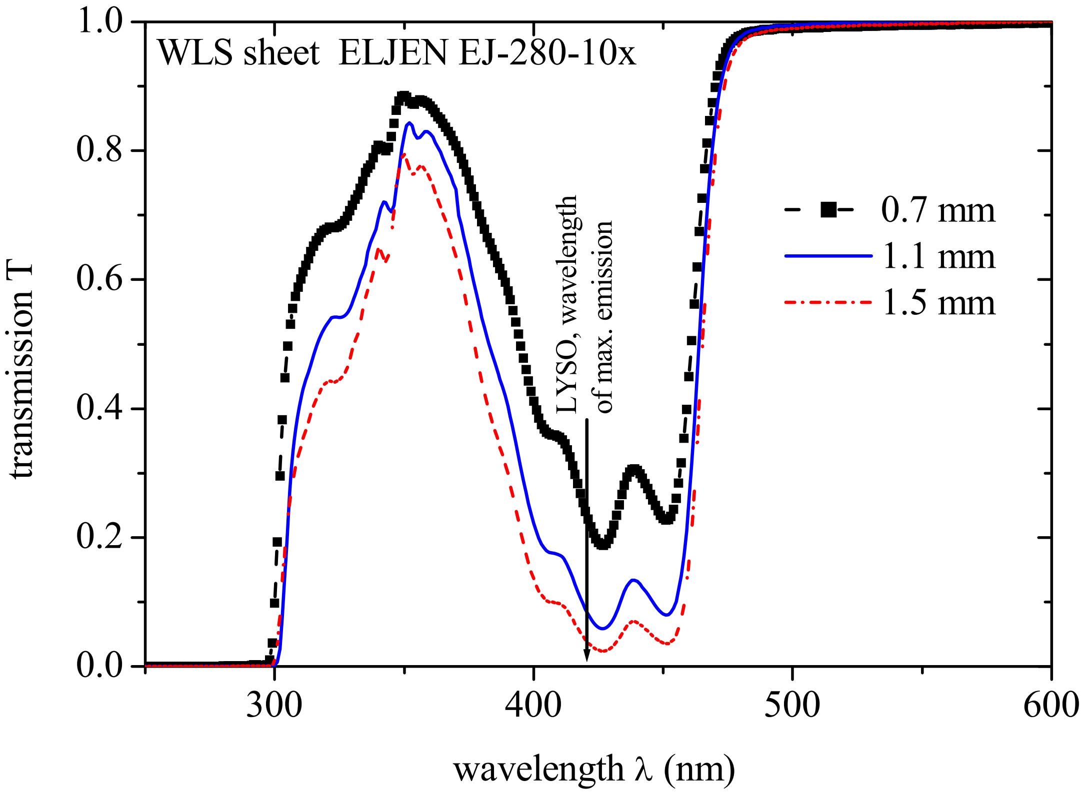






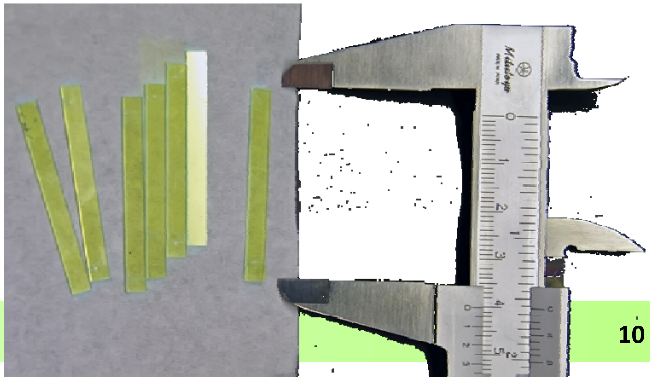
Wave Length Shifting Strips

WLS material:	**Polyvinyltoluene + dopant**
Manufacturer:	**ELJEN Technology**
Dimensions:	**0.9 x 3 x 40 mm^3**



EJ 280

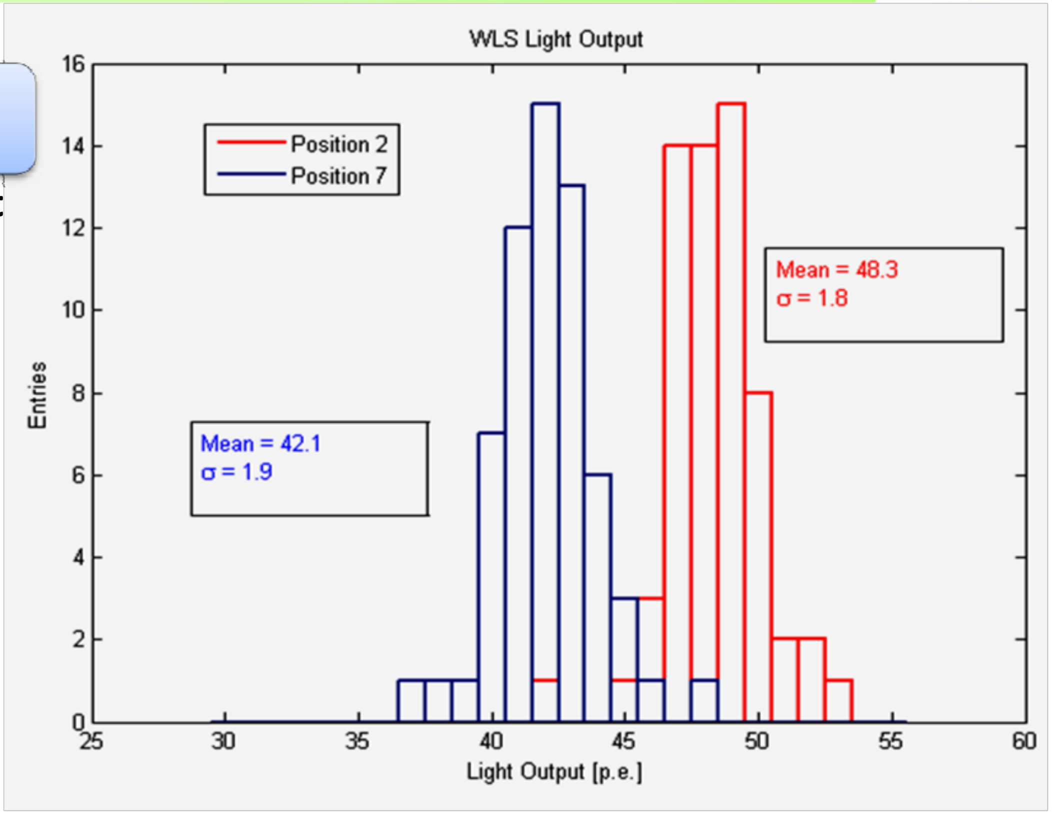
- **Shifts blue light into green**
- Density: **1.023 g / cm^3**
- Absorption length: **1.2 cm**
- Index of refraction: **1.58**
- Maximum of absorption: **425 nm**
- Maximum of emission: **490 nm**
- Decay time: **8.5 ns**
- Quantum efficiency of fluorescent material: **0.86 %**
- Doping: **10x with respect to standard**



Wave Length Shifting Strips

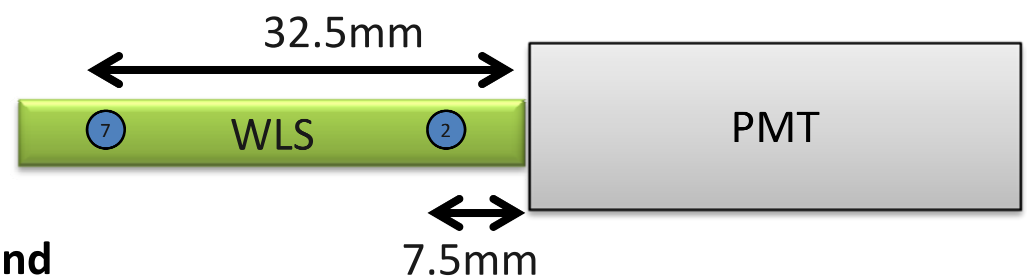
Test setup

- Lecroy oscilloscope with GPIB readout
- Signal generator with 10ns pulse width
- Blue LED (420nm) and Light guide
- NIM module HV power supply
- PMT Hamamatsu R1450
- Inject light at 2.5mm and up to 37.5mm with 5mm steps



61 samples tested

- Two points measured at 7.5mm and 32.5mm
- average loss : 6 p.e. over 25mm



WLS will be coated with Al at one end

Photodetectors

Photo detectors: **MPPC**

Manufacturer: **Hamamatsu**

Two different types for WLS and LYSO

MPPC LYSO: **S10362-33-50-C**

- active area: 3 x 3 mm^2
- 3600 pixels of (50 μm)^2
- Ceramic package 5.9 x 6.6 mm^2

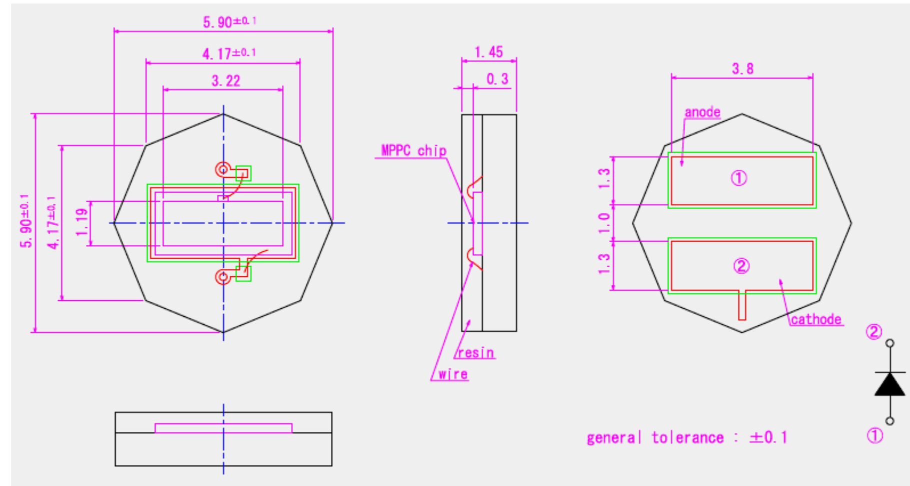
MPPC WLS: **custom made MPPC**

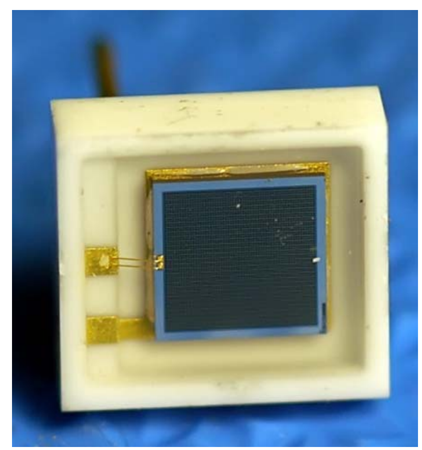
- active area 3.22 x 1.19 mm^2
- 1200 pixels of (50 μm)^2
- octagonal plastic package

Operation voltage: **70 V**

Gain: **7.5 10^5**

Hamatsu 3x3mm-MPPC-OCTAGON-SMD





S10362-33-50-C

Mechanical Construction

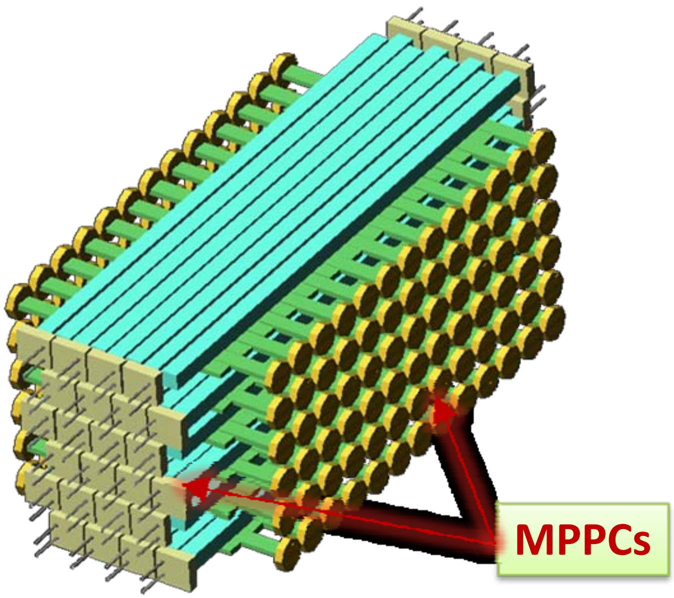
Two identical modules

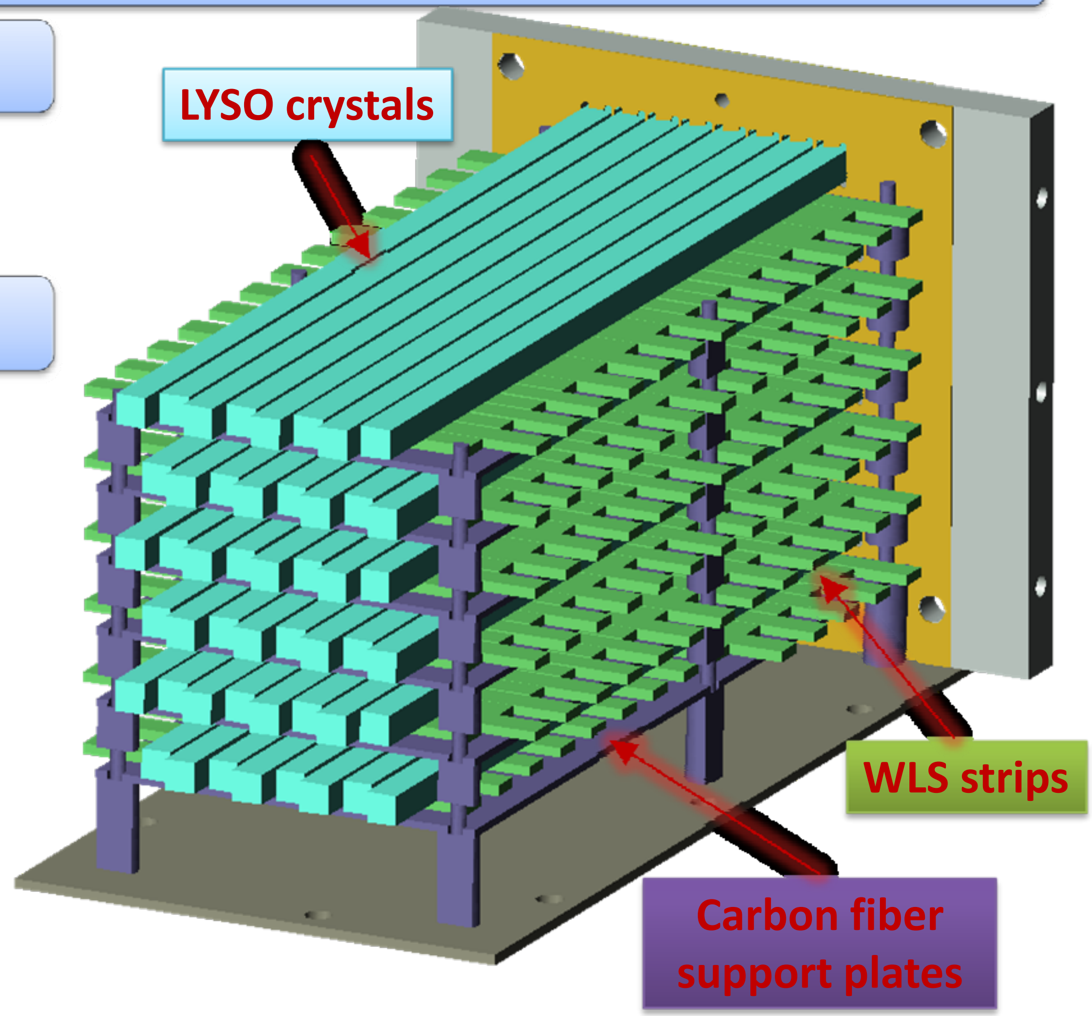
6 layers of 8 LYSO bars

- 3.5 mm crystal pitch within a layer
- the layers are shifted by ½ the pitch with respect to each other

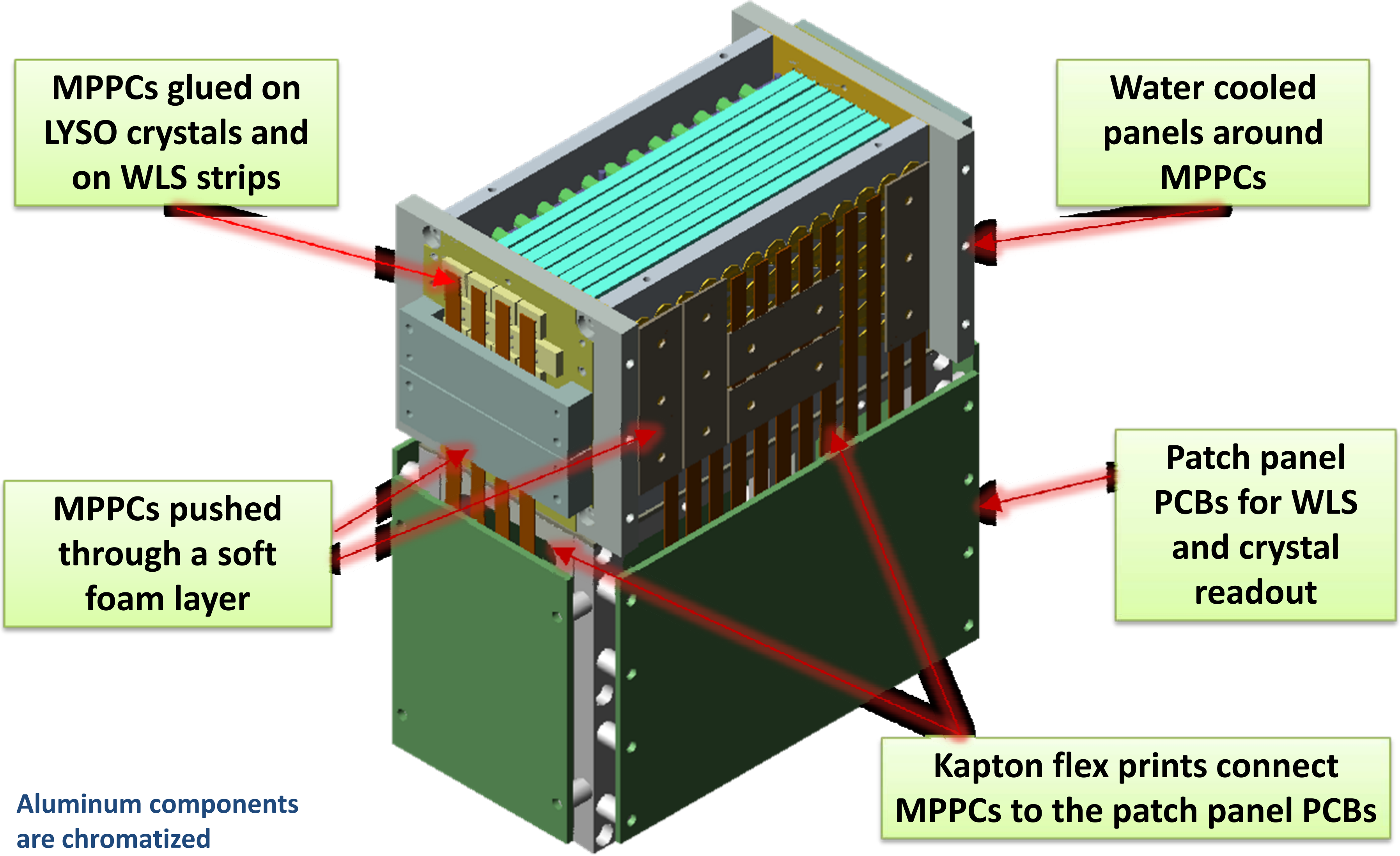
6 layers of 26 WLS strips

- 3.2 mm pitch within a layer





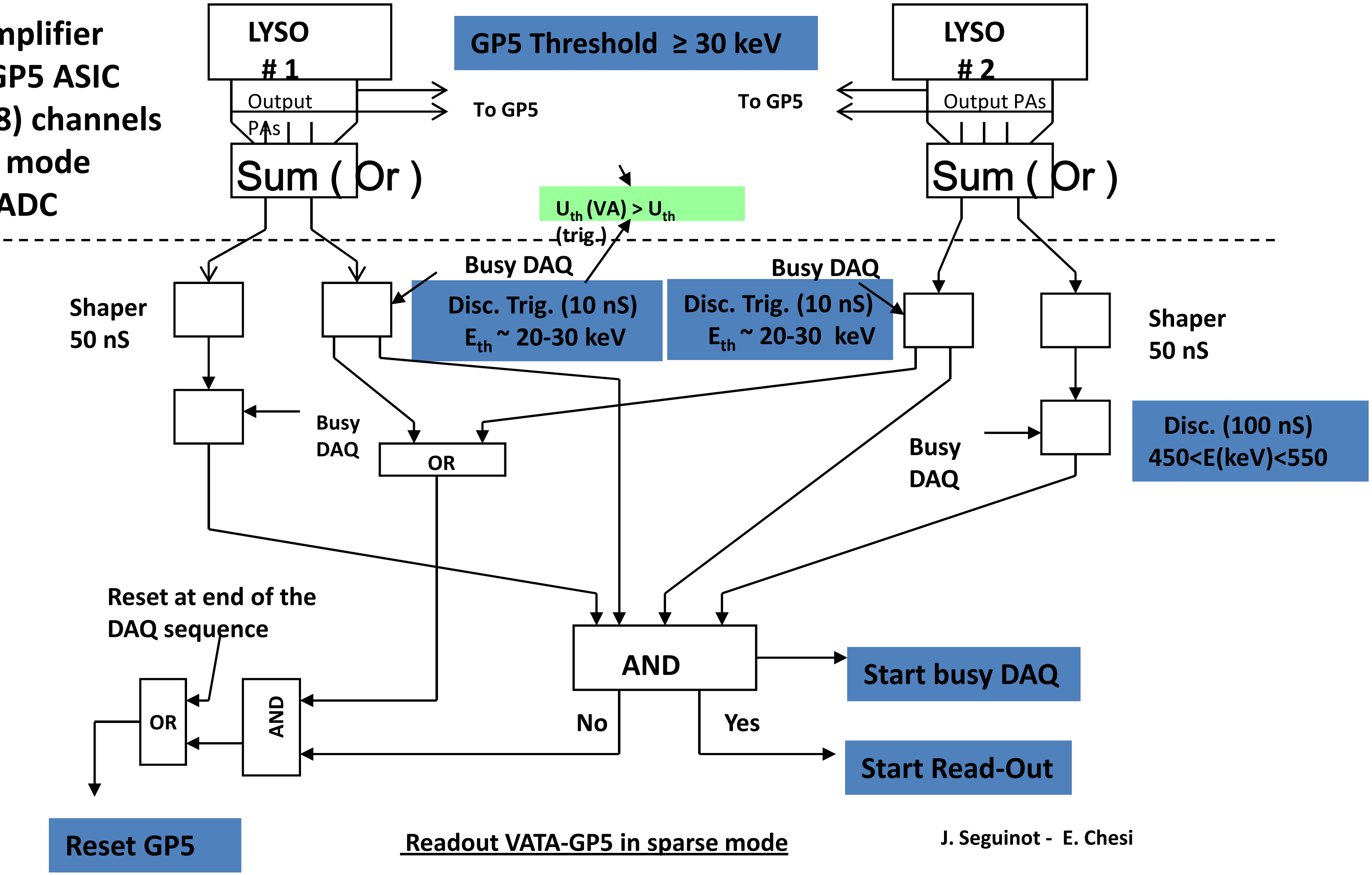
Mechanical Construction



Aluminum components are chromatized

Trigger

- Fast amplifier
- VATA GP5 ASIC
- 64 (128) channels
- sparse mode
- 10 bit ADC

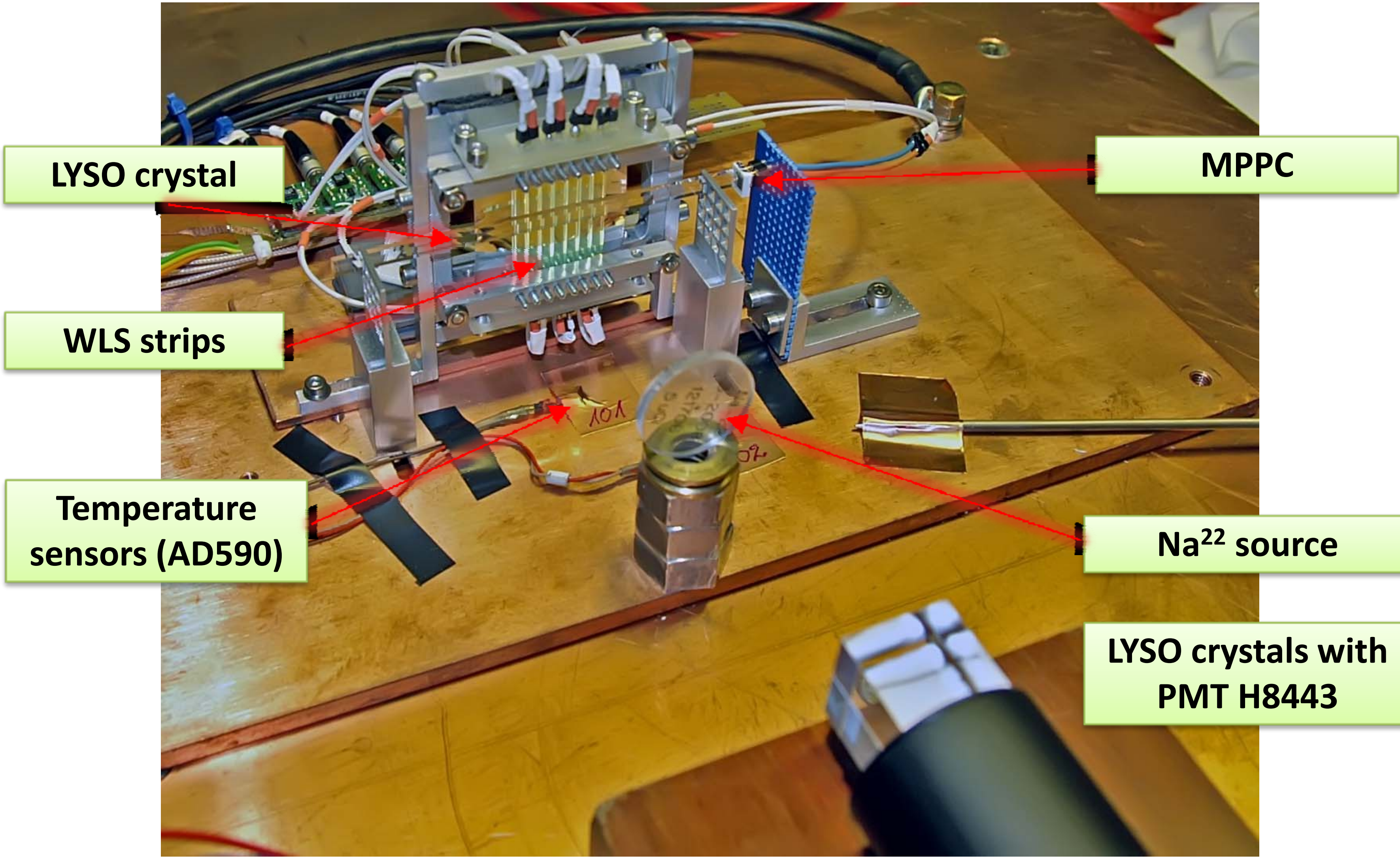


Readout VATA-GP5 in sparse mode

J. Seguinot - E. Chesi

05/02/2008

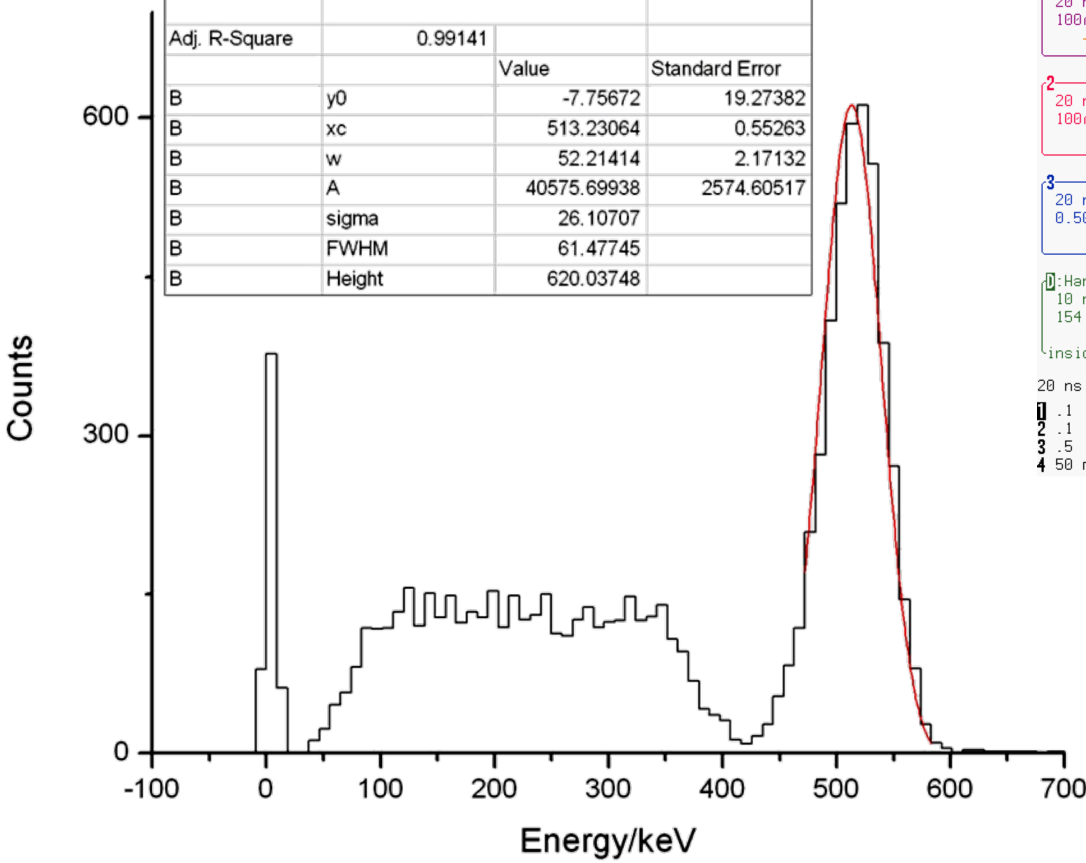
Test Setup



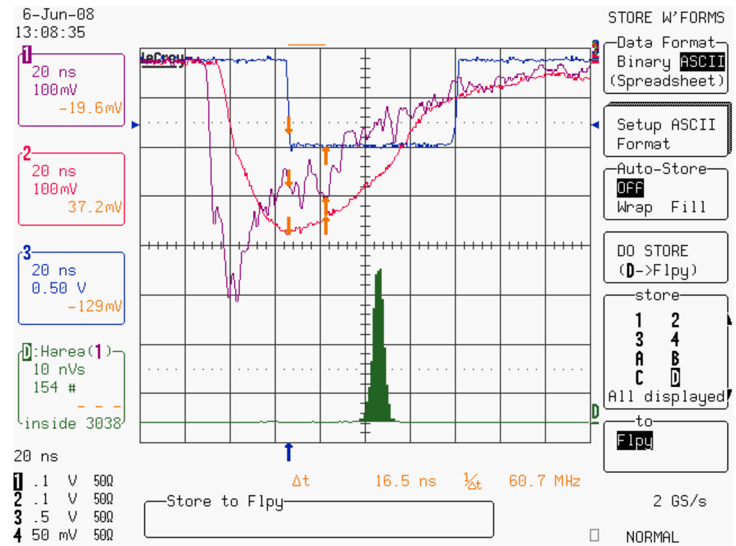
LYSO crystal
WLS strips
Temperature sensors (AD590)
MPPC
Na^{22} source
LYSO crystals with PMT H8443

LYSO Measurement

Spectrum of the Na^{22} source measured with the MPPC in coincidence



Equation	y=y0 + (A/(w*sqrt(PI/2)))*exp(-2*((x-xc)/w)^2)		
Adj. R-Square	0.99141		
		Value	Standard Error
B	y0	-7.75672	19.27382
B	xc	513.23064	0.55263
B	w	52.21414	2.17132
B	A	40575.69938	2574.60517
B	sigma	26.10707	
B	FWHM	61.47745	
B	Height	620.03748	



Peak position: **513. 2 keV**

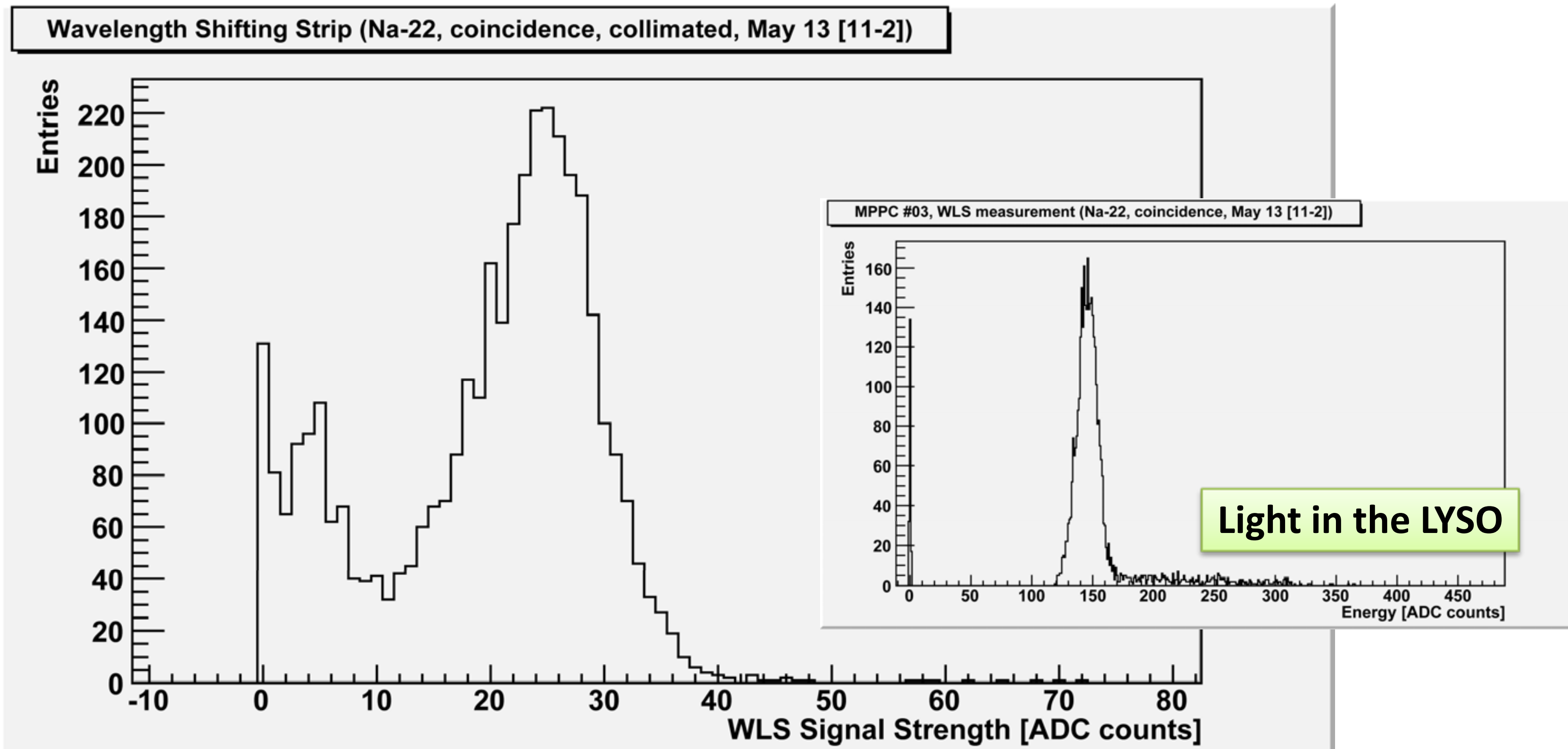
FWHM: **61.5 keV**

Energy resolution: 12.0 %

WLS Measurement

Light in the WLS measured with the Na^{22} source with the MPPC in coincidence

Peak = 73 photo electrons in one WLS



Summary

Novel Concept of PET scanner

- axially oriented crystals with WLS strip readout of the z coordinate
- Separates photon pair detection efficiency and spatial resolution
- Principle is proven
- Detector components are selected
- Mechanics is being fabricated
- Electronics is under development
- First results with Na^{22} source are very promising
- Start testing with the two detector modules this year