CHIPP Plenary Meeting
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Introduction
AX-PET Concept
Crystals
Wave length shifting strips
Photo detectors
Mechanics
Electronics
Test setup
**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 ($\beta^+$ emitter)
- Example: FDG...fluorodeoxyglucose 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 $\gamma$'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**
**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**

**Photon pair detection efficiency**

Very important, in particular in clinical applications

- Length of the crystals: \( L \)
- Attenuation length of the crystals: \( \lambda_a \)

\[
\epsilon_2 = \left(1 - e^{-\frac{L}{\lambda_a}}\right)^2
\]

**LYSO:** \( \lambda_a = 1.2 \text{ cm} \)
- \( L = \lambda_a \Rightarrow \epsilon_2 \sim 40\% \)
- \( L = 2 \times \lambda_a \Rightarrow \epsilon_2 \sim 75\% \)

**Pet with radial oriented crystals**

\( x, y \) resolution given by crystals cross section

\( z \) resolution depends on crystal length \( L \)
**Depth of interaction (DOI)**

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

**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

\[ \delta_p = L \cdot \sin \alpha \]
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
Measurements were carried out and the results were published


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

48 readout channels        156 readout channels

6 layers of 8 crystals

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.”
Crystal material: LYSO
Manufacturer: Saint-Gobain
Dimensions: 3 x 3 x 100 mm³

All (116) crystals are delivered

Prelude 420™

- Chemical composition: Lu₉YSiO₂₅
- non hygroscopic
- Density: 7.1 g / cm³
- 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
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**
  - \( \lambda = (41.9 \pm 0.6) \text{ cm} \)

- **Number of p.e.**
  - \( N_{\text{pe}} = 1287 \pm 13 \)

- **Energy resolution (FWHM)**
  - \( \delta/E = (11.0 \pm 0.4) \% \)

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### LYSO Lambda Distribution

- **Entries**: 47
- **Mean**: 43.55 cm
- **RMS**: 5.076
- **\( \chi^2 / \text{ndf} \)**: 6.386 / 8
- **Constant**: 9.21 ± 1.86
- **Mean**: 41.93 ± 0.58
- **Sigma**: 3.071 ± 0.500

### LYSO Resolution Distribution

- **Entries**: 47
- **Mean**: 4.695
- **RMS**: 0.134
- **\( \chi^2 / \text{ndf} \)**: 2.336 / 3
- **Constant**: 2.25 ± 11.42
- **Mean**: 0.030 ± 4.687
- **Sigma**: 0.031 ± 0.168

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LYSO Nzero Distribution

- **Entries**: 47
- **Mean**: 1288
- **RMS**: 73.48
- **\( \chi^2 / \text{ndf} \)**: 1.194 / 4
- **Constant**: 12.03 ± 2.34
- **Mean**: 1287 ± 13
- **Sigma**: 77.78 ± 11.62

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LYSO Resolution Distribution

- **Entries**: 47
- **Mean**: 4.695
- **RMS**: 0.134
- **\( \chi^2 / \text{ndf} \)**: 2.336 / 3
- **Constant**: 11.42 ± 2.25
- **Mean**: 4.687 ± 0.030
- **Sigma**: 0.168 ± 0.031
Wave Length Shifting Strips

WLS material: Polyvinyltoluene + dopant
Manufacturer: ELJEN Technology
Dimensions: 0.9 x 3 x 40 mm³

EJ 280
- Shifts blue light into green
- Density: 1.023 g / cm³
- 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

WLS sheet ELJEN EJ-280-10x

transmission T

300 400 500 600
wavelength λ (nm)

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W. Lustermann, ETH-Zurich
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
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 $10^5$
Mechanical Construction

Two identical modules

6 layers of 8 LYSO bars
- 3.5 mm crystal pitch within a layer
- the layers are shifted by \( \frac{1}{2} \) the pitch with respect to each other

6 layers of 26 WLS strips
- 3.2 mm pitch within a layer
Mechanical Construction

- MPPCs glued on LYSO crystals and on WLS strips
- Water cooled panels around MPPCs
- MPPCs pushed through a soft foam layer
- Patch panel PCBs for WLS and crystal readout
- Kapton flex prints connect MPPCs to the patch panel PCBs

Aluminum components are chromatized
• Fast amplifier
• VATA GP5 ASIC
• 64 (128) channels
• sparse mode
• 10 bit ADC

LYSO #1

Output PAs

Shaper 50 nS

Busy DAQ

Disc. Trig. (10 nS) \( E_{th} \sim 20-30 \text{ keV} \)

Busy DAQ

Disc. Trig. (10 nS) \( E_{th} \sim 20-30 \text{ keV} \)

Busy DAQ

Shaper 50 nS

Busy DAQ

Busy DAQ

Disc. (100 nS) \( 450 < E(\text{keV}) < 550 \)

Reset at end of the DAQ sequence

AND

OR

AND

OR

Start busy DAQ

Start Read-Out

Readout VATA-GP5 in sparse mode

GP5 Threshold \( \geq 30 \text{ keV} \)

To GP5

Output PAs

LYSO #2

U_{th}(VA) > U_{th} (trig.)
Test Setup

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

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

Equation: 
$$y = y_0 + (A/(w \cdot \sqrt{2} \cdot \pi)) \cdot \exp(-2\cdot((x-x_c)/w)^2)$$

<table>
<thead>
<tr>
<th>Adj. R-Square</th>
<th>Value</th>
<th>Standard Error</th>
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<td>0.99141</td>
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 Peak position: 513.2 keV  
 FWHM: 61.5 keV  
 Energy resolution: 12.0 %
Light in the WLS measured with the Na$^{22}$ source with the MPPC in coincidence

Peak = 73 photo electrons in one WLS

Wavelength Shifting Strip (Na-22, coincidence, collimated, May 13 [11-2])

Light in the LYSO
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