

Development of TOF High-Resolution Detector Module with Depth of Interaction Identification for Positron Emission Tomography

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First ClearPEM Technologies





Time resolution 2.8 ns FWHM







Energy Resolution - 22Na

ASICs (2x192 channels)

APD based double readout

of the LYSO crystals

DOI resolution 2.8 mm

ClearPEM prototypes have First shown excellent performance. But, a commercial system would require to significantly bring down production costs in order to be competitive

Image resolution 1.3 mm

FWHM

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Development of the high resolution detector module with Depth of Interaction (DOI) for the future ClearPEM and other

small animal PET

- Cost effective
- High sensitivity
- Same performance as the ClearPEM detector module (spatial resolution, energy resolution)
- Good coincidence timing resolution

Why SiPM?

- Fast
- Efficient (Low operational voltage, high gain,...)
- compact with Small dead area

New High resolution Detector Module



- 1. Coupling more than 1 crystal per detector
- 2. Getting DOI information with single side readout



4x4 MPPC array from Hamamatsu Active area 3x3 mm² Pitch 3.1 mm



Crystals: 1.53x1.53x15mm LYSO Gaps 70 micron Totally reflective separation foil

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4x4 MPPC array from Hamamatsu

Active area 3x3 mm²

Pitch 3.1 mm

Crystal Matrix and photodetector

Lateral surface of

the crystal is optically depolished



New method for DOI





Lateral surface of the crystal is optically depolished. It makes the correlation between the DOI and the light collected by the detector

Patent PCT EP2015/074462

Readout Electronics





FEB/A



FEB/D



- A compact front end board (FEB/A)
- On the back side of the FEB/A lies the front end electronics with TOF ASIC (TOFPET1 ASIC)
 - Time and ToT digitization
 - Event rate: 160 kHz per channel
 - > Optimized for low power (10 mW per channel)
- Front End Board type D (FEB/D) reads the data from 8 FEB/A boards

• The DAQ board is a PCIe data acquisition board that collects the data from the front end FEB/D board using optical links

Extraction of Energy Information



- The energy information can be extracted by applying the Time Over Threshold (TOT)
- The time duration of the signal above threshold can be related to the energy released in the detector



Crystal Identification & DOI algorithms

Crystal Identification

•
$$U = \frac{\sum_{i=0}^{N} x_i \times E_i}{E}$$

• $V = \frac{\sum_{i=0}^{N} y_i \times E_i}{E}$

Depth of Interaction Parameter

•
$$W = \frac{E_{max}}{E}$$



- E_i : Energy deposited by the ith MPPC channel
- x_i and y_i : (x,y) positions of the centers of the i-th channel
- *E*: Sum of the deposited energies in all the channels

- E_{max} : Maximum energy among the ideposited energies
- *E*: Sum of the deposited energies in all the channels

U

Geant4 simulation





2/18/16

the 14th Vienna Conference on Instrumentation Vienna, Austria 15th-19th February 2016

Crystal Identification





Schematic of the set-up

Crystal Identification



Solution for the crystal identification in the cornes?



3D map of the (U,V,W) coordinates

- The lateral crystals distributions are tilted
- Using an appropriate rotation in 3D we can get a nice 2D map with all the 64 crystals clearly identified



Corrected 2D map of the (U,V) coordinates

Crystal Identification





Energy Resolution



HMHM 0

olution 0.25

۸ 0.1

0.2

Select the events in one crystal and plot the sum of the energies deposited in all the MPPCs for each event





Distribution of the energy resolution for all the 64 crystals

3D distribution of the energy resolution for a block of 8x8 crystals

Energy resolution for central crystals 18.29% FWHM

Depth of Interaction





Illustration of the experimental electronic collimation set-up used to evaluate DOI resolution

Depth of Interaction





Histogram of the W variable or 6 different z position along the crystal length for 511 keV events in photopeak



Linear correlation between the between the center of the irradiation spot and the position of the w histogram peak.

$DOI = A \times W + B$

Depth of Interaction



DOI resolution:

- Extraction of the fitting function
 DOI = A×W + B
 for each of the 64 crystals
- plotting 1D histogram of Dol(measured)-Dol(real) for each of the 64 crystals.
- Gaussian fitting to estimate Dol resolution.



Distribution of the DOI resolution for all the 64 crystals



3D distribution of DOI resolution

average DOI resolution over all the 64 crystals in 6 different depths is 5.17mm FWHM









Illustration of the coincidence experimental set-up used

Coincidence timing resolution is 531 ps FWHM





We have developed a TOF and high resolution detector module composed of

- 64 depolished LYSO pixels separated by reflective foil couple to 16 MPPC array
- 1 light guide on top of the crystal and grease an optical coupling between the crystal and MPPC
- Reflective foil as a mirror on top of the light guide

With high performance

- Excellent Identification of all the 64 crystals
- DOI resolution of <u>5.17 mm</u> FWHM
- Energy resolution @511 keV <u>18.29%</u>
- Coincidence time resolution <u>531 ps</u> FWHM
- Commercially viable

Future work: Using TOFPET2 ASIC



- Improved timing measurement
 - Aiming at PET CTR of 200 ps
- Linear energy measurement in the range 0-1500 pC
 - Compatible with high gain SiPMs
 - Charge integration ADC
- Event rate up to 600 kHz per channel
 - Suitable for PET modules with light sharing
- Reduced power consumption
 - ➢ 5-8 mW/channel
- Submitted to fabrication (will be received in one week)

Newest version of the TOFPET ASIC





Results with a similar detector configuration at CERN:

- DOI resolution of <u>3.99 mm</u> FWHM (CAEN DT5740 Digitizer)
- Energy resolution @511 keV after correction with DOI <u>14.6%</u> (CAEN DT5740 Digitizer)
- Coincidence time resolution <u>300 ps</u> FWHM (Nino Chip at CERN)



Thank you for your attention!