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# EXPERIMENT DETAILS IN TIME RESOLUTION MEASUREMENTS OF LYSO SCINTILLATOR

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In this research, we have performed experimental measurements of coincidence time resolution with a custom-built test-bench. In the scope of this work, we discussed technical issues and data validation in the CTR experiment on an example of Saint-Gobain 2 x 2 x 3 mm lutetium-yttrium oxyorthosilicate ($Lu_{1.8}Y_{.2}SiO_5 : Ce$) crystals. The primary objective of the presented experimental works is to develop instruments for the experimental validation of newly created scintillation materials, as a step toward way the 10-ps time-of-flight PET challenge.

**Keywords:** *coincidence time resolution (CTR); heterostructured scintillating matherials; 511 keV gamma detector; LYSO; PET; fast timing; constant fraction discriminator (CFD); annihilation events*

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## 1. INTRODUCTION

The technical level of the modern, practically implemented PET (positron emission tomography scanners) with assistive CT (X-rays computed tomography) is declared in a range around 180-300 ps, coincidence resolution time (CTR). Reviewing the open data form industry leaders: Siemens Biograph Vision with time of flight performance 214 ps [1], Discovery MI with LightBurst Digital 4-Ring Detector with Timing Resolution 385 ps [2], Philips Vereos with PET timing resolution 310 ps FWHM (full width at the half maximum) [3], NeuEra Series PET/CT from Neusoft Medical with 180 ps grade fully digitzed based on third generation ASIC digital chip [4], Canon PET/CT scanner Cartesion Prime with SURECount digital PET detector 263 ps ToF (time-of-flight) resolution [5], MiFound ScintCare PET/CT 730T with 380 ps resolution, Mediso AnyScan TRIO-TheraMAX SPECT/CT with resolution of 3.3 mm (FWHM) maintained by high-density sensor arrangement (123 PMTs per detector head) [7], United Imaging uMI Panorama GS declared system with 189 ps temporal resolution first full-body PET/CT scanner with time-of-flight (TOF) resolution better than 200 ps [8].

In principle, the shown evolution of the technical design in the PET scanning industry affects to reducing the radiation dose (currently 5–25 mSv, whole body) and a shortening of the procedure time (currently around 15 min), with a patient's mental comfort [9]. To achieve this ambitious goal, it is essential to develop a PET experiment test-benches for the characterization of a new scintillation material [10]. Since the acquisition boards and data processing capabilities are far in the sub-picosecond range, the new scintillation materials should be significantly improved in light yield and decay time.

It might be some boost from speeding up the photo-sensors, self single-photon time resolution (SPTR) and photon detection efficiency [12, 11], improving the photon detection efficiency (PDE, currently 50-63%), and lower operation voltage $V_{br}$ (breakdown voltage). In this direction, the main focus in the PET industry on developing and characterizing new scintillation materials is crucial.

## 2. MATERIALS AND METHODS

It was prepared two identical scintillators LYSO [14], cut and polished (all sides) in a size of 2 x 2 x 3 mm. Prepared crystals were installed on multi pixel photon counters (MPPC) Broadcom AFBR-S4N44P014M [11] with an Cargille Meltmount media [13]. Additional wrapping with PTFE tape (300 um) used to improve the entire light collection. A simplified experimental diagram is presented on Fig.1

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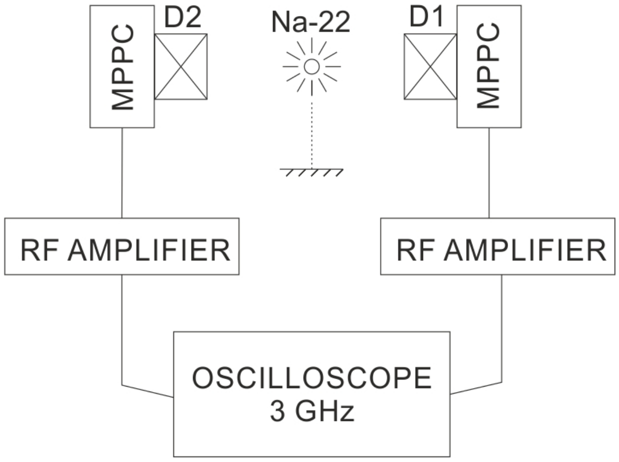


**Figure 1.** Experimental setup. D1, D2 - LYSO crystals. Readout outputs are connected directly to oscilloscope.

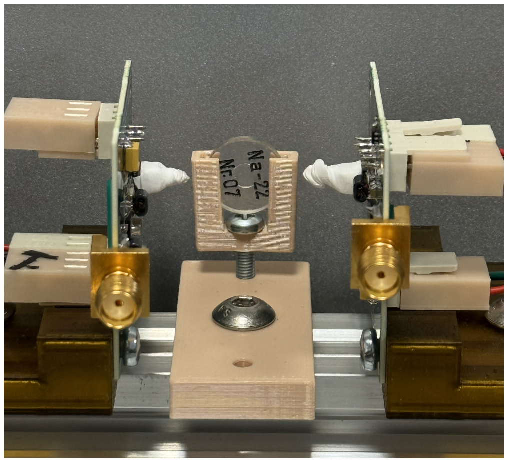


**Figure 2.** Dark box for CTR measurements with installed PCBs and mounted scintillators LYSO.

All the prepared acquisition parts were placed inside a dark box with external BNC connectors and power outputs. On the Fig.2 presented an experiment geometry, two acquisition boards (left and right channel) installed on the V-rail, Na-22 source mounted on beige holder in the geometrical center. It was used two custom HV boards (C11204-01 with the temperature feedback loop). MPPC boards with the installed crystals were connected directly to the oscilloscope Lecroy WP7300A (3GHz, 20GS/s in 2ch mode). High voltage was 39V for both channels. Typical signals of coincidence events are shown on Fig.3 Custom designed amplifier used for the MPPC readout, Fig.4 presents the schematic diagram of the implemented topology: differential input to single output with balun decoupling. The ADA4960-1 is a high performance, differential amplifier (U3) optimized for RF and IF applications. Temperature feedback loop (U2) LM94021 is a linear, precision analog output temperature sensor.

**Figure 3.** Pulses from coincident events from Na-22 isotope. Corresponding left and right channels, 20GS/s, full bandwidth 3GHz. Baseline noise 2mV avg.

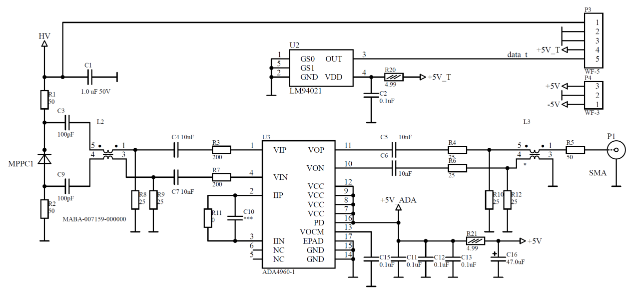

**Figure 4.** Schematic of the one channel, differential amplifier used with maximum gain 18dB

## 3. DATA ANALYSIS

To verify the limits of time measurement capabilities the test run was processed. Test signal from LBE-1322 Fast Rise time Variable Frequency Pulser was split and applied to LeCroy Ch2 and Ch3 with coaxial cables (external cable delay added). Specified rise and fall time for used pulse generator was 30 ps Fig.5. Using the LeCroy builtin math functions it was measured CTR value for the test signals: FWHM = 9.5ps for 3870 "coincidence" events, repeatable signal Fig.7.

In parallel, the raw test pulses were recorded to the host PC for further analysis with our custom code. In the Fig.12 presented results of signal processing with our code it is almost identical to the built-in LeCroy math results and correspond to the generator specification (oscilloscope bandwidth limitation of 3GHz).

## 4. EXPERIMENTAL RESULTS AND DISCUSSION

LYSO scintillator is a well-known material suitable for equipment verification. CTR results for LYSO but with different experimental equipment were examined by many researcher groups [15, 16, 17]. The measured value is in a

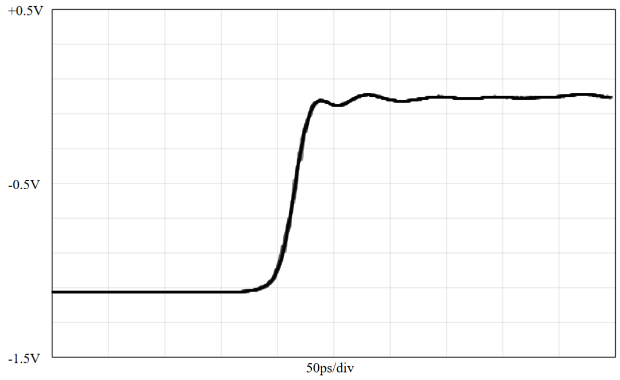


**Figure 5.** Typical test signal, rise time 30 ps.

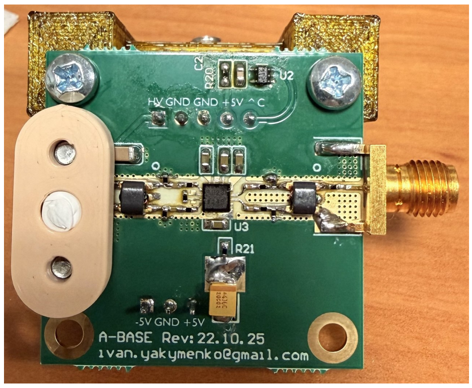


**Figure 6.** Designed PCB, one channel, MPPC covered with crystal holed (beige plastic), SMA output, U2 temperature sensor, U3 amplifier


**Figure 7.** Experiment simulation using the external pico-second generator. Results: mean 58.342ps, sdev 5.309ps. DUT: LeCroy WP7300 3GHz 10-20GSa/s

range from 100 ps to 600 ps and depends on the used acquisition path, crystal quality, etc. On the first stage, we performed an energy cut to limit the ROI to 511 keV. Fig.9 represents the spectrum from both channels and Fig.10 demonstrates the selected photopeak. The prepared dataset was processed with the CFD function to correct the rise time walk, Fig.11, and achieve a zero crossing point. The final distribution Fig.8 represents the experimental CTR of 226 ps. Analyzing the presented result, we should consider several possible factors that may contribute to the resulting CTR: defects in LYSO crystals, possibly non-identical acquisition channels, and errors in the CTR calculation algorithm (such as the baseline calculation for zero-crossing detection). 226 ps result is in line with a lot of reported results. A pair of 511 keV $\gamma$-quanta could be recoiled in the surrounding material, entering the scintillator with lower energy. Different input energies may affect the resulting signal deviation. New scintillation material with a "stable" light production mechanism in a specified energy bandwidth may reduce the signal deviation in a coincidence registration experiment. This work aims to gain a deeper understanding of CTR measurement details and address the identified problems in future test-bench modifications.

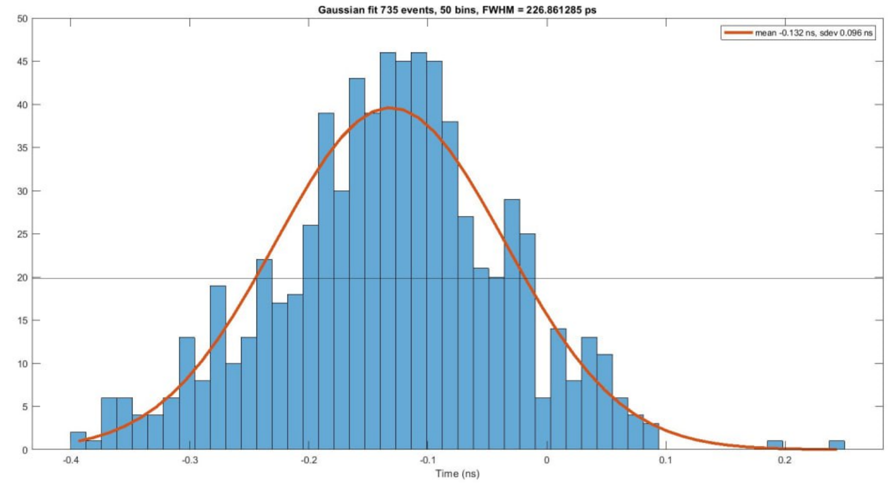


**Figure 8.** Experimental results for CTR measurements of LYSO scintillators.

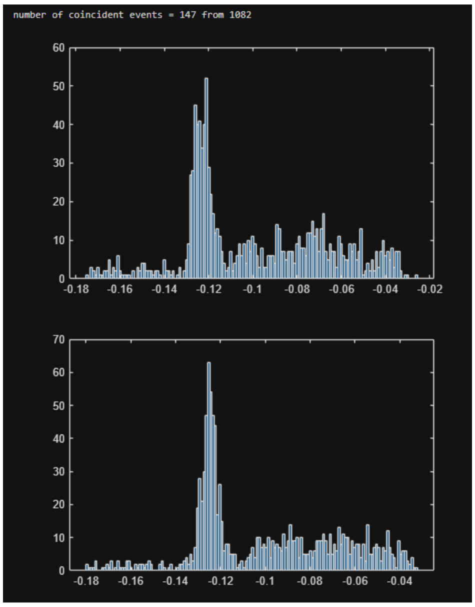


**Figure 9.** Spectra for LYSO scintillator, two channels, Na-22, input signal polarity negative

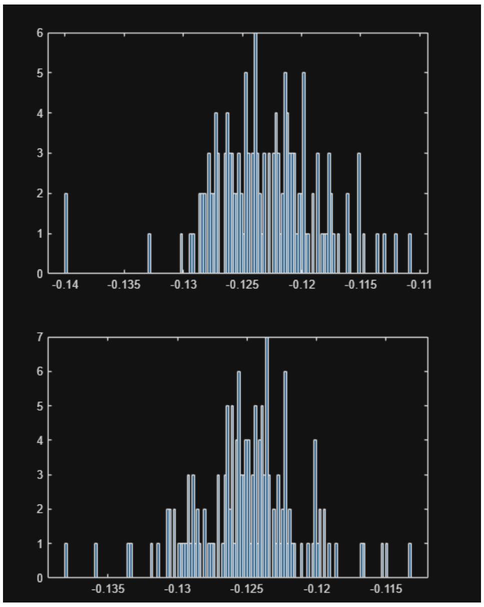

**Figure 10.** Energy cut applied for LYSO scintillator spectra

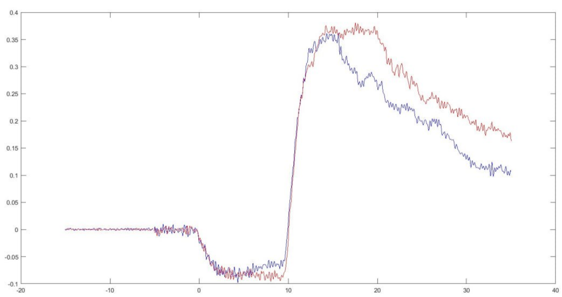

**Figure 11.** Pulses with applied CFD, zero crossing point

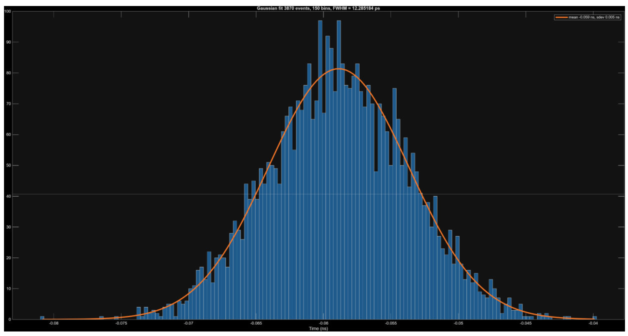

**Figure 12.** Raw pulses from generator processed with custom code: FWHM = 12.28ps 3870 events, mean 59ps, sdev 5ps.

### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## ОСОБЛИВОСТІ ЕКСПЕРИМЕНТУ З ВИЗНАЧЕННЯ ЧАСОВОГО РОЗДІЛЕННЯ СЦИНТИЛЯТОРА LYSO

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У цьому дослідженні ми провели експериментальні вимірювання роздільної здатності за часом збігу за допомогою спеціально розробленого випробувального стенду. В рамках цієї роботи ми обговорили технічні питання та валідацію даних в експерименті CTR на прикладі кристалів ортосилікату лютецію-ітрію ($LYSO : Ce$) Saint-Gobain розміром 2 х 2 х 3 мм. Основною метою представлених експериментальних робіт є розробка інструментів для експериментальної валідації новостворених сцинтиляційних матеріалів, на шляху до детекторів ПЕТ з часовим 10-пс.

**Ключові слова:** *роздільна здатность за часом збігу(РЗЧЗ); гетероструктуровані сцинтиляційні матеріали; 511 КеВ детектор гамма випромінювання; LYSO; ПЕТ; швидка обробка сигналів; дискримінатор постійної фракції (ДПФ); анігіляційні події*