Study on Coincidence Time Resolution with SiPM and TOFPET-ASIC utilizing LYSO, GAGG and GFAG

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I. Introduction

The combination of KETEK silicon photomultipliers (SiPM) and PETsys TOFPET (time-of-flight positron emission tomography) application specific integrated circuits (ASIC) provides all requirements for high performance timing measurements in positron emission tomography (PET) applications. The TOFPET ASIC uses the principle of time-over-threshold (ToT), a common method for the readout of analogue SiPMs, especially in the context of PET. Main aim of this work is a study on the coincidence time resolution (CTR) of the radiation detection system (scintillator, detector and readout electronics), with respect to different scintillators. The focus is on LYSO, since the used ToT ASIC is optimized for it. In addition, the performance of GFAG and GAGG is analyzed.

II. Experimental methods

All results were acquired with the latest timing optimized KETEK PM3350T SiPM, having a 3×3 mm^2 active area, a 50 μm cell pitch and a breakdown voltage of 24.5 V. The PM3350T, operated at 30.0 V, has an absolute photon detection efficiency of 47% at 420 nm and 33% at 520 nm, as well as a high gain of $\sim 7.1 \cdot 10^6$.

The main focus is on the performance of the combination of this detector and the PETsys evaluation kit based on the TOFPET ASIC with 64 individual channels each. Besides, important characteristics of the TOFPET ASIC are a 25 ps r.m.s intrinsic time resolution and 300 pC dynamic range. ToT requires the use of two independent threshold values, Th_T, on the one hand, provides the timestamp of an event, with Th_E, on the other hand, the length of the pulse is extracted, as a measure for its charge content. Both thresholds can be set separately for each channel in discrete values with a resolution of 6 bit. Throughout this work, Th_E remained at a fixed value of 15 DAC (digital-analog-converter) units, which corresponds to approximately 30 p.e. (photoelectrons). The influence of Th_T has been studied in this work. The obtained ToT-energy-spectra are searched for the 511 keV annihilation peak, which is then fitted by a Gaussian. Events within three sigma around the mean are considered for coincidences. With the readout system three different scintillating crystals, each with a size of $3 \times 3 \times 5$ mm^3, were analyzed: LYSO with a peak emission wavelength of 420 nm, decay time of 40 ns and effective Z of 65, as well as GFAG (520 nm, 50 ns, 52) and GAGG (520 nm, 88 ns, 54). All crystals were wrapped in PTFE and coupled to the detector with Dow Corning 1-2577 low V.O.C. conformal coating. To verify the results and as a benchmark, a discrete coincidence setup was used with dedicated amplifiers and a LeCroy WaveRunner 64MXi-A digital oscilloscope to measure the CTR. A ^{22}Na point source with an activity of 925 kBq was used for all measurements.

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III. Results

A. Setup Evaluation with LYSO

Figure 1 shows two short scans over the bias voltage with LYSO coupled to the detector and Th_T at 24 DAC units above the baseline. The best result of 294 ps FWHM was achieved when keeping the entire setup environment at approximately 18°C and setting the bias voltage to 30.0 V. Another scan was performed without a cooling system, for which the temperature was monitored on the ASIC surface, converging to 31°C within the first minutes of the measurement. Both measurements show better CTR with increasing bias voltage. CTR values are $> 30\%$ higher for the non-cooled measurements. Higher voltages were not measured due to gain limitations.

B. Comparison of GAGG, GFAG and LYSO

Unfortunately a temperature stabilized setup environment was only available for certain measurements, thus, all measurements in section III-B were performed without cooling, with the aim to relatively compare the scintillators. Figure 2 shows the scan over Th_T for LYSO, GFAG and GAGG at 28.0 V and it can be observed, that GAGG shows the highest CTR values, due to a slower rising edge compared to GFAG and LYSO. Besides, GFAG and GAGG have a peak emission wavelength of 520 nm yielding a PDE of 33% compared to LYSO with 420 nm and 47%, which also degrades the performance. Looking at the trend of the measurements in figure 2, the expected behavior as shown in [1] can be seen. When setting Th_T to the baseline level, the CTR is very high due to random

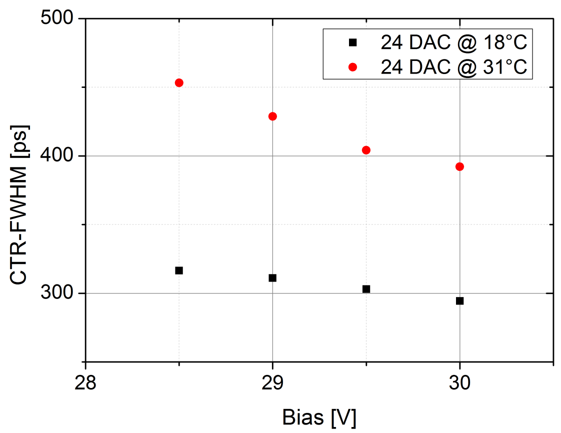

Fig. 1. CTR results for LYSO versus different operating voltages for a setup environment with and without temperature stabilization at 18°C. For both scans, the best results were achieved at 30.0 V, with $> 30\%$ higher results for the non-stabilized measurements.

coincidences triggered by noise and the slope of the rising edge, which is less steep at lower signal values. The best CTR could be achieved at approximately 10 DAC values above the baseline. GFAG and GAGG degrade considerably more rapid than LYSO with increasing Th_T, which can be explained, that the ASIC is possibly saturated by the higher charge generated by GFAG and GAGG.

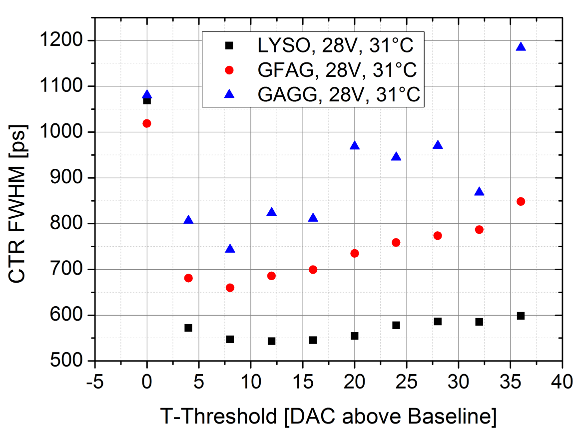

Fig. 2. Scan over Th_T at 28.0 V bias voltage for GAGG, GFAG and LYSO. Once the threshold is above the baseline noise, a minimum is reached for all scintillators. Further increasing Th_T has significant impact on GFAG and GAGG, whereas LYSO only degrades slightly.

Section III-A stated that the performance increases with higher bias voltage for LYSO, however, a quite different behavior for GFAG and GAGG can be observed in figure 3. Unlike LYSO, the CTR for GFAG and GAGG degrades rapidly at higher voltages, which can be explained by the longer decay times and therefore longer pulses. More specific, with rising bias voltage the pulse length as well as the time spread increase and the ToT values tend to fluctuate, leading to a degraded energy spectrum. As a result, the 511 keV photopeak is no longer clearly distinguishable, thus, a rise of scattered events in the CTR spectrum occurs and therefore the CTR degrades.

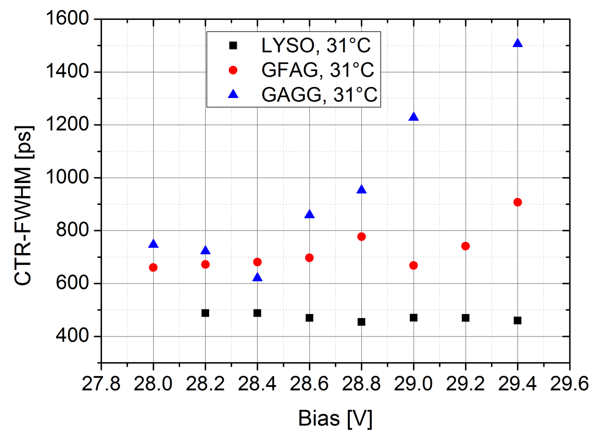

Fig. 3. Scan over bias voltage at $Th_T = 15$ DAC above basline for GAGG, GFAG and LYSO. The poor energy resolutions for GFAG and GAGG at higher voltages lead to high CTR values, whereas LYSO slightly improves with increasing bias.

The discrete benchmark setup as a reference resulted in 248 ps FWHM for LYSO, 329 ps for GFAG and 663 ps for GAGG at a bias voltage of 30.0 V at room temperature.

IV. Conclusion and Outlook

Chen et al. reported a CTR value of 214 ps FWHM using a $3.1 \times 3.1 \times 15$ mm^3 LYSO crystal, SiPMs and ToT-ASICs [2]. Comparable measurements using a KETEK SiPM and PETsys readout electronics were described in this work. In comparison a CTR of 273 ps with LYSO and Hamamatsu MPPC (Multi photon pixel counter) was achieved [3]. The given setup performs best with LYSO in a cooled environment, reaching a CTR of 294 ps FWHM. GFAG and GAGG could not fully exploit their intrinsic performance, as the measurements are very sensitive towards changes in bias and threshold settings and do not catch the performance of LYSO. Following works will include measurements within a temperature stabilized environment to overcome the degradation in performance caused by the heat dissipation of the ASIC. Furthermore, the next generation readout ASIC, which overcomes the current limitations and is expected to be fully capable to handle any scintillator with maximum performance, will be studied.

References

[1] Seifert, Stefan. Silicon Photomultipliers and Monolithic Scintillators for Time-of-Flight PET. TU Delft, Delft University of Technology, 2012.

[2] Chen, Huangshan, et al. "A dedicated readout ASIC for Time-of-Flight Positron Emission Tomography using Silicon Photomultiplier (SiPM)." 2014 IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC). IEEE, 2014.

[3] Bugalho, Ricardo, et al. "Design and performance of an ASIC for TOF applications." Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC), 2013 IEEE. IEEE, 2013.