Timing characteristics of inter-crystal optical crosstalk in BGO-based TOF-PET detectors

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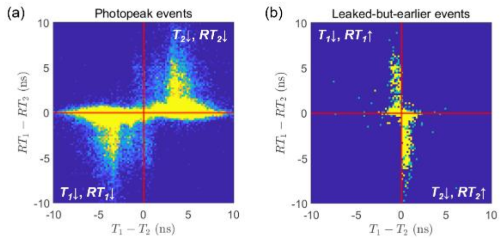
Bismuth germanate (BGO) has re-emerged as a promising scintillator for time-of-flight positron emission tomography (TOF-PET) owing to its ability to detect prompt Cherenkov photons generated within a few picoseconds following a 511-keV gamma-ray interaction [1]. While reflectors are commonly used in pixelated block detectors to achieve optical isolation between crystals, previous studies have reported that non-negligible inter-crystal optical crosstalk persists even when reflectors are applied to individual crystals [2]. Under photon-limited conditions utilizing Cherenkov emission, such crosstalk can potentially degrade the timing performance of BGO detectors. Therefore, we experimentally investigate the timing characteristics of inter-crystal optical crosstalk events in a Cherenkov-based BGO PET detector under different reflector conditions.

A 1 × 2 BGO crystal array (3.9 × 3.9 × 15 mm³) with three different reflectors ($BaSO_4$, ESR, and TiO_2) was coupled to a 2 × 2 silicon photomultiplier (SiPM) array. In coincidence analysis, events in which the channel with the lower deposited energy registered an earlier timestamp were identified as *leaked-but-earlier* events, associated with inter-crystal optical crosstalk. To characterize the timing behavior of these events, rise-time distributions were analyzed. Furthermore, the impact of *leaked-but-earlier* events on detector performance was evaluated by measuring the coincidence timing resolution (CTR) using two timestamping strategies: the earliest detected signal (*Early*) and the channel with the larger energy deposit (*Energy-based*). *Leaked-but-earlier* events were observed with a consistent occurrence of approximately 3% across all reflector conditions. Notably, although these events exhibited a lower temporal photon density—resulting in broader and slower rise-time distributions—they produced earlier timestamps than the primary interaction site. However, incorporating these timestamps using the *Early* timestamping method did not yield a meaningful improvement in timing performance, as the fraction of *leaked-but-earlier* events was insufficient to sharpen the fast component of the timing distribution.



Joint distributions of timing differences and rise-time differences between two neighboring channels for (a) photopeak events and (b) leaked-but-earlier events when $BaSO_4$ is applied to the BGO crystals.

The results demonstrate that, in BGO detectors utilizing Cherenkov photons, stable time pick-off is largely influenced by the total number of detected photons, which affects the temporal photon density and rise-time characteristics, even though inter-crystal optical crosstalk photons may arrive earlier than those originating from the primary interaction site. These findings provide a useful basis for the development of BGO-based TOF-PET detector modules that achieve high timing performance while remaining suitable for scalable system implementation.

1. S. E. Brunner and D. R. Schaart, "BGO as a hybrid scintillator/Cherenkov radiator for cost-effective time-of-flight PET," *PMB*, 62, 4421 (2017).
2. C. Trigila et al., "Intercrystal optical crosstalk in radiation detectors: Monte Carlo modeling and experimental validation," *IEEE TRPMS*, 8, 734 (2024).

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