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A Comprehensive Study on the Timing Limits Using High Light Yield Crystals and High-frequency Front-end Circuit for TOF PET Detectors

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Purpose–The coincidence time resolution (CTR) values can be improved by increasing photostatistics, which in the PET detector occurs with a high light yield (LY) of scintillation crystals. The two main contributors to the LY are the intrinsic LY of the scintillation crystal and the light transfer efficiency, which depend on crystal material, dimensions, and wrapping conditions. We report on a systematic study on achievable CTR performance with high LY scintillation crystals coupled to state-of-the-art high-frequency electronics followed by a DRS4-based 1GSPS digitizer.

Methods–Various high LY scintillation crystals, including LGSO, LYSO:Ce:Ca, LYSO:Ce:Mg, were investigated to measure relative LY and achievable CTR values under differing physical conditions such as crystal pixel size and reflector material. For a fast timing channel, high-frequency readout electronics were constructed employing passive compensation for the SiPM detector capacitance. The compensation was implemented using a 3 GHz balun transformer connected between both ends of the SiPM so that a balanced-to-unbalanced converted signal propagates into the RF amplifier.

Results–With the optimized leading-edge threshold, the measurements yielded CTR values of 177 ps for LGSO crystal wrapped with ESR film, 142 ps with Teflon, and 377 ps with the black tape. The Teflon tape yielded not only the best LY but also in terms of the CTR among different reflector materials. With the crystal wrapped with black tape, the LYs significantly deteriorated, which also caused the worst CTR value. The double-doped crystals showed sub-150 ps CTR, which is similar to or slightly better than the LGSO crystals and corresponds to the increased LY.

Conclusion–In this study, the photostatistical effect on the potential temporal resolution was comprehensively demonstrated. Also, it was also shown that high-frequency electronics still can be fully exploited with a relatively low sampling ratio showing encouraging results.

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