Investigation of High-Sensitivity TOF-PET Modules with Depth-of-Interaction Capability

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Low-dose imaging and small-animal positron emission tomography (PET) require detector modules with very high sensitivity. The use of high-density scintillators, such as bismuth germanate (BGO), and long scintillation crystals can significantly improve detection efficiency. However, when using long scintillators, the depth-of-interaction (DOI) of gamma rays introduces parallax errors and image degradation if not properly corrected. This work investigates detector concepts with DOI capability to mitigate these effects while maintaining good energy and time performance.

We study and compare different DOI-encoding approaches using 20 mm-long BGO and LYSO:Ce scintillator matrices with depolished lateral surfaces. Two detector configurations are investigated: a double-sided readout, in which each matrix is coupled to silicon photomultiplier (SiPM) arrays on both ends, and light-sharing DOI-encoding modules that utilize a single SiPM array and a light guide. These two detector concepts are compared with standard PET modules without DOI capability. Detector performance is evaluated in terms of coincidence time resolution (CTR), energy resolution, and DOI resolution using both custom-developed readout electronics and commercial readout systems.

The advantages and limitations of each detector configuration and readout electronics are assessed. The benchmark performance is achieved using a 16-channel low-power, low-noise, high-frequency readout electronics, which enables efficient exploitation of the fast scintillation component of LYSO:Ce as well as the ultra-fast Cherenkov emission in BGO. Using the light-sharing DOI concept with LYSO:Ce, a CTR of approximately 130 ps and a DOI resolution of about 2 mm as full width at half maximum (FWHM) are achieved. These results are compared with measurements obtained using the other readout electronics that offer a scalable solution while achieving competitive results.

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