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The influence of the number of Cerenkov photons on the timing resolution of a BGO PET detector.

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The PET-detector time resolution (DTR) using BGO can be improved by using not only scintillation, but also Cerenkov photons. Geant4/GATE Monte Carlo simulations were performed for 511 keV photon interactions in a BGO crystal of 3 x 3 x 20 mm3. In 13720 interaction events, the electrons, scintillation and Cerenkov photons were followed until the photons entered the SiPM, where immediate detection was assumed (SPTR = 0). We fitted the probability distribution model proposed in [1] to the resulting photon detection times, to obtain a model for scintillation and for Cerenkov detection times. On average, 924 photons were detected. A 511 keV interaction in BGO produces around 17 Cerenkov photons, on average only 3.24 were detected.
To determine the DTR provided by these optical photons, a maximum likelihood (ML) estimator was implemented, which estimates the interaction time from the sorted list of photon detection times.
To study the influence of the number of Cerenkov photons on the DTR, simplified simulations were done, using the model of [1] with the fitted parameters as ground truth. The number of detected scintillation photons was assumed Poisson distributed with expectation 924, the number of detected Cerenkov photons was also assumed Poisson, but different expectation values were simulated. For each Cerenkov expectation value, 10000 interaction events were simulated by randomly sampling the model of [1]. From each set of 10000 interactions, the DTR was quantified as the standard deviation (std) of the observed ML-estimated interaction times.
For an expected number of [0, 1, 2, 3.24, 4, 6] detected Cerenkov photons, the observed DTR-std was equal to [327, 267, 177, 109, 83, 48] ps. These results show that even a slight increase in the number of detected Cerenkov photons produces a noticeable improvement of the DTR.

[1] S. Seifert, H. van Dam, D. Schaart, "The lower bound on the timing resolution of scintillation detectors", Phys. Med. Biol. 2012; 57: 1797 - 1814.

Primary authors: TRIGILA, Carlotta (Department of Biomedical Engineering and Department of Radiology, UC Davis, One Shields Avenue, Davis,CA 95616, USA.); RONCALI, Emilie (Department of Biomedical Engineering and Department of Radiology, UC Davis, One Shields Avenue, Davis,CA 95616, USA.); NUYTS, Johan (KU Leuven, University of Leuven, Department of Imaging and Pathology, Nuclear Medicine & Molecular imaging; Medical Imaging Research Center (MIRC), B-3000, Leuven, Belgium.); DEFRISE, Michel (Department of Nuclear Medicine, Vrije Universiteit Brussel, B-1090, Brussels, Belgium.); LECOQ, Paul (Polytechnic University of Valencia, Spain.); GUNDACKER, Stefan (Department of Physics of Molecular Imaging Systems, Institute for Experimental Molecular Imaging, RWTH Aachen University, Forckenbeckstrasse 55, 52074 Aachen, Germany.)

Presenter: NUYTS, Johan (KU Leuven, University of Leuven, Department of Imaging and Pathology, Nuclear Medicine & Molecular imaging; Medical Imaging Research Center (MIRC), B-3000, Leuven, Belgium.)

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