Fundamentals of Ultrafast Timing

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The timing resolution of radiation detectors is a matter of importance in a variety of applications. Time-of-flight positron emission tomography (TOF PET) is one of the more demanding ones, because of the relatively low energy (511 keV) of the primary information carriers. Nevertheless, clinical TOF-PET systems with coincidence resolving times (CRT) between 325 ps and 400 ps FWHM have recently been developed. Even better CRTs, well below 100 ps FWHM, have been achieved in laboratory by various groups. Such ultrafast timing is typically achieved with detectors in which the energy of the primary information carrier is converted into a fast luminescent signal via scintillation, Cherenkov emission, hot intraband luminescence, quantum-confined emission, or another physical process. An intriguing question is whether or not it will physically be possible to achieve CRTs in the order of ~10 ps FWHM [1]. Such CRTs would enable positioning the event with ~mm accuracy along the line-of-response (LOR), causing a paradigm shift in PET by eliminating the need for image reconstruction. The further improvement of CRT values requires a thorough understanding of the principles that govern the time resolution of radiation detectors based on luminescence. Whereas first works in this direction were published in the 1950's already, the fundamentals of modern timing theory—based on order statistics—have been formulated in Delft in the early 2010's [2,3]. In the meantime, this theoretical framework has been validated as well as extended by a variety of groups worldwide. This presentation summarizes the essentials of modern timing theory and present an overview of ongoing developments towards the further improvement of time resolution. These topics will be addressed from a practical point of view, highlighting how the theory may be used to guide the research into new light sensors, luminescent materials, and detector designs for ultrafast timing.

[1] D.R. Schaart, S. Seifert, H.T. van Dam, G. Borghi, D.N. ter Weele, and P. Dorenbos, "Prospects for achieving < 100 ps FWHM coincidence resolving time in time-of-flight PET," ICTR-PHE 2012, Geneva, Feb 27 - Mar 2, 2012. Radiotherapy and Oncology 102 (Suppl 1), S86-S87, 2012.

[2] M.W. Fishburn and E. Charbon, "System Tradeoffs in Gamma-Ray Detection Utilizing SPAD Arrays and Scintillators" IEEE Transactions on Nuclear Science 57, 2549-2557, 2010.

[3] S. Seifert, H.T. van Dam, and D.R. Schaart, "The Lower Bound on the Timing Resolution of Photon Counting Scintillation Detectors," Physics in Medicine and Biology 57, 1797-1814, 2012.