Timing measurements of LYSO crystals with fast photodetectors for PET-TOF probes

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Positron emission tomography (PET) is considered one of the most sensitive in–vivo diagnostic imaging modality, although with spatial resolution lower than computed tomography (CT) and magnetic resonance imaging/spectroscopy (MRI/MRS). The PET technique is based on the detection of back-to-back 511 keV gamma photons originating from the annihilation of e^+ with atomic electrons, after the administration to the patient of a β^+ emitting bio-molecule. In the conventional PET system, a ring of detectors is placed around the test body and the reconstruction of the annihilation vertex is performed by the intersection of several back-projection lines, as illustrated in Fig. 1 (left).

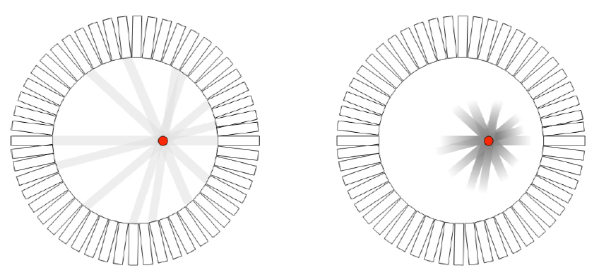

Figure 1. The PET concept. Localization of e^+e^- annihilation point is obtained by intersecting the back-projection lines between two opposite scintillators measured in coincidence [1].

If the time difference Δt between two coincident back-to-back detectors is also measured, then the location of the annihilation point is additionally constrained by $\Delta x = (c/2)\Delta t$ where c is the light speed (Fig. 2). This is the concept of time of flight PET (PET-TOF).

The project TOPEM [2], through the INFN Commissione Scientifica Nazionale 5 (Particle accelerators, detectors, electronics and interdisciplinary applications) is developing an endorectal PET-TOF MRI probe for the diagnosis and follow-up of prostate cancer, which is one common disease. Multimodality imaging can play

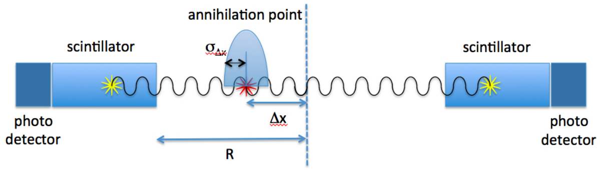

Figure 2. The TOF concept. Annihilation point localization along the coincidence path between the two scintillators is improved by measurement of the time difference Δt between the two signals.

a significant role by merging anatomical and functional details from simultaneous PET and MRI/MRS scans for guiding biopsy, diagnosis and follow up. Dedicated prostate imagers can achieve superior sensitivity, spatial resolution and contrast. Exploiting the TOF capability allows an increase in the SNR/NECR and also permits elimination of bladder background. The internal probe is used in coincidence with an external dedicated detector and/or a standard PET ring. Performance is dominated by the endorectal detector with improvements in both spatial resolution and efficiency. The electronics must measure coincidences with a precision of 300 ps or less, and be small enough to be connected to the internal detector. For compactness and MRI compatibility, Silicon Photomultipliers (SiPM) are used. Their time jitter is negligible so the expected time resolution is a direct function of the sqrt of photoelectron number related to the PDE. Extensive ongoing simulation by Geant4 allows study of the scintillator geometry, coupling to the SiPMs and their pixel dimensions. A front-end electronics is being developed including, in a first phase, pre-amplification and discrimination only. Measurements for characterization of the performance of different SiPMs (temperature behavior, PDE etc) in comparison with standard fast phototubes are ongoing. Preliminary data with SiPM arrays from FBK and Hamamatsu reading light generated in small LYSO crystals, show TOF resolutions of 350 ps FWHM, not far from the goal of at most 300 ps.

In particular, participants from Lecce and Bari are taking care of reference measurements with LYSO crystals read out by fast phototubes, in order to quote the best achievable timing performance in standard situation. The measurements are being performed with a setup illustrated in Fig. 3, based on conventional signal treatment, by means of NIM/CAMAC amplification, discrimination, trigger logic and digitization of time and charge information. Time of flight resolutions as low as 225 ps FWHM have been measured (Fig. 4) for gammas releasing their whole energy into the crystals. In addition, several algorithms are being tested for the analysis of PMT signals acquired by a digital scope with high bandwidth and high sampling rate (LeCroy 7300A) to push the timing performance to the limit.

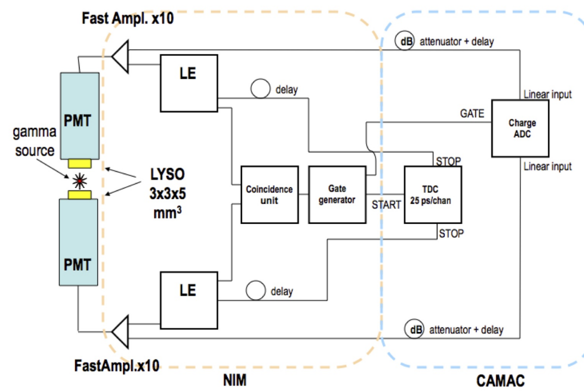

Figure 3. Signal processing for high resolution timing measurement with ^{22}Na gamma source.

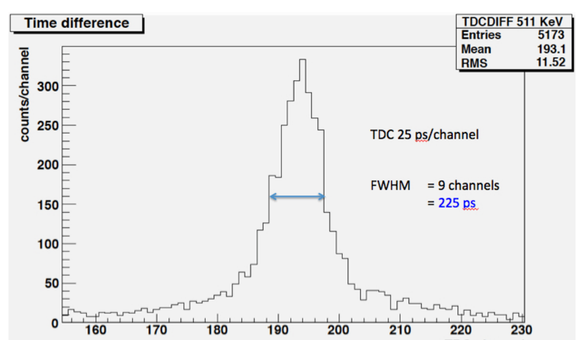

Figure 4. TOF measured for 511 keV $\gamma-\gamma$ correlated events from ^{22}Na e^+e^- annihilation. LYSO 3×3×5 mm^{3}polished crystals were directly coupled from one 5 mm long face to Hamamatsu R9880U110 PMTs. Other faces were wrapped in teflon.

REFERENCES

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