Time and depth of interaction measurements with photon minidetectors for PET-TOF probes

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The project TOPEM (funded through the INFN/CSN5) is developing a small time of flight positron emission tomography (PET-TOF) probe for prostatic cancer diagnosis. It will employ 2D arrays of small gamma detectors ($1.5 \times 1.5 \times 10$ mm^3 LSO/LYSO pixels) individually coupled to silicon photomultipliers (SiPM). The probe will be used as a vertex detector in tracking coincidence with a conventional full body PET, in order to increase the space resolution at the required small scale. In addition, the choice of SiPM is mandatory for low power consumption, good time resolution, immunity from magnetic field (if used in combination with MRI).

Efficiency, space resolution and time resolution are the critical parameters in the game. LYSO/LSO crystals are known to provide high light yield (25K photons/MeV) and fast light release ($\tau = 50$ ns). SiPM, on the light detection side, are capable of intrinsic time resolution of tens of ps. In the combination of the two aspects, the geometric form factor, the surface treatment of the crystals, and the optical coupling to the SiPM must be optimal for maximizing the performance in terms of time resolution, so to achieve the design value of less than 250 ps. The gamma rays depth of interaction (DOI) is an important parameter for the reduction of the parallax effects in PET, and can be measured by integrating the light arriving on both ends of a crystal. Good DOI resolution (≤ 3 mm) exploits the light attenuation length of the scintillator, however this light loss must be optimized in order to get the best timing resolution, which is on the contrary spoiled by poor light yield. In order to study this optimization as a function of the crystal surface treatment and wrapping, a measurement plan is being performed, with a set of different LYSO crystals, different surface conditions and different wrapping.

Timing measurements with coincident 511 KeV gamma-gamma events from ^{22}Na were reported in the last Annual Report [1]. Here we focus on the simultaneous DOI and TOF measurement, performed according to the setup of Fig. 1.

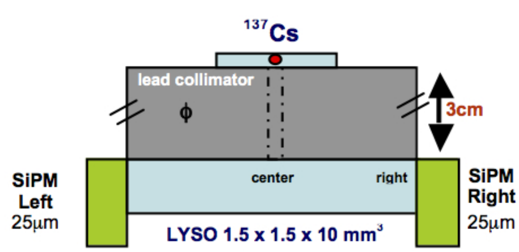

Figure 1. Scheme of the detector set-up for the DOI/TOF measurements with SiPMs.

A ^{137}Cs gamma source is used to excite scintillation on a LYSO crystal in a small spot defined by a lead collimator. Light is read out at both ends by two SiPM photodetectors. Individual right and left linear signals are split to get charge integration in appropriate analog to digital converters (ADC), and to measure time of flight difference after discrimination through a leading edge (LE) discriminator. Time measurement was performed with a time to amplitude converter (TAC) and an ADC. Typical time difference spectrum is displayed in Fig. 2.

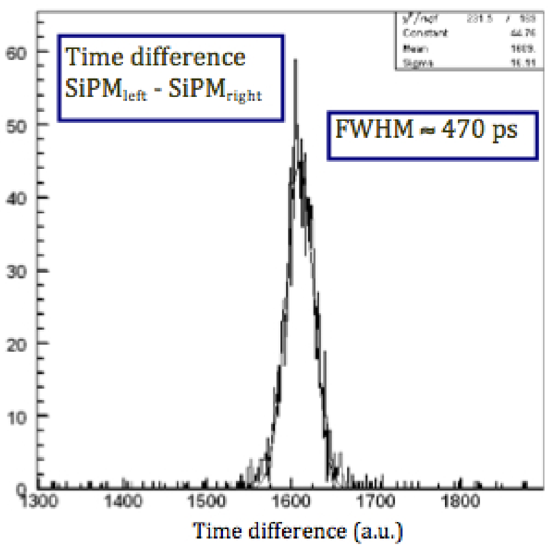

Figure 2. Spectrum of time difference between the two SiPMs in the measurement with setup of Fig. 1.

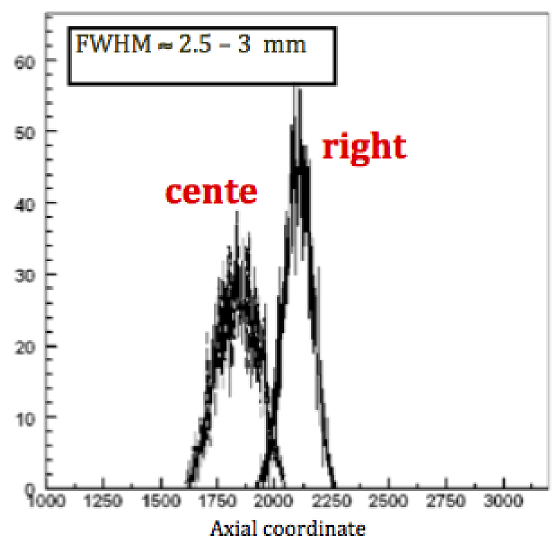

Figure 3. Spectrum of depth of interaction for two position of the collimated gamma source with setup of Fig. 1.

SiPMs were biased at 72.9 V and the LE threshold was set to 1.5 photon equivalent.

The DOI spectra were obtained on an event-by-event basis by scaling the charge on one conventional end with the sum of the total light detected by both end SiPMs. The sensitivity to the source position is clearly shown by results of Fig. 3, and the FWHM is estimated to be ranging from 2.5 to 3.0 mm.

SiPM photodetectors seem to show both good TOF resolution with reasonable DOI capability, which were demonstrated simultaneously for the first time. The plan is now to go for a systematic selection of optimal SiPM and crystal manufacturers.

REFERENCES

1. R. Perrino et al., *Annual Report 2009-2010*