Intrinsic limits of photon timing in LYSO scintillating crystals

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The timing properties of a detection system made of an inorganic scintillator crystal coupled to a fast photodetector (conventional or Silicon photomultiplier) have recently been investigated both experimentally and theoretically, aiming at the expected improvement of positron emission tomography imaging resolution by means of the time-of-flight technique.

In recent years, several authors [1–3] have investigated the fundamental limits of timing precision for inorganic scintillators by considering some formal implications of the statistical nature of the light emission process. They have calculated analitically the coincidence time resolution starting from the time dependent Poisson distribution which describes with high accuracy the physical process of scintillation light emission.

Here a different approach is reported. A toy Montecarlo code was developed in the Cern ROOT framework, based on the stochastic sampling of random variates according to the appropriate rate models. The code has been checked for internal coherence by simulating a homogeneous process with constant rate $\lambda(t) = \lambda_0$ which results in known Poisson counting statistics with mean value $\Lambda(t) = \lambda_0 t$ and exponential interarrival time distribution.

Following [1–3], the scintillation process was modeled in two approximations: the first with single exponential photon emission rate

$$\lambda(t) = \frac{R}{\tau_d} e^{-t/\tau_d} \qquad (1)$$

where R and τ_d are the total number of photons emitted and the decay time, respectively, as usually reported for slow scintillators; the second with inclusion of the rise time τ_r, which becomes relevant for fast scintillators, as remarked by Shao/Seifert, according to the following time-dependent rate

$$\lambda(t) = R\frac{\tau_r + \tau_d}{{\tau_d}^2} e^{-t/\tau_d}(1 - e^{-t/\tau_r}) \qquad (2)$$

The time parameters of the simulation in the case of a LYSO scintillator are $\tau_d = 40$ ns, $\tau_d = 0.5$ ns. If we consider the time distribution of any single subsequent photon, the first photon displays the best probability profile at all light intensities R (Fig. 1 shows the case with $R = 4500$, which is the average photon yield measured [4] for the release of 1 MeV in a $3 \times 3 \times 5$ mm^3 LYSO crystal).

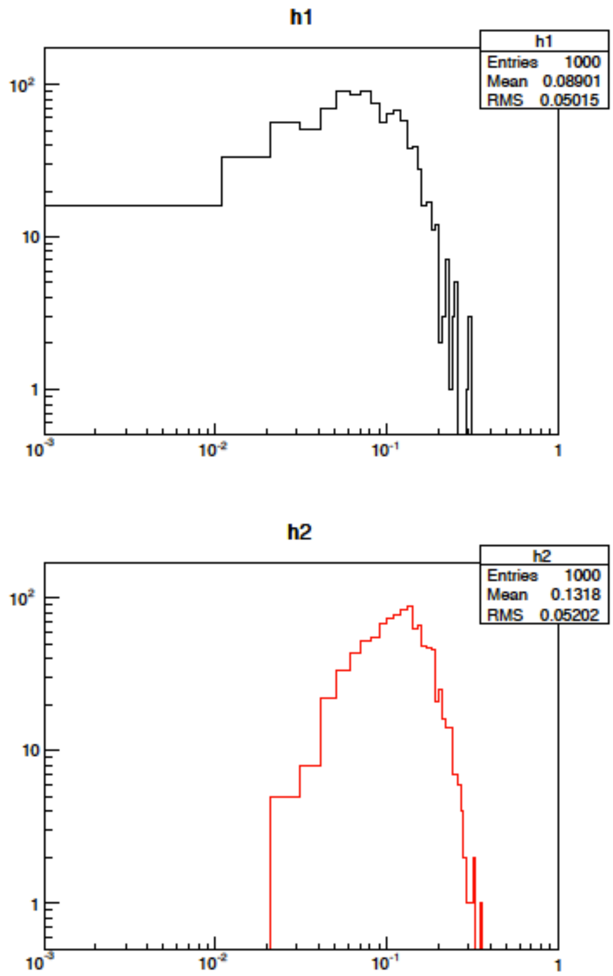

Figure 1. Time distribution [unit=ns] of the photon 1 (top) and 2 (bottom) as simulated with probability density from Eq. (2), with $\tau_r = 0.5$ ns and $\tau_d = 40.0$ ns (time parameters of LYSO).

In addition, the time resolution, in terms of the RMS of the timing distribution of Fig. 1, decreases according to $1/\sqrt{R}$ with increasing light yield R, as shown for photon 1 in Fig. 2.

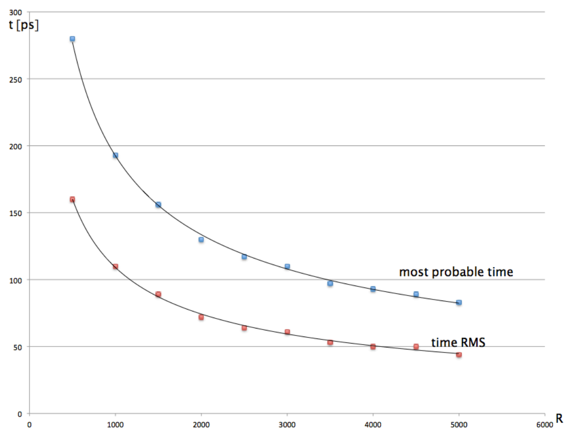

Figure 2. Most probable time and RMS for photon 1 as a function of light yield R. The best-fit curve is proportional to $1/\sqrt{R}$.

This work is in progress and the effect of transit time and transit time spread due to the photodetector will be included through a convolution of the time-dependent rate with a normal distribution.

According to the present results, the minimum RMS or time resolution for the single measurement in the case of single photon triggering would be at best 50 ps for LYSO crystals used to detect 1 MeV energy deposit. This would be of 70 ps in the case of PET 511 KeV photopeaks, which would be folded into a $\sqrt{2} \times 70 \approx 100$ ps coincidence time resolution for two identical back-to-back detector units.

REFERENCES

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