Detailed Monte-Carlo simulation of SiPM-based scintillation detectors for PET

J. Breuer, S. Cho, M. Aykac, R. Grazioso and M. Schmand

Siemens Healthcare
Molecular Imaging
91301 Forchheim
Germany

PhotoDet 2012

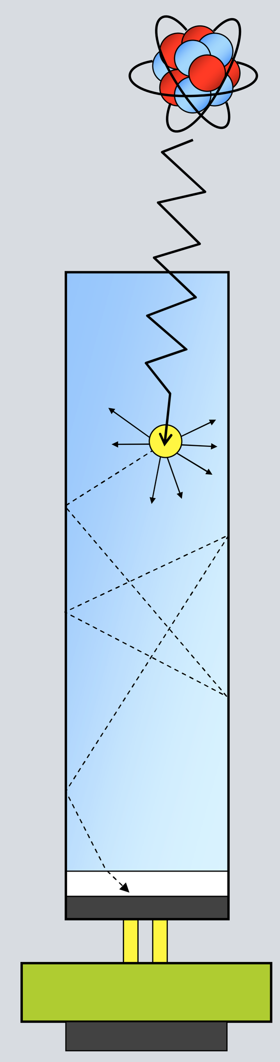
Introduction

Simulations are a very useful and powerful tool for designing scintillation detectors. Silicon Photomultipliers (SiPMs) exhibit a multitude of features that need to be taken into account. In this work, we present a detailed Monte-Carlo simulation of SiPM-based scintillation detectors. This simulation allows forecasts for time and energy resolution.

Methods

Simulation steps:

- The interactions of the 511 keV photons are simulated with GEANT.
- The generated scintillation photons are simulated with the commercial optical simulation software ZEMAX. Based on the total traveled path it is possible to determine detection time and location of each scintillation photon.
- Subsequently, the cell level processes in SiPMs (i.e. dark counts, crosstalk, afterpulsing and cell recovery) are modeled based on measured electronics response functions from the lab setup. (See Fig. 1)
- Finally, the read-out electronics are simulated (e.g. amplifier and leading edge discriminator)



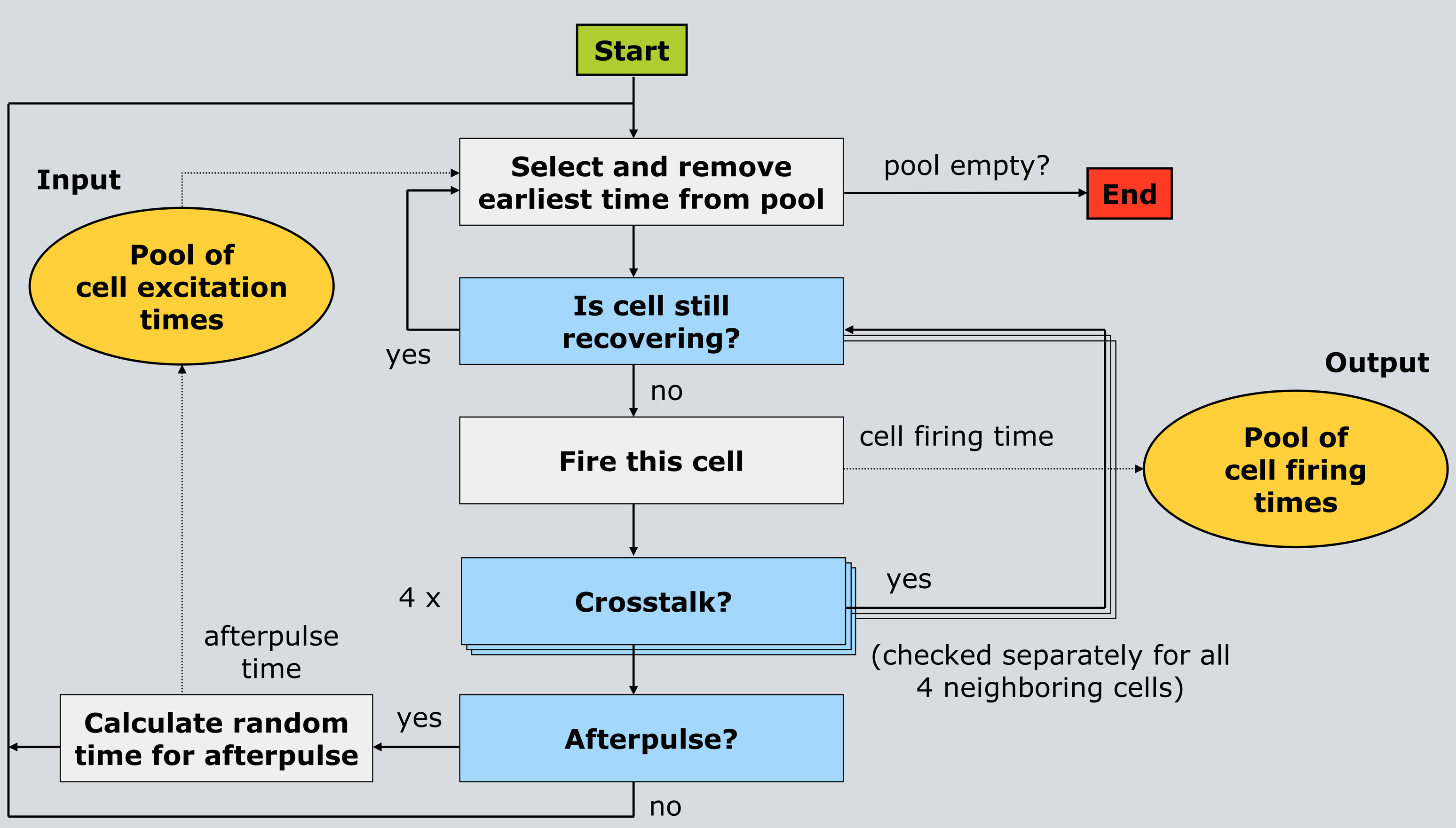


Fig. 1: The flow diagram describes how the intrinsic processes in the SiPM are modeled on the cell level. The input pool of cell excitation times is generated based on the outcome of the ZEMAX simulation. The output pool of cell firing times is translated into an electronic signal by convolution with a standard single PE pulse shape which depends also on the amplifier used.

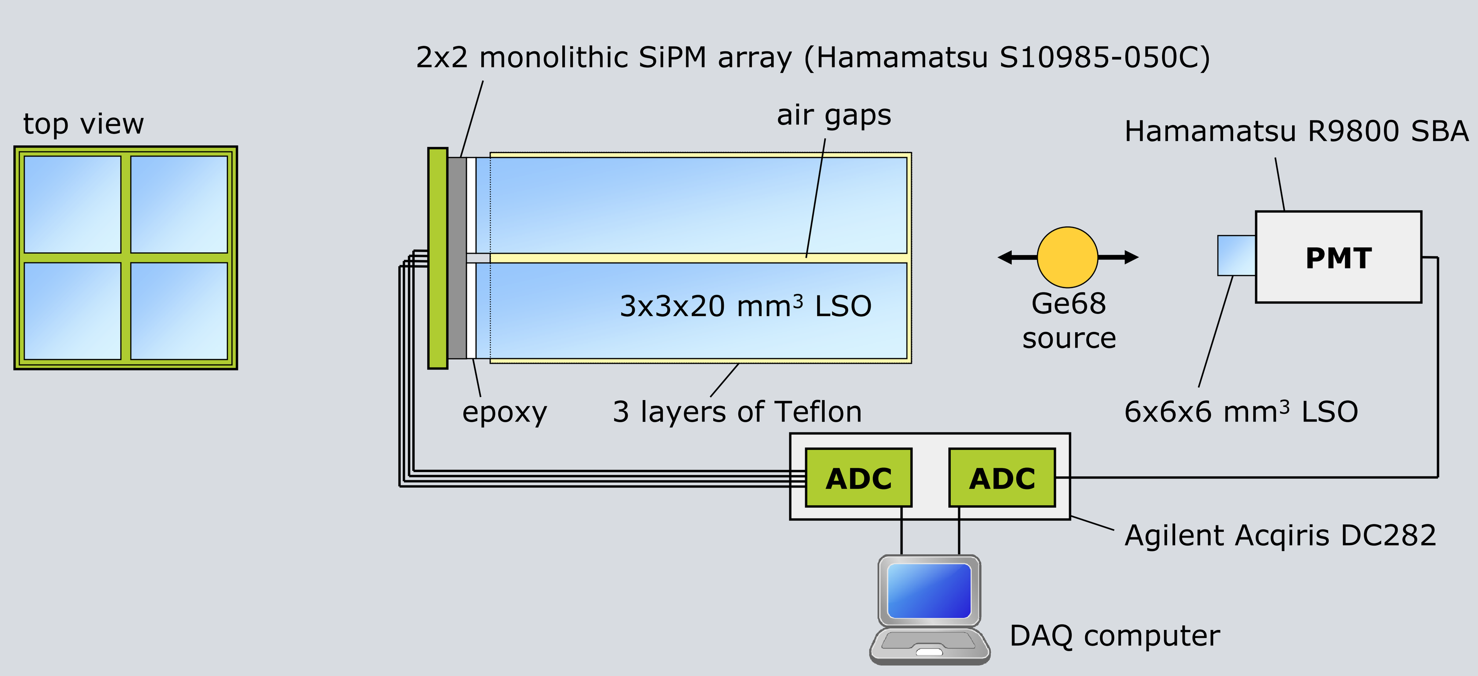


Fig. 2: The displayed experimental setup is used to measure the time resolution of a 2x2 array of LSO crystals coupled to a 2x2 monolithic SiPM array. A PMT/LSO detector is used as reference detector (contribution: 125 ps FWHM). All 5 signals were digitized separately. The 4 digitized SiPM signals were summed and fed into a leading edge discriminator (LED). The measurements were carried out at 21°C and 71.3V bias voltage (= 2.5V overvoltage).

Results

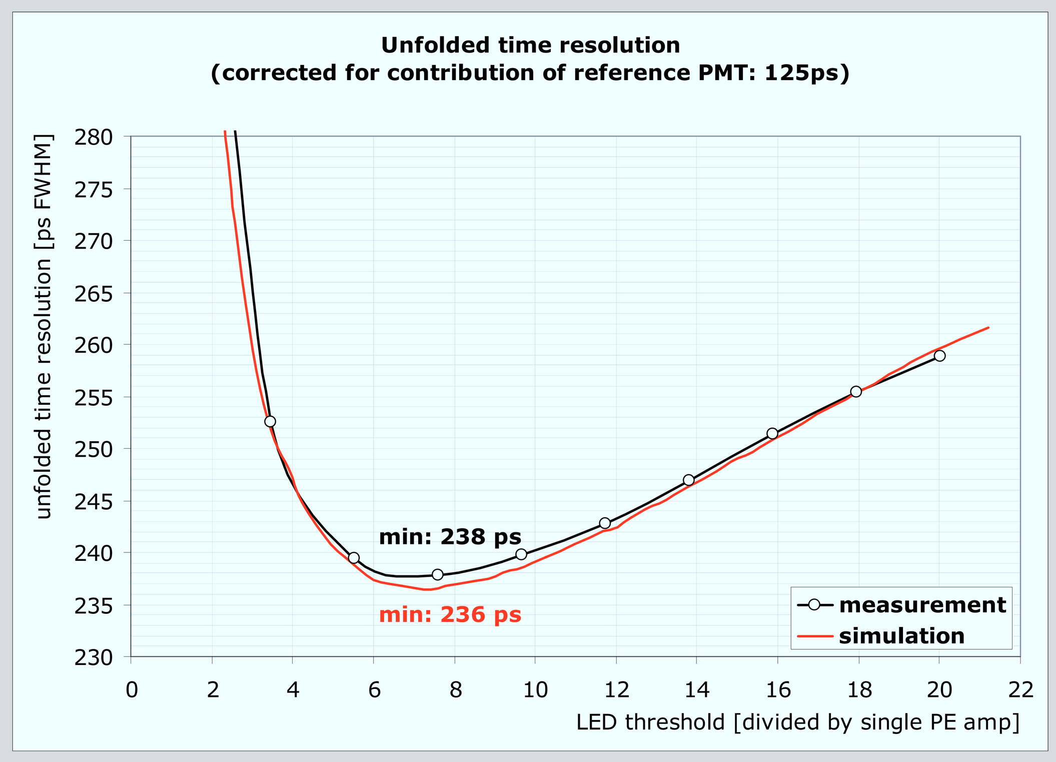


Fig. 3: The plot shows a comparison of the measured and the simulated unfolded time resolution for different LED threshold values. The energy window was set to 430 to 650 keV. The curves show the average timing for all 4 crystals in the array. Overall, there is a very good agreement in the shape of the curves. The coincident time resolution would be approximately 335 ps.

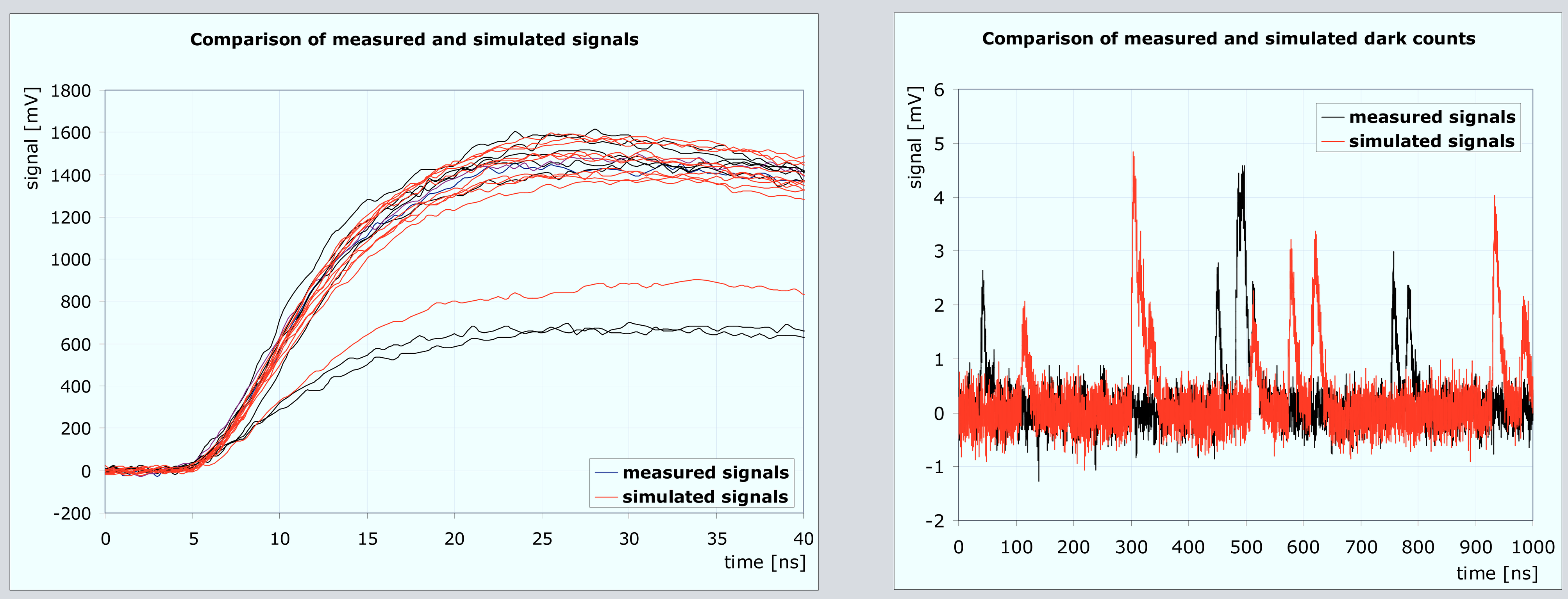


Fig. 4: The plots show a comparison of measured and simulated signals. The left plot displays the signals for detected 511 keV photons. The right plot compares the baseline with dark counts and electronic noise. The noise level is much higher in the left plot because the dynamic range of the digitizer had to be increased to cover the whole pulse amplitude.

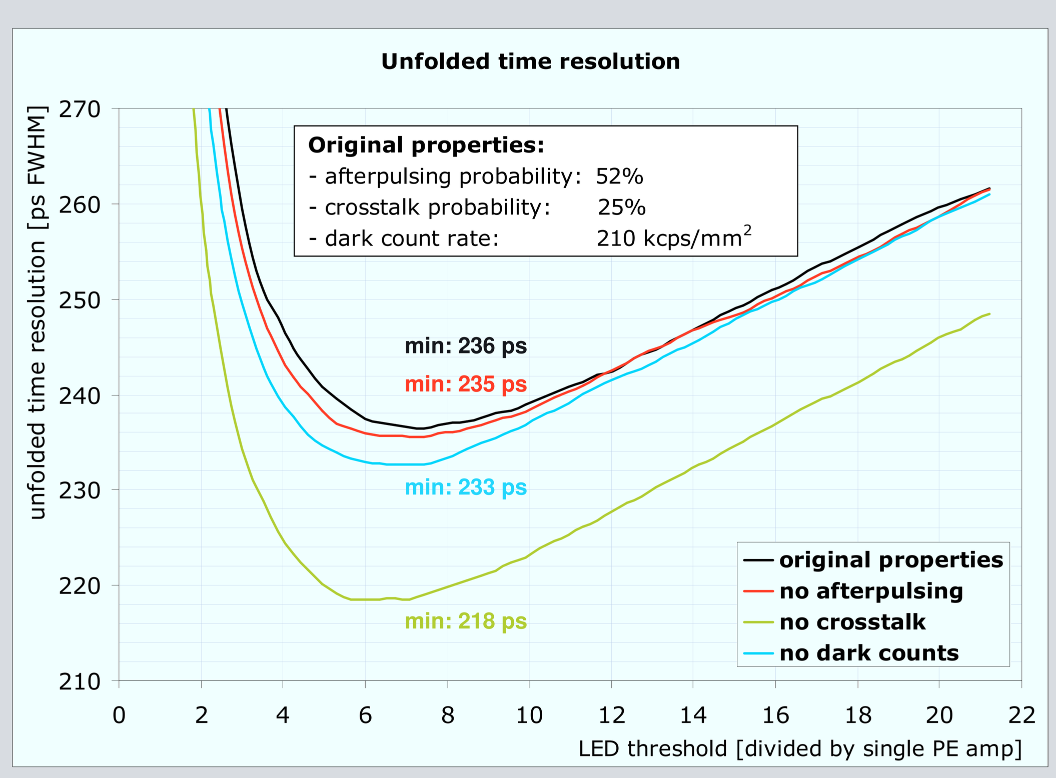


Fig. 5: To study how the intrinsic SiPM properties affect the time resolution, the simulation was repeated with afterpulsing, crosstalk or dark counts switched off. The plot shows the resultant unfolded timing. In this case, crosstalk has the strongest influence on the timing. However, for other detector designs, materials and triggering schemes other properties can play a bigger role.

Conclusions

The presented simulation uses the Monte-Carlo method to model the cell level processes of SiPMs in detail. The results show that it is possible to reproduce experimentally determined characteristics of the detectors very precisely. Therefore, the simulation tool can be used to identify and prioritize key parameters that define the detector performance (e.g. crosstalk).