New Approaches for Improvement of TOF-PET

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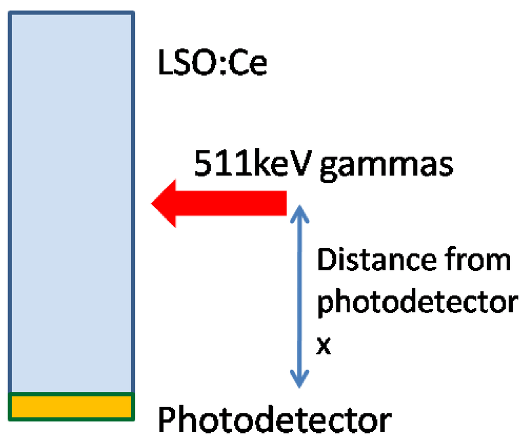
Introduction

Advances in detector technology led to the construction of time of flight (TOF) positron emission tomography (PET) devices, resulting in enhanced signal-to-noise ratio. Goal of this work is improvement of TOF for PET by a better understanding of statistics of photon creation and photon transport in scintillation detectors including the impact of the Cherenkov effect, with emphasis on photon transport. Due to their insensitivity to magnetic fields and thus the possibility to use them in hybrid TOF-PET-NMR scanners, Silicon photomultipliers (SiPM) are the photodetectors of choice.

Photontransport and Time Resolution



The time resolution of scintillation detectors is, int. al., depending on the photon transport from the point of interaction to the photodetector. To investigate its impact on the time resolution simulations using Geant4 were performed. A schematic drawing of the setup can be seen in the figure on the left. For the simulation, gammas with 511keV were shot from the side into the crystal with various distances to the photodetector. The emitted photons are collected at the photodetector and their arrival time, energy and creation process are logged. Plots of the arrival time can be seen in figure 1.

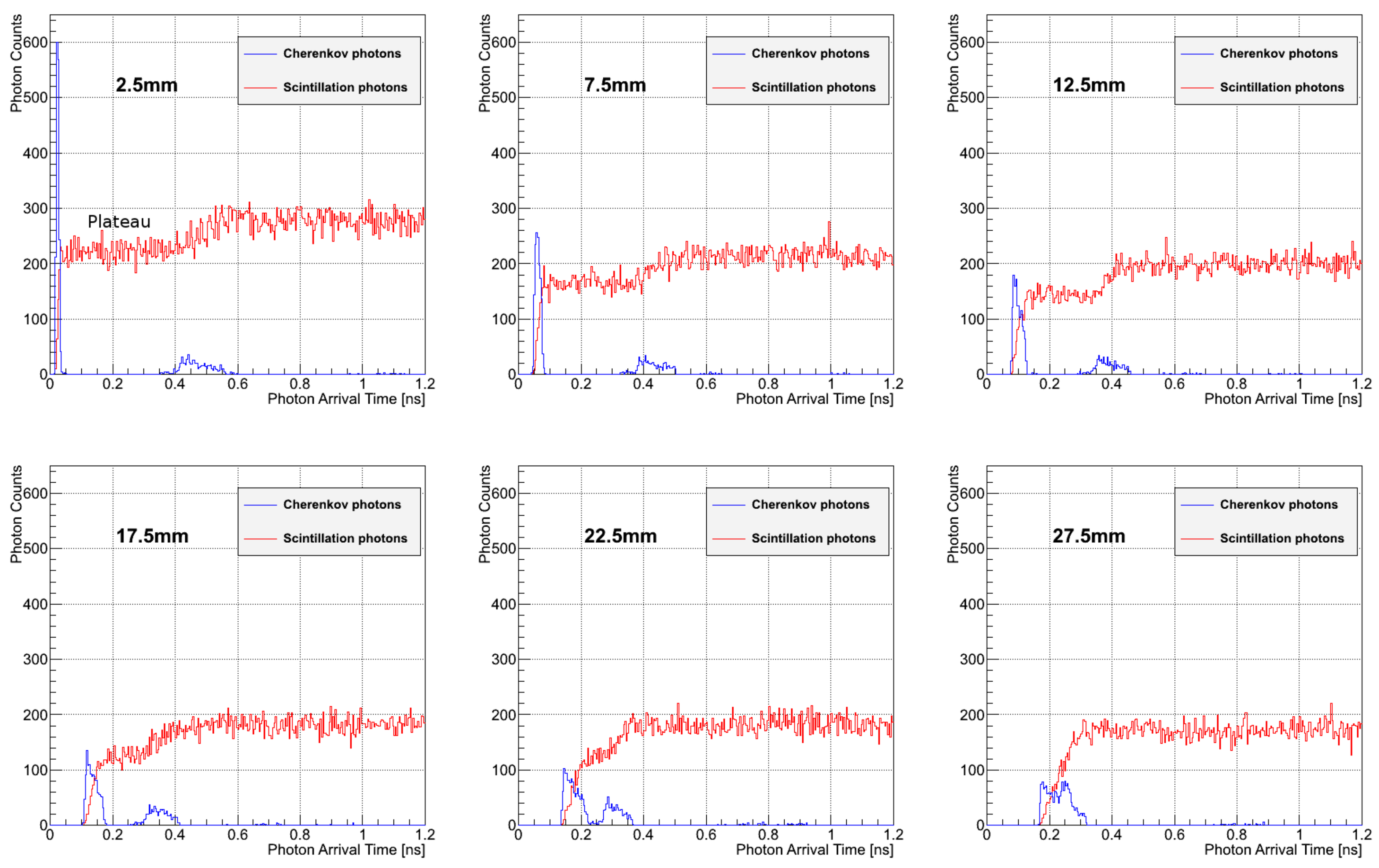


Figure 1: Accumulated photon arrival times for 10^4 gammas per distance, various depths of interaction and different creation processes. The distance of the gamma source to the photodetector is given on each plot).

For all distances, the time distribution of Cherenkov photons forms a sharp peak, especially at short distances of the gamma source to the photodetector. After this peak a second peak for the Cherenkov photons is visible, coming from the photons traveling to the opposite direction, away from the photodetector, get reflected at the end of the crystal and reach the photodetector afterwards. The time for this photon transport is correlated to the crystal length.

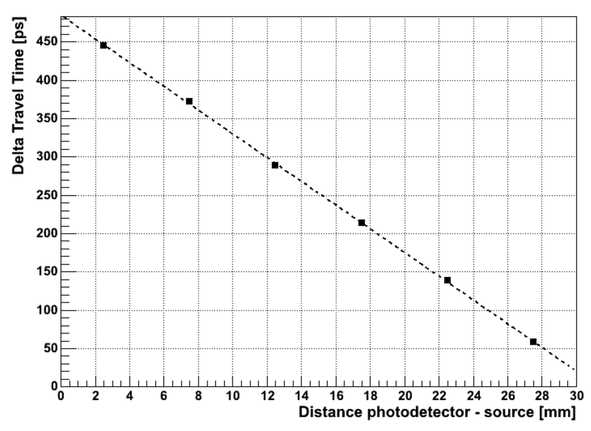


Figure 2: Delta photon arrival time of direct and reflected photons, estimated by the distance of the first two bunches of photons created by the Cherenkov process.

For the photons, created by scintillation, a similar distribution is visible: After a first rise, the distribution forms an intermediate plateau, with a duration correlated to the length of the crystal. Again the first rise and the intermediate plateau is caused by scintillation photons traveling towards the photodetector, the second smaller rise again is caused by photons traveling in opposite direction, get reflected and reach the detector with a delay, correlated to the crystal length. Comparing the slopes of the arrival times of Cherenkov photons to scintillation photons, for good timing it is crucial to be able to detect as many Cherenkov photons as possible. Unfortunately, many of them are lost in real detector systems due to low quantum efficiency in the UV range. **Analyzing scintillation pulse shapes and detection of the first and second rise, can give information about depth of interaction, which could help reducing, e.g., parallax errors or increasing spatial resolution of PET systems.**

Coincidence Time Resolution

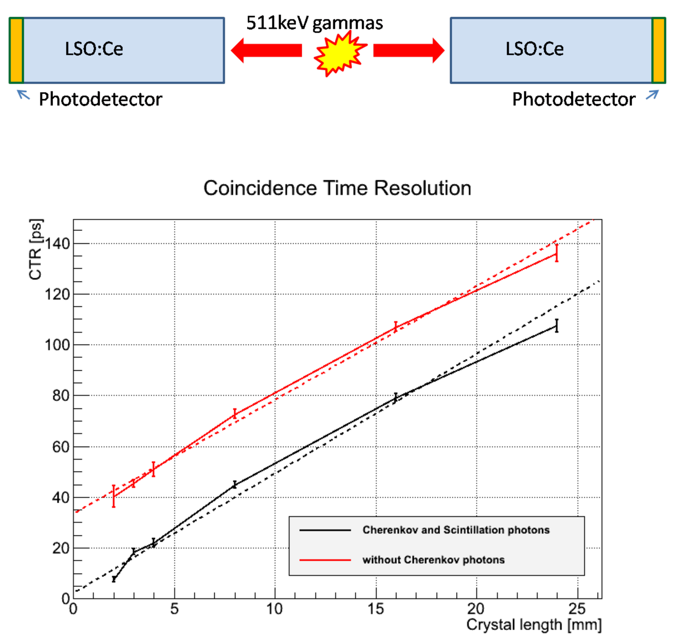
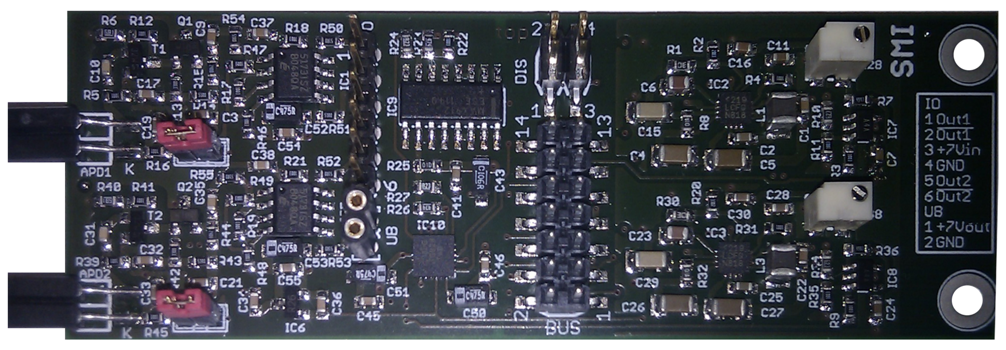


Figure 3: Setup (top) and theoretical coincidence time resolution of LSO vs crystal length (below).

For determination of the theoretical limits of coincidence time resolutions (CTR) and influence of the crystal lengths, simulations were performed. In figure 3, the resulted CTR is plotted for various crystal lengths. Again, detection of Cherenkov photons has an impact on time resolution. Including their detection improves the CTR for about 30ps for all crystal lengths. The dashed lines are indicating a linear fit of the data points to visualize the nonlinear dependency of the CTR on the crystal lengths.

Electronics Development

Good TOF performance for SiPM readout and flexibility for high granularity detectors require optimized readout electronics. Therefore, a prototype of a computer controlled preamplifier-discriminator board was developed. One board consists of two independent signal channels. The SiPM signals can be read out directly in analog mode or via the time-over-threshold discriminator, quasi digitally, both outputs using low-voltage-differential signals (LVDS). Bias voltage and discriminator threshold of the preamplifier-discriminator board are controlled by PC via a master board (Arduino Leonardo).



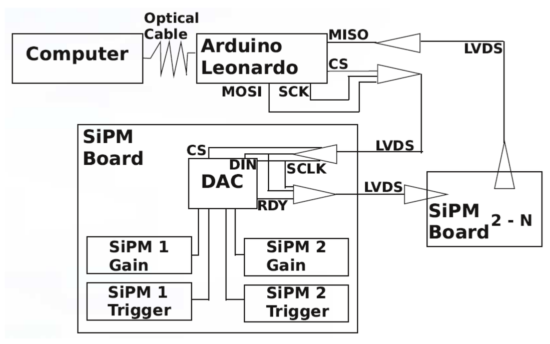


Figure 4: Picture (left) and layout (right) of the preamplifier-discriminator board.

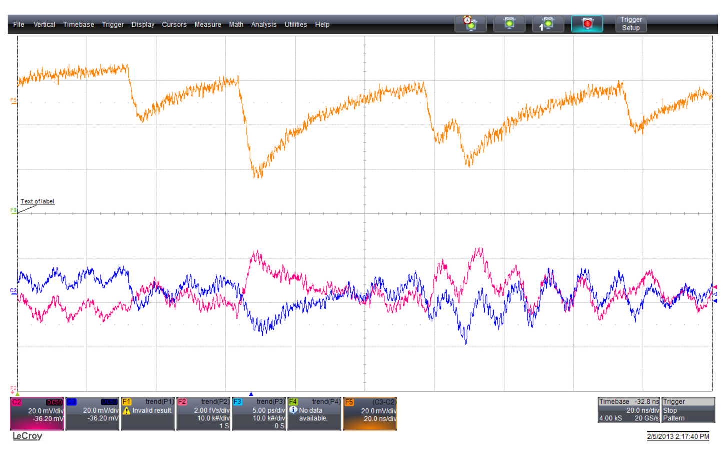


Figure 5: Screen shot of the SiPM anode and cathode signals (blue, purple) and their difference (orange) in a high noise environment and a 10cm twisted pair cable between SiPM and preamplifier.

As suggested by other groups, [1, 2], SiPMs allow to use both, the cathode and anode for signal readout. A simple change of the board allows to connect the cathode to one preampflifier channel and the anode to the other channel. Making use of this feature allows either to increase the slope of the signal (better timing) or to increase the distance between SiPM and the preamplifier without loss of performance due to pick up noise, which is an important feature for high granularity SiPM-based PET detector designs. An example screen shot of the signals is shown in figure 5.

Summary and Conclusion

Photon transport is an important factor influencing the time resolution of scintillation detectors as used for TOF-PET. For better timing performance it is important, not only to detect as many scintillation photons as possible but also to **optimize the detection efficiency for Cherenkov photons**, which are emitted mostly at wavelengths in the UV. Therefore, research on photodetectors for improvement of quantum efficiency, especially in the UV-range, and research on faster readout electronics is crucial to approach the theoretical limits of TOF-PET.

References

[1] F. Powolny et al., “Time-Based Readout of a Silicon Photomultiplier (SiPM) for Time of Flight Positron Emission Tomography (TOF-PET),” IEEE Transactions on Nuclear Science, vol. 58, no. 3, pp. 597-604, 2011.
[2] C. Parl et al., “Double-Side-readout technique for SiPM-matrices,” IEEE Nuclear Science Symposuim & Medical Imaging Conference, pp. 1486-1487, Oct. 2010.

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