Potential of depth-of-interaction-based detection time correction in Cherenkov emitter crystals for TOF-PET

UC DAVIS HEALTH

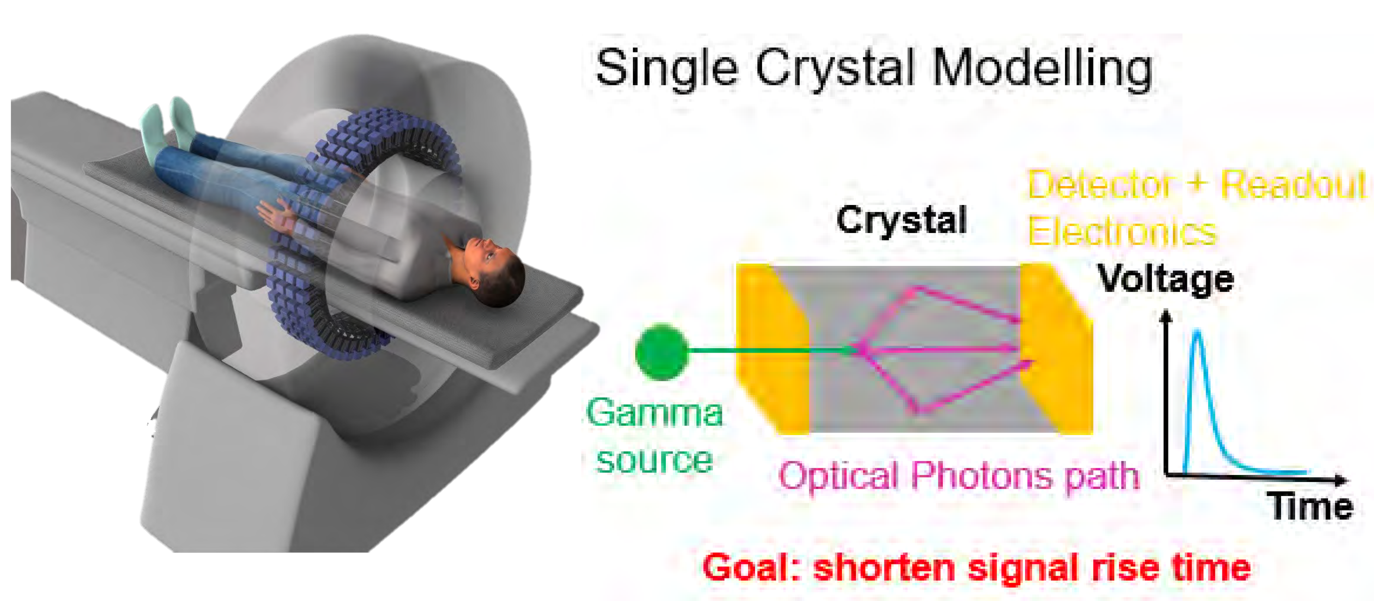
Department of Biomedical Engineering
Department of Radiology

Xuzhi He
Gerard Arino-Estrada
Carlotta Trigila
Emilie Roncali

Introduction

Rapid advancements in quantitative medicine sets new requirements for Positron Emission Tomography (PET) in terms of spatial resolution, timing resolution, quantification, and sensitivity. State-of-the-art commercial PET/CT scanners can achieve 3 mm spatial resolution and 230 ps timing resolution. Improving timing resolution is one of the most promising avenue to develop the next generation detectors with greater performance. We are using prompt photons emitted in a few picoseconds to develop ultrafast PET detectors, with 30 ps timing. we present simulation work carried out to understand the physics of new detectors and optimize them. We are conducting simulations with an original optical model developed by our group and released in opensource software GATE.

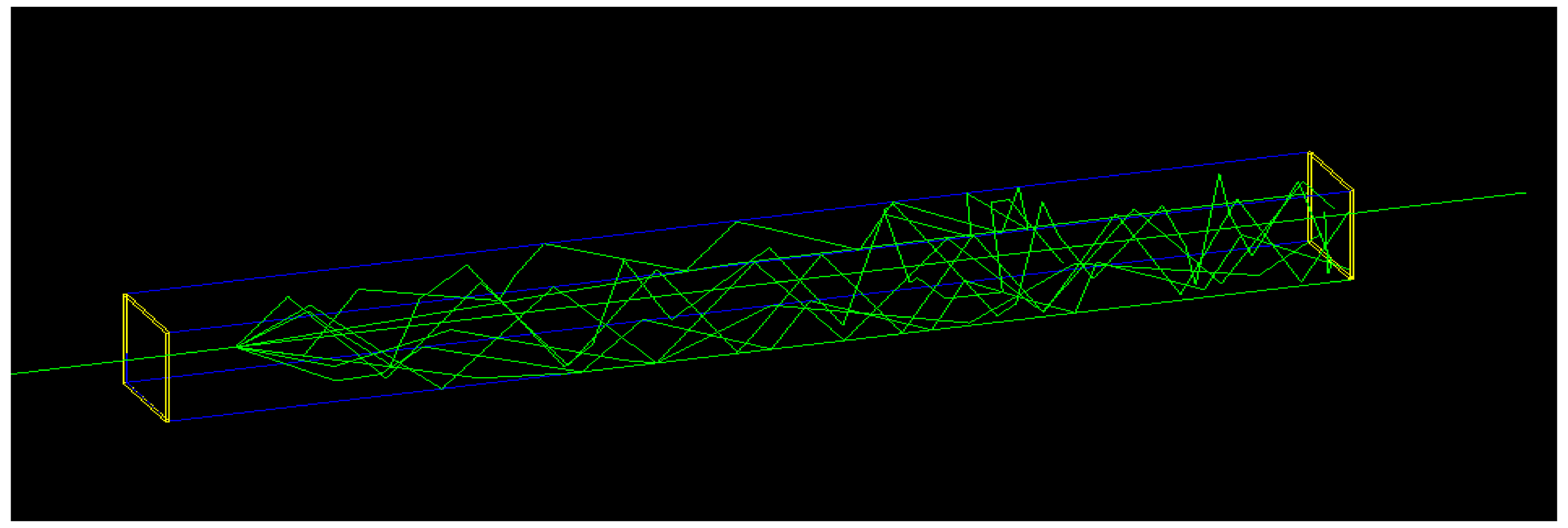
Design/Sample

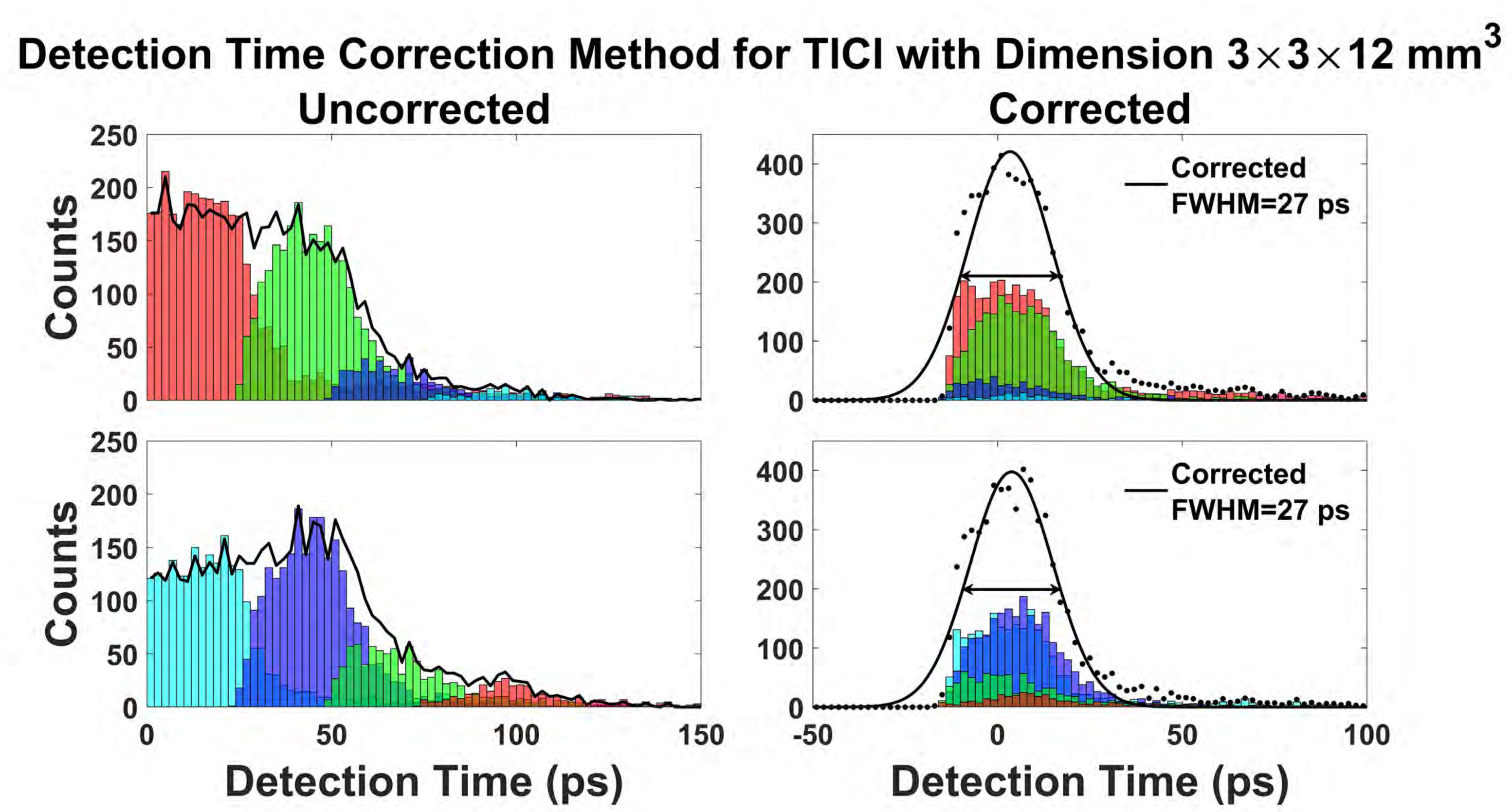


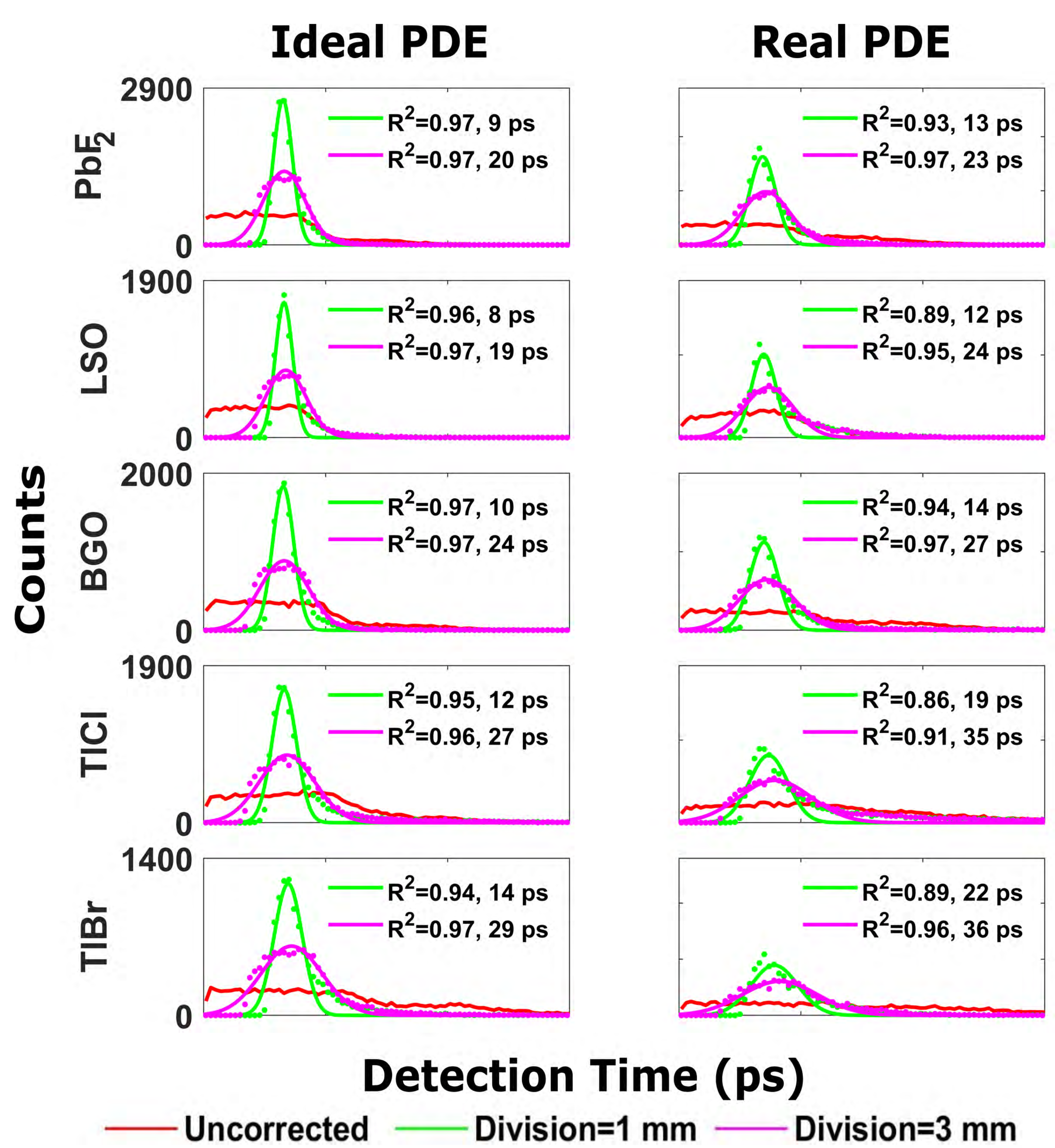
Analysis

We modeled physics process inside single crystal. A gamma point source will emit gamma photon and deposits its energy at crystal. Numerous optical photons will be emitted and travel inside crystal. Their final states will be recorded, including momentum, arrival time, photon energy etc. After gamma photons energy deposition, photodetector will generate electrical signal, shown as blue curve above. We tag each gamma photon by the first detected optical photon, of which the arrival time is defined as detection time. We make histogram for the detection time and estimate the FWHM of the detection time distribution. Gamma photons may deposit energy at different position in crystal. We segment crystal into multiple regions and assort detection time distribution into different regions where gamma photons deposit their energy. Finally, we correct each detection time distribution based on different crystal regions.

Results







Our simulation tool is an open-source software called GATE Montel Carlo, which is based on the other open-source physics package Geant4. The left side picture depicts an event process. A scintillator, shown as blue frame, is coupled with dual photodetectors in yellow frame to collect optical photons. A gamma photon deposits energy on left hand side and many emitted optical photons travel and propagate to right photodetector. Here is a special case: Cherenkov photons emission. Cherenkov photons will emit when electrons velocity is faster than light phase velocity in this material. Some crystals don't emit scintillation photons and emit Cherenkov photons only, such as TlBr, PbF_2 etc. Scintillation photons emission is isotropic and both photodetectors have equal chance to collect scintillation photons, while Cherenkov photons have preference to propagate towards photodetector far from gamma source. Optical photons' reflectance behavior at crystal's surface was previously modeled by another open-source software Davis-LUT.

Depth-of-Interaction(DOI) refers to the distance between surface where Gamma photon enters and position where Gamma photon deposits energy. The second picture reveals how we use DOI information to correct detection time distribution. The crystal material is TlCl with dimension $3 \times 3 \times 12\ \mathrm{mm}^3$. We segment crystal into four regions and make detection time distribution based on different crystal region, such as red, green, blue and cyan histogram on left side. Next, we shift detection time distribution in each region by different specified time duration. After that, we accumulate each shifted detection time to obtain the DOI-corrected detection time distribution. Finally, we use Gaussian model to fit the accumulated shifted detection time distribution and estimated their FWHM. As shown on left second picture, the first row represent the photodetector near Gamma source while the second refer to the photodetector far from Gamma source. Corrected detection time distribution conspicuously has much better performance than uncorrected.

We conducted simulation for other materials: PbF_2, LSO, BGO and TlBr, and took photodetector's photon detection efficiency, different crystal segmentation into considerations. These materials had the same dimension. Red, magenta and green curves represent uncorrected, DOI division=3 mm and 1 mm cases, respectively. Apparently, green curve has narrower FWHM than magenta ones. On the other hand, non-ideal PDE can be detrimental to detector's timing performance.

Summary

DOI-corrected detection time distribution exhibited extraordinary performance Compared with traditional uncorrected detection time distribution. The smaller the DOI Division is, the better timing resolution will achieve. Furthermore, better PET imaging's timing resolution makes promise for more progress in neural science research, cancer study and metabolism process investigation.

Conclusions/Further Study

Photodetector's photodetection efficiency still limits the PET detector's performance. We will conduct photonic crystal research to enhance the optical photons' extraction from scintillator and improve timing resolution more in the future. On the other hand, we will try to improve DOI resolution from electronics readout circuits as well. Improving these two factors are potential to manufacture the next generation of Position Emission Tomography scanner.

Acknowledgements

Thanks to Dr, Arino-Estrada, Dr, Trigila and Dr, Roncali's help and advice.

This work has been funded by NIH awards R01 EB027130 and R01-EB029533.