Using Silicon Photomultipliers (SiPM) for Time Domain Diffuse Optics (TD-DO) in Medical Diagnostics

1. Introduction.

The application of near-infrared and red light has gained significant traction in medical diagnostics due to its simplicity, non-invasive nature, and absence of radiation exposure for patients. Current technologies, such as pulse oximeters and optical tomography systems, rely on continuous wave (CW) light. However, the capabilities of these technologies are limited by light scattering in biological tissues. To address this limitation, picosecond light pulses and photodetectors with high time resolution can be employed to track individual photons penetrating into diffuse media. This opens the door to innovative applications, including non-invasive imaging of brain tissue through the skin and skull. Such advancements hold immense potential for rapid diagnosis of conditions like ischemia and strokes, as well as real-time monitoring of brain oxygenation during surgical procedures. The proposed method can be also applied in other fields, such as environmental research.

2. Practical knowledge and hands-on experience obtained during the internship.

1. Gain practical experience working with silicon photomultipliers (SiPMs), including their setup, signal acquisition;
2. Learn the operating principles of semiconductor lasers, particularly those functioning in the picosecond mode;
3. Develop proficiency in experimental data acquisition, processing, and analysis for time-resolved optical measurements;
4. Gain experience with specialized electronics and software used in photon detection and timing measurements.
5. * Measurements with a phantom/biological tissues.

3. Description of scientific work.

3.1. Measurement setup diagram.

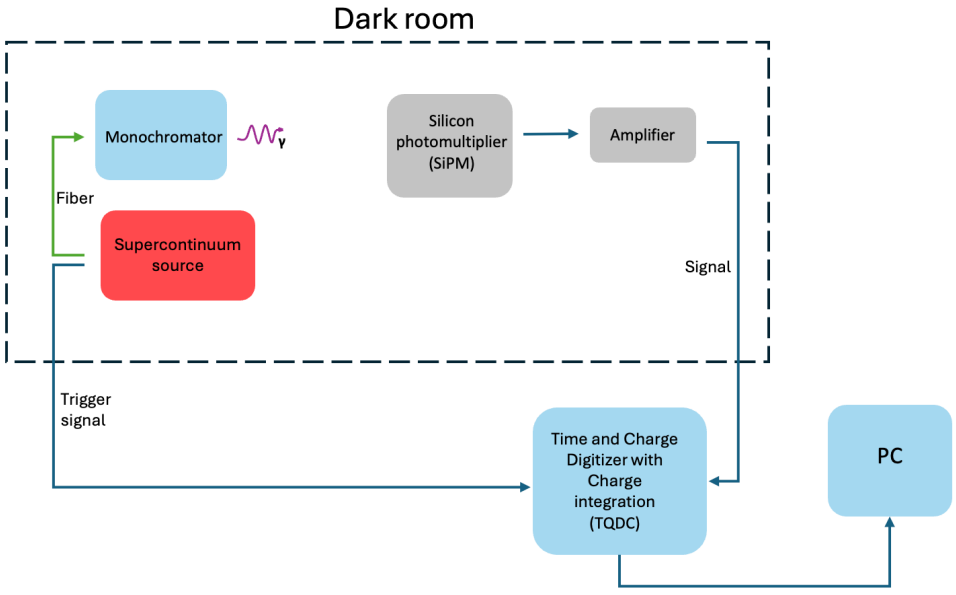

Figure 1. Scheme of SiPM and super continuum laser research at different wavelengths (450nm-1300nm)

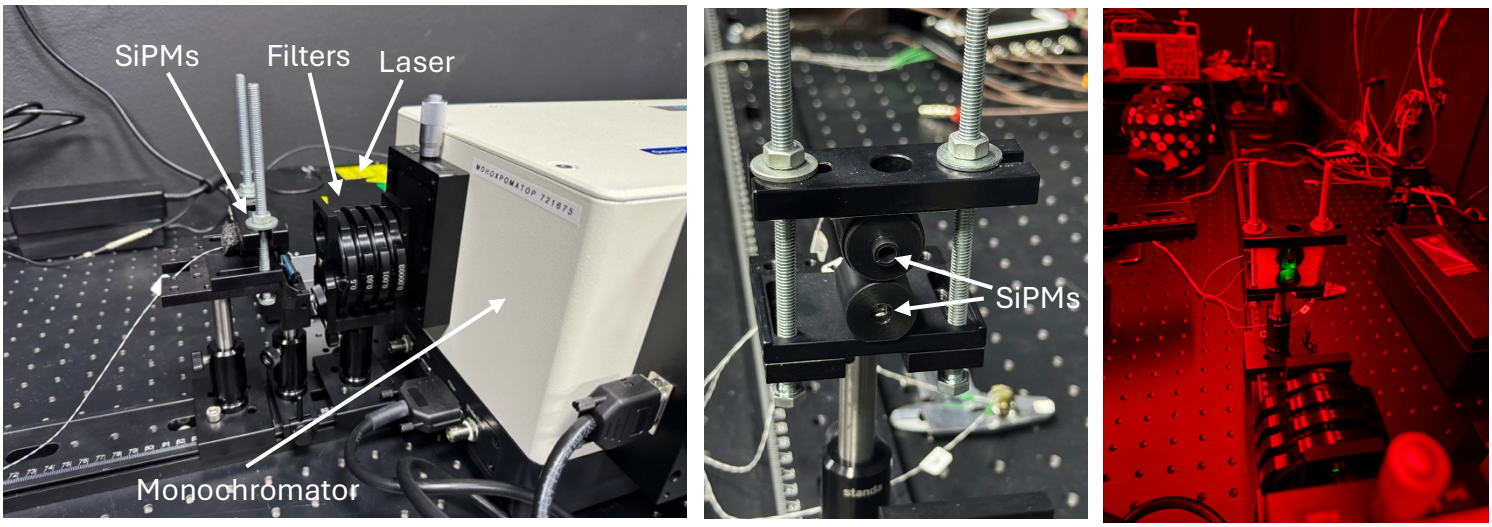

Figure 2. Photos of the measuring stand. The stand consists of a monochromator (Omni-2005i), a supercontinuum laser (SSP-SC-5-500-FC), a set of light-absorbing filters, and silicon photodetectors. All measurements are carried out in a light-insulated dark room.

3.2. Scientific Work Plan.

The student is required to make measurements with different models of SiPMs, photomultiplier tube (PMT) at different wavelengths from a laser operating in single-photoelectron mode. The obtained data will contain the time distribution of the delay between the laser trigger and the light registration by the photodetector, which will allow a comparison of the time resolution of the photodetector from the wavelength.

*Measurements on living phantoms, such as blood oxygen measurement using a picosecond laser and photodetector (SiPM).

3.3. Presentation to the sector staff on the results of scientific work.

4. Prerequisites for students.

1. Students of **3rd year or above**.
2. **Experience with Photodetectors** (preferably silicon photomultipliers – SiPMs): Basic knowledge of the principles of operation, signal processing, and practical usage of photodetectors in experimental setups.
3. **Data Acquisition and Signal Processing**: Experience or readiness to work with DAQ systems, analog/digital signal processing.
4. **Basic knowledge of statistics and data analysis:** Understanding of statistical methods used in experimental physics, including error estimation, fitting, and hypothesis testing.
5. **Programming Skills:** Python3 (NumPy, Pandas, Matplotlib, SciPy), C++ (ROOT CERN Framework).
6. **Laboratory Experience**: Practical skills in assembling and testing optical or electronic setups. Safe handling of sensitive equipment (e.g., lasers, photodetectors, power supplies).

5. Literature.

Time-Domain Near-Infrared Spectroscopy and Imaging: A Review. Yukio Yamada, Hiroaki Suzuki and Yutaka Yamashita.

Measurement of Snowpack Density, Grain Size, and Black Carbon Concentration Using Time-domain Diffuse Optics. Connor HENLEY, Joseph L. HOLLMANN, Colin R. MEYER, Ramesh RASKAR.

6. Number of participants.

Two students from South Africa may participate in this internship.

7. Project Manager.

Sharov Vladislav Igorevich, Junior Researcher, Dzhelepov Laboratory of Nuclear Problems.

Research Interests: data analysis and photodetector studies. I am part of the JUNO-TAO collaboration (China) and participated in the development of a test bench for large-scale characterization of SiPMs arrays for the TAO detector. Currently, I am studying semiconductor lasers operating in the picosecond mode and silicon photodetectors for applications in medical diagnostics.