Employing multiphoton quantum interference for selected quantum information processing tasks

Principal Investigator: Dr. hab. Magdalena Stobińska

Quantum mechanics has been studied for almost 100 years. It became a cornerstone of many scientific disciplines, especially in the fields of physics, chemistry, materials engineering and electronics. Quantum effects make it possible to overcome various limitations resulting from the laws of classical physics. For example, quantum information processing enables enormous gains in computation speed. Many computer algorithms are underpinned by the Fast Fourier Transform (FFT) which decomposes a digitized signal, e.g. a voice or an image, into a spectrum which is then analyzed and processed to achieve filtering and compression. Even though the FFT computation time scales almost linearly with the size of the data set, it becomes a bottleneck in the contemporary times of Big Data processing. The quantum counterpart of FFT – the Quantum Fourier Transform (QFT) allows one to reduce the processing time by thousands of times. For this reason, it became a cornerstone of quantum algorithms which enable e.g. fast data searching or breaking RSA ciphers with quantum computers. A novel area, where quantum systems show advantages, is quantum simulations. They enable us to investigate and better understand topological effects in quantum matter. Their discovery was awarded with the Nobel prize in 2016. The potential of these materials is seen in e.g. electronics and spintronics. Quantum simulations allow to overcome limits of computer modeling and design materials before they are fabricated in a lab.

Quantum photonics is one of the most advanced quantum platforms. Although it is difficult to scale it up compared to quantum superconducting systems and the set of available quantum states of light is rather limited, this platform possesses many advantages. Photonic circuits are cost-effective and easy to use. They do not require any expensive setups and the technology of their production is being advanced by companies building fiber telecommunication systems. Similarly to electronic integrated circuits, quantum integrated optics allows one to develop *lab-on-a-chip* solutions and perform complex operations in a controlled way.

The goal of the project is to deepen our understanding of multiphoton quantum interference, especially in the time domain. Quantum interference is one of the most intriguing phenomena in nature and one of the most important resources of quantum technologies. In the case of temporal platform, a train of narrow single-photon pulses undergo dispersion in a nonlinear medium. Individual pulses start to overlap and interfere. We will study this interference towards its applications in quantum computations and quantum simulations of topological materials. This goal is motivated by results obtained in 2019 by Dr. hab. Stobińska and her collaborators. The first is theoretical and experimental investigation of quantum interference of multiphoton Fock states on a beam splitter and demonstration it instantaneously computes a Quantum Fourier–Kravchuk Transform (QKT). This allows one to use this device as an efficient, specialized quantum computer with vast number of applications. The second result is to show that such multiphoton quantum interference enables fast quantum simulations of topological materials, which are characterized by unusual symmetries. These findings constitute starting points for the current project.

The project consists of three fascinating Objectives which cover theoretical and experimental study of multiphoton quantum interference, finding links between various optical systems and mathematical operations (transforms) they realize and performing quantum simulations of materials which exhibit topological phase transitions. The results will allow us to understand the essence of complex quantum interference, to systematically enhance the palette of applications of quantum photonic systems and to investigate topological phenomena in new materials. We hope that they will encourage engineers and chemists to find new, interesting applications. Besides theoretical studies performed by means of analytical and numerical methods, we plan to realize proof-of-concept demonstrations with the quantum photonic platform in the time domain, developed at the Faculty of Physics UW.

The project will be carried out by a team consisting of two postdocs and two PhD students which will perform the tasks under supervision of Dr. hab. Stobińska. This team will profit from the existing international collaboration network developed by the PI. The network comprises scientists form several top European institutions investigating quantum optics, including the University of Oxford and the Imperial College London (the group of Prof. Ian Walmsley). Thanks to this collaboration, the young scientists will gain the opportunity to obtain a unique know-how and experience in both scientific and R&D work. This will allow them to meet the requirements of the current job market and will boost their future careers in both academia and other economic sectors.