Characterization of high-resolution single-photon time-tagging measurement based on time-to-frequency mapping

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Quantum physics describes the smallest particles, such as atoms or photons. With its development, new phenomena have been discovered, including quantum superposition, e.g., a particle can exist in two places simultaneously, or quantum entanglement necessary for quantum teleportation or quantum computations. For such computations, one needs to encode quantum information on a single particle, e.g., on a single photon – a quantum pulse of light. It is traveling with the speed of light, which makes it perfect for transmitting quantum information. To encode it on a single photon, one needs to choose one of the possible degrees of freedom. It can be polarization, position, shape, or color (wavelength) of a single photon or its arrival time. Within this project, we focus on time and wavelength, because such encoding can be used for transmitting quantum information in the already existing fiber network. However, to use it, one has to develop methods of direct measurement of the wavelength of single-photon and of its arrival time.

The already existing measurement techniques allow for measuring single photons wavelength with high resolution for a wide range of wavelengths. A measurement is direct when we can describe the color of every single photon that is detected. Measuring wavelengths of quantum light pulses is then frailly easy, however direct measurement of single photons arrival time still presents a challenge. It is a result of the limited timing resolution of single-photon detectors. Other existing techniques are indirect, e.g., through interference, and require to measure a large number of single photons, or in other words, gathering comprehensive statistics, to describe properties of arrival times of quantum light pulses. There are techniques that provide direct measurements and high timing resolution. However, they can only verify if photon arrived at a particular point in time, but do not monitor multiple points in time simultaneously.

The aim of this project is a characterization of a new method of measurement of single photons' arrival time. It is based on the time-to-frequency mapping, i.e., the color of each photon is changed depending on the detection time. Then from the measured wavelength, one can tell when the photon was detected. Because wavelength measurement features high resolution and it can be performed directly, one can obtain a straightforward method for highly-resolved measurement of single photons in time. In particular, during the project, a temporal shaper of quantum light pulses will be built. Then, using it, the complete characterization of the time-to-frequency mapping will be performed.

Obtained results will expand an experimental toolbox for single photons characterization. Because the experimental setup for the above-described method is straightforward and easy to implement in comparison to other methods, it will have a positive influence on our knowledge about surrounding us quantum world. Moreover, from the application point of view, such a method could be implemented within quantum communication or quantum cryptography protocols, which will have an impact on technical development. For example, it will lead to increased security of electronic communication, such as e-mail encrypting. In particular, the method is naturally compatible integrated optics, thus optical processors, and with an already existing fiber network, because the time-to-frequency mapper itself consists of fiber components.