Master thesis and internship[BR]- Master's thesis : Development of a Laser Source of Entangled Photons for Space Quantum Key Distribution[BR]- Integration internship

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Development of a Laser Source of Entangled Photons for Space Quantum Key Distribution

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Abstract

With the arrival of new quantum technologies, especially quantum computers, the data security as we know it is at risk because classical encryption protocols are easily decrypted by quantum computers. There is therefore an urgent necessity to develop secure systems, resistant against quantum threats. Quantum key distribution (QKD), which represents the technologies that use both quantum and classical channels to exchange cryptographic keys, could be a solution to this security problem. Indeed, by relying on fundamental principles of quantum mechanics, these distribution protocols enable highly secure transmissions. Among the principles of the technique, the present thesis concentrates on the polarization-entanglement of photons. This quantum property denotes a strong correlation between the polarizations of two photons, such that performing a measurement on one photon instantaneously affects the measurement on the polarization of the other.

The main objective of this project is to implement an entangled photon source that generates pairs of entangled photons with orthogonal polarizations, making them useful in entanglement-based QKD protocols. The design of the source takes inspiration from the Micius satellite, which is a QKD Chinese mission that successfully demonstrated the use of polarization-entangled photons to exchange cryptographic keys. The experimental setup involves a non-linear crystal (PPKTP) located at the center of a Sagnac interferometer (perfectly symmetric loop within which photons propagate in opposite directions). The crystal is pumped by a laser beam at 405 nm to trigger a non-linear phenomenon (spontaneous parametric down-conversion) that annihilates pump photons to create pairs of photons at a wavelength of 810 nm. The present work describes the development of this source and discusses the results that emerged from it.

Detailed correlation measurements, supported by the coincidence counts between two single-photon detectors, confirmed the simultaneous generation of photons in the crystal, marking their entanglement in time. A spectral analysis was performed to verify the wavelength of the photons emitted by the source. This proved that the photons had effectively the same wavelength of 810 nm, highlighting their indistinguishability. Part of the conducted visibility measurements yielded promising results, with a visibility of 92% for photons propagating in the Sagnac loop in one direction. This indicated a great efficiency of the non-linear phenomenon in one pumping direction of the crystal. However, challenges related to the alignment of the setup were identified and appeared to be somehow inhibiting the efficiency of the non-linear phenomenon when the crystal is pumped in the opposite direction. Potential solutions and further improvements of the experiment have therefore been proposed to address these issues, along with the necessary adjustments to make the source suitable for space-based QKD applications.

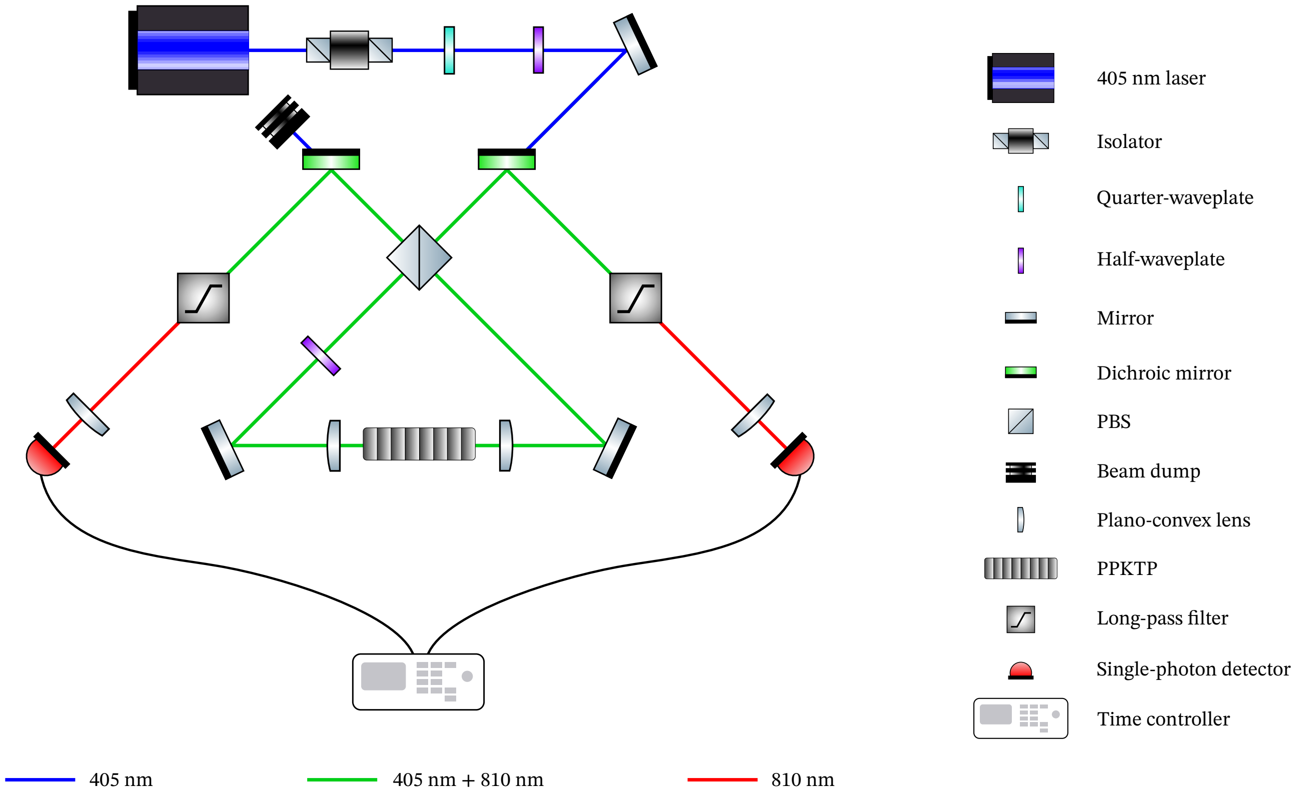

Figure 1: Schematic of the developed source of polarization-entangled photons. The triangular loop formed by two mirrors and a polarizing beam splitter, located at the center of the setup, corresponds to the Sagnac interferometer in which photons are propagating in opposite directions.

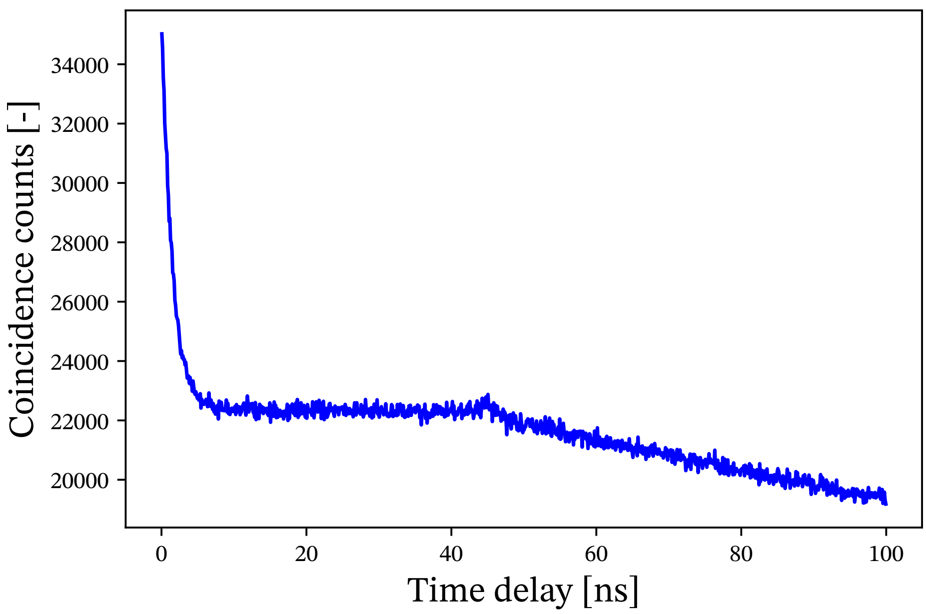

Figure 2: Number of coincidence counts plotted against the time delay between two detection events. Acquisition during 1 minute with a laser output power of 4 mW. The curve represents the frequency at which a detection at one of the two single-photon detectors occurred after a specific time delay following a detection event at the other detector. This shows that many photons are detected simultaneously at both detectors, which suggests the presence of pairs of entangled photons.