Reconfigurable time-bin processor for multi-photon quantum interference

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The interference of non-classical states of light is crucial for a wide range of quantum-enhanced applications on photonic platforms. However, implementing complex quantum protocols requires an increasing number of physical resources, such as more photon sources, larger interferometers, and multiple detectors.

In this talk, I will present the realization and operation of a highly efficient programmable quantum photonic processor, based on time-bin encoding and comprised of a quantum-dot single-photon source, a programmable time-bin interferometer, and one detector. Our time-bin interferometer makes repeated use of a single active, tunable optical element in a loop-based architecture, enabling interference to occur entirely in a single spatial mode [1]. Our approach is thus highly resource-efficient compared to standard spatial encoding, as it does not require active demultiplexing of a single-photon source or building an array of multiple identical emitters. Furthermore, all multi-photon processing is carried out by analyzing the time-tags of a single detector.

We programmed our device for multi-photon interference experiments with varying numbers of photons, and the size of the experiments was increased at will, utilizing a constant number of programmable physical resources. In practice, the experiment size is mainly constrained by source efficiency, allowing us to observe interference of up to 8 photons in 16 modes [2].

Our results can serve as a foundation for a future resource-efficient universal photonics quantum processor.

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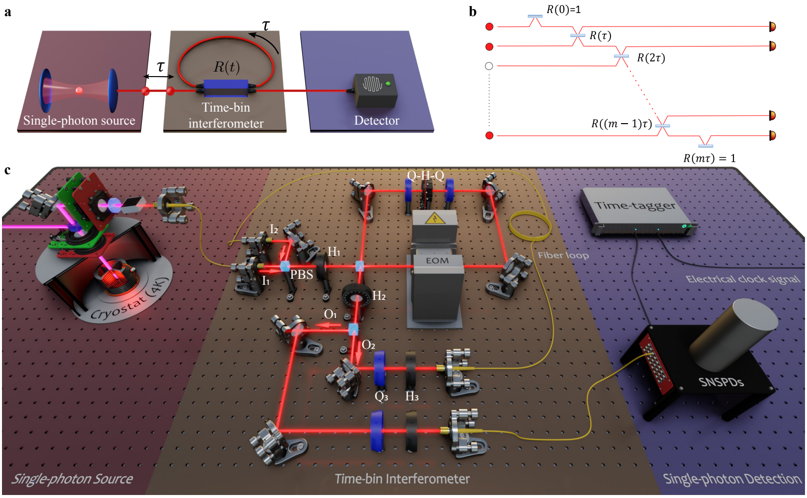

Fig. 1: Time-bin multi-photon interferometric network. a Time-bin multi-photon processor. One single-photon source, one time-bin loop interferometer, and one detector implement the processor. **b** Representation of time-bin multimode interferometer. The combination of a tuneable beamsplitter and delay loop implements a network of m modes: an arbitrary sequence of beamsplitter operations between consecutive time-bins, with $m-1$ reflectivities $R(k\tau)$, $k{=}1,..,m-1$. The input time-bins contain either vacuum or a single-photon. Boundary initial and final reflectivities $R(0){=}R(m\tau){=}1$ correctly initialise and terminate the time-bin experiment. **c** Depiction of the setup. The source (left) is an InGaAs quantum dot coupled to a micropillar cavity, kept at 4 K inside a cryostat. A confocal setup is used to pump and collect resonance-fluorescence, then sent to a time-bin interferometer: an effective time-varying beamsplitter with two inputs I_1, I_2 and two outputs O_1, O_2, with one output connected (looped) to one input via a 100 ns fibre-based delay ($\sim$ 20 m). The free-space electro-optic phase modulator (EOM) controls the time-varying reflectivity, which can be reconfigured to any value every 100 ns. Half-wave plates H_1, and H_2, are kept at $\pi/8$ degrees. H_3, and quarter-wave plate Q_3 ensure that light traversing the loop arrives with vertical polarisation into loop input I_2 again. After traversing the loop a number of times, all photons and time-bins exit the interferometer and are detected with only one detector. The resulting statistics is reconstructed by post-processing events registered by the time-tagger.

References

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