

Scaling photonic systems for quantum information processing

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Scaling photonic quantum simulations and computations requires many controllable modes and input states with many photons. Here we review different approaches for the experimental implementation of future multi-dimensional photonic quantum systems.

High-dimensional photonic quantum systems promise a change of paradigm for various applications in information processing systems, for example in advanced communication systems and in high-performance computing and simulation of quantum systems. They can shift the boundaries of today's systems and devices beyond classical limits and seemingly fundamental limitations. The use of complex photonic systems, which comprise multiple optical modes as well as nonclassical light, has been proposed in various theoretical works over the last decades and illustrate the versatility of photonic systems. However, the implementation of scalable architectures requires advanced setups of high complexity, which poses considerable challenges on the experimental side.

Here we review different approaches to advance current experimental approaches for scaling multi-dimensional photonic quantum systems. These comprise non-linear integrated quantum devices, source engineering and pulsed temporal modes as well as time-multiplexed architectures.

Non-linear integrated quantum devices with multiple channels can offer the combinations of different functionalities, such as sources and fast electro-optic modulations, on compact monolithic structures. We discuss concepts, current fabrication technologies and the toolbox of integrated devices, which are tailored for photonic quantum information processing. Pulsed photon temporal modes are defined as field-orthogonal superposition states and constitute a high dimensional quantum system, which is naturally present in non-linear state preparation. The control of these temporal modes is key for the realization efficient quantum network architectures based on quantum inference. In integrated structures the pulsed temporal modes typically occupy only a single spatial mode and thus they can be efficiently used in single-mode fibre communication networks. Finally, time-multiplexed quantum systems are a versatile tool for the implementation of a highly flexible platform with many modes and dynamic control of the underlying graph structures. This enables source multiplexing for realizing efficient entanglement generation as well as the realization of flexible high-dimensional circuitries for the exploration of photonic quantum simulations.