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Quantum optics and information science in multi-dimensional photonics networks

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Classical optical networks have been widely used to explore a broad range of transfer phenomena based on coherent interference of waves, which relate to different disciplines in physics, information science, and even biological systems. At the quantum level, the quantized nature of light, this means the existence of photons and entangled states, gives rise to genuine quantum effects. Yet, to date, quantum network experiments typically remain very limited in terms of the number of photons, reconfigurability and, maybe most importantly, network size and dimensionality.

Photonic quantum systems, which comprise multiple optical modes as well as highly non-classical and sophisticated quantum states of light, have been investigated intensively in various theoretical proposals over the last decades. However, their implementation requires advanced setups of high complexity, which poses a considerable challenge on the experimental side. The successful realization of controlled quantum network structures is key for many applications in quantum optics and quan- tum information science.

Here we present three different approaches to overcome current limitations for the experimental implementation of multi-dimensional quantum networks. Non-linear, integrated quantum devices with multiple channels allow to combine several functionalities on a single monolithic structure, e.g. photon pair generation, circuitry and fast routing. The photon temporal modes of ultrafast pulsed quantum light are defined as sets of field orthogonal superposition states; they span an attractive high-dimensional Hilbert space for quantum communication applications. Finally, pulsed light in combination with designed fibre loop geometries is harnessed for realizing quantum walks as a test-bed for the photonic quantum simulation.

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