Quantum Estimation of One or More Parameters Based on Multiphoton Interference of Single Photons and Squeezed Light

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Quantum interference is one of the most intriguing phenomena in quantum physics at the very heart of the development of quantum technology in the current quantum industry era. It underpins fundamental tests of the quantum mechanical nature of our universe as well as applications in quantum computing, quantum sensing and quantum communication.

I will give an overview of multiphoton sensing techniques enabling the ultimate quantum sensitivity, given by the quantum Cramér-Rao bound, by employing sampling measurements which resolve the inner degrees of freedom, such as time, frequency, position, and polarization, of single photons interfering at a beam splitter [1–5]. This includes: estimation of the transverse displacement between photons and the position of a given source for applications in super-resolved single-molecule localization microscopy, by circumventing the requirements in standard direct imaging of camera resolution at the diffraction limit, and of highly magnifying objectives [1, 2]; multi-parameter estimation of the polarization state of two interfering photonic qubits for applications in quantum information networks [3]; imaging of nanostructures, including biological samples, and nanomaterial surfaces, with arbitrary values of thickness through estimation of photonic time delays [4]; ultimate quantum sensitivity in single-photon spectroscopy based only on sampling time-resolved detections [5]; superresolution imaging beyond the Rayleigh limit of incoherent sources via two-photon interference sampling measurements in the transverse momenta [6].

I will also describe how the metrological power of quantum interference of single photons is intimately connected with an exponential speed-up in quantum optical networks, particularly in the development of scalable boson sampling experiments [7–13].

Finally, I will show novel quantum interference techniques based on linear optical networks with squeezed light for the measurements with Heisenberg-scaling sensitivity of a single parameter [14–18] or multiple parameters [19]. Applications can range from environmental sensing to high-precision biomedical imaging, characterization of nanomaterials, navigation, gravity tests and quantum networks of high-precision clocks.

This research opens a new paradigm based on the interface between the physics of quantum interference, quantum sensing and quantum exponential speed-up with experimentally feasible ”real world” photonic sources.

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