The wavefunction of a quantum particle leads to distinctly non-classical mechanical effects. An important example is quantum tunneling, which enables scanning tunneling microscopy, Josephson junctions, and flash memory. An equally puzzling effect is quantum backflow—an interference effect where a free quantum particle with positive momentum exhibits negative probability current at some space-time point, seemingly moving backwards. This is explained by the distinction between local properties such as probability density and probability current and global properties such as momentum, which require knowledge of the entire wavefunction.

The term ‘quantum’ in quantum backflow underscores the stark contrast between classical and quantum particle dynamics. The broader concept of ‘backflow’—a wave phenomenon where the flow of some quantity (such as energy or probability) in certain regions of space-time is opposite to the flow direction of its constituent elementary waves—is explored experimentally and theoretically with classical and quantum light in this thesis. Our experimental observations of anomalous transverse ‘local’ linear and orbital angular momentum in simple optical two-beam interference using a Shack-Hartmann wavefront sensor, provide new insights and highlight that ‘backflow’ in such scenarios is quite common, owing to the practical impossibility of creating the constituent beams with perfectly equal amplitudes. These observations are extended to the single photon regime.

It ought to be noted that the flow of energy, quantified by the Poynting momentum, is co-directional with the measured local momentum only in the case of linearly polarized paraxial fields in free space. As discussed in a dedicated chapter of the thesis, this assumption no longer holds true for vector fields.

Despite the observations of backflow in optical systems, the prospect of experimentally observing the counter-propagation of a massive quantum particle, such as an electron, remains a compelling challenge. A proposal, to observe the phenomenon with electrons in a transmission electron microscope, is discussed in this thesis.