PhD THESIS DEFENSE: Quantum Optics at its best: from quantum interferometry to quantum metrology

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Quantum optics experiments are currently the most advanced techniques to under- stand, verify and simulate quantum phenomena. However, to access all the perfor- mance available in quantum states of light, one needs to address fundamental opera- tional limits. In quantum mechanics, the measurement strategy affects the quantum state; therefore, to access all the degrees of freedom available in the quantum states, one must implement the optimal feasible measurement. In this thesis, I investigate how to perform more precise measurements in optics, namely slit-interference and image resolution, by exploiting the quantum mechanical nature of light.

A complete description of multi-slit interference must include nonclassical paths, Feyn- man paths that goes through two or more slits. Prior work with atomic interference in the

double-slit experiment with cavities as which-way detectors, has shown these paths to be experimentally inaccessible. In this thesis I show how such a setup can detect nonclassical paths with 1% probability, if different nonclassical paths are in- cluded. I also show how this setup can be used to erase and restore the coherence of the nonclassical paths. In the same chapter I demonstrate how the same setup could implement an exact measure of Born-rule violation. And in the last part I debate about the figures of merit in the literature to test the Born-rule.

During more than one century, there was a fundamental limit on image resolution; due to diffraction effects in finite detectors apertures, one cannot resolve two incoher- ent sources very close to each other, e.g. stars. In the last decade, the formalism of quantum information allowed new proposals for sub-diffraction limited resolution or super-resolving measurements. Nevertheless, these measurements are susceptible to misalignment. In this thesis, I suggest alternative measurement strategies to incorpo- rate misalignment in super-resolution imaging, showing that sub-diffraction limited resolution is still possible. The proposed measurements can be implemented using linear optical transformations and offer an advantage in the case of estimation and discrimination of two incoherent point sources allowing one to quantify the mitigat- ing effects of misalignment. Moreover, I propose a collective measurement strategy, on two or more photons, that estimates the separation between two incoherent point sources and is oblivious to misalignment.

In an optics experiment, the quantum state verification relies on tomography measure- ments on copies of the prepared state. The error in tomography experiments is called confidence region, and it defines the region in which the quantum state is found with the desired probability. There are different methods to compute confidence regions; in this thesis, I analyze the capability of the known methods by resolving two nearby quantum states using a finite amount of measurement data.

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