Quantum Metrology: Toward the Ultimate Precision Limits

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Quantum Metrology concerns the estimation of parameters, like a phase shift in an interferometer, the magnitude of a weak force, or the time duration of a dynamical process, taking into account the quantum character of the systems and processes involved. Quantum mechanics brings in some new features to the process of parameter estimation. The precision of the estimation becomes now intimately related to the possibility of discriminating two different quantum states of the probe corresponding to two different values of the parameter to be estimated. Also, possible measurements must abide by the rules of quantum mechanics. At the same time, quantum properties, like squeezing and entanglement, may help to increase the precision. Recent results, obtained in our group, demonstrate that hyperentanglement helps to achieve precision beyond the standard limit [1], establish the relationship between quantum metrology and weak measurements [2], and propose a general framework to parameter estimation in open systems [3,4]. This talk will review some of this recent achievements, with applications to optical interferometry [3] and the quantum speed limit [4]. This last topic may be understood as a precise statement and generalization of the energy-time uncertainty relation to open systems. For a review, see [5].

Set-ups for quantum parameter estimation. a General algorithm to estimate an unknown parameter $x$ of an arbitrary dynamical process. The probe, prepared in a known initial state, is sent through a physical channel. A measurement is performed on the final state, from which the parameter $x$ is estimated. b Set-up for estimating a phase shift $\theta$ in an optical interferometer.