Heisenberg-limited metrology without entanglement

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PACS 03.67.-a – Quantum information
PACS 06.20.Dk – Measurement and error theory

Abstract – It is common experimental practice to improve the signal-to-noise ratio by averaging many measurements of identically prepared systems. If the systems are independent, the overall sensitivity of the measurement, defined as the smallest resolvable change of the quantity under consideration, improves as \(1/\sqrt{N}\). In the context of quantum optics, such a scaling behavior is known as the standard quantum limit (SQL). Quantum enhanced measurements promise the exciting possibility to improve this scaling behavior. Indeed, if the \(N\) systems are initially entangled, one may achieve in principle a \(1/N\) scaling of the sensitivity, known as the “Heisenberg limit”. Unfortunately, decoherence has so far limited the implementation of such “quantum enhanced protocols” with entangled subsystems to rather small values of \(N\). Here we show that a measurement setup in which \(N\) quantum systems interact with a \(N+1\)st system allows one to achieve Heisenberg limited sensitivity, without using or ever creating any entanglement. The method is robust under local decoherence, in the sense that local decoherence changes only the prefactor but not the scaling with \(N\). We present a general theoretical framework for this new kind of measurement scheme, and propose a possible application in high precision measurements of the length of an optical cavity, where the \(N+1\)st system is an environment, and collective decoherence itself produces the signal [1, 2].

REFERENCES