How to Optimize the Shape of Quantum Light in Quantum Metrology?

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Because of the 1/N^2 quantum limits in optical measurements (x=0.5 for standard quantum noise and 1 for Heisenberg limited measurements), the best strategy for maximum sensitivity is to use states of light with very high photon number N. In this respect, multimode Gaussian states of light, encompassing intense coherent states, squeezed states and EPR entangled states, are the best practical choice. This strategy has indeed been successfully implemented to reduce the quantum noise floor in the gravitational wave interferometers which use ultra-intense lasers and vacuum squeezed state. We have generalized this approach to any parameter estimation by optical means, and found the expression of the quantum Cramer Rao limit when one uses multimode non-classical Gaussian states, with the possibility of optimizing not only the multimode Gaussian quantum state, but also the shape of the modes in which the state “lives”.

We have identified in particular a “noise mode”, the quantum fluctuations of which are responsible for the noise in the estimation, and given techniques enabling us to reach the quantum Cramer-Rao limit. We have implemented this approach and improved parameter estimation beyond the standard quantum noise in the case of measurements of frequency shifts and beam displacements.

Application: interferometric measurement of phase

One retrieves Caves configuration:
- an intense coherent state on one input port
- a vacuum squeezed state on the other.
implemented now on gravitational interferometers

Application: measurement of transverse displacement

also implemented in ranging and measurement of frequency shifts can also improve clock synchronization

V. Thiel, J. Roslund, Jian Pu, C. Fabre, N. Treps, Quantum-limited measurements of distance fluctuations with a multimode detector, Quantum Science and Technology 3, 044008 (2017)