Squeezed-entangled states significantly enhance precision in optical quantum metrology

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Quantum metrology aims to harness the power of quantum mechanics to make ultra-precise measurements. A crucial advantage of quantum metrology is that it provides high precision with a significantly lower particle flux. This is an important requirement for many applications such as in biological sensing [1], where disturbing the system can damage the sample, or in gravitational wave detection [2], where the lasers in the interferometer interact with the mirrors enough to degrade the measurement [3].

It is known that an interferometer that utilizes a stream of independent particles is capable of measurement precision at the shot noise limit, $1/\sqrt{n}$, where n is the total number of particles used in the probe state. However, by making use of quantum mechanical properties this can be improved to the "Heisenberg limit", $1/n$, for example by using highly entangled NOON states [4] or squeezed states [5, 6].

Indeed, the most commonly used optical quantum states employ either squeezing or entanglement to enhance measurements, but here we utilise both these techniques to create squeezed-entangled states, and use the quantum Fisher information to show that substantial improvements can be gained over states that use squeezing or entanglement in isolation. We then show how the squeezed-entangled states can be created using present day, or near future, technology, and we obtain a precise phase readout by mixing the two modes at a beam splitter, followed by photon counting at the outputs [7, 8], as shown in Fig. 1. Finally, we simulate an experiment to show that these states can be used to measure a phase with sub-classical precision, even in a lossy interferometer. Our results extend the capabilities of practical quantum metrology schemes and highlight the significant improvements exhibited by states that combine both squeezing and entanglement to enhance phase measurements.

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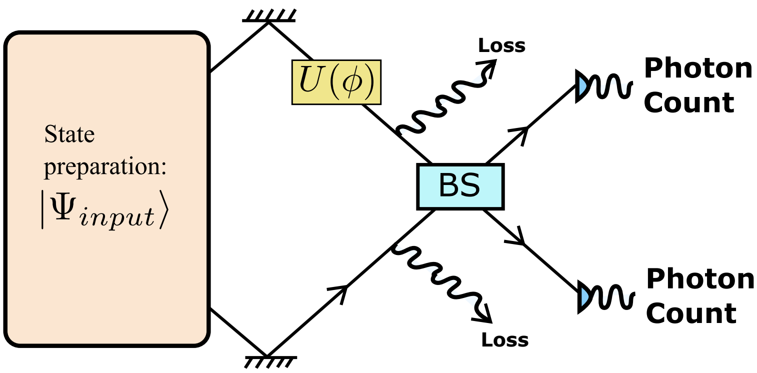

FIG. 1: This scheme can be used to measure a phase ϕ using the input quantum state $|\Psi_{input}\rangle$, which we take here to be a squeezed-entangled state. The phase information can be obtained by mixing the states at a 50:50 beam splitter, and counting photon numbers at the outputs.