Optimal multiphoton phase sensing and measurement

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Multipartite entangled states can help to increase the precision of phase sensing. When the N photons are in a maximally entangled state, the phase uncertainty can be as low as $1/N$, which is $\sqrt{N}$ times more precise than the standard quantum limit (SQL) [1]. To achieve this optimal phase sensitivity, it is necessary to distinguish even and odd photon numbers by performing a parity measurement at the output of the interferometer. However, parity measurements are extremely difficult to realize with current photon detection technologies, since they require high-fidelity resolution of $N+1$ different photon distributions between the output ports. In recent experiments, researchers have demonstrated precision beyond the SQL, for two and four photons, using only one or two photon-number detection patterns instead of parity measurements [2]. To realize efficient phase sensing at higher photon numbers, it is therefore important to consider the optimal phase sensitivities obtained when only a single interference fringe is detected.

Here we show that for single fringes, the maximally-entangled NOON state [1] does not achieve optimal phase sensitivity when $N > 4$. Instead, the optimal single fringe sensitivity is achieved by the Holland-Burnett (HB) state [3], which is generated by the interference of two input beams with equal photon numbers. We experimentally demonstrate the enhanced phase sensitivity of a single photon-counted fringe of the six-photon HB state and show that it has higher phase sensitivity than a single NOON fringe of equivalent visibility. Specifically, our single-fringe six-photon measurement achieves a phase variance three times below the standard quantum limit.

We will also discuss the use of adaptive measurements with sequences of 4, 2 and 1-photon path-entangled states to achieve ab-initio measurement of an unknown phase, demonstrating an experimental uncertainty below the SQL [4].

References: