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Measurement precision beats standard quantum limit

For physicists, measuring the precise magnitude of a physical quantity is a key to understanding quantum mechanics. However, there is a limit to how precise a measurement can be made, which is governed by quantum mechanical laws.

In search of a more precise measurement of quantum phases, researchers from the University of Science and Technology of China have demonstrated a new measurement method that relies on multi-photon entanglement and the interference effect it generates.

“High resolution quantum phase measurements will help to measure other related physical parameters with high precision, such as time shift, distance, etc.,” physicist Fangwen Sun told *PhysOrg.com*. Sun is currently with the Optical Nanostructure Laboratory at Columbia University in New York.

In their study, which is published in a recent issue of *Europhysics Letters*, Sun and his colleagues describe an experiment where they achieve a phase measurement precision that surpasses the standard quantum limit, and nearly reaches the Heisenberg limit.

“The scheme can be generalized to high-photon-number states,” Sun said. “There is no fundamental obstacle to achieve the precision approaching the Heisenberg limit.”

As the researchers explain, the standard quantum limit is not the ultimate limit for measurement precision of quantum phases. Using a technique called squeezed-state-based interferometry, previous studies have already surpassed the standard quantum limit. However, the Heisenberg limit is considered the ultimate limit. Although researchers have proposed a number of schemes to approach this limit, none have been realized due an effect called loss.

“The standard quantum limit is achieved with a regular source of light such as a laser,” Sun explained. “It goes as 1/N1/2 for N photons. The Heisenberg limit goes as 1/N for N photons. It can be achieved with quantum sources of light that exhibit special entanglement properties.” But, he added, “It has been proven that the Heisenberg limit is the true quantum limit and cannot be surpassed.”

In their experiment, the researchers designed a method that is not as sensitive to loss as the previous proposals, and so it has a higher probability of resulting in an extremely precise measurement. First, the physicists generated an entangled state by injecting a two-photon Fock state into a beam splitter. Then, the entangled photons traveled through a line of optical elements including a half-wave plate, interference filter, and phase shifter. At the end, the physicists used a recently developed method called quantum state projection to extract the phase information from the entangled photons.

“It is the collective effect of all the photons that improves the precision,” Sun said, explaining why better photon entanglement results in higher precision measurements. “The higher entanglement, the more collective effect.”

With their new measurement technique, the researchers achieved a phase measurement precision of 0.506 for a two-photon state and 0.291 for a four-photon state. By contrast, the precision values set by the standard quantum limit are 0.707 and 0.5, respectively. For comparison, the Heisenberg limit has values of 0.289 and 0.25, which are thought to be impossible to achieve.

Nevertheless, the physicists hope that, with anticipated improvements in technology leading to more efficient multi-photon detectors, the measurements might yield even more precise results.

More information: Sun, F. W.; Liu, B. H.; Gong, Y. X.; Huang, Y. F.; Ou, Z. Y., Guo, G. C. “Experimental demonstration of phase measurement precision beating standard quantum limit by projection measurement.” *Europhysics Letters*, 82 (2008) 24001.