Super resolution phase measurements -- without entanglement

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“People have been trying to make entangled states of various physical systems, and this is hard to do,” Kevin Resch tells *PhysOrg.com*. “But if you can get the same result from measuring entanglement rather than preparing it, then it can make things much easier.”

What Resch, a scientist at the University of Waterloo in Ontario, Canada, is proposing is a time-reversal scheme for measuring the oscillations associated with photon entanglement. “Rather than preparing the state and then measuring,” he continues, “we measured the state that others were trying to prepare.”

Work on this experiment, which demonstrated super resolution without creating entangled states, was performed by an international team of scientists, with the actual experiment done in Andrew White’s Quantum Technology Laboratory at the University of Queensland in Brisbane, Australia. Participants include scientists from Imperial College in London, University of Bristol in the U.K., the University of Vienna in Austria and Griffith University in Brisbane, Australia. The results are published in *Physical Review Letters*, in a paper titled, “Time-Reversal and Super-Resolving Phase Measurements.”

“Quantum mechanics,” Resch explains, “is largely a tool for predicting probabilities. To find these, there are essentially three steps: preparation of an initial state, the evolution of that state, and the detection, or measurement, of a final state. The time reversal we refer to swaps the roles of the preparation and measurement steps.”

Resch says that in addition to being easier than trying to prepare an entangled state, starting with the measuring step also provides the ability to use more photons in metrology: “Reversing the roles of preparation and measurement have allowed us to see phase super-resolution of up to six photons.” He explains that this technique was developed mainly to aid in quantum metrology, the ability to measure to super-precise levels. Prior to this work, only four photons had been used for quantum metrology. “Six photons have been entangled for other purposes,” Resch allows, “but for phase super-resolution, previous experiments had demonstrated up to four.”

Another benefit to come from this demonstration was a further demarcation between phase super-resolution and phase super-sensitivity. “In metrology,” Resch explains, “there are two effects: resolution and sensitivity. For the most part, people have assumed that they are mainly equivalent.” Resch says that phase super-resolution describes rapid oscillations in an interference pattern, while phase super-sensitivity deals reducing phase uncertainty. “We have drawn a line between the two,” he continues. “We have derived separate criteria that have to be satisfied in order to claim super-sensitivity from super-resolution.

In order to get the super-resolution phase measurements, Resch and his colleagues created a device that was designed to measure six individual photons. “Rather than preparing the photons in an entangled state, we performed an entangling measurement. We used six photon detectors and recorded the events when all of them fired at the same time. We found that the oscillations are the same as those that follow a time-forward method of preparing entanglement.”

The time-reversal approach, however, is very general. Resch explains that though it appears to work well with metrology, “it remains an interesting open question which other quantum protocols can be similarly simplified through a time-reversal approach.”

Resch hopes that this technique will be able to make better measurements of very small features. “Many of the most sensitive measurements in quantum mechanics have to do with measuring fringes, looking for the applications where measuring more rapid oscillations gives better measurement.” He compares these fringes to markings on a ruler, pointing out that a meter stick with no markings would be inefficient for measuring objects much smaller than a meter. Add additional markings, though, and the meter stick becomes a more precise tool.

Resch continues, “One needs a good ruler to measure small length changes. This might be a useful technique in metrology, with many future applications.”

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