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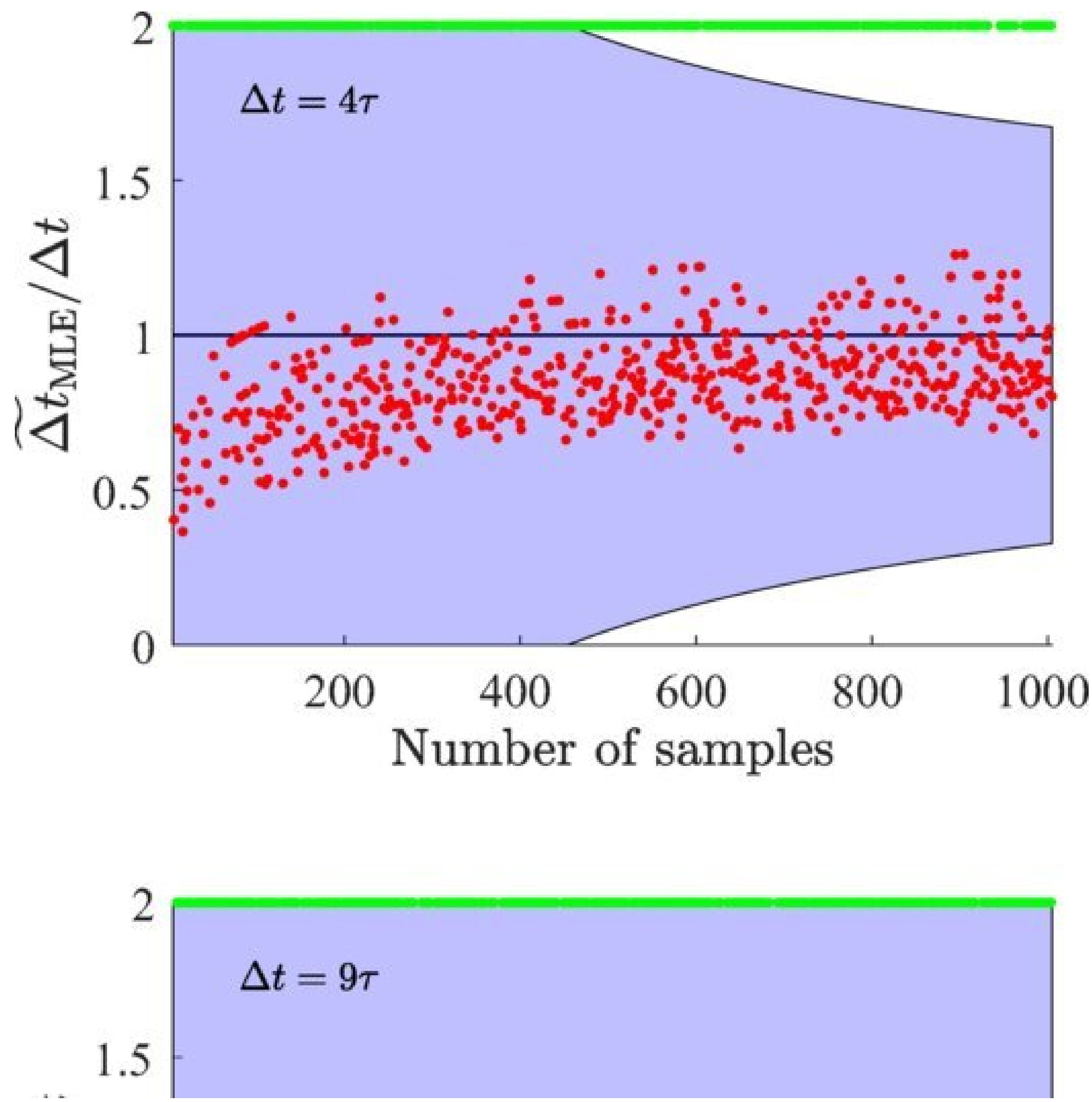
Scientists demonstrate unprecedented sensitivity in measuring time delay between two photons

April 25 2023



Numerical simulations of the estimation for delays Δt=4τ,9τ through the nonresolving technique, with η≃0.8 . In this regime, the Cramèr-Rao bound drastically increases as the Fisher information in Eq. (13) decreases exponentially for increasing Δt . Moreover, many iterations fail to yield a finite estimate of the delay due to the statistical fluctuations in the number of coincidence and bunching events observed, as it can be seen from the density of green points, each one representing a failed estimation. Credit: *Physical Review Applied* (2023). DOI: 10.1103/PhysRevApplied.19.044068

A team of researchers has demonstrated the ultimate sensitivity allowed by quantum physics in measuring the time delay between two photons.

By measuring their interference at a beam-splitter through frequency-resolving sampling measurements, the team has shown that unprecedented precision can be reached within current technology with an error in the estimation that can be further decreased by decreasing the photonic temporal bandwidth.

This breakthrough has significant implications for a range of applications, including more feasible imaging of nanostructures, including biological samples, and nanomaterial surfaces, as well as quantum enhanced estimation based on frequency-resolved boson sampling in optical networks.

The research was conducted by a team of scientists at the University of Portsmouth, led by Dr. Vincenzo Tamma, Director of the University's Quantum Science and Technology Hub. The findings of the study are published in the journal *Physical Review Applied*.

Dr. Tamma said, "Our technique exploits the quantum interference occurring when two single photons impinging on the two faces of a beam-splitter are indistinguishable when measured at the beam splitter output channels. If, before impinging on the beam splitter, one photon is delayed in time with respect to the other by going through or being reflected by the sample, one can retrieve in real time the value of such a delay and therefore the structure of the sample by probing the quantum interference of the photons at the output of the beam splitter.

"We showed that the best precision in the measurement of the time delay is achieved when resolving such two-photon interference with sampling measurements of the two photons in their frequencies. Indeed, this ensures that the two photons remain completely indistinguishable at detectors, irrespective of their delay at any value of their sampled frequencies detected at the output."

The team proposed the use of a two-photon interferometer to measure the interference of two photons at a beam-splitter. They then introduced a technique based on frequency-resolving sampling measurements to estimate the time delay between the two photons with the best possible precision allowed by nature, and with an increasing sensitivity at the decreasing of the photonic temporal bandwidth.

Dr. Tamma added, "Our technique overcomes the limitations of previous two-photon interference techniques not retrieving the information on the photonic frequencies in the measurement process.

"It allows us to employ photons of the shortest duration experimentally possible without affecting the distinguishability of the time-delayed photons at the detectors, and therefore maximizing the precision of the delay estimation with a remarkable reduction in the number of required pairs of photons. This allows a relatively fast and efficient characterization of the given sample paving the way to applications in biology and nanoengineering."

The applications of this breakthrough research are significant. It has the potential to significantly improve the imaging of nanostructures, including biological samples, and nanomaterial surfaces. Additionally, it could lead to quantum-enhanced estimation based on frequency-resolved boson sampling in optical networks.

More information: Danilo Triggiani et al, Ultimate Quantum Sensitivity in the Estimation of the Delay between two Interfering Photons through Frequency-Resolving Sampling, *Physical Review Applied* (2023). DOI: 10.1103/PhysRevApplied.19.044068

Provided by University of Portsmouth