Researchers stabilize photon interference in optical chips using topological wave propagation

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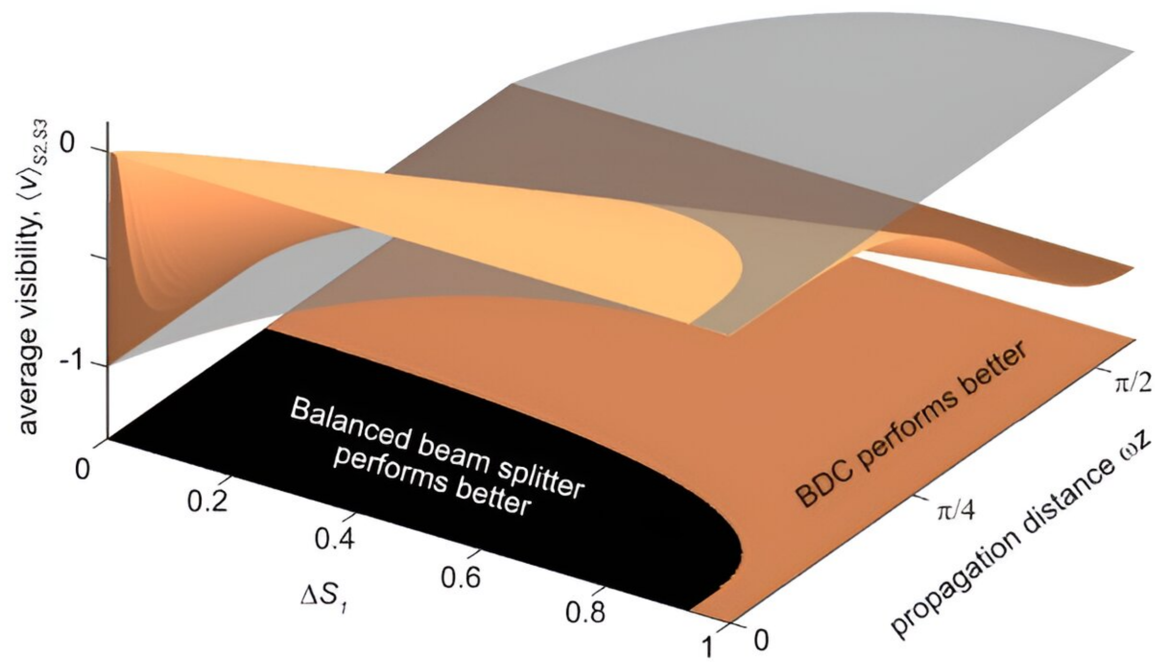

HOM visibility under perturbations in the input state. Average HOM visibility when both input photons are perturbed by Δ□□when being launched in the BDC (orange) of different propagation distances □□z and a balanced beam splitter (BS, gray). The bottom plane separates parameter regions for parameters (Δ□□, □□z), in which either the beam splitter (black region) or the BDC (orange region) achieves better visible quantum interference. Credit: *Science* (2024). DOI: 10.1126/science.ado8192

A collaboration of Professor Szameit's research group at the University of Rostock with researchers from the Albert-Ludwigs-Universität Freiburg has succeeded in stabilizing the interference of two photons in optical chips with the concept of topologically protected wave propagation. The research results are published in *Science*.

Scientific innovation often arises as synthesis from seemingly unrelated concepts. For instance, the reciprocity of electricity and magnetism paved the way towards Maxwell's theory of light, which, up until now, is continually being refined and extended with ideas from quantum mechanics.

In a similar vein, the research group of professor Alexander Szameit at the Institute of Physics at the University of Rostock explores light evolution in optical waveguide circuits in the presence of topology. This abstract mathematical concept was initially developed to classify solid geometries according to their global properties.

Szameit explains, "In topological systems, light only follows the global characteristics of the waveguide system. Local perturbations to the waveguides such as defects, vacancies and disorder cannot divert its path."

In 1987, the physicists Hong, Ou and Mandel observed the behavior of photon pairs in a beam splitter in an experiment that until recently had been independent of topology. They discovered that a photon, which interferes with itself due to its behavior as an electromagnetic wave, is also able to form interference patterns together with other light particles.

In addition to entanglement as a further fundamental feature of quantum light particles, this groundbreaking discovery has proven to be an instrumental ingredient for new optical quantum technologies, including quantum computers.

In a joint effort with colleagues from the Albert-Ludwigs-Universität Freiburg, the researchers have managed to combine topologically robust propagation of light with the interference of photon pairs. "This result is truly a milestone," says Szameit, who has been searching for such a connection for a long time.

Max Ehrhardt, doctoral candidate and first author of the work, states, "Quantum technologies struggle with ever-increasing complexity. Hence, topological protection of optical elements is a much-needed design tool to ensure proper operation regardless of the finite manufacturing tolerances of the optical elements."

The physicists attribute the observed peculiar behavior to the quantum nature of light. "Pairs of photons that see each other perceive the waveguide structure as twisted. This causes them to link up, as if they were dancing along the twisted dance floor as a couple. Photons that pass through the waveguide separately only experience a conventional flat surface. So, we have a topological difference," continues Ehrhardt.

"We were amazed just how far we could deform our waveguide system without any impact on quantum interference," states the group's senior scientist Dr. Matthias Heinrich.

"Our waveguide systems provide a rich pool of possibilities for constructing topological systems for light. The symbiosis with quantum light is just the beginning," says Szameit.

More information: Max Ehrhardt et al, Topological Hong-Ou-Mandel interference, *Science* (2024). DOI: 10.1126/science.ado8192

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