Researcher discusses a new type of collective interference effect

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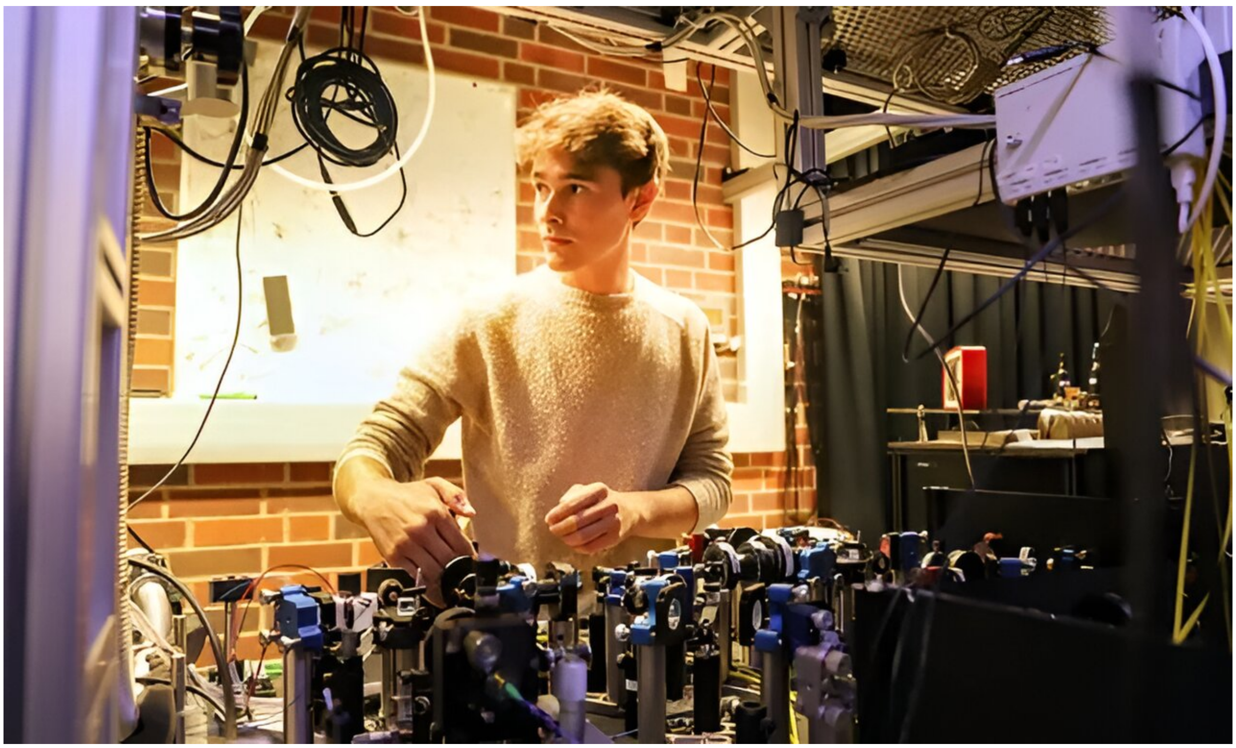

Tommaso Faleo in the laboratory at the Department of Experimental Physics. Credit: University of Innsbruck

A team led by Robert Keil and Tommaso Faleo from the Department of Experimental Physics has investigated the relationship between entanglement and interference in quantum systems of more than two particles in the laboratory.

Together with researchers from the University of Freiburg, Germany, and Heriot-Watt University, U.K., they gained new insights into the behavior of multi-particle quantum systems. In the interview, Tommaso Faleo explains how interference patterns of more than two photons can be interpreted.

Your group at the Department of Experimental Physics has just published a new research paper in the *Science Advances*, in which you link the fascinating quantum phenomena of entanglement and interference. What was the aim of your work?

Faleo: The aim of the research was to explore and better understand the relationship between entanglement and interference in systems involving more than two particles. The interference dynamics in such multi-particle systems are particularly complex, and the presence of entanglement introduces an additional layer of complexity.

We focused on examining how interference patterns emerge when some of the particles are in an entangled state and what their specific characteristics are.

Could you briefly explain what entanglement and interference stand for?

Entanglement is a purely quantum phenomenon in which the properties of two or more particles become interlinked, such that they can no longer be described as independent entities, no matter how far apart they are. This fundamental aspect of quantum mechanics puzzled early researchers in quantum physics and now underlies several applications in quantum technologies.

In classical physics, waves can give rise to interference patterns when their amplitudes add up constructively (enhancing each other) or destructively (canceling each other out). This is analogous to interference in quantum mechanics, where the probability amplitudes of different outcomes can combine to increase or decrease the likelihood of certain events.

Two-particle interference adds another layer to this quantum interference and arises from the indistinguishability of identical particles. First demonstrated by Hong, Ou, and Mandel in 1987, this effect is now the key to many optical quantum technologies. Multi-photon interference is the extension of this effect to more than two particles.

You investigated interference patterns of more than two photons. What did you see in the experiment?

When analyzing systems with more than two particles, the interference patterns become significantly more complex than in the basic Hong-Ou-Mandel experiment. We observed that these patterns are influenced not only by the quantum states of the individual particles but also by the entanglement shared among some of them.

In our interference scenario, the particles' entanglement bridges the spatial gap between separate interferometers, introducing an interference pattern that depends on the overall quantum state of all the particles involved, and is inaccessible when one or more particles are excluded from the dynamics.

These results provide new insights into the behavior of multi-particle quantum systems and how their states influence interference patterns.

What are the implications of the findings for further research?

The results showcase a new type of collective interference effect that combines entanglement with the highly complex dynamics of multi-particle systems. This contributes to our understanding of how quantum mechanics works in many-body systems, potentially leading to both new theoretical insights and developments in quantum technologies.

More information: Tommaso Faleo et al, Entanglement-induced collective many-body interference, *Science Advances* (2024). DOI: 10.1126/sciadv.adp9030

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