Contribution ID: **143**

Type: **Talk**

Non-Adiabatic Holonomic Quantum Computing in Integrated Quantum Optics

Saturday, November 26, 2022 9:30 AM (15 minutes)

Quantum computing is among the most promising new research areas of modern physics. At its heart, it leverages non-classical effects in certain quantum systems to dramatically speed up computations and information processing. Addressing the need for highly stable quantum systems, a particularly promising paradigm for the design of quantum computers is holonomic quantum computing [1], i.e. the notion of implementing quantum gates as non-Abelian geometric phases. We present the experimental realization of non-adiabatic holonomic quantum gates and a quantum algorithm in integrated photonics.
The geometric phase accumulated by a propagating quantum system depends exclusively on its path through the underlying Hilbert space. As such, it stands in contrast to the dynamical phase, which records the passage of time. Due to their purely geometrical evolution, holonomies, i.e. multi-dimensional geometric phases [2], benefit from topological protection. In particular, the evolution described by non-adiabatic holonomies [3] is completely time- independent, making them especially suited for the design of holonomic quantum gates [4,5].
Quantum optics constitutes a particularly versatile platform for quantum information processing. It allows for the desired miniaturization and, due to the bosonic nature of photons, even the synthesis of holonomies of higher dimension as larger and more capable computational units [6,7]. Our demonstration consists of three waveguides in a planar geometry fabricated by femto-second laser direct inscription [8]. Exciting this structure with a single photon allows for the creation of a two-dimensional non-adiabatic holonomy.
As a proof of principle, we experimentally realize three prominent quantum gates: Pauli-X, Pauli-Z and Hadamard, as well as a small quantum algorithm: the quantum coin-flip game [9]. We find high fidelities, showcasing the high accuracy of our quantum optical realization of non-adiabatic holonomic quantum gates and gate sequences. Our findings pave the way towards universal holonomic quantum computing.

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Category

Other

Authors: NEEF, Vera (Institut für Physik, Universität Rostock, Albert-Einstein-Straße 23, 18059 Rostock, Germany); PINSKE, Julien (Universität Rostock); HEINRICH, Matthias (Universität Rostock); SCHEEL, Stefan (Universität Rostock); SZAMEIT, Alexander (Universität Rostock)

Presenter: NEEF, Vera (Institut für Physik, Universität Rostock, Albert-Einstein-Straße 23, 18059 Rostock, Germany)

Session Classification: Physics Talks - Quantum Effects, Materials Physics

Track Classification: Physics talks