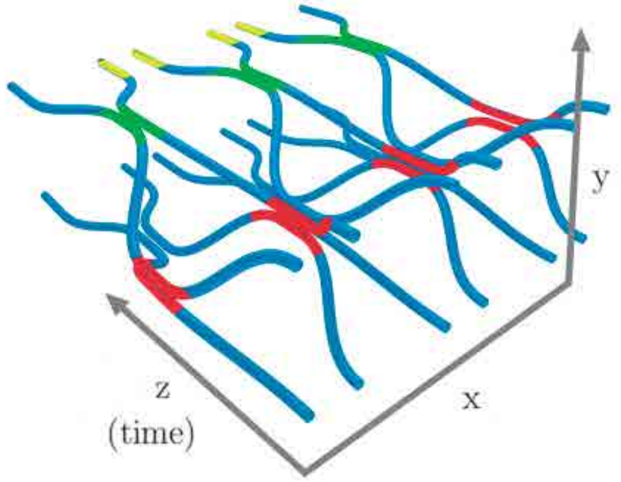
QuSim

Integrated Photonics Quantum Simulations

QuSim paved the way to understand, control, and even exploit the constructive effects of static random noise in quantum dynamics, and proposed an experimental implementation with integrated quantum photonics to study and simulate such effects. Normally detrimental, disorder noise could actually lead to more robust or performing quantum information tasks and to their reliable experimental implementation with integrated photonics.



Main Project Team	
Yasser Omar	**PIQT-Lx**
Manfred Niehus	OCP-Av
Fabio Sciarrino	University of Rome
Octavi Boada	PIQT-Lx
Leonardo Novo	PIQT-Lx
Indicators	
Funding	40k €
Journal Papers	6
Two Main Publications	
L.N. Novo, M. Mohseni, Y. Omar, Disorder-assisted quantum transport in suboptimal decoherence regimes, "Scientific Reports", Vol. 6, No. 18142, January, 2016.	
O. Kerans, L.N. Novo, F. Sciarrino, Y. Omar, Quantum walks in synthetic gauge fields with three-dimensional integrated photonics, "Physical Review A", Vol. 95, No. 1, pp. 013830, January, 2017.	

PROJECT WEBPAGE URL
https://www.it.pt/Projects/Index/2073

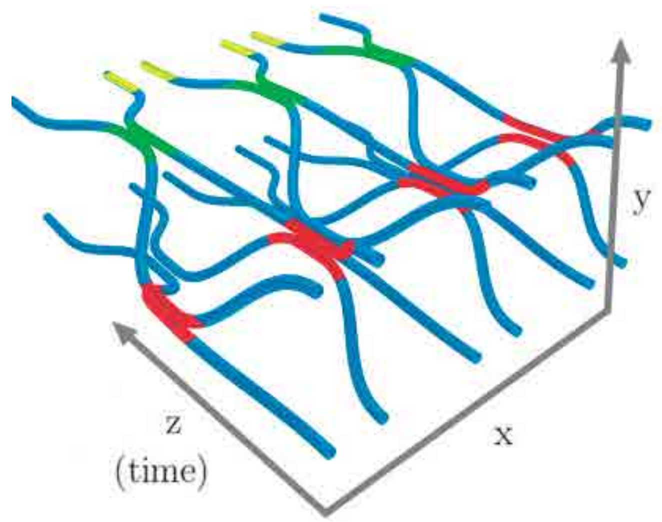


Fig. 1 Diagram of part of the proposed three-dimensional integrated photonic circuit to realize the simulation of synthetic magnetic fields.

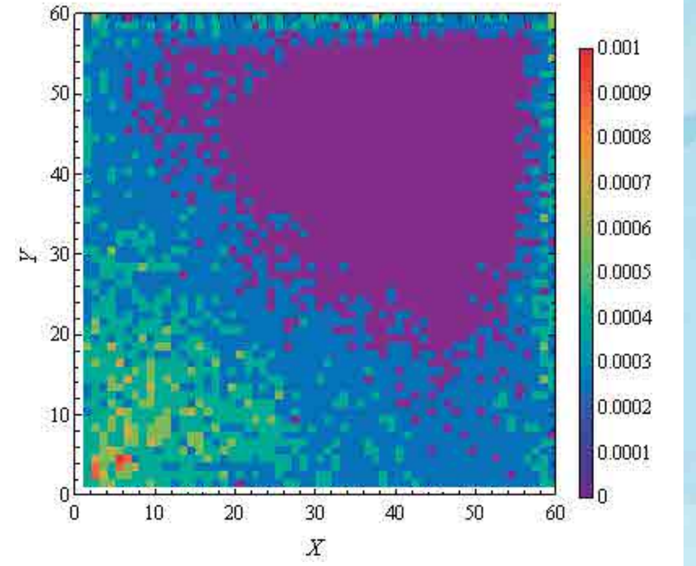


Fig. 2 Probability distribution resulting from the simulation of our integrated photonics implementation of a discrete-time quantum walk on a two-dimensional lattice in nonzero magnetic field with disorder, starting at position (X,Y) = (1,1). The quantum walk propagates mainly along the edges of the lattice. The presence of topologically-protected edge states that do not localize allows for the propagation of the photon to the opposite corner of the lattice.

GENERAL MOTIVATION AND OBJECTIVES

Quantum simulation is a very promising quantum technology, exploiting quantum systems and their properties to simulate efficiently the dynamics of other quantum systems. Namely, quantum simulation allows the study of large complex quantum systems by processing information much faster than classical computers. This opens the way not only for fundamental studies of quantum matter and fields, but also for finding novel quantum materials for energy-efficient electronics, as well as new molecules for pharmaceutics and fertilizers, amongst other promising applications.

Many platforms have been proposed for implementing quantum simulation. Integrated quantum photonics is emerging as one of the most promising platforms, taking advantage of integrated linear optics elements and the quantum properties of light.

The actual scalable implementation of quantum simulation is generally challenging. Typically, quantum systems are very sensitive to noise and environmental effects, which reduce the quantum coherence in these systems, thus hindering their computational advantage.

However, it was recently found that, in some cases, these detrimental factors can actually help the quantum dynamics. The goal of this project was to show that it is possible to have disorder-assisted quantum dynamics. Furthermore, it aimed at developing experimental proposals based on quantum light and integrated photonics that can lead to testing experimentally and simulating disorder-assisted and disorder-robust quantum dynamics.

CHALLENGE

Project QuSim was developed in collaboration between the Physics of Information and Quantum Technologies Group at Instituto de Telecomunicações and the Quantum Optics Group at the University of Rome "La Sapienza". The expertise of the former on theoretical quantum information and environment-assisted quantum dynamics, and the expertise of the latter on experimental quantum optics and integrated quantum photonics, namely with their unique three-dimensional photonic chips, proved to be the right combination to tackle the challenging goals of this project: to study disorder-assisted and disorder-robust quantum dynamics, and develop proposals for their future experimental implementation with integrated photonics, once better single photon sources and other technological developments allow for improved scalability of this platform.

WORK DESCRIPTION AND ACHIEVEMENTS

We investigated, theoretically, quantum transport in different network structures in the presence of disorder and environmental dephasing noise. We discovered that dephasing, which normally reduces the quantum character of the dynamics, can actually improve the quantum transport efficiency not only in the disordered case, but also in the ordered one. Remarkably, we found that in weak dephasing regimes, away from optimal levels of environmental fluctuations, the average effect of increasing disorder is to improve the transport efficiency until an optimal value for disorder is reached. Our results established the existence of disorder-assisted quantum dynamics, and put forward the possibility of exploiting disorder as a resource for more efficient quantum transport. Furthermore, this could have applications for engineering nanoscale energy funnelling systems.

We also investigated the possibility of designing photonic devices capable of disorder-resistant transport and information processing. Namely, we proposed to exploit three-dimensional integrated photonic circuits in order to realize two-dimensional discrete-time quantum walks in a background synthetic magnetic field. The field is generated by introducing appropriate phase shifts between waveguides. We find that, in the disordered case, the magnetic field enhances transport due to the presence of topologically-protected edge states that do not localize. Our proposal introduced a flexible platform for the experimental study of multiparticle quantum walks in the presence of synthetic gauge fields, paving the way towards topologically robust transport of many-body states of photons.

Finally, these results inspired new research beyond the QuSim project, studying the robustness of quantum algorithms in the presence of disorder, as well as their potential implementation with integrated photonic quantum processors.