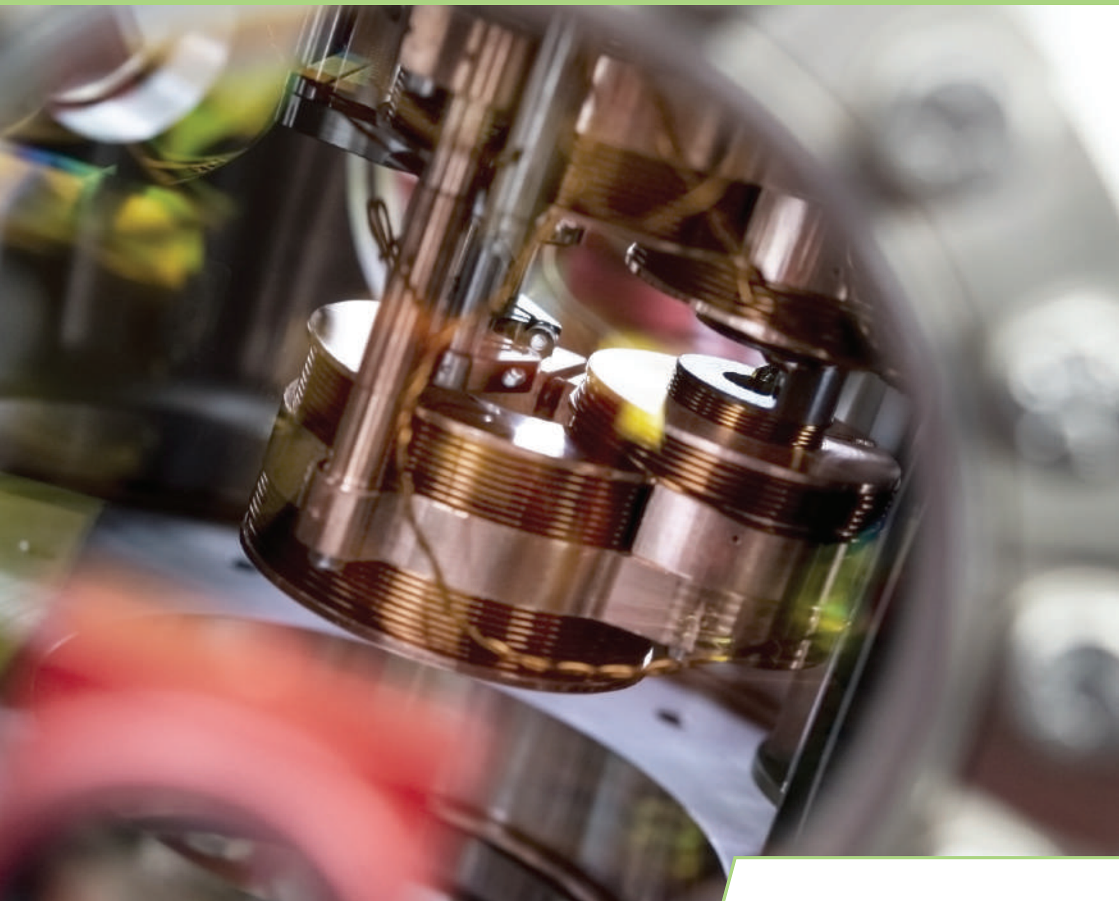
QUANTUM INFORMATION NATIONAL LABORATORY



Quantum Information
National Laboratory
HUNGARY

National Research, Development
and Innovation Office
Hungary

PROJECT FINANCED
FROM THE NRDI FUND

Dear Reader,

The birth of Quantum Mechanics at the beginning of the 20th century, i.e. the discovery of new laws of motion which rule the microscopic world of photons, electrons and atoms, changed not only our scientific perception of Nature but also modern society. Neither nuclear energy, nor the immeasurable impact of lasers and electronics in our everyday life would have been possible without the quantum revolution. A 100 years later however, at the beginning of the 21st century, we once again face the tantalising prospect of **exploiting the weird laws of quantum mechanics in applications that could revolutionise both communication and computation.** Communication, by way of quantum security and computation, by way of classically impossible logic.

Deploying scientific success in new technologies however, requires a concerted effort of experts from different backgrounds. Accordingly, large-scale collaborative programs have been launched at various levels, ranging from national initiatives to the European flagship program for quantum technology. In fact, the **Hungarian Government was early to recognise the importance of getting on this train and introduced a national excellence program for quantum technology** in 2017.

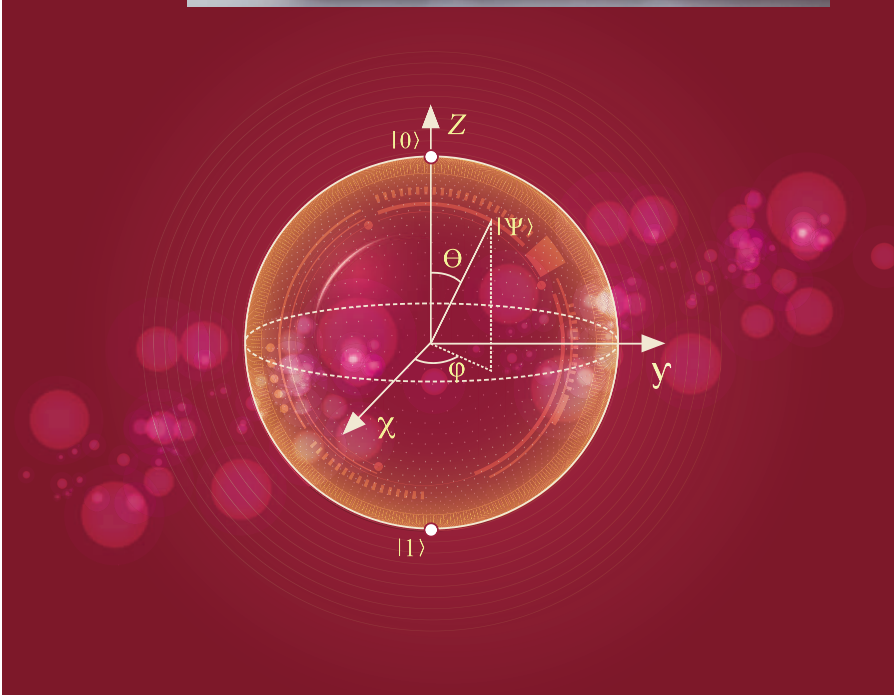
It was this program that kicked-off the organisation of the Hungarian quantum community and which subsequently led to the **formation of the Quantum Information National Laboratory (QNL) in 2020.** Although QNL is now a mature and well organised institution, we, the original organisers, are very happy to see the many young faces and the multitude of projects and ideas that continue to support the revolution.

Indeed, many of the grandfathers of quantum theory were Hungarian: Eugene Wigner, John von Neumann, and Edward Teller, to name a few. And I believe that Hungarians still have a special affection for the mystery of quantum mechanics: something I see in my various encounters with the public. Now that the Martians have left the room however, we, the collaborators of the QNL, are enthusiastic to live up to this heritage and to play our part in the amazing international endeavour to **tame quantum particles for devices that will change our lives in the 100 years to come.**

Dr. Peter Domokos

Research Professor
QNL Consortium Leader


LM1-B/M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QUANTUM INFORMATION NATIONAL LABORATORY (QNL)

MISSION

The Quantum Information National Laboratory **boosts the research and development activity of the Hungarian scientific community** within the unfolding second quantum revolution which aims at the exploitation of the enormous advancements in our ability to detect and manipulate single quanta for new kinds of applications.

STRATEGIC GOALS

- Realisation of a regional quantum communication network which can be joined to the pan-European quantum internet.
- Development of hardware components for quantum information processing based on atoms and artificial atoms, and sustain the necessary laboratory background at the international forefront level.
- Formation of the knowledge base and a pool of experts necessary to exploit the application potential of quantum computers operated as a remotely accessible large-scale infrastructure.

Place of implementation:
Budapest, Hungary

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E-mail: qnl@wigner.hun-ren.hu

Homepage:
qi.nemzetilabor.hu

Consortium leader:
HUN-REN Wigner Research Centre for Physics

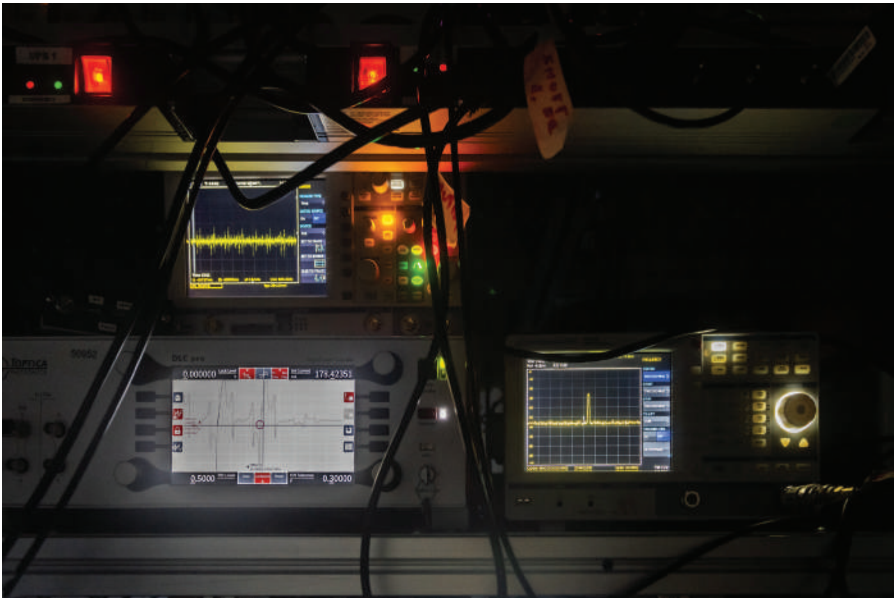
Consortium partners:

Budapest University of Technology and Economics

Eötvös Loránd University Budapest

Quantum Information National Laboratory HUNGARY

HUNGARIAN NATIONAL LABORATORY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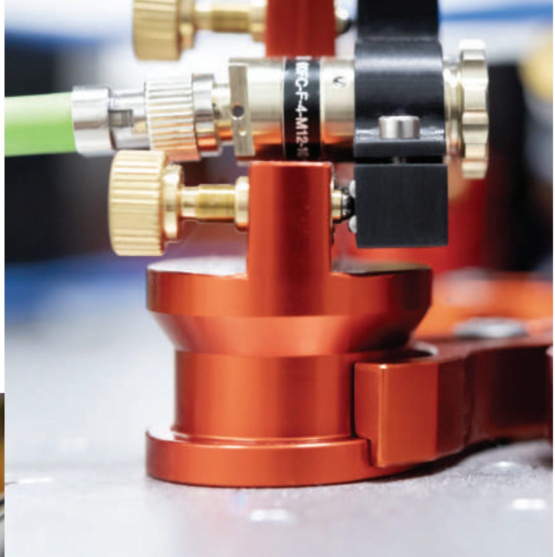

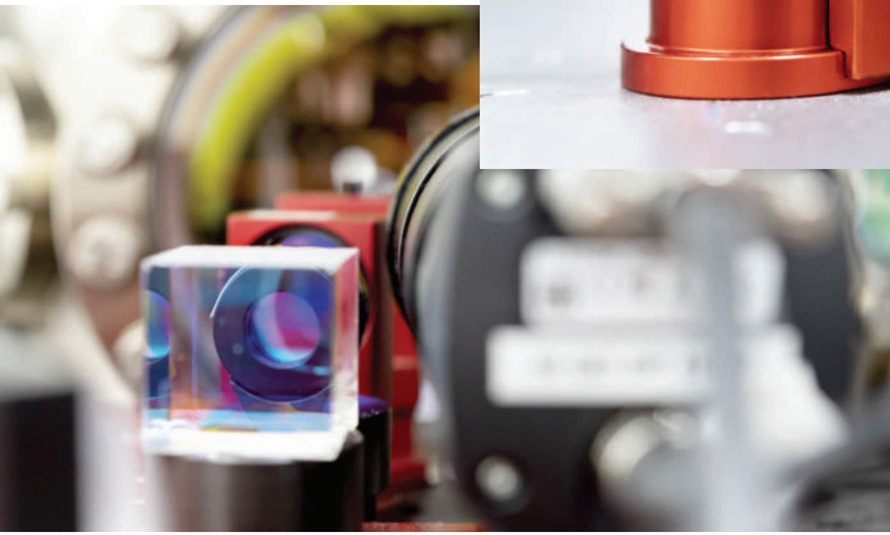

PARTNERS

HUN-REN Wigner
Research Centre for Physics

Budapest University
of Technology and Economics

Eötvös Loránd University Budapest

National Research, Development
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HUN-REN WIGNER RESEARCH CENTRE FOR PHYSICS

The HUN-REN Wigner Research Centre for Physics is one of the most highly staffed research centres of the Hungarian Research Network (HUN-REN). Its predecessor institute was founded in 1950 on the KFKI scientific campus, which is located at the border of Budapest, in a beautiful forest environment of the Buda hills. Today the Centre consists of two main institutes: Institute for Particle and Nuclear Physics and Institute for Solid State Physics and Optics.

Its mission is to **conduct exploratory research in various fields of physics in local laboratories, and to coordinate Hungarian efforts in international projects.** The priority research fields are as follows: particle physics, nuclear physics, general theory of relativity, gravity, space physics, solid-state physics, statistical physics, atomic and molecular physics, classic and quantum optics, laser physics, laser-induced fusion, quantum technology, quantum information technology, and computation sciences.

Homepage
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BUDAPEST UNIVERSITY OF TECHNOLOGY AND ECONOMICS

The primary mission of the Budapest University of Technology and Economics (BME) is to **train professionals in engineering, information technology, natural sciences, economics, business, and management** for the relevant sectors of the national economy.

Further missions of the BME are education, the cultivation of science, scientific research, and creation, encompassing basic and applied research, the development of technical products and services, and the exploitation of the results, which form the innovation chain.

BME has over 1,200 research and teaching staff and nearly 22,000 students in its eight faculties. The Quantum Information National Laboratory involves researchers from the Faculty of Natural Sciences and the Faculty of Electrical Engineering and Informatics, who have been actively engaged in the theoretical aspects of quantum computing, quantum communication, quantum technology, and the development of experimental systems over the past decades.

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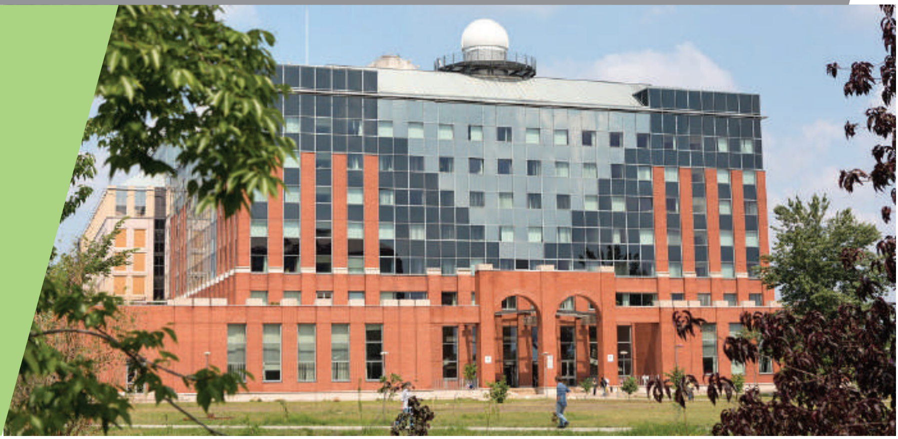
PARTNERS

EÖTVÖS LORÁND UNIVERSITY BUDAPEST



Eötvös Loránd University Budapest, or ELTE, is a public research university in Budapest, Hungary.

It was founded in 1635 by Cardinal Péter Pázmány as a Catholic institution for theology and philosophy. Today, it has nine faculties and offers a wide range of degree programs in various fields of science, humanities, law, education, and social sciences.

ELTE is **one of the largest and most prestigious universities in Hungary, with a history of excellence and innovation.** It is affiliated with five Nobel laureates, as well as other distinguished scholars and scientists.

ELTE
EÖTVÖS LORÁND
UNIVERSITY

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www.elte.hu

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WORK PACKAGES

1. Realization of a quantum communication network
2. Quantum interfaces
3. Development of qubit storage based on solid-state systems
4. Optical laboratory for quantum information
5. Quantum computation and simulating quantum systems
6. Software technology for quantum computing

National Research, Development and Innovation Office
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WORK PACKAGES

REALIZATION OF A QUANTUM COMMUNICATION NETWORK

1

INTRODUCTION

Quantum communication networks offer superior security compared to encryption algorithms we use to protect communication lines today. Quantum key distribution (QKD) protocols enable distant parties to share secure keys, which can be used for encryption in classical networks. In this process, information is encoded in photons, which can be transmitted over optical fibers or over free-space channels. Our goal is to work on methods and devices which can be used in a regional quantum network.

RESEARCH TOPICS

- Developing systems and methods for fiber-based quantum communication
- Developing systems and methods for free-space quantum communication
- Developing and analyzing optical quantum random number generator
- Developing tools for quantum internet
- Building entangled photon pairs at telecommunication wavelengths

Contact
Dr. László Bacsárdi
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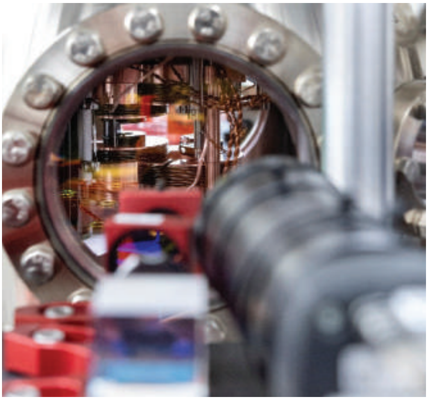
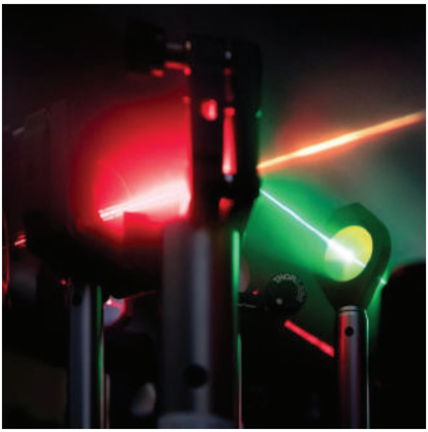
Fun fact:
In 2022, we set up a national QKD record with 20 km using own developed system.

WORK PACKAGES

QUANTUM INTERFACES

2





INTRODUCTION

We prepare **building blocks of quantum information processing from natural and artificial atoms.** Our aim is to use the variety of quantum resonances of atoms for nonlinear optical interactions, in order to coherently transfer quantum information between optical and microwave photons.

RESEARCH TOPICS

- Developing coherent microwave-optical conversion by cold atoms in a cavity QED setup
- Developing optically detected magnetic resonance techniques with diamond nitrogen-vacancy and related solid-state defect centers for realizing spin-photon interface and quantum sensors
- Developing single photon emitters at telecom wavelength from rare-earth ions in nanocrystals

Fun fact:
We levitate atoms in a ultra-high vacuum chamber with background pressure less than in outer space, and cool them with lasers to a temperature of 10 μK (1/100000th of that in outer space).

Contact
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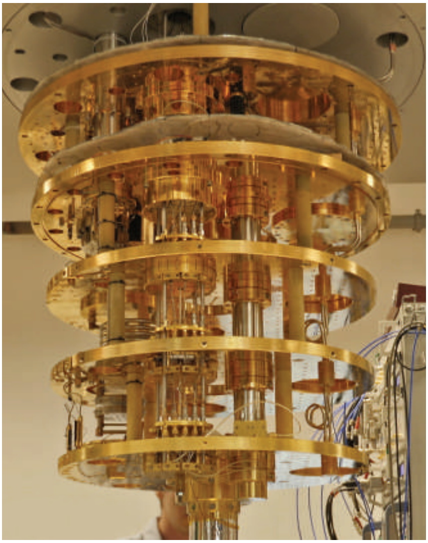
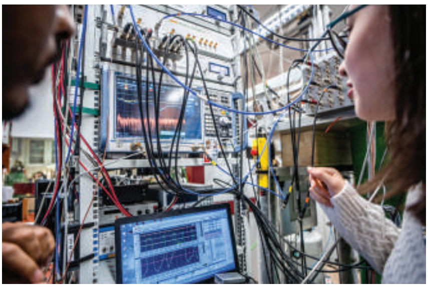
DEVELOPMENT OF QUBIT STORAGE BASED ON SOLID-STATE SYSTEMS

3





INTRODUCTION

Quantum-bit storage realizations are **essential components of quantum computing and communication systems**. Solid-state realizations are among the most promising candidates for this purpose. We investigate exotic magnetic system, superconducting qubit, and solid-state defect spin-based realizations using a combined theoretical and experimental effort.

RESEARCH TOPICS

- Implementing and manipulating telecom-wavelength-compatible quantum storage
- Topological spin structures in magnetic data storage
- Quantum-domain intelligent memory networks
- Semiconductor-superconductor hybrid qubits

Contact
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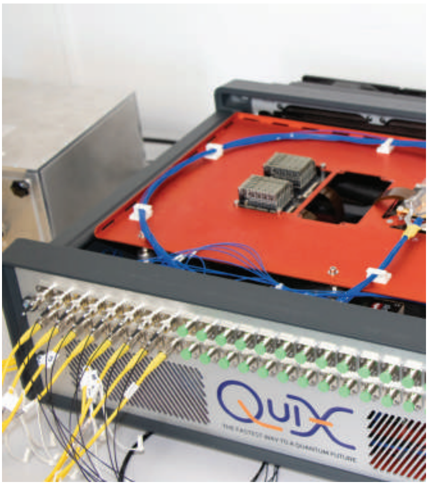
Fun fact:
In our laboratory, we have the highest magnetic field in Hungary. Our NMR magnet is continuously cooled to -269 °C since June 2012 and its magnetic field would decay to its half after 100,000 years!

WORK PACKAGES

OPTICAL LABORATORY FOR QUANTUM INFORMATION

4



INTRODUCTION

The Optical Quantum Information Laboratory Development work package aims to **develop photon-based quantum computers** with the most advanced technology experimentally. The program consists of three main activities: Procurement and installation of quantum elements for the quantum optical laboratory, Implementation and comparison of boson counting experiments with simulations and control experiments to improve the reliability of quantum calculations.

RESEARCH TOPICS

- Investigating and optimizing computing capabilities of an 8x8 mode Quix optical chip
- Perform and compare boson counting measurements with the Piquasso simulation software
- Chip calibration and accurate adjustment of the unitary scattering matrix
- Reduce quantum errors by optimizing the chip's calibration parameters with machine learning algorithms

Contact
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WORK PACKAGES

QUANTUM COMPUTATION AND SIMULATING QUANTUM SYSTEMS

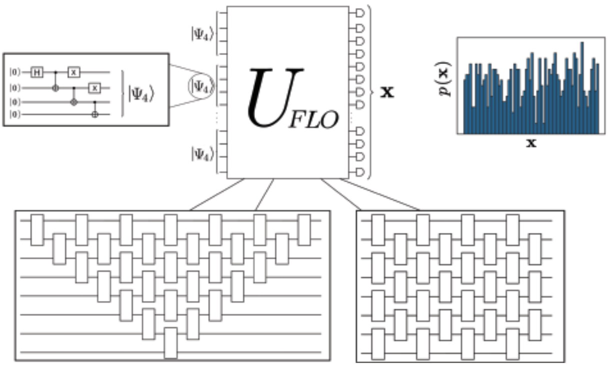
5

INTRODUCTION

We conduct research in various aspects of quantum computing and related subjects in quantum information. In particular, we develop algorithms, **tests and benchmarks for various types of quantum computers and hybrid computation,** as well as apply tensor network methods to efficiently simulate large quantum systems of practical relevance.

RESEARCH TOPICS

- Theoretical aspects and applications of hybrid quantum-classical computation
- Testing and benchmarking gate-based quantum computers
- Adapting quantum algorithms for optical quantum computers
- Optimization of the performance of adiabatic quantum computing
- Application of tensor network methods for simulating quantum systems



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Fun fact:
We use quantum methods to solve hard classical tasks and classical techniques to solve difficult quantum problems.

WORK PACKAGES

SOFTWARE TECHNOLOGY FOR QUANTUM COMPUTING

6

PIQUASSO

Contact
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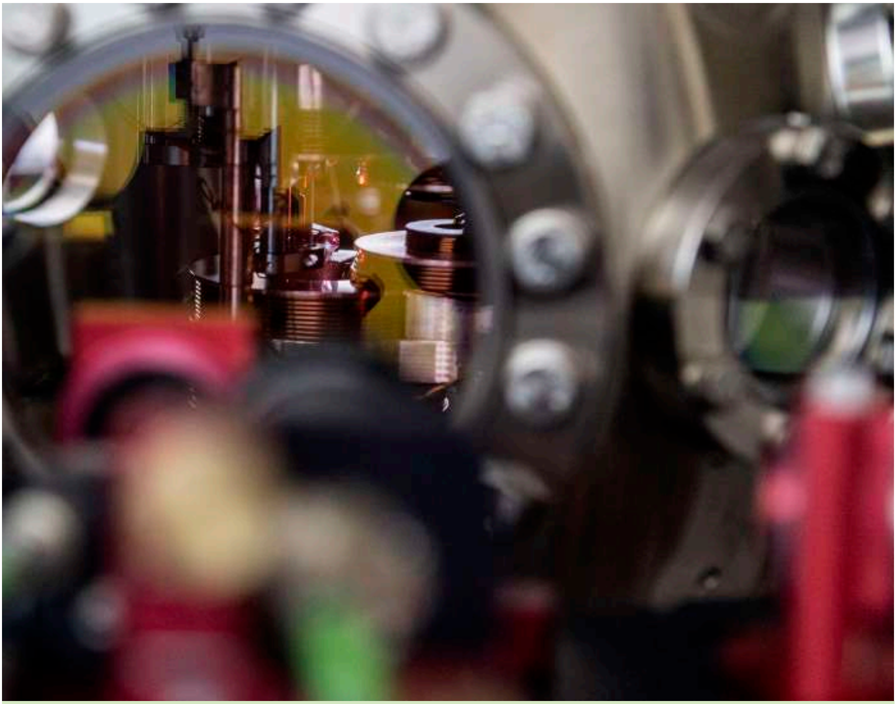
kto@inf.elte.hu

INTRODUCTION

Quantum software technology is a key enabler to the widespread applicability of quantum computers. In this work package, we design and implement quantum programming languages and software development tools including application programming interfaces, code optimizers, and quantum computer simulators. We also explore the foundations and application areas of quantum algorithms such as machine learning and quantum resistant cryptography.

RESEARCH TOPICS

- Developing Piquasso, a simulator for photonic quantum computers
- Leveraging CPU-, FPGA-, and TSP-based acceleration to achieve superior performance for the simulation of photonic quantum computers
- Developing SQUANDER, which provides a novel solution to decompose any unitary operator into a sequence of one-qubit rotations and two-qubit controlled gates
- Investigating various methods to produce unitary designs
- Post-quantum cryptography



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