Laboratory of Theoretical Physics of Nanosystems

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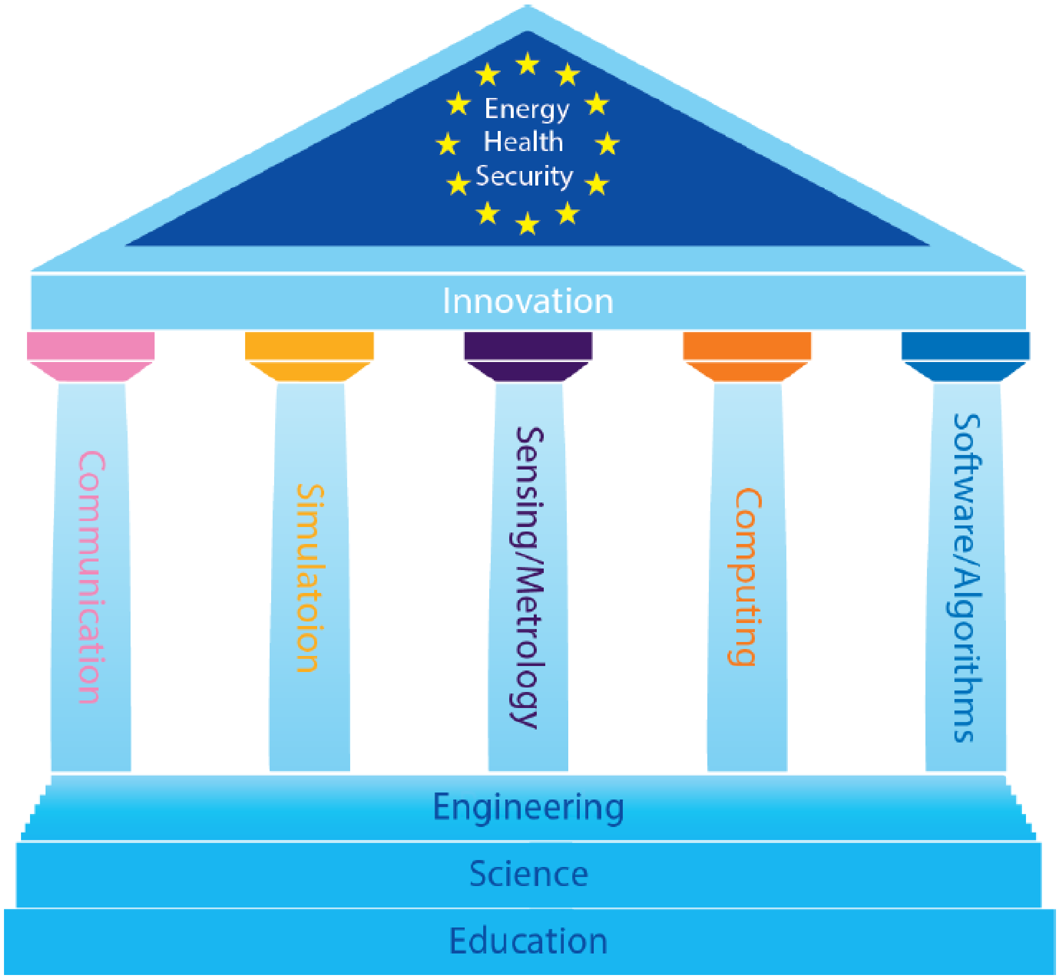
Research areas

- Theory and numerical modeling of open quantum systems
- Quantum optics and photonics
- Linear and nonlinear optical devices: simulation and design optimization

Goal: explore the frontiers of modern quantum science and technology

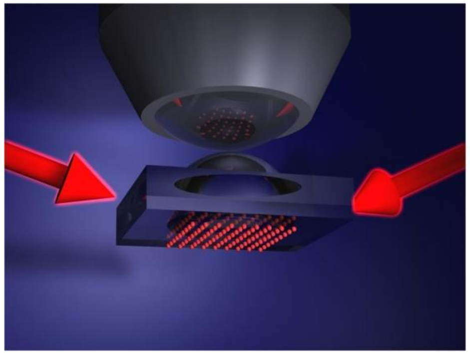
https://www.epfl.ch/labs/ltpn/

EC FET-Flagship Initiative on Quantum Technology: €1 billion funding, start 2018



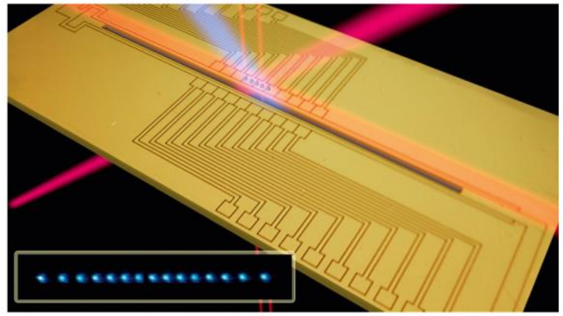
Quantum Science and Technology Platforms

Ultracold atoms in optical lattices



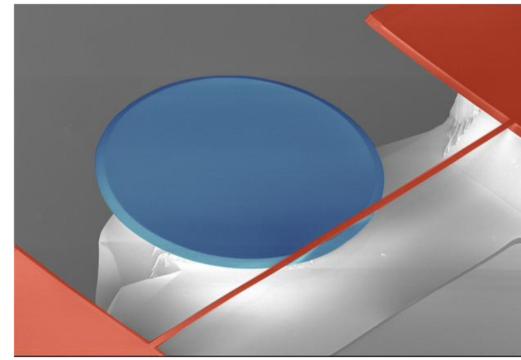
Rev. Mod. Phys. **80**, 885 (2008)

Trapped ions



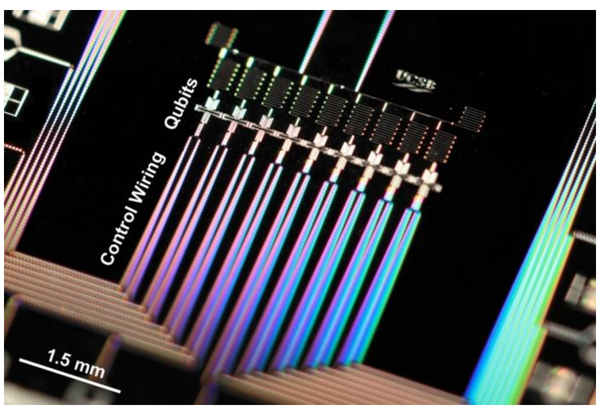
Nature Physics **8**, 277 (2012)

Opto & electromechanical systems



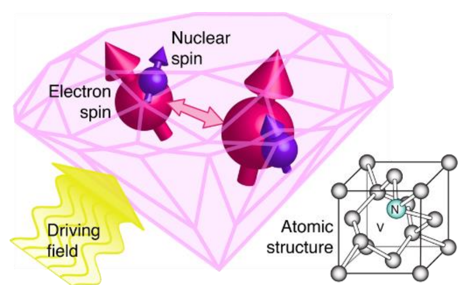
Phys. Rev. X **7**, 011001

Superconducting circuits



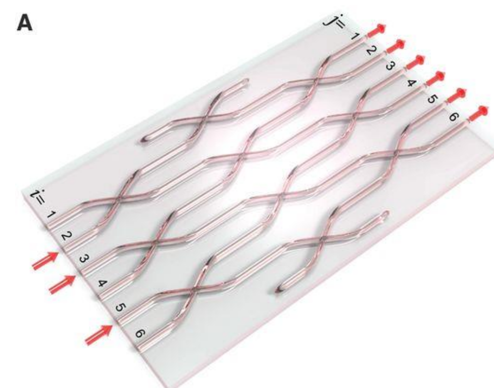
Nature **543**, 171 (2017)

Vacancies in diamond



PNAS **107**, 8513 (2010)

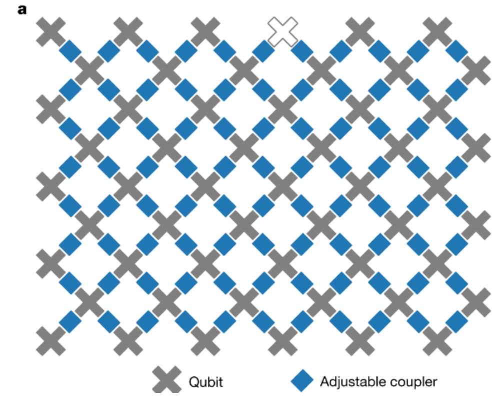
Integrated photonics



Nature Phot. **11**, 361 (2017)

Biggest actors at play

https://research.google/teams/applied-science/quantum/



2019: Google achieves *quantum supremacy:* [*Nature* **574**, 505 (2019)]()

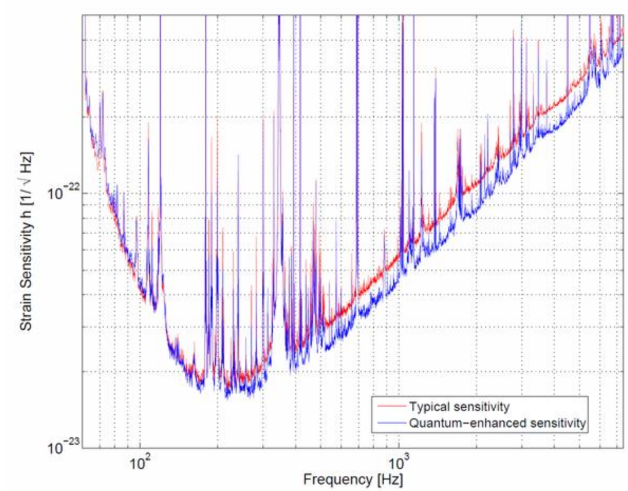
https://www.microsoft.com/en-us/quantum

https://www.ibm.com/quantum-computing/


NEWS · 15 FEBRUARY 2019

Gravitational-wave observatory LIGO set to double its detecting power

A planned US$35-million upgrade could enable LIGO to spot one black-hole merger per hour by the mid-2020s.



Challenges for theoretical physics

- **Understand fundamental processes** in many-body quantum systems under the conditions of QT operations (non-equilibrium, strong correlations, environment-induced noise, etc.). Link to quantum information.
- **Enable core quantum technologies**, e.g. by benchmarking quantum architectures with classical simulations, conceive new quantum measurement and readout protocols, etc.
- **Develop novel devices and processes**, e.g. single or correlated photon sources, optimized designs for integrated photonics, quantum algorithms and quantum error correction codes, etc.
- Develop new numerical methods for open quantum systems.
- …

Common features to all QST systems

- **Many-body**: Modeling typically requires advanced computational techniques
- **Open and noisy**: System in interaction with external baths, require open quantum system formalism

Lindblad-Von Neumann equation for the density operator

$$\frac{d\hat{\rho}}{dt} = -i[\hat{H}, \hat{\rho}] - \frac{1}{2}\sum_j \left[\{\hat{K}_j^\dagger \hat{K}_j, \hat{\rho}\} - 2\hat{K}_j \hat{\rho} \hat{K}_j^\dagger\right]$$

Several approaches: Exact solution, stochastic Schrödinger equation, Quantum Monte Carlo, Variational tensor and neural networks, etc.

Systems: Photonic devices, interacting spins, Cavity-QED, Superconducting circuits, etc.

Goals: Study critical phenomena, model noise and decoherence, develop novel sources of single or entangled photons, etc.

TP-IV at the Laboratory of Theoretical Physics of Nanosystems (V. Savona)

Topic 1: Modeling non-equilibrium steady state in many-body open systems

Model the behavior of many-body quantum systems (Bosons, spins) in presence of driving and dissipation. Characterize dissipative phase transitions and their universal properties.

1st term: Introduction to theory and methods for open quantum systems
2nd term: Work on specific problems

Requirements:	**Good skills in numerical simulations (Matlab)**
Prérequis:	**Physique Quantique I, II**
Main sources:	**H. P. Breuer, F. Petruccione, *The Theory of Open Quantum Systems***

Methods

Master equations for the density operator in open quantum systems
Quantum stochastic equations (quantum jump) method
Analytical approximations

Objectives

Learn the theoretical tools to model open quantum systems (e.g. for applications in *quantum information* and *quantum state engineering*)
Realistically model and predict experimental results

TP-IV at the Laboratory of Theoretical Physics of Nanosystems (V. Savona)

Topic 2: Quantum algorithms and quantum computing

Develop skills in digital quantum computing and quantum algorithms. Conceive and code quantum algorithms for various purposes, e.g. for digital quantum simulation or optimization, quantum search, quantum games, ... Learn how to use the IBM-Q platforms and its publicly available quantum computers.

1st term: Learn quantum computing (Nielsen & Chuang) and the IBM-Q platform
2nd term: Work on specific problems

Requirements:	**Good skills in numerical simulations (python, Qiskit)**
Prérequis:	**Physique Quantique I, II**
Main sources:	**Nielsen & Chuang, *Quantum Computation and Quantum Information***
	John Preskill's lecture notes on *quantum computation*

Methods

Digital quantum computing, linear algebra, quantum mechanics

Objectives

Learn the basik skills of a quantum software engineer, the fundamental quantum algorithms, and the recent quantum error correcting protocols.
Develop original quantum codes or solve specific problems on a quantum computer

TP-IV at the Laboratory of Theoretical Physics of Nanosystems (V. Savona)

Topic 3: Modeling and optimization of photonic crystal structures

Model the electromagnetic modes, linear and nonlinear properties of photonic structures such as photonic crystal and ring resonators. Make use of highly specific methods developed in-house and of commercial simulation software. Apply global optimization algorithms and machine learning techniques to optimize various properties: quality factor, spectrum, field distribution, nonlinear optical instabilities, dissipative solitons and frequency combs. Application: sensing, all-optical switching and modulation, high-precision light sources, cavity quantum electrodynamics.

1st term: Introduction to theory and numerical simulation methods
2nd term: Work on specific problems

Requirements:	**Some numerical simulation skills (Matlab)**
Prérequis:	**Electrodynamique Classique**
Main sources:	**J. D. Jackson, *Classical Electrodynamics***

Methods

Guided-mode and Bloch-mode expansions for the Maxwell problem
Use of first-principle Maxwell solvers

Objectives

Design, model and optimize various photonic structures (for example, for bio-sensing or as advanced light sources). Realistically model and predict experimental results

Practical info

- Possible alternative topics available
- Place for **only few students**. Quality better than quantity!
- Prérequis: Physique Quantique I et II. Good skills with Matlab and/or python
- For all additional information, contact **vincenzo.savona@epfl.ch**

Find these slides at:

https://www.epfl.ch/labs/ltpn/