Quantum tools for future scientific research

Prerequisites: quantum mechanics

Quantum science stemmed from the revolutionary idea, push forward about thirty years ago by R. Feynman, to replace classical hardware with quantum hardware to attack one of the most complex problems in physics, i.e., the quantum many-body problem. Nowadays, quantum science is a fast developing field encompassing tools and concepts from condensed matter, quantum optics, theoretical physics, and information theory. Quickly it has become evident that this new paradigm could lead to a complete novel technology that could be used both for scientific and practical applications. Currently, there is a fast-growing zoo of possible novel research directions opened by this new class of tools. This course aims to introduce the student to this new area of research.

We will quickly review the basics of quantum information theory and some of the most promising applications of quantum technologies for future research. In particular, we will present the achievements and the challenges obtained by quantum simulators, dedicated quantum hardware built to simulate interesting but hardly accessible physics: from models to study for high-Tc superconductors or topological systems, critical systems, quantum chemistry or lattice gauge theories where Monte Carlo methods efficiency is hindered by the sign problem. Finally, we will review the first quantum computations and quantum simulations and their possible applications in quantum chemistry, computer science, nuclear physics, and high-energy physics. Connections with the IBM quantum cloud service and didactic program will be explored.

The course will have a hybrid structure, with frontal lessons and seminars held by the students to present the most recent quantum simulators applications.