Università degli Studi di Napoli
"Federico II"

Dottorato internazionalizzato in
Quantum Technologies

International PhD program in Quantum Technologies

Università di Camerino

Consiglio Nazionale delle Ricerche

PhD in Quantum Technologies courses - 39th cycle

University of Naples "Federico II" - University of Camerino - CNR - National Council of Researches, Florence

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Apart from the courses listed below, every year a PhD Quantum Technologies Summer School is organized:
- **in 2019 the School was organized by the Napoli node**
- **in 2020 it was organized, in remote, by the CNR Florence node: for the program go the link**
- **in 2021, again in remote, the School was organized by the QT group at Camerino**
- **in 2022, the School was held at Catania, organized by the Neapolitan QT group**
- **in 2023, the School was held at Trieste, under the responsibility of the QT CNR group at Florence**

- ## Courses proposed from the University of Camerino

1c) Quantum Computation

by Stefano Mancini – stefano.mancini@unicam.it

given originally for the Laurea Magistrale at Camerino during the first semester AY 2024/25
Lectures for 42 hours and 6 credits.

[Interested graduate students can follow the set of recorded lectures.]
Graduate students will agree with the teacher about a specific topic (related with those described in the lectures), which the students will have to elaborate on and summarize in a written report.

2c) Quantum Information

by Stefano Mancini – stefano.mancini@unicam.it

given originally for the Laurea Magistrale at Camerino during the first semester AY 2023/2024
Lectures for 42 hours and 6 credits.

[Interested graduate students can follow the set of recorded lectures.]
Graduate students will agree with the teacher about a specific topic (related with those described in the lectures), which the students will have to elaborate on and summarize in a written report.

3c) **Quantum Annealing, Monte Carlo Simulations and machine learning Algorithms**

by Sebastiano Pilati – sebastiano.pilati@unicam.it

Lectures for 6 hours and 1 credit. Scheduled for the first half of July 2024.

4c) **Dynamics of open quantum systems**

by David Vitali – david.vitali@unicam.it

given specifically in Camerino for the Unina – Unicam - CNR PhD program in Quantum Technologies approx. schedule: 2 hours per week, starting on Friday Jan 19th – till April 2024:
Lectures for 24 hours and 4 credits.
Available via Webex and lectures will be recorded.
Graduate students will agree with the teacher about a specific topic, related with those described in the lectures, which the students will have to elaborate on and summarize in a written report.

- **Courses proposed from the University of Naples & CNR – SPIN, Naples**

1n) **Quantum Algorithms**

by Giovanni Acampora – giovanni.acampora@unina.it
and
by Autilia Vitiello – autilia.vitiello@unina.it

Theoretical Computer Science, The Leap from Classical to Quantum Computation, Quantum Architectures, Quantum Algorithms
Lectures for 30 hours and 5 credits: the course is also proposed to all the PhD students in Computational Intelligence

2n) **Introduction to Quantum Information**

by Rosario Fazio – rosario.fazio@unina.it

Basics (qubits, quantum gates and simple protocols), Decoherence and dissipation in quantum systems, Accuracy and control of quantum protocols, Quantum simulators - intro, Quantum information and statistical mechanics
Lectures for 15 hours and 2 credits

3n) **Quantum Superconducting Technologies: Principles, Engineering & Interfaces - part 1**

by Francesco Tafuri – francesco.tafuri@unina.it
Davide Massarotti - davide.massarotti@unina.it
Domenico Montemurro - domenico.montemurro@unina.it

to be given in late Spring 2024
Lectures for 24 hours and 3 credits.

4n) **Quantum Superconducting Technologies: Principles, Engineering & Interfaces - part 2**

by Giampiero Pepe – giovannipiero.pepe@unina.it

Lectures for 24 hours and 3 credits.

Lectures for 6 hours and 1 credit.

5n) **Quantum Communication**

by Alberto Porzio - alberto.porzio@unicas.it

Specifically thought for graduate students a general introductory part is followed by a focus on optical experimental quantum communication.
The course consists of Lectures for 20 hours and 3 credits, to be given according to the requests by the PhD students.

6n) **Static and Dynamics of Quantum Phase transitions in closed an open systems**

by Vittorio Cataudella – vittorio.cataudella@unina.it
Antonio De Candia – antonio.decandia@unina.it
Giulio de Filippis – giulio.defilippis@unina.it
Carmine Antonio Perroni – carmineantonio.perroni@unina.it

7n) **Solid State qubits**

by Procolo Lucignano – procolo.lucignano@unina.it
Gabriele Campagnano – gabriele.campagnano@spin.cnr.it

n.b.: this undergraduate course (with lectures for 30 hours and 5 credits) is offered in the frame of the **MSc course in Quantum Science and Engineering**

8n) **Fuzzy models and approximate reasoning in data analysis**

by Ferdinando Di Martino – ferdinando.dimartino@unina.it

- **CNR - Florence**

1f) **Quantum photonic technologies**

by CostanzaToninelli – costanza.toninelli@ino.cnr.it
Marco Bellini – marco.bellini@ino.cnr.it
Alessandro Zavatta – alessandro.zavatta@ino.cnr.it

Lectures for 18 hours and 3 credits during the second semester (June – July 2024)

Graduate students will agree with the teachers about a specific topic (related with those described in the lectures), which the students will have to elaborate on and summarize in a written report.

2f) Quantum Simulations with Atoms

by Giacomo Roati – giacomo.roati@ino.cnr.it
Alessia Burchianti – burchianti@lens.unifi.it
Jacopo Catani – jacopo.catani@ino.cnr.it
Chiara D'Errico – chiara.derrico@ino.cnr.it
Luca Tanzi – tanzi@lens.unifi.it

Lectures for 18 hours and 3 credits. Beginning scheduled from the 2nd week of March 2024
Graduate students will agree with the teachers about a specific topic (related with those described in the lectures), which the students will have to elaborate on and summarize in a written report.

3f) Quantum metrology and sensing

by Luca Pezzé - luca.pezze@ino.cnr.it
Nicole Fabbri - nicole.fabbri@ino.cnr.it

Lectures for 18 hours and 3 credits, scheduled on next February – March 2024 (dr. Pezzi), on April – May (dr. Fabbri)
Graduate students will agree with the teachers about a specific topic (related with those described in the lectures), which the students will have to elaborate on and summarize in a written report.

4f) Quantum paradoxes

by Augusto Smerzi – augusto.smerzi@ino.it

Lectures for 12 hours and 3 credits during the first semester (from the beginning of October – till end of December 2024)
Graduate students will agree with the teachers about a specific topic (related with those described in the lectures), which the students will have to elaborate on and summarize in a written report or seminar.

Dynamics of open quantum systems

Lecturer	**David Vitali** david.vitali@unicam.it
Credits (planned)	4
Planned hours	24
Planned schedule and location	From January 19th, 2024: each Friday, 2 hours
Prerequisites	Quantum mechanics basic mechanics statistical, physics
Description	The course aims at providing the basic tools for describing driven dissipative systems in which the interaction with a reservoir cannot be neglected. Master equations, Langevin equations will be derived and discussed. Application to a set of quantum technology platforms will be studied

Fuzzy models and approximate reasoning in data analysis

Lecturer	**Ferdinando Di Martino** ferdinando.dimartino@unina.it
Credits (planned)	6
Planned hours	42 (the course is jointly proposed with the PhD program in Computational Intelligence)
Planned schedule	March - July 2024 Modules: - Fuzzy sets and extension principle. Characteristic functions. Type of fuzzy sets. Fuzzy numbers. Examples. - Fuzzy relations. Triangular norm operators. Projections and Cylindrifications. Examples. - Fuzzy relation equations. Fuzzy relation equation systems Examples in physics. - Direct and Inverse Fuzzy transform Examples. - Fuzzy clustering concepts Fuzzy partitional clustering. Fuzzy C-means and its variations. Examples. - Approximate reasoning concepts. Linguistic variables and fuzzy rules. Fuzzification and defuzzification models. Generating fuzzy rules from numerical and categorical data. The Wang & Mendel model. Examples. - Fuzzy systems. Inference process. Mamdani and Takagi-Sugeno models. Examples - Type-2 fuzzy sets. The e footprint of uncertainty. Interval Type-2 fuzzy sets and their implementation. IT2 Fuzzy Systems. Type-reduction process. Examples.
Prerequisites	Set theory, Boolean logic, statistical treatment of observational data
Description	The course will deal with fuzzy set theory, fuzzy transform, approximate reasoning, fuzzy systems and its applications in physics. In physics it is often necessary to deal with vague or imprecise information for the analysis of experimental data. One type of imprecision is that managed in the statistics of experimental data through statistical inference approaches and uncertainties estimation. These approaches, however, have a not negligible computational complexity and are unsuitable for managing sets of vague and imprecise information which, on the other hand, constitute the knowledge base of human reasoning processes. Fuzzy set theory allows us to manage qualitative and fuzzy information in a formal and rigorous way in order to create models for data analysis and data mining and approximate reasoning frameworks through the use of inferential rules that translate and model human reasoning. This course initially introduces fuzzy set theory and then explores fuzzy-based methods and models of data analysis, data mining and approximate reasoning. Finally, the type-2 fuzzy sets and their implementation in the construction of intelligent systems will be treated. During the course various examples of fuzzy-based methods and techniques of data analysis applied to fields of physics will be made.

Introduction to Quantum Information

Lecturer	**Rosario Fazio** rosario.fazio@unina.it
Credits (planned)	2
Planned hours	15

Planned schedule and location	beginning scheduled around February/March 2024
Prerequisites	Quantum Mechanics
Description	1. Elements of Quantum Mechanics Density matrix formalism, Bloch sphere for spin-1/2, reduced density matrix, Schmidt decomposition, purification 2. Quantum Measurement projective measurement, POVM 3. Open quantum systems CPT maps, Quantum Operations, Master Equation, Examples 4. Entanglement Bell and GHZ states, Measures of Entanglement 5. Quantum computation Quantum gates, Basics of Quantum algorithms. Quantum Error Correction 6. Entanglement in Many-Body systems 7. Entanglement and critical phenomena 8. Physical implementations of a quantum computer

Quantum Algorithms

Lecturers	**Giovanni Acampora** giovanni.acampora@unina.it **Autilia Vitiello** autilia.vitiello@unina.it
Credits (planned)	4-6
Planned hours	20hrs to 30hrs
Planned schedule and location	**after the Summer school** **Napoli Monte S. Angelo**
Prerequisites	Linear Algebra, Foundations of Computer Science
Description	Introduction (3-5 hours) Theoretical Computer Science (5-7 hours) The Leap from Classical to Quantum Computation (3-5 hours) Quantum Architectures (3-5 hours) Quantum Algorithms (6-8 hours) This module introduces the basic concepts of the design of quantum algorithms. Specifically, the module deals with the following topics: introduction to Hilbert spaces; difference among deterministic, probabilistic and quantum systems; a brief introduction to quantum architecture: from the qubit to quantum gates; introduction to quantum algorithms: Deutsch-Josza algorithms, Simon's periodicity algorithm, Grover's search algorithm, Shor's factoring algorithm; theoretical computer science and classes of problem complexity; an overview of quantum programming languages and libraries. Exam will be conducted by requiring students to carry out a project on the implementation of quantum algorithms.

Quantum Communication

Lecturer	**Alberto Porzio** alberto.porzio@unicas.it
Credits (planned)	4/6
Planned hours	20h to 24h

Planned schedule	**Second semester 2023**
Prerequisites	Quantum mechanics; Quantum Optics (basic)
Description	The program overviews: a) basic principles of quantum information (entanglement, Bell inequalities, no-cloning theorem, measurement theory in QM, coherence and de-coherence); b) the concepts of fidelity and state reconstruction (with experimental aspects); c) q-bit and Continuous Variable QI (with examples of physical implementations); d) simple quantum protocols (quantum cryptography and teleportation); e) intrinsic and technological limits of QI.

Quantum Computation

Lecturer	**Stefano Mancini** stefano.mancini@unicam.it
Credits (planned)	6
Planned hours	42
Planned schedule and location	Camerino First semester Lectures transmitted via streaming and recorded on WEBEX
Prerequisites	Quantum mechanics formalism
Description	Quantum circuits Universal sets of logical quantum gates Random number generation Deutsch-Josza and Simon algorithms Quantum Fourier transform Factorization and Shor algorithm Hidden subgroup problem Searching and Grover algorithm Black box Boolean functions evaluation

Quantum Information

Lecturer	**Stefano Mancini** stefano.mancini@unicam.it
Credits (planned)	6
Planned hours	42
Planned schedule and location	Camerino First semester Lectures transmitted via streaming and recorded on WEBEX
Prerequisites	Quantum mechanics formalism; basics of probability theory
Description	Information and entropy: classical view Mixed quantum states Information and entropy: quantum view Channel maps Data compression Information transmission Error correcting codes Channel capacities Quantum cryptography

Quantum Paradoxes

Lecturer	**Augusto Smerzi** augusto.smerzi@ino.it
Credits (planned)	3
Planned hours	12
Planned schedule and location	Firenze, First semester – September-December 2024 Lectures transmitted via streaming and notes
Prerequisites	Quantum Mechanics
Description	• The quantum theory of weak and strong measurements – 2 hrs • Contextuality and the Kocken-Specker theorem – 1 hr • The Einstein-Podolski-Rosen paradox - 1 hr • Non-locality, realism and free will - 2 hrs • No-signaling, no-cloning – 1 hr • The GHZ paradox and Hardy's impossibility – 1 hr • The Bohm, Everett and Copenhagen interpretations – 1 hr • The statistical interpretation and the PBR theorem - 1 hr • The several friends of Wigner – 2 hrs *Lecture notes are available on request.*

Quantum Sensing and Metrology

Lecturer	**Luca Pezzè** luca.pezze@ino.cnr.it **Nicole Fabbri** nicole.fabbri@ino.cnr.it
Credits (planned)	3
Planned hours	18
Planned schedule and location	Firenze First semester – September-December 2024 Lectures transmitted via streaming and recorded on WEBEX
Prerequisites	Quantum mechanics formalism; basics of probability theory
Description	<u>Theory of quantum sensing and metrology</u> (12 hrs) • Parameter estimation (Cramer-Rao, Maximum Likelihood, Bayesian estimation) - 3 hrs • Fundamental bounds on phase sensitivity (Heisenberg limit, quantum Fisher information, Bayesian bounds) - 1.5 hrs • Statistical speeds and entanglement - 3 hrs • Useful entanglement in quantum metrology - 2 hrs • Multipartite entanglement – 1 hr • Metrological entanglement in experiments - 1.5 hrs <u>Quantum sensing experiments</u> (6 hrs) • Overview on quantum sensing platforms and operational definitions - 1 hrs • A nanoscale quantum sensor: the diamond NV center - 2 hrs - General introduction on colour centers in diamond - Diamond Material Engineering - NV sensing applications • Sensing by quantum coherence - 3 hrs - Ramsey protocol - Decoherence and the fundamental limit to sensitivity - Dynamical decoupling - Noise spectroscopy - Quantum optimal control for quantum sensing Lecture notes are available on request.

Quantum Superconducting Technologies: Principles, Engineering & Interfaces -- part 1

Lecturer	**Francesco Tafuri** francesco.tafuri@unina.it **Davide Massarotti** davide.massarotti@unina.it **Domenico Montemurro** domenico.montemurro@unina.it
Credits (planned)	3
Planned hours	24
Planned schedule	May/June 2024
Prerequisites	Elementary Quantum Mechanics and Solid State Physics
Description	Quantum hardware is what transforms the novel concepts of quantum computation and communication into reality. The key challenge is to control, couple, transmit and read out the fragile stage of quantum systems with great precision, and in a technologically viable way. This course aims at illustrating some aspects of this key challenge in realizing quantum hardware and technology, focusing on solid state and superconducting hardware. Some key notions on advanced solid state physics will be introduced as a bridge to standard courses. Description by keywords: • Introduction to Mesoscopic with Superconductivity, Order and Excitations in Condensed Matter • Macroscopic Quantum Phenomena, broken symmetry variables • Superconducting Devices, the Josephson effect and dissipationless conversion, Andreev reflection, introduction to dissipation, decoherence and noise, macroscopic quantum tunneling and its foundations on dynamics, correlation and response, diffusion and Langevin theory • Topological defects, vortex pairs and notes on vortex matter and dynamics, topological quantum numbers in nonrelativistic physics • Nanoscale Processing for Advanced Devices • Superconducting and hybrid qubits, principles of superconducting design, phase-, charge- and flux qubits, from transmon to fluxonium (from macroscopic quantum tunneling to Rabi oscillations and more) • Josephson bifurcation amplifier, SQUIDs and qubit read-out • Sensors at the quantum limit, quantum memories • Superconducting single photon detectors, principles of operation, interface with quantum optics experiments

Solid State qubits

Lecturers	**Procolo Lucignano** procolo.lucignano@unina.it **Gabriele Campagnano** gabriele.campagnano@spin.cnr.it
Credits (planned)	5
Planned hours	30h
Planned schedule and location	Second semester 2024 Napoli Monte S. Angelo *(this course is offered in the frame of the undergraduate MSc course in Quantum Science and Engineering)*
Prerequisites	Solid State physics, Quantum Mechanics
Description	Solid State Universal quantum gates (10-14h) - Spins in double quantum dots - Spin Defects in Solids

	- Superconducting qubits Adiabatic quantum computation (4-6 h) - Quantum annealing with superconducting qubits - Dissipative Landau-Zener - Experimental implementation Topological quantum computation (6-10 h) - One dimensional superconducting systems and Majorana Fermions - Majorana Braiding and fusion

Static and Dynamics of Quantum Phase transitions in closed an open systems

Lecturer	**Vittorio Cataudella** vittorio.cataudella@unina.it **Antonio De Candia** antonio.decandia@unina.it **Giulio De Filippis** giulio.defilippis@unina.it **Carmine Antonio Perroni** carmineantonio.perroni@unina.it
Credits (planned)	3
Planned hours	24
Planned schedule	October / November 2024
Prerequisites	
Description	Aim of the course is to characterize the transitions between different quantum phases both from theoretical and experimental point of view. First we will review thermal continuous phase transitions, like the Berezinskii–Kosterlitz–Thouless one, then we will concentrate on quantum phase transitions, like those in quantum XY and spin-boson models, at zero and finite but small temperature. Finally, we will focus on a different type of quantum phase transitions that occur on intermediate time scales, known as dynamical quantum phase transitions. These equilibrium and non-equilibrium transitions will be analyzed not only in the case of closed but also open systems, where the role of the environment can be active into the modification of the order, the nature and the occurrence of these phenomena. The presence of these transitions typically impacts the behavior of quantum materials, such two-dimensional ones, with varying the applied gate voltage and magnetic field.