Cluster of Excellence
Matter and Light for Quantum Computing (ML4Q)

Cluster of Excellence ML4Q • Pohligstr. 3 • D-50969 Cologne • Germany

MATTER AND LIGHT FOR QUANTUM COMPUTING

https://ml4q.d

ML4Q Platforms for Quantum Technologies course 2025

24 – 28 March 2024

Overview

Date	Topic	Lecturer	Location*
Mon 24.03.	Introduction to Quantum Information and Algorithms	Markus Müller	FZJ
Tue 25.03.	Quantum algorithms and Entanglement theory & Out of equilibrium open quantum systems	Andrea Nava	Düsseldorf
Wed 26.03.	Quantum optics for quantum computing with ultracold atoms and semiconductors	Andrea Bergschneider & Nina Stiesdal	Bonn
Thu 27.03.	Superconducting and semiconductor qubits	Rami Barends, Seyed Akbar Jafari, Vincent Mourik	Aachen
Fri 28.03.	Basics of topological quantum computation & Basics of quantum circuits	Erwann Bocquillon & Xhek Turkeshi	Cologne

* Detailed information will be provided separately to the registered participants.

The detailed schedule can be will be found on page 3. The classes will usually start around 10:00 and finish around 17:00 and there will be a lunch break.

The presentations on papers for the graded assessment are planned for the week of 7-11 April. Exact dates will be provided soon.

Course content

Day 1, 24.03.2025 (FZJ)

On this day students will get a brief hands-on introduction to quantum information and quantum circuits. We will discuss ingredients of quantum algorithms, and in particular Grover's quantum search algorithm. Furthermore, we will introduce basic theoretical concepts and recent experimental breakthroughs in quantum error correction, which will be crucial to protect

future scalable quantum computers against noise. In addition, a joint lunch, lab tours and discussions with other quantum technology research groups at Forschungszentrum Jülich are planned.

Day 2, 25.03.2025 (Düsseldorf)

During the second day we will join (for two lectures) the 'Spring R(h)ein Quantum School', where students will be introduced to the concept of quantum algorithms and entanglement theory. In addition, the concepts of topological phase transitions and Mpemba effect in open quantum systems will be discussed.

Day 3, 26.03.2025 (Bonn)

During this day, we explore ways to interface photons with quantized matter for the realization of tailored qubits. We will give a basic introduction to light–matter coupling on the example of the two-level system. We will use this formalism to treat specific realistic quantum systems and discuss how to reach sizable coupling between single photons and those systems, for instance by using cavities or collective effects. After that, we will give an overview on ML4Q projects done in Bonn followed by lab tours and a Meet & Greet poster session with the Bonn PhD students.

Day 4, 27.03.2025 (Aachen)

In the morning session we will have two lectures on superconducting qubits and spin qubits. The afternoon session will consist in two lab tours to showcase how the above two types of qubits are produced in the lab.

Day 5, 28.06. 2025 (Cologne)

The aim of this day is to introduce students to two notions of quantum computation. First, we will discuss quantum circuits, sampling and understand how one can accurately define and benchmark quantum advantage, with case studies on recent articles.

Second, we'll describe basics of topological quantum computation, and present experimental efforts aiming at realising it. In addition there will be a poster session and lab tours from ML4Q groups.

Schedule

Day 1

Monday 24.03.2025– Introduction to Quantum Information and Algorithms (FZ Jülich)	
10:15	Pick-up of visiting students from Hauptwache (Main Entrance)
10:30 – 10:40	Welcome Short Overview of Week and Day Programme
10:40 – 11:40	Morning Lecture: Introduction to Quantum Information, Computation and Algorithms covering: - High level motivation - Dirac notation and quantum circuit model - Complexity classes, Grover algorithm
11:40 – 11:50	Coffee Break
11:50 – 12:10	Tensor network methods and quantum control research (TBC)
12:10 – 12:30	Quantum algorithms research
12:30 – 14:00	Joint Lunch at Seecasino
14:00 – 14:20	Quantum computing research @Jülich Supercomputing (TBC)
14:30	Coffee Break
14:45 – 15:30	Afternoon Lecture Introduction to Quantum Information, Computation and Algorithms covering: - Basic Quantum Error correction with the 3-qubit repetition code and topological codes
15:50 – 16:20	HNF, Molecular-Beam-Epitaxy Lab (TBC)
16:30	Departure

Day 2

Tuesday 25.03.2025 – Quantum algorithms and Entanglement theory & Out of equilibrium open quantum systems (Düsseldorf, part of "Spring R(h)ein Quantum School")	
09:00 -10:30	Lecture: Quantum Algorithms (Mariami Gachechiladze, TU Darmstadt)
10:30 – 11:00	Coffee break
11:00 – 12:30	Lecture: Topology and out of equilibrium dynamics (Andrea Nava, HHU Düsseldorf, ML4Q)
12:30 – 14:00	Lunch break
14:00 – 15:30	Lecture: Entanglement Theory (Anna Sanpera, Universitat Autònoma Barcelona)
15:30 – 16:00	Coffee break
16:00 – 17:00	Lecture: Mpemba effect in open quantum systems (Andrea Nava, HHU Düsseldorf, ML4Q)

Day 3

Wednesday 26.03.2025 – Quantum optics for quantum computing with ultracold atoms and semiconductors (Bonn)	
9:30–10:00	Arrival, Wegelerstr. 8
10:00–11:30	Lecture: Light–matter interaction: Fundamentals
11:45–13:00	Lecture: Enhancing light–matter interaction for quantum technologies
13:00 – 14:00	Lunch break
14:00–14:30	Pre–labtour presentation of Bonn ML4Q activities
14:45–16:00	Lab tour (2x 25 minutes)
16:00–17:30	Meet&Greet poster session (with Brezels and Bananas)

Day 4

Thursday 27.03.2025 – Superconducting and semiconductor qubits (Aachen)	
10:00 – 11:00	Quantum computing with superconducting qubits (Rami Barends)
11:30 – 12:30	Quantum computing with spin qubits (Vincent Mourik)
12:30 – 14:00	Lunch break
14:00 –15:00	Lab tour to Hendrik Bluhm's lab
15:00 – 15:30	Transfer between the labs
15:30 – 16:30	Lab tour to Rami Barends' lab

Day 5

Friday 28.03.2025 – Basics of topology quantum computation & Basics of quantum circuits (Cologne)	
10:00 – 12:00	Lecture: Sampling quantum circuits & Benchmarking quantum advantage — Case study of the recent Google papers
12:00 – 13:30	Lunch break
13:30 – 15:30	Lecture: Introduction to topological quantum computation and topological qubits
15:30 – 17:00	Lab tours & poster session