A cross-faculty master program! of the three schools Basic Sciences, Engineering, and Computer and Communication Sciences

Section de Science et Ingénierie Quantiques SSIQ

**Director**: Prof. Nicolas Macris (IC)

**Co-directors**: Prof. Edoardo Charbon (STI) and Prof. Giuseppe Carleo (SB)

SSIQ also offers a minor

go.epfl.ch/master-quantum-science

Contact: nicolas.macris@epfl.ch
This program aims to train a new generation of “quantum proficient” engineers who will be part of the “second quantum revolution”.

Engineers that understand and use the quantum paradigm shifts in:

• Information processing (communication, storage, encryption)
• Computation and simulation
• Metrology and sensing

Diploma and title awarded:

MSc Science et ingénierie quantiques - MSc Quantum science and engineering

Ingénieur en science quantique (ing. quant. dipl. EPF)

• Consecutive master for physicists EPFL
• Others must apply until 15 April
  (minimal admission condition GPA 4.5)
The second quantum revolution: what is it about?

Laws of quantum physics known since the 1930’s have led to our modern understanding of the atomic nature of matter and all solid state phenomena and photonics and much more...

Major role in modern technology. For example transistors and integrated circuits, lasers and tunnel effect microscopes.

This has completely reshaped our world. But with these devices information is processed classically.

In the 1970’s – 1990’s it was realized that one could use quantum laws to process information in radically new ways (Benioff, Landauer, Wiesner, Feynman, Deutsch, Bennett,...)

The concept of quantum bit – the QUBIT – is the new unit of information here. It behaves radically differently than the classical bit and offers new computational resources!

Currently massive investments are done in QSE worldwide.
Primitive principles of qubits:
• superposition
• entanglement
• measurement
• unitary evolution

Paradigm shifts and applications in:
• Efficient algorithms e.g., factoring,…
• Complexity theory
• Quantum machine learning
• Optimization algorithms
• Quantum chemistry
• Quantum key distribution
• Random number generators
• Error correction
• Distributed information in networks
• Metrology, Sensing
Quantum effort worldwide

- **Quantum Canada**
  - CA$1.36b = $1.1b

- **United Kingdom**
  - £1b = $1.3b

- **Netherlands**
  - 765m € = $904m

- **Germany**
  - 2.6b € = $3.1b

- **China**
  - $10b

- **Russia**
  - Р50b = $663m

- **South Korea**
  - W44.5b = $37m

- **Japan**
  - ¥50b = $470m

- **Taiwan**
  - NT$8b = $282m

- **Australia**
  - AU$130m = $98.5m

- **New Zealand**
  - $36.75m

- **India**
  - ₹73b = $1bn

- **Singapore**
  - S$150m = $109m

- **US National Quantum Initiative**
  - $1.2b

- **European Quantum Flagship**
  - 1b € = $1.1b

Global effort 2021
$24.4b (estimate)

©2021 QURECA Ltd – Confidential and Proprietary

Source: QURECA quantum resources & careers
"There are so few Quantum Software Engineers that, for us today, anyone who can code and has read the first seven chapters of the Nielsen and Chuang book qualifies”

Matthias Troyer, Microsoft (~3 years ago)
Profile of a quantum engineer?

- Must include skills and knowledge in Computer Science, Engineering, and Physics / Mathematics / Chemistry
- Few Master’s programs worldwide offer such a multidisciplinary educational profile
- At EPFL, in IC, STI, and SB, there is today a vast portfolio of research and teachings relevant to the QSE domain
- EPFL new center for Quantum Science and Eng. fosters research and collab. among teams
- EPFL Quantum Computing Association
  
  https://www.epfl.ch/campus/associations/list/qc/
Basic structure of the master

- Master’s thesis: 30 ECTS
- Project in SHS: 6 ECTS
- Internship: 12 ECTS
- Semester projects: 16 ECTS
- Bloc of core courses: 16 ECTS
- Group of Option courses: 40 ECTS
Course requirements

- **Bloc of core courses** 16 ECTS + average GPA $\geq 4$.

- **Group of option courses** 40 ECTS. Pass each class separately ($\geq 4$). Choose one **specialization**:
  
  - A: Quantum information and computation
  - B: Quantum hardware and engineering

  At least 30 credits in the specialization. Possible to choose 10 credits in other specialization. (conseillers d’études will help students compose the study plan matching their ambitions)

- **Two semester projects** 8 ECTS each. In SB, STI, IC labs.

- **SHS Courses & projets** 6 + 6 = 12 ECTS (colleges of humanities and management).

- **Internship** of min 8 weeks, 12 ECTS.

- **Master thesis** 30 ECTS. In EPFL research lab 17 weeks, in industry 25 weeks.
<table>
<thead>
<tr>
<th>Core courses</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantum Physics I</td>
<td>5</td>
</tr>
<tr>
<td>Introduction to Quantum Science, Technology and Applications</td>
<td>5</td>
</tr>
<tr>
<td>Quantum Information Processing</td>
<td>4</td>
</tr>
<tr>
<td>Quantum Computation</td>
<td>4</td>
</tr>
<tr>
<td>Solid State Systems for Quantum Information</td>
<td>4</td>
</tr>
<tr>
<td>Physics of semiconductors devices</td>
<td>4</td>
</tr>
<tr>
<td>Quantum and Nanocomputing</td>
<td>6</td>
</tr>
</tbody>
</table>

Carefully choose basic **core courses** depending on your background.

- Mandatory for non-physicist
- Mandatory for all students
- Two introductory classes quant info and computation
- Two introductory classes for hardware related courses
- Intro to the “quantum stack”
Quantum Physics I (3rd year bachelor in PHYS - instructor G. Carléo) 5 ECTS

Anybody that did not have a real quantum physics class must follow this class. This is BASIC.

Introduction to quantum science technology and applications (with instructors from PHYS, STI, IC) 5 ECTS

Will give a broad vision of the QSE domain. 3 modules with introductions on

- Information processing and computer science aspects (IC)
- Physics and algorithms, qubit platforms (SB)
- Hardware, metrology (STI)

**Recommended prerequisites for non-physicists in next editions of the master:**
- Quantum Physics I (PHYS-313) or other quantum physics class on campus (planned in STI)
- One of Quantum Information Processing (COM-309) or Quantum computation (CS-308)
<table>
<thead>
<tr>
<th>Specialization A: Quantum Information and computation</th>
<th>Specialization B: Quantum hardware and engineering</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information Theory and Coding</td>
<td>Foundations of Data Science</td>
</tr>
<tr>
<td>Foundations of Data Science</td>
<td>Machine Learning</td>
</tr>
<tr>
<td>Computational Complexity</td>
<td>Advanced Machine Learning</td>
</tr>
<tr>
<td>Advanced Algorithms</td>
<td>Mathematics of Data: From Theory to Computation</td>
</tr>
<tr>
<td>Cryptography and security</td>
<td>Deep Learning</td>
</tr>
<tr>
<td>Advanced cryptography</td>
<td>Advanced logic synthesis and quantum computing</td>
</tr>
<tr>
<td>Machine Learning</td>
<td>Quantum Information and Quantum Computing</td>
</tr>
<tr>
<td>Optimization for Machine Learning</td>
<td>Quantum Transport in Mesoscopic Systems</td>
</tr>
<tr>
<td>Artificial Neural Networks</td>
<td>Semiconductor Physics and Light-Matter Interaction</td>
</tr>
<tr>
<td>Advanced logic synthesis and quantum computing</td>
<td>Nonlinear Optics for Quantum Technologies</td>
</tr>
<tr>
<td>Distributed Algorithms</td>
<td>Quantum Electrodynamics and Quantum Optics</td>
</tr>
<tr>
<td>Low Rank Approximation Techniques</td>
<td>Quantum Optics and Quantum Information</td>
</tr>
<tr>
<td>Machine Learning forPhysicists</td>
<td>Statistical Physics IV</td>
</tr>
<tr>
<td>Quantum Information and Quantum Computing</td>
<td>Advanced Topics in Quantum Science and Technology</td>
</tr>
<tr>
<td>Computational Quantum Physics</td>
<td>Statistical mechanics</td>
</tr>
<tr>
<td>Quantum Transport in Mesoscopic Systems</td>
<td>Semiconductor Devices I</td>
</tr>
<tr>
<td>Semiconductor Physics and Light-Matter Interaction</td>
<td>Semiconductor Devices II</td>
</tr>
<tr>
<td>Nonlinear Optics for Quantum Technologies</td>
<td>Nanoelectronics</td>
</tr>
<tr>
<td>Quantum Electrodynamics and Quantum Optics</td>
<td>Lab in Nanoelectronics</td>
</tr>
<tr>
<td>Quantum Optics and Quantum Information</td>
<td>Photonic systems and technology</td>
</tr>
<tr>
<td>Solid State Physics III</td>
<td>Fundamentals of Solid-State Materials</td>
</tr>
<tr>
<td>Statistical Physics IV</td>
<td>Superconducting electronics: A materials perspective</td>
</tr>
<tr>
<td>Advanced Topics in Quantum Science and Technology</td>
<td>Introduction to crystal growth by epitaxy</td>
</tr>
<tr>
<td>Statistical mechanics</td>
<td>Properties of semiconductors and related nanostructures</td>
</tr>
<tr>
<td>Fundamentals of Solid-State Materials</td>
<td>Atomistic and Quantum Simulations of Materials</td>
</tr>
<tr>
<td>Molecular Dynamics and Monte Carlo Simulations</td>
<td>Nanotechnology</td>
</tr>
<tr>
<td>Computational Methods in Molecular Quantum Mechanics</td>
<td>Metrology</td>
</tr>
<tr>
<td>Introduction to Electronic Structure Methods</td>
<td>Molecular Dynamics and Monte Carlo Simulations</td>
</tr>
<tr>
<td>Molecular Quantum Dynamics</td>
<td>Computational Methods in Molecular Quantum Mechanics</td>
</tr>
</tbody>
</table>

Options
40 ECTS

Strong classical IT component is also needed in industry

The two specializations overlap
Examples of menu for a specialization on quantum information and computing:

**Bloc courses - example 1** - 16 ECTS and average GPA at least 4
- *Quantum Physics I (PHYS-313)*, Giuseppe Carleo, Fall, 5 ECTS
- **To be created 2022.** *Introduction to Quantum Science, Technology and Applications*, instructors from various schools, Fall, 5 ECTS
- *Quantum Information Processing (COM-309)*, Nicolas Macris, Fall, 4 ECTS
- *Quantum Computation (CS-308)*, Nicolas Macris, Spring, 4 ECTS

**Bloc courses - example 2** - 16 ECTS average GPA at least 4
- **To be created 2022.** *Introduction to Quantum Science, Technology and Applications*, instructors from various schools, Fall, 4 ECTS
- *Quantum Computation (CS-308)*, Nicolas Macris, Spring, 4 ECTS
- *Solid State Systems for Quantum Information (PHYS-464)*, Pasquale Scarlino, Spring, 4 ECTS
- *Physics of semiconductors devices (MICRO-312)*, Pierre-André Besse, Fall, 4 ECTS
Group option courses 40 ECTS

- *Information Theory and Coding* (COM-404), Emre Telatar, Fall, 8 ECTS
- *Cryptography and security* (COM-401), Serge Vaudenay, Fall, 8 ECTS
- *Machine Learning* (CS-433), Martin Jaggi, Nicolas Flammarion, Fall, 8 ECTS
- *Quantum Information and Quantum Computing, (PHYS-641)*, Vincenzo Savona, Spring, 4 ECTS
- *Computational Quantum Physics* (PHYS-463), Giuseppe Carleo, Spring, 4 ECTS
- *Computational Methods in Molecular Quantum Mechanics (CH-452)*, Sara Bonella, Fall, 4 ECTS
- *Statistical physics IV* (MSE-436), Tobias Kippenberg, Spring, 6 ECTS

Or for example replace COM 401 by:

- *Computational Complexity* (CS-524), Mikka Göös, Fall, 4 ECTS
- Statistical mechanics (MSE 421), Michelle Ceriotti, Spring, 4 ECTS
Example study plan for a specialisation on quantum hardware engineering:

Bloc courses - example 1 – 16 ECTS and average GPA > 4

- *Quantum Physics I (PHYS-313)*, Giuseppe Carleo, Fall, 5 ECTS

- **To be created 2022.** *Introduction to Quantum Science, Technology and Applications*, instructors from various schools Fall, 5 ECTS

- *Physics of semiconductors devices* (MICRO-312), Pierre-André Besse, Fall, 4 ECTS

- *Quantum Computation* (CS-308), Nicolas Macris, Spring, 4 ECTS

Bloc courses - example 2 – 16 ECTS and average GPA > 4

- *Quantum Physics I (PHYS-313)*, Giuseppe Carleo, Fall, 5 ECTS

- **To be created 2022.** *Introduction to Quantum Science, Technology and Applications*, instructors from various schools, Fall, 5 ECTS

- *Quantum and Nanocomputing* (MICRO-435), Edoardo Charbon, Fall, 6 ECTS

- *Solid State Systems for Quantum Information* (PHYS-464), Pasquale Scarlino, Spring, 4 ECTS
Group option courses 40 ECTS

- *Deep Learning*, Francois Fleuret (EE-559), Spring, 4 ECTS
- *Semiconductor Devices I* (EE-557), Elison Matioli, Fall, 4 ECTS
- *Semiconductor Devices II* (EE-567), Adrian Ionescu, Andras Kis, Spring, 4 ECTS
- *Photonic systems and technology* (EE-440), Camille Brès, Spring 4 ECTS
- *Metrology* (MICRO-428), Claudio Bruschini, Edoardo Charbon, Georg Fantner, Spring, 3 ECTS
- *Metrology practicals* (MICRO-429), Claudio Bruschini, Edoardo Charbon, Georg Fantner, Spring, 2 ECTS
- *Fundamentals of Solid-State Materials* (MSE-423), Nicola Marzari, Fall, 4 ECTS
- *Superconducting electronics: A materials perspective* (MSE-438), Philip Moll, Johannes Walter, Spring, 3 ECTS
- *Quantum Transport in Mesoscopic Systems* (PHYS-462), Mitali Banerjee, Fall, 4 ECTS
- *Nonlinear Optics for Quantum Technologies* (PHYS-470), Christophe Galland, Fall, 4 ECTS
- *Semiconductor Physics and Light-Matter Interaction* (PHYS-433), Raphaël Butté, Fall, 4 ECTS
Companies in QSE domain - internships and master thesis in industry
Job prospects, examples:

- **Academic research** → PhD in QSE. Many exciting possibilities in Switzerland and worldwide!

- **Research centers** → CSEM, PSI, IBMQ, CERN (Switzerland), ICFO (Spain), CQT (Singapore), VCQ, ESQ, IQOQI (Austria), Quantum Alliance (Germany), .................................................................

- **Startups and medium sized companies** → MIRAEX (photonic sensing) QuantumMachines (qubit control systems) QuiX (photonic computing) Qnami (sensing) IDQ (crypto, communications)............................

- **Big tech companies** IBM, Microsoft, Google, Intel, NEC, Righetti, Atos, .......

*Industry needs engineers at all levels of the classical to quantum stack from “quantum aware” to “quantum proficient”. The program prepares you well also in the classical IT sector.*
Important deadlines and informations

• Application deadline 15 April on EPFL master’s page  
  https://www.epfl.ch/education/master/programs/quantum-science/
  For non-physicists necessary requirement for admission is GPA of 4.5

• For Physics EPFL students the master is consecutive

• Anybody applying for a bourse d’excellence must submit his application
  by 15 April deadline (same process for internal, external, physics EPFL, other sections etc)

• We offer a MINOR. This can be a good deal if you hesitate changing section.

• For any info contact nicolas.macris@epfl.ch (prog. dir IC)  
  or edoardo.charbon@epfl.ch (STI) giuseppe.carleo@epfl.ch (SB)

• **List and syllabus of courses of master and minor** (subject to change).
  New section website: to be created...
THANK YOU FOR YOUR ATTENTION

WE HOPE TO SEE MANY OF YOU NEXT SEPTEMBER!

https://www.epfl.ch/education/master/programs/quantum-science/

Edoardo Charbon (STI)  Giuseppe Carléo (SB)  Nicolas Macris (IC)