ML4Q

MATTER AND LIGHT FOR QUANTUM COMPUTING

ML4Q CLUSTER OF EXCELLENCE

AT A GLANCE

UNIVERSITY OF COLOGNE

RWTH AACHEN UNIVERSITY

UNIVERSITÄT BONN

JÜLICH Forschungszentrum

ML4Q
AT A GLANCE

ML4Q stands for Matter and Light for Quantum Computing. The Cluster of Excellence set off in 2019 for a long collaborative journey in order to develop new computing and networking architectures using new findings in the fundamental research in solid-state physics, quantum optics, and quantum information science.

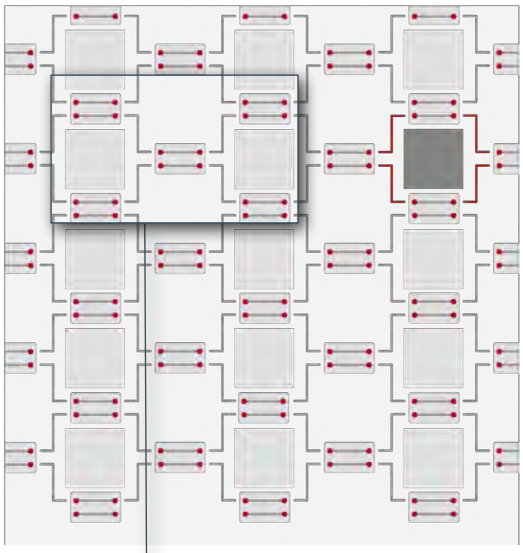
THE CLUSTER'S MISSION

Using the principles of quantum mechanics, it is the long-term goal of ML4Q to develop new computing and networking architectures with a power beyond anything classically imaginable. Quantum computers could be powerful tools in key areas such as materials design, pharmaceutics, or artificial intelligence. Quantum communication could be made effectively secure. ML4Q builds on the complementary expertise in the three key research fields of solid-state physics, quantum optics, and quantum information science to develop the best hardware platform for quantum information technology, and provide comprehensive blueprints for a functional quantum information network.

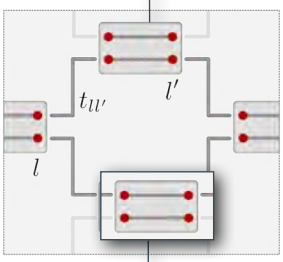
The long-term goal of the cluster is to realize network and processing architectures protected by error correction protocols and eventually connected to a quantum version of the internet. This goal defines a hierarchy of challenges, both in fundamental science and in technology, which must be overcome at early and intermediate stages.

qubits	processing	connectivity
for information storage	quantum information	through quantum links

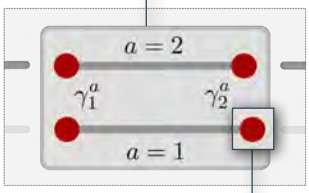
THE VISION



The processor units of a network comprise arrays of qubits whose implementation requires scalable designs. We envision to realize these units by the end of the second funding period.



The ML4Q core projects are dedicated to the development of both spin qubit platforms as well as topologically protected Majorana qubits as an alternative platform with the prospect of superior performance in the long term.



As Majorana-based quantum information hardware is still in its infancy, major intermediate challenges need to be overcome. These include the actual engineering of Majorana qubits.

On an even more fundamental level, first significant achievements in the realization and optimization of quantum materials harboring Majorana states are subject of the running research in Focus Area 1 and 2.

THE SCIENTIFIC APPROACH

The scientific structure of ML4Q spans four Focus Areas, each addressing a specific set of problems relevant to the cluster's mission. All Focus Areas include theoretical as well as experimental components and transcend the boundaries of disciplines and institutions.

Focus Area 1 aims to identify and explore novel topological hardware platforms for quantum information processing, including hybrid structures of topological insulators and superconductors as well as the ways to realize parafermions.

Focus Area 2 aims to realize Majorana qubits as a promising alternative to superconducting qubits or spin qubits. In parallel, protocols for readout, manipulation, and error correction are designed.

Focus Area 3 designs novel schemes of quantum control, error correction and mitigation. It investigates the operation of quantum devices under realistic noisy environmental conditions and explores topological and computational quantum matter subject to external driving.

Focus Area 4 focuses on the linkage of quantum processing units. Specifically, it takes steps towards realizing integrated atomic/optical and solid-state platforms and implementing quantum links between heterogeneous qubit setups.

Following the midterm review in June 2022, the scientific program of ML4Q was restructured to span three Focus Areas, each addressing a specific set of problems relevant to the cluster's mission (**A**: Majorana devices and topological matter | **B**: NISQ and error-aware quantum computing | **C**: Quantum networks and interconnects). As part of the new structure, projects funded from 2023 onwards include research on NISQ computing and novel 2D materials.

OPPORTUNITIES FOR YOUNG SCIENTISTS

Attracting and retaining the best young talents in the field by offering competitive career opportunities is a top priority for ML4Q. Current offers include:

- Undergraduate grants
- Undergraduate research internship
- Independence grants for postdoctoral researchers
- New tenure-track professorships
- ML4Q Research School with cluster-specific courses, e.g. "Platforms for Quantum Technologies" for Master students
- Master program for Quantum Technology in Aachen as well as specialized lectures on quantum technologies in Bonn and Cologne

PARTICIPATING INSTITUTIONS

ML4Q is a cooperation by the University of Cologne, University of Bonn, RWTH Aachen University as well as the Forschungszentrum Jülich. Partner institutions are the Heinrich Heine University Düsseldorf, the Fraunhofer Institute for Laser Technology ILT and the Fraunhofer Institute for High Frequency Physics and Radar Techniques FHR.

FUNDING

ML4Q is funded since January 2019 within the Excellence Strategy of the German federal and state governments. The first funding period ends in 2025.

ML4Q IN NUMBERS

267
MEMBERS AND ASSOCIATES

52
PROFESSORS

89
INTERNATIONAL SCIENTISTS

116
PHD STUDENTS

50
FEMALE SCIENTISTS

49
ADMINISTRATIVE & TECHNICAL STAFF

4
NEW HIRED ML4Q PROFESSORS

122
PUBLICATIONS* IN 2022

48
POSTDOCS

8
OPEN CALL PROJECTS AND INDEPENDENCE GRANTS

32
PUBLICATIONS* IN 2022
WITH TWO OR MORE ML4Q GROUPS INVOLVED
(10 CROSS-SITE PUBLICATIONS)

*including preprints

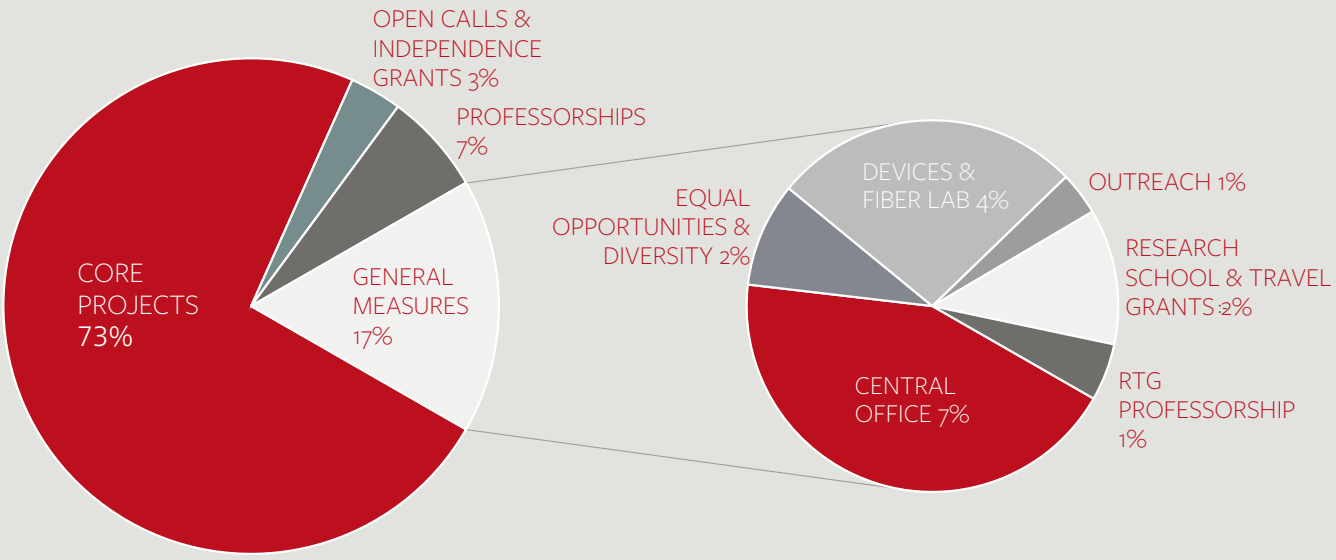
MIRA SHARMA

Through my research journey, I have come to discover that dreams are realities present in another plane, just waiting to be realized. Today, I am thankful for the opportunity to transform one of my cherished dreams into reality through my PhD studies here in Aachen.

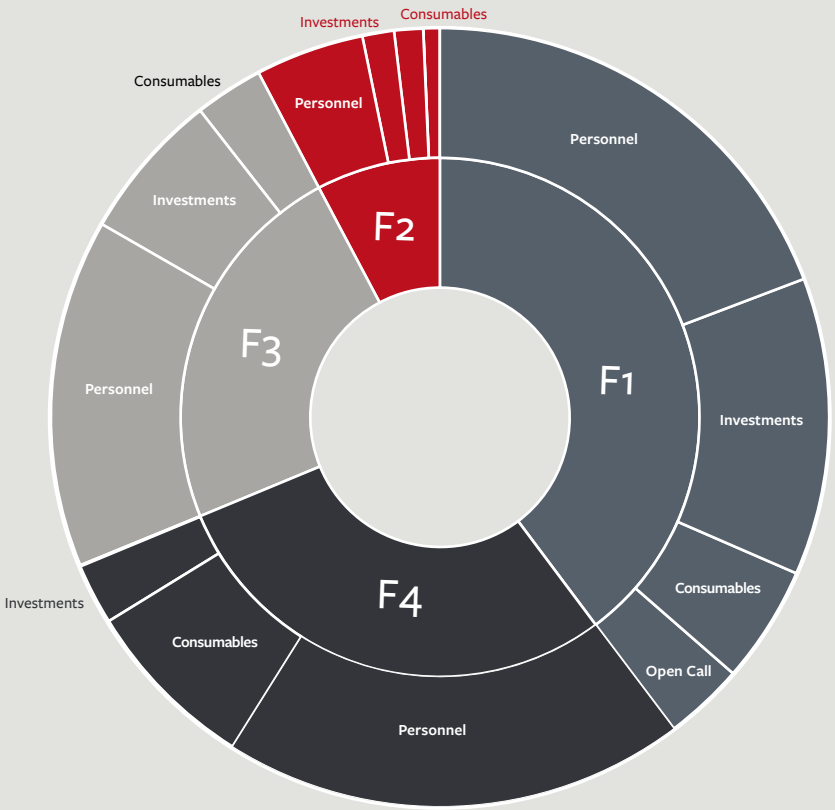
Mira Sharma completed her Master's degree in Physics from Aix-Marseille University in France and has embarked on her PhD journey in 2021.
She is currently a member of David DiVincenzo's group in Aachen, where her research primarily focuses on the theoretical aspects of Silicon-Germanium qubit technologies.

ML4Q **IN NUMBERS**

CORE PROJECTS & CENTRAL MEASURES



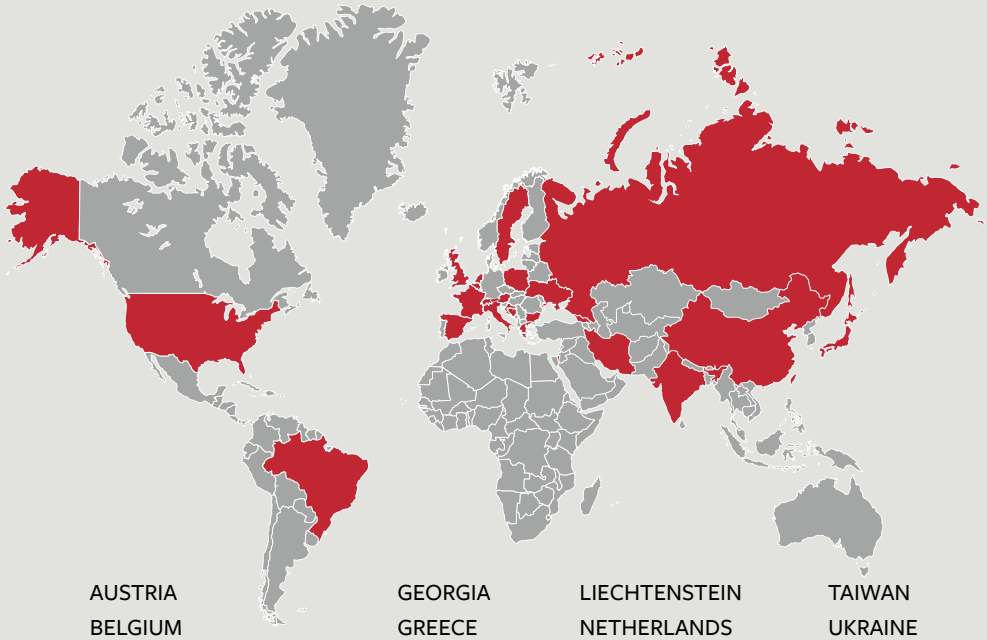
In 2022, almost three quarters of the expenses were dedicated to personnel, instrumentation and consumables in the core projects. Several Open Call projects had their last funding year in 2022. With 3 ML4Q faculty hirings starting in 2021/2022, 7% of the annual budget was dedicated to professorships. Compared to the previous years, expenses for supporting measures (research school, equal opportunities, workshops and outreach) as well as the ML4Q Fiber Lab, ML4Q Devices and the central office increased to make up one sixth of the annual budget.



All Focus Areas include theoretical as well as experimental components bringing different needs for personnel, consumables and instrumentation. Here is an overview of the allocation of core project funds in 2022 broken down by Focus Area and type of fund. The start of new ML4Q professors in 2022 was supported by an increase in investments.

INTERNATIONALIZATION

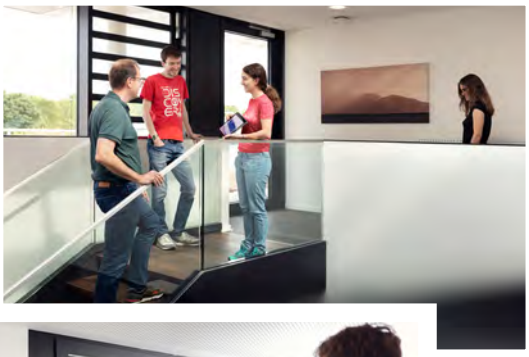
All academic groups continued to grow in 2022, with a relatively high increase in postdoctoral fellows. 33% of ML4Q members and associated members are international scientists coming from 25 countries (see map below). As in previous years, postdoctoral scientists still show the highest level of internationalization (58%) while the internationalization in other academic groups is roughly half as high.

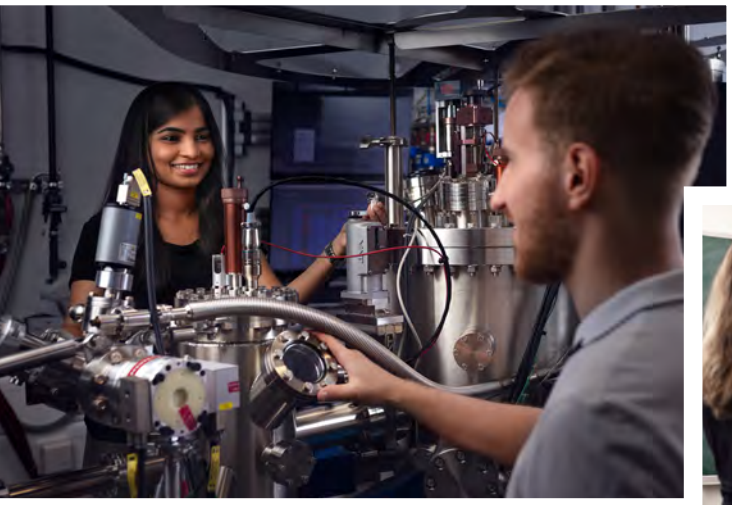


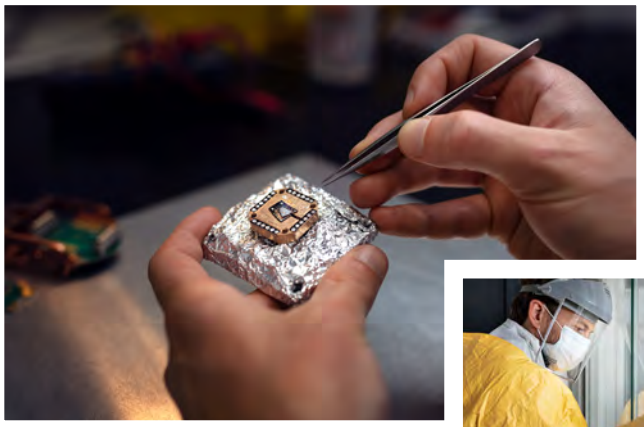
AUSTRIA
BELGIUM
BOSNIA & HERZEGOVINA
BRAZIL
BULGARIA
CHINA
FRANCE
GEORGIA
GREECE
INDIA
IRAN
ISRAEL
ITALY
JAPAN
LIECHTENSTEIN
NETHERLANDS
POLAND
RUSSIA
SPAIN
SWEDEN
SWITZERLAND
TAIWAN
UKRAINE
USA
UNITED KINGDOM

4 SITES – 4 YEARS

A photo gallery from previous reports

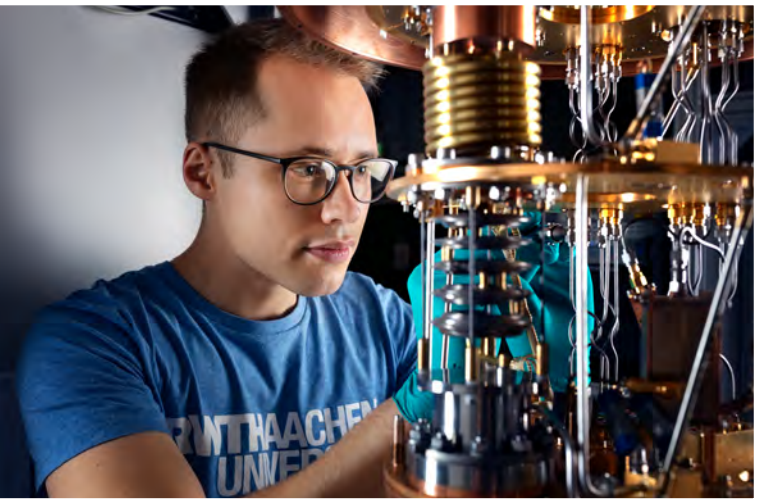


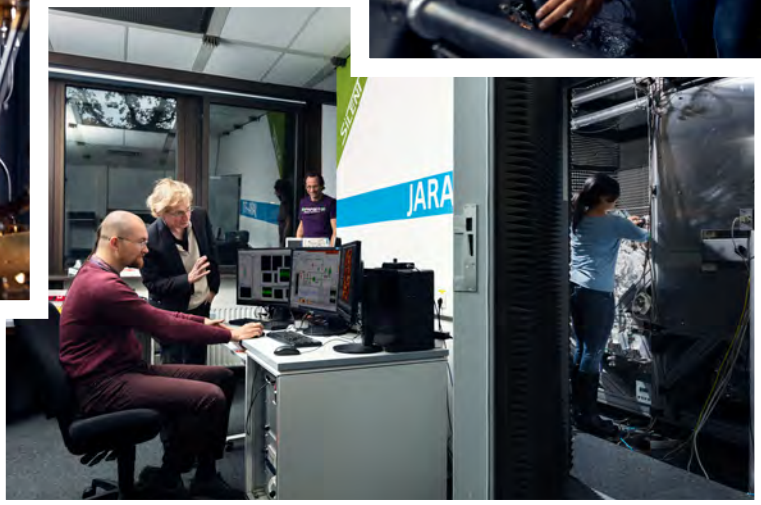


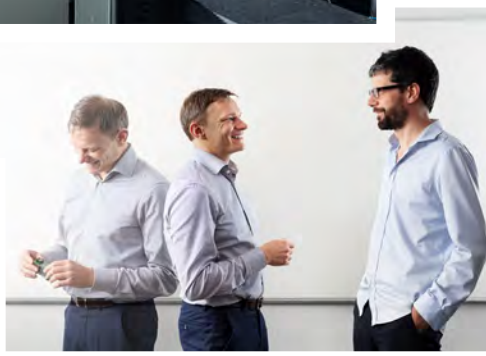


2019

ML4Q set off in 2019 for a long collaborative journey. The cluster involved in its first year of funding over 150 members and associated members, a number which continued to grow in the following years. First communication and networking measures were established to enhance cross-site collaborations. The images selected for the first annual report showcase several Cologne research groups working both in experiment and theory to contribute to the project's overall success.

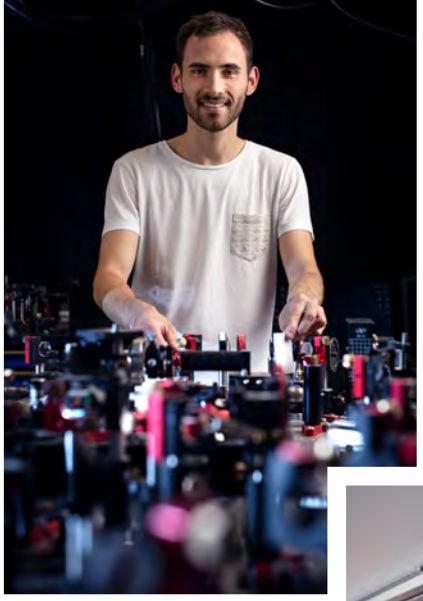


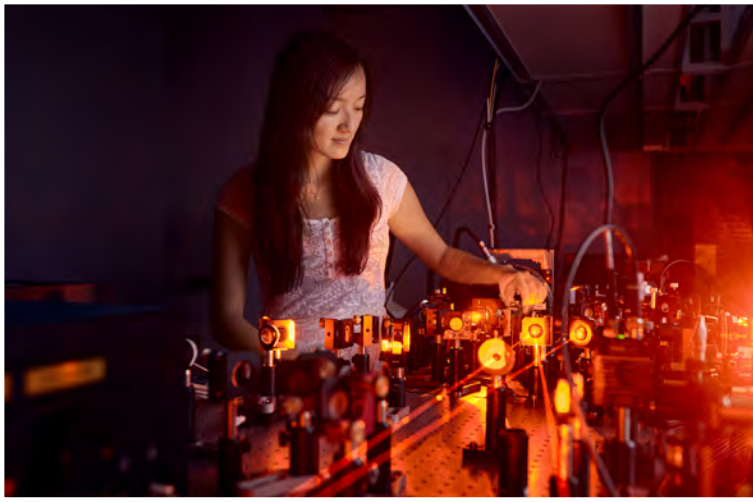


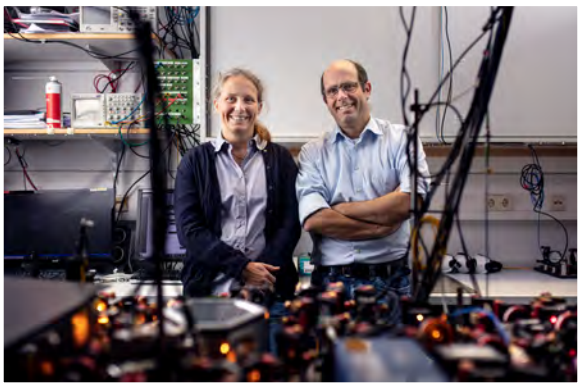


2020

Our journey continues as the cluster grows to involve almost 200 members and associated members. Despite – or rather because of the shift to video-conferencing – cross-group collaborations intensified and brought forth more than 20 joint publications, some of which were highlighted in the second annual report of the cluster's activities. The images selected for this report featured research groups from RWTH Aachen University.

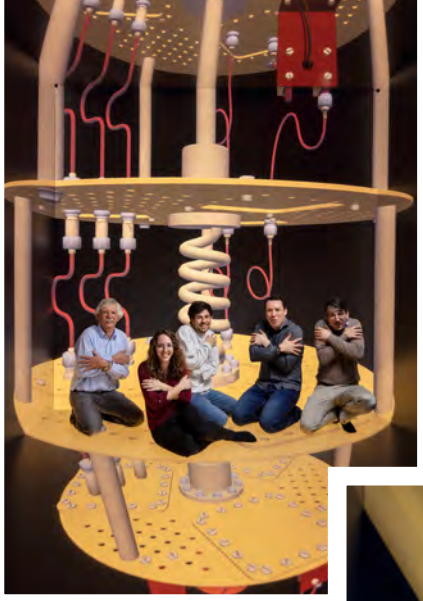


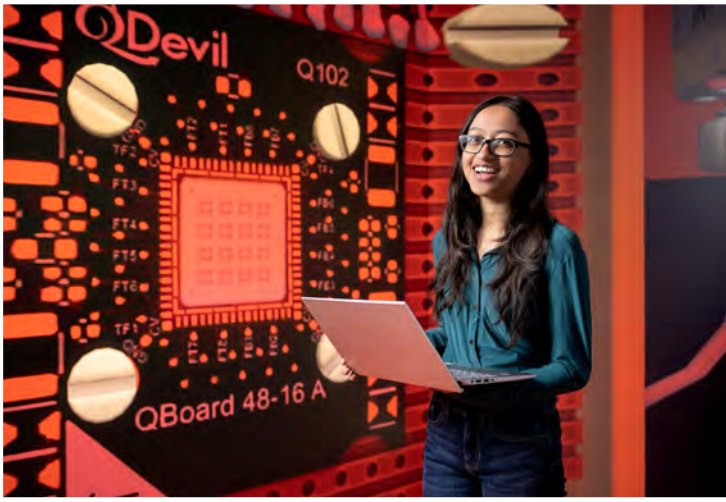




2021

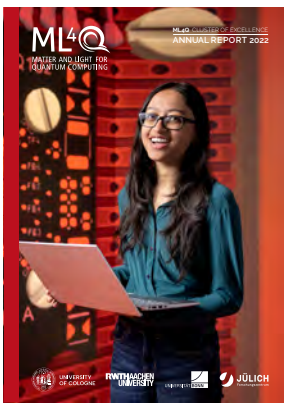
The cluster – meanwhile comprising almost 250 members and associated members – is successful in recruiting excellent young scientists, thus establishing several professorships at all sites, who were portrayed in the third annual report. The report is visually enriched by captivating images showcasing the research groups affiliated with the University of Bonn.





2022

To ensure optimal project alignment and progress, the cluster underwent in 2022 a comprehensive midterm evaluation. This evaluation provided a valuable opportunity to assess the program's direction, make necessary adjustments, and strategically reallocate resources for enhanced outcomes in the remaining funding period. The outcome of the midterm evaluation is shown in more detail on pages 18-21. The images chosen to illustrate the report depict cluster members from Forschungszentrum Jülich alongside the objects of their research, beautifully capturing the dynamic interplay between their work and its tangible results.



CONTACT

CLUSTER OF EXCELLENCE MATTER AND LIGHT FOR QUANTUM COMPUTING (ML4Q)

SPOKESPERSON
Prof. Yoichi Ando, University of Cologne

VICE-SPOKESPERSONS / SITE REPRESENTATIVES
Prof. Hendrik Bluhm, RWTH Aachen University
Prof. Simon Stellmer, University of Bonn
Prof. David Gross, University of Cologne
Prof. Detlev Grützmacher, Forschungszentrum Jülich

ML4Q CENTRAL OFFICE COLOGNE
University of Cologne
Pohligstr. 3
50969 Cologne, Germany

ml4q-office@uni-koeln.de
Tel.: +49 (0) 221 470-3665

www.ml4q.de
twitter.com/ML4Q_cluster
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