COMPETENCE CENTER QUANTUM COMPUTING BADEN-WÜRTTEMBERG
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In order to advance application-oriented research on quantum computing, the Fraunhofer-Gesellschaft, in collaboration with IBM Germany, is founding a national network with competence centers in seven German states. In Baden-Württemberg, the Competence Center »Quantum Computing« was launched in February 2020 and is jointly coordinated by the Fraunhofer Institute for Applied Solid State Physics IAF in Freiburg and the Fraunhofer Institute for Industrial Engineering IAO in Stuttgart.

The competence center has been given cloud access to IBM quantum computers in the USA since April 2020. From January 2021, a quantum computer will be put into operation in Ehningen, operating under German law. The systems provided are state of the art and offer the local business and innovation landscape a multitude of application-oriented developments. At the same time, a great potential for competence building and competitive advantages in the field of Next Generation Computing opens up for economy and science.

The goal of the competence center is to successfully make quantum computing a decisive future technology and to participate in the added value of this new technology already today by building up specialist competencies in Baden-Württemberg and Germany at an early stage. Members and partners of the Competence Center from research and industry will have access to the IBM quantum computers and can benefit from a training program that is currently being established by Fraunhofer IAF and Fraunhofer IAO.

This brochure will inform you about the Competence Centre, opportunities for collaboration, and training services. We’re looking forward to hearing from you.

Prof. Dr. Dr.
Oliver Ambacher
Institute Director
Fraunhofer IAF

Prof. Dr.-Ing. Prof. e. h.
Wilhelm Bauer
Institute Director
Fraunhofer IAO
Ladies and gentlemen,

Quantum computing offers completely new possibilities to overcome the limitations of classical, digital computers. Quantum computers will be able to solve business-related problems in a very short time instead of years. In future, these advantages may also revolutionize the solution of complex optimization problems with artificial intelligence.

We want to make the great innovation potential of quantum computing available for economic and scientific applications in the state as early as possible and gain an important localational advantage. Baden-Württemberg is the state of hidden champions and the leading innovation region in Europe. We offer excellent conditions and a large number of application areas for which quantum computing can be useful.

Having an IBM quantum computer in our state is a great success and an enormous opportunity for Baden-Württemberg. The state government is providing a total of up to 40 million euros to work together with the Fraunhofer-Gesellschaft, industry and scientific institutions in the state to establish, develop and transfer an innovative knowledge and technology base for quantum computing.

With the Competence Center, we want to further develop our ecosystem of quantum technologies from universities, research institutes, start-ups and companies in Baden-Württemberg together in a way that is internationally visible. The Competence Center will also provide important impulses for the development of an innovative quantum hardware and software industry in Baden-Württemberg and stimulate the establishment of companies in the fields of micro- and nanoelectronics and quantum informatics.

I cordially invite all interested companies, universities and non-university research institutions to become actively involved in the work of the Competence Center as members and project partners to jointly help shape the future of Baden-Württemberg.

Dr. Nicole Hoffmeister-Kraut MdL

Foreword
Dr. Nicole Hoffmeister-Kraut
Minister of Economic Affairs, Labour and Housing
Baden-Württemberg

»The establishment of the new »Competence Center Quantum Computing« in Baden-Württemberg is a beacon project with international appeal.«
In cooperation with IBM Germany, the Fraunhofer-Gesellschaft is establishing a national competence network in the research field of quantum computing. The aim is to develop quantum-based computing strategies for the next generation of high-performance computers. With the participation of currently eleven Fraunhofer Institutes, specialist expertise is being pooled in regional competence centers.

Within the Competence Center »Quantum Computing Baden-Württemberg«, the first IBM quantum computer in Germany will be set up in Ehningen near Stuttgart. This will offer the existing high-tech landscape of industry, SMEs and start-ups the unique opportunity to use high-performance computers for their application-oriented research and development.

Since April 2020, the Competence Center and its partners have had cloud access to state-of-the-art IBM quantum computers in the USA. This enables a wide range of research topics from essential algorithms, software development and the design of elementary logic operations to the control of the quantum processor in the actual computing process. The performance parameters of the quantum computers are geared to the high demands of a research infrastructure with a focus on socially and economically relevant applications.

The »Q System One« provided by IBM in Ehningen from 2021 is also state of the art (quantum volume = 30). In addition, the location in Baden-Württemberg enables this IBM quantum computer to be operated under German law. In terms of data protection and IP security, this is an essential core of the overall initiative and an important prerequisite for broad participation by national industry.

The Competence Center »Quantum Computing Baden-Württemberg« is jointly coordinated by Fraunhofer IAF in Freiburg and Fraunhofer IAO in Stuttgart. Please do not hesitate to contact us for further information.
PROJECTS

Within the Competence Center Baden-Württemberg, joint projects are funded by the Ministry of Economics, Labour and Housing Baden-Württemberg. All universities and non-university research institutions with their headquarters or location in Baden-Württemberg are eligible to apply. Interested companies in the state can participate as associated partners, but will not receive funding.

The first call for proposals was published on 29.6.2020; the deadline is 30.8.2020. The projects are to start on 1.1.2021 and will run for two years.

Topics include:
- Quantum computing for the design of novel materials and quantum chemical reactions
- Quantum computers and quantum algorithms for the optimization of complex state systems
- Development and demonstration of powerful quantum memories and quantum processors

It is expected that at least 25% of the project costs will be spent on the use of the quantum computer. A ticket model was created for this purpose (see right).

All further information on the joint projects is available at: https://www.iaf.fraunhofer.de/CCQC

COMPUTING TIME

We offer access to the IBM quantum computer for all interested users regardless of where they are based. In 2020, you can gain cloud access to IBM quantum computers stationed in the USA. From 2021 onwards, you will be able to access the quantum computer in Ehningen, which is operated under German law. The access is subject to a user contract and export control.

We work with a ticket model in which you secure a calendar month’s access to the quantum computer for each ticket purchased. The following (provisional) prices apply:

- for project partners: 9.770 € / calendar month
- for external customers: 11.621 € / calendar month

The prices are exclusive of VAT and are quoted per user. If several users of an organization want to access the quantum computer, each user must purchase an individual ticket. Tickets cannot be shared or transferred.

We recommend that you also make use of our training courses (see next page). Training courses are offered for »basic« and »advanced« users.

If you are interested, please contact us at: kqc@iaf.fraunhofer.de
TRAINING COURSES

Quantum programming made easy!

In order to provide as many interested parties as possible with fast access to and efficient use of IBM quantum computers, Fraunhofer IAF (Freiburg) and Fraunhofer IAO (Stuttgart) each have their own computer pool. These consist of ten workstations and a classical high-performance computer for training and education purposes, which are connected to the IBM quantum computers.

From autumn 2020, users will be able to build up expertise in programming IBM quantum computers here. Application-specific algorithms can be developed and tested using the »Qiskit« software. Initially, this is done via cloud access to IBM computers located in the USA. From 2021, it will be possible to work on the computer located in Ehningen, which is operated under German law.

The cloud quantum computers used for training purposes offer the following features:

- Qubits: up to 53
- Size of a qubit: ≈ 100 µm
- Operation temperature (qubits): = 15 mK
- Time per quantum gate: ≈ 25 – 100 ns
- Quantum gate errors: < 0.5 % (1 qubit gate)
- Coherence time: > 50 µs
- Measurement error: < 5 %
- Quantum gate errors: < 2.5 % (2 qubit gates)

The quantum computer stationed in Ehningen will offer a quantum volume of 30 and improved error correction. These configurations allow trainings from essential algorithms, quantum gate design to software development.

Applications for which quantum computers are offer advantages and for which our testing and training offer is particularly interesting:

- Optimization of logistical process flows
- Coordination and organization of complex automated production lines
- Resource-optimized management of fleets and autonomous vehicles
- Forecast of financial developments
- Simulation of molecules and chemical reactions

Training modalities

The training courses are user- and interaction-centred and are held in small groups at Fraunhofer IAF and Fraunhofer IAO. Depending on previous knowledge, you can choose between a »basic« and an »advanced« course (see right). This enables you to gain initial experience with IBM quantum computers by working with predefined test tasks or to further expand your existing expertise by contributing your own application examples.

For further information and dates, please contact us at: kqc@iaf.fraunhofer.de
### BASIC

**Target audience**
You have little to no experience in programming and using quantum computers.

**Learning objectives and contents**
- Understanding the basic concepts: qubits, superposition, entanglement, quantum gates, etc.
- Understanding the different architectures of quantum computers, hardware and software
- Basic programming with the Qiskit software for simple applications
- Technical introduction to the IBM quantum computer
- Used algorithms: German, Grover, Shor and others

**Training form**
50% basics (lectures with examples and quiz)
50% application (group and individual work on specified exemplary cases)

**Programs**
- Qiskit
- Python

**Training dates and locations**
Training courses are continuously offered at Fraunhofer IAF in Freiburg and Fraunhofer IAO in Stuttgart. To find out the next dates, please contact us at kqc@iaf.fraunhofer.de.

**Price**
1 Ticket
This includes one calendar month of use on the IBM quantum computer, an approximately two-week training course including all documentation and catering on site. Participation requires a user contract and a successful export control.

### ADVANCED

**Target audience**
You already have experience in using quantum computers and can program some algorithms yourself.

**Learning objectives and contents**
are defined according to the interests and needs of the participants. Possible topics include:
- Advanced quantum algorithms, e.g. classical quantum mechanical hybrid algorithms (like VQE or QAOA) or Quantum Machine Learning
- Techniques to correct or reduce errors
- Introduction to »Qiskit Pulse« (a deeper level of programming which includes more control options)

**Training form**
40% basics (As lectures with examples and quiz)
60% application (group and individual work on specified exemplary cases)

**Programs**
- Qiskit
- Python

**Schulungstermine und -Orte**
Training courses are continuously offered at Fraunhofer IAF in Freiburg and Fraunhofer IAO in Stuttgart. To find out the next dates, please contact us at kqc@iaf.fraunhofer.de.

**Kosten**
1 Ticket
This includes one calendar month of use on the IBM quantum computer, an approximately two-week training course including all documentation and catering on site. Participation requires a user contract and a successful export control.
FREQUENTLY ASKED QUESTIONS

QUANTUM COMPUTER

Does the Fraunhofer-Gesellschaft monitor which computing processes I carry out on the quantum computer?
No, we do not monitor your data.

Is there enough computing capacity available for all users?
With up to 100 users we do not expect any capacity problems. The load also depends on the complexity of the algorithms that are used. If we notice that capacity peaks occur on certain days and at certain times, we reserve the right to assign usage times in order to guarantee all users seamless use of the quantum computer.

What does the user contract cover?
Before you can access the quantum computer, access rights, system and data protection regulations and export control are regulated by a user contract. Every user has to sign a user contract with the Fraunhofer-Gesellschaft.

Why is export control necessary?
Although the quantum computer is located in Baden-Württemberg and operated under German law, it is an American system. Therefore, export control is necessary before access can be granted.

Does every person have to buy a ticket or can I buy a ticket as an organization as a whole?
At least one ticket must be purchased per user (= individual person). Tickets cannot be shared or transferred.

Is there a discount for several users or when purchasing several monthly tickets?
Since we work on a cost price basis, we are unfortunately unable to offer a discount.

TRAININGS

How often do trainings take place?
We regularly offer training courses at Fraunhofer IAF in Freiburg and Fraunhofer IAO in Stuttgart. Since there are no fixed dates, but trainings take place from 5 participants on, we ask you to register informally by e-mail at kqc@iaf.fraunhofer.de if you are interested. We will contact you as soon as possible with an offer and suggested dates.

Do you offer online trainings?
In general, we recommend coming to our institutes, as the exchange between trainer and participants as well as the interaction with each other is key to the learning success. At the same time, we are working on an online training concept with which we can offer you just as effective a learning success as at our institute. Please inform us by e-mail at kqc@iaf.fraunhofer.de if you are only interested in online training so that we can estimate how many users would be interested in online trainings.

Does the price include accommodation?
It does not; accommodation has to be booked separately. However, we are happy to recommend a selection of hotels and guest houses in Freiburg.
STATEMENTS

Prof. Dr. Joachim Ankerhold
Director of the Institute for complex quantum systems, Ulm University, Co-Director of the Center for Integrated Quantum Science & Technology (IQST)

Quantum technologies are on everyone’s lips these days. They are of particular importance for Baden-Württemberg as a high-tech location, especially quantum computing. As a disruptive technology, its translation into concrete applications still requires some patience, but the cooperation with IBM and the close combination of industry-oriented and basic research already enables us to develop an optimal ecosystem in order to be at the forefront of international research. «

Dr. Thomas Strohm
Coordinator for Quantum technologies, Bosch Research

Quantum computing is capable of creating profound new technological possibilities. Baden-Württemberg is a state of tinkerers and inventors. The numerous technology companies here will benefit greatly from access to a quantum computer. We therefore expect the Competence Center to provide first and foremost technical competence and the ability to advise the participating companies with expertise on quantum computing. Easy and open access to quantum computers is equally important. «

Dr. Sebastian Zanker
CTO and Co-Founder, HQS Quantum Simulations

At HQS we are involved in the development of simulation software that allows quantum computers to be used to predict material properties. From the Competence Center we expect close contacts and cooperation with partners from industry, who are potential users of our software, as well as research institutes, who work together with us on topics such as error reduction or efficient simulation algorithms. «

Prof. Dr. Guido Burkard
Chair of Theoretical Solid State Physics and Quantum Information, University of Konstanz

The Competence Center gives us the opportunity to pool and expand the expertise in quantum computing available in Baden-Württemberg and to close gaps between basic research and application. Research plays an important role here, because while the first prototypes are already available, the competition for the best ideas for the realisation and use of quantum computers is still in full swing. «
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