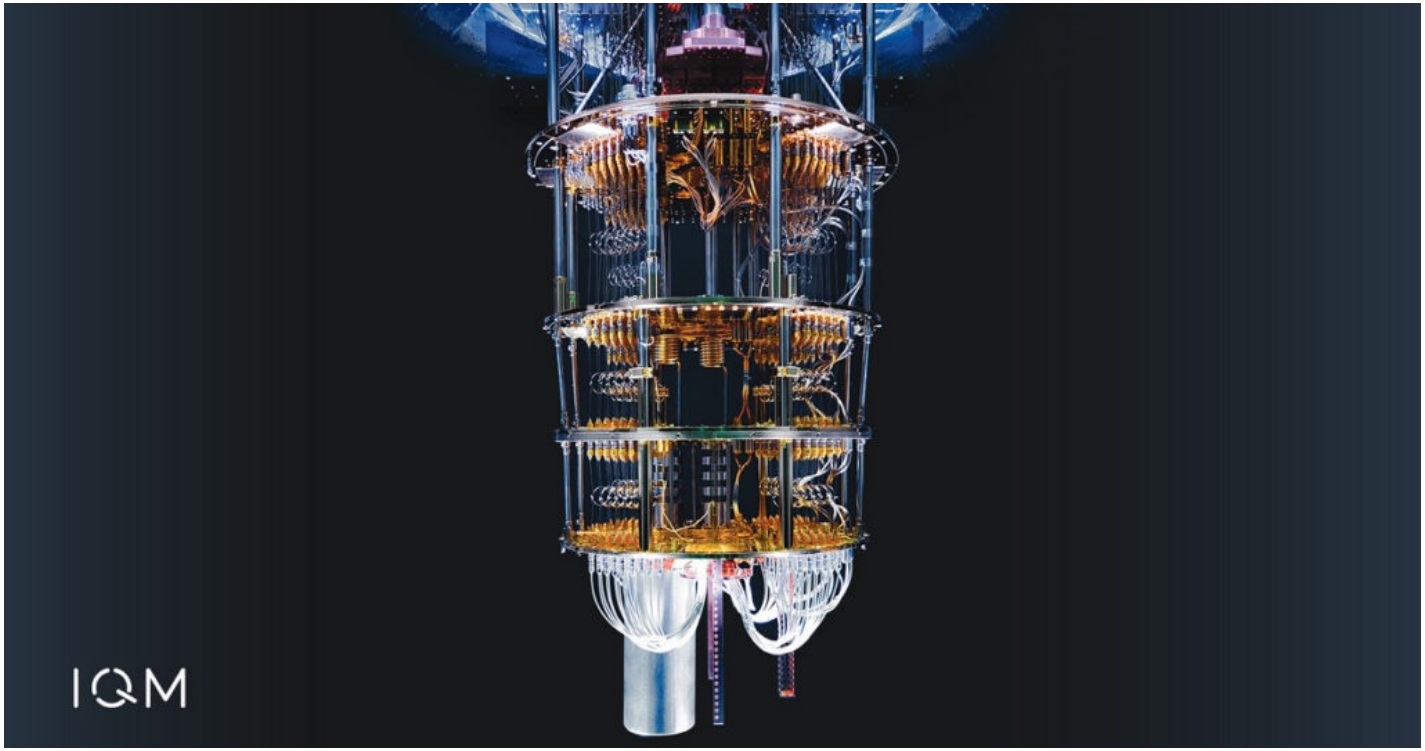
DeiC Q-Access Roadshow

March 5, 2025



Europe takes a quantum leap: LUMI-Q consortium signs contract to establish quantum computer in the Czech Republic

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Outline

1. **Introduction to DeiC's Quantum Department**

2. **Background on Quantum Computing**
   a. Classical vs. Quantum
   b. Algorithms
   c. Applications

3. **Landscape of Quantum Computing**
   a. Hardware Implementations
   b. Global Providers of Software and Cloud Access
   c. Denmark's National Strategy and Initiatives

4. **Overview of DeiC's Q-Access Initiative**
   a. Two-mode Access Strategy
   b. Consulting Service with Quantum Experts

5. **Q-Access via Microsoft Azure**
   a. Application and Evaluation Process
   b. Step-by-step Demo
   c. Provider Status Updates

6. **Q & A with Q-Access Team and Microsoft**

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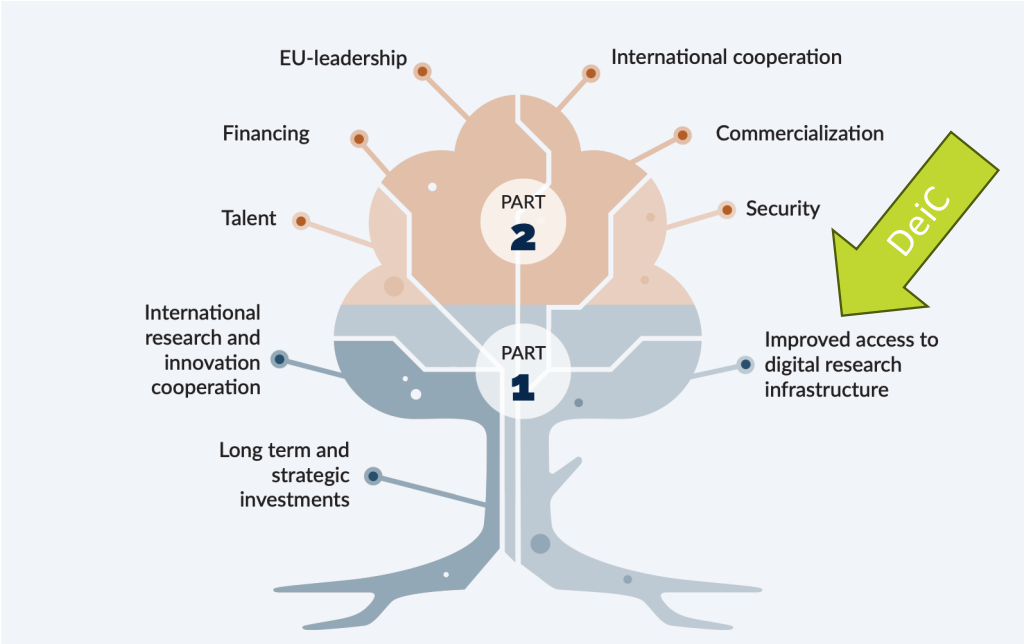
1. Introduction to DeiC's Quantum Department

The Objective of the Strategy for Quantum Technology - Part 1

> Denmark aims to have one of the world's leading quantum research environments and to have the ability to effectively translate research into new, usable technology.

Link between Part 1 and Part 2



A (very) small example of the Danish Quantum landscape. Which is in a form of ”superposition”

(Defence)

(Life Science)

(Cyber)

(AI)

(Research / innovation)

(Transport)

(Hardware & infrastructure)

(Branch organisations)

(Investors and accelerators)

(International)

(Authorities)

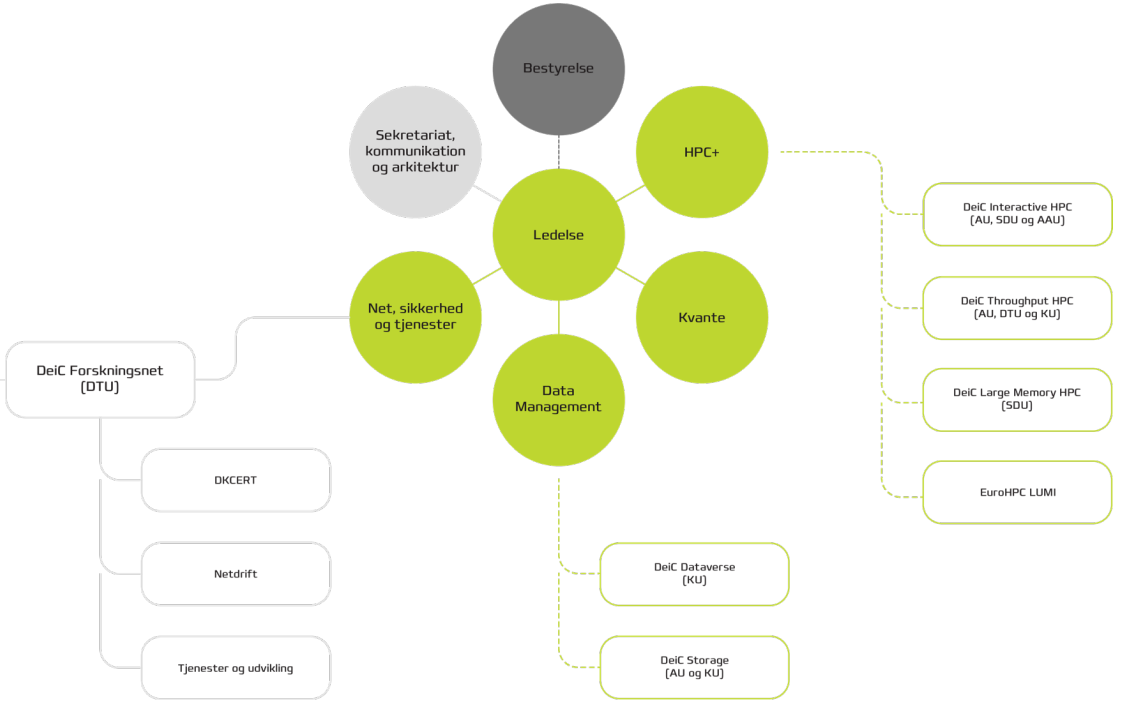
(Counselling)

(Banking)

Overview of DeiC

The **Danish e-Infrastructure Consortium (DeiC)** develops and coordinates access to digital research infrastructure for Danish universities, enabling research and education at a high international level.

The research network is a high-speed network that connects Danish universities and research institutions.



DeiC's Quantum Department

DeiC's Quantum Department is the newest department in DeiC, established as part of the implementation of the Danish government's national quantum strategy.

Initiatives

Q-Competence

- Disseminate skills and increase understanding of the potential and risks of quantum technology.
- Financial support for developing quantum computing material and events.

Q-Algorithm

- DQA Academy to boost work in developing and testing quantum algorithms and the associated software stack.
- Scholarships for Ph.D. students and Postdocs.

Q-Access

- Calls for specialized access to quantum computers.
- Access via Microsoft Azure for testing.
- Consulting service with quantum experts.

Niels Bohr Quantum Summer School

Two-week summer school, for the next 4 years, for both Danish and international Ph.D. students to learn about quantum computing and attract talent to the quantum community in Denmark.

LUMI-Q

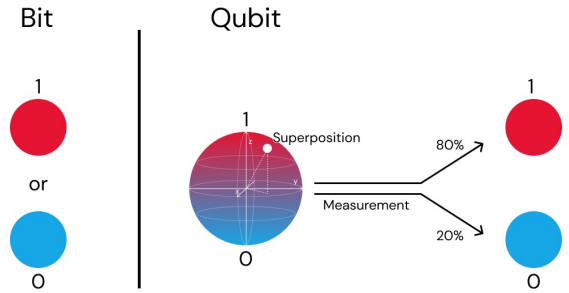
The LUMI-Q consortium has signed a contract to set up a quantum computer, purchased from IQM in Finland and deployed in the Czech Republic.

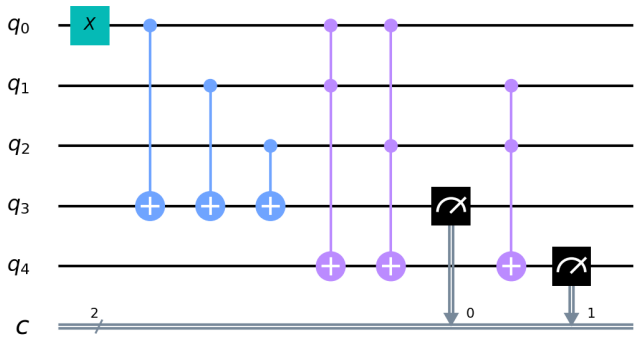
2. Background on Quantum Computing

Background on Quantum Computing

Classical vs. Quantum Bits

- Classical bits are either 0 or 1, while quantum bits (qubits) have a probability of being either 0 or 1 when measured.
- Qubits allow for an entirely new way of computing.
- Physical qubits are two-state physical quantum systems (ranging from photons to ions) located within a quantum processing unit (QPU).





Quantum Circuit Model

- A model for computation in which a sequence of quantum gates and measurements are applied to a set of qubits.
- Typically, this defines a single execution of a shot on a QPU.
- Gates are unitary operation on one or more qubits. In particular, they are always reversible, as opposed to measurements, and their complexity grows exponentially in the number of qubits.

Quantum Algorithms

- Leveraging this new way of computing requires both high-fidelity hardware implementations of qubits and gates as well as new quantum algorithms.

Algorithm	Problem	Quantum Complexity	Classical Complexity	Speedup
Shor's Algorithm	Factoring integers	$O(poly(N))$	$O(\exp N^{1/3} (\log N)^{2/3})$	Exponential
Grover's Algorithm	Unstructured search	$O(\sqrt{N})$	$O(N)$	Quadratic
HHL Algorithm	Solving certain linear systems $Ax = b$	$O(poly(\log N, 1/\epsilon))$	$O(poly(N, \log 1/\epsilon))$	Exponential
Hamiltonian Simulation	Simulating quantum systems (e.g. chemistry, materials)	$O(poly(\log M, t))$	$O(poly(M, t))$	Exponential

Applications

Domain	Example Use Cases	Algorithms
Cryptography	• Breaking RSA/ECC (factoring, discrete log) • Search for symmetric key attacks	• Shor's Algorithm • Grover's Algorithm
Finance	• Portfolio optimization • Option pricing	• QAOA, Variational Algorithms • Amplitude Estimation
Pharmaceuticals	• Drug discovery • Protein folding/structure optimization	• Hamiltonian Simulation • Variational Quantum Eigensolver (VQE)
Machine Learning	• Classification and clustering • Generative models	• QNNs and QGANs • HHL-based Linear Algebra
General Optimization	• Combinatorial optimization • Scheduling, resource allocation	• QAOA, Variational Algorithms • Grover's Algorithm
General Linear Algebra	• Solving large linear systems • Matrix inversion	• HHL Algorithm • Quantum Singular Value Transform

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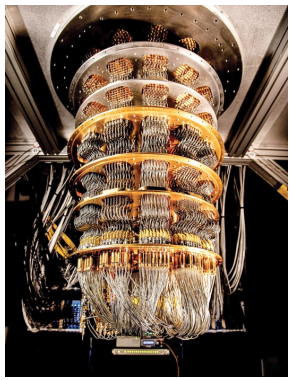
3. Landscape of Quantum Computing

Implementing a Quantum Computer



Leaders in Superconducting QC

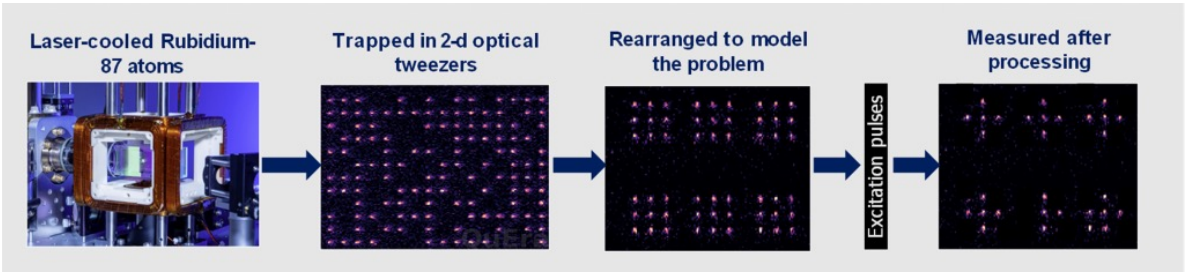
IBM (🇺🇸)
Google (🇺🇸)
Amazon (🇺🇸)
Rigetti (🇺🇸)
SEEQC (🇺🇸)
Qolab (🇺🇸)
Bleximo (🇺🇸)

D-Wave (🇨🇦)
Anyon (🇨🇦)
Nord Quantique (🇨🇦)
Oxford Quantum Circuits (🇬🇧)
QuantWare (🇳🇱)
Alice & Bob (🇫🇷)
IQM (🇫🇮)

Fujitsu (🇯🇵)
NEC (🇯🇵)
Origin Quantum (🇨🇳)
Huawei (🇨🇳)
Tencent (🇨🇳)

Leaders in Neutral Atom QC

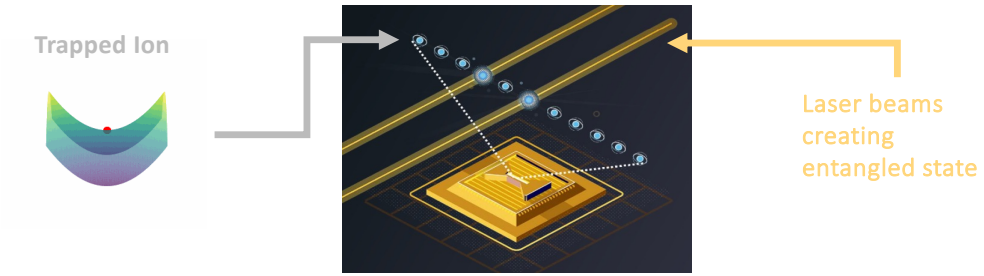
QuEra (🇺🇸)
Pasqal (🇫🇷)
Infleqtion (🇺🇸)
Atom Computing (🇺🇸)
planqc (🇩🇪)
NanoQT (🇯🇵)

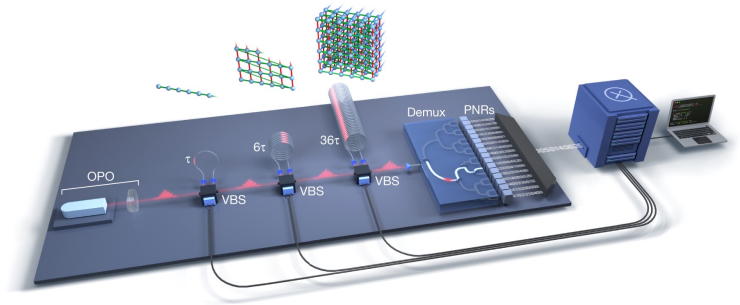


Implementing a Quantum Computer

Leaders in Trapped Ion QC

Quantinuum (🇺🇸)
IonQ (🇺🇸)
Universal Quantum (🇬🇧)
Oxford Ionics (🇬🇧)
AQT (🇦🇹)
Qubitcore (🇯🇵)



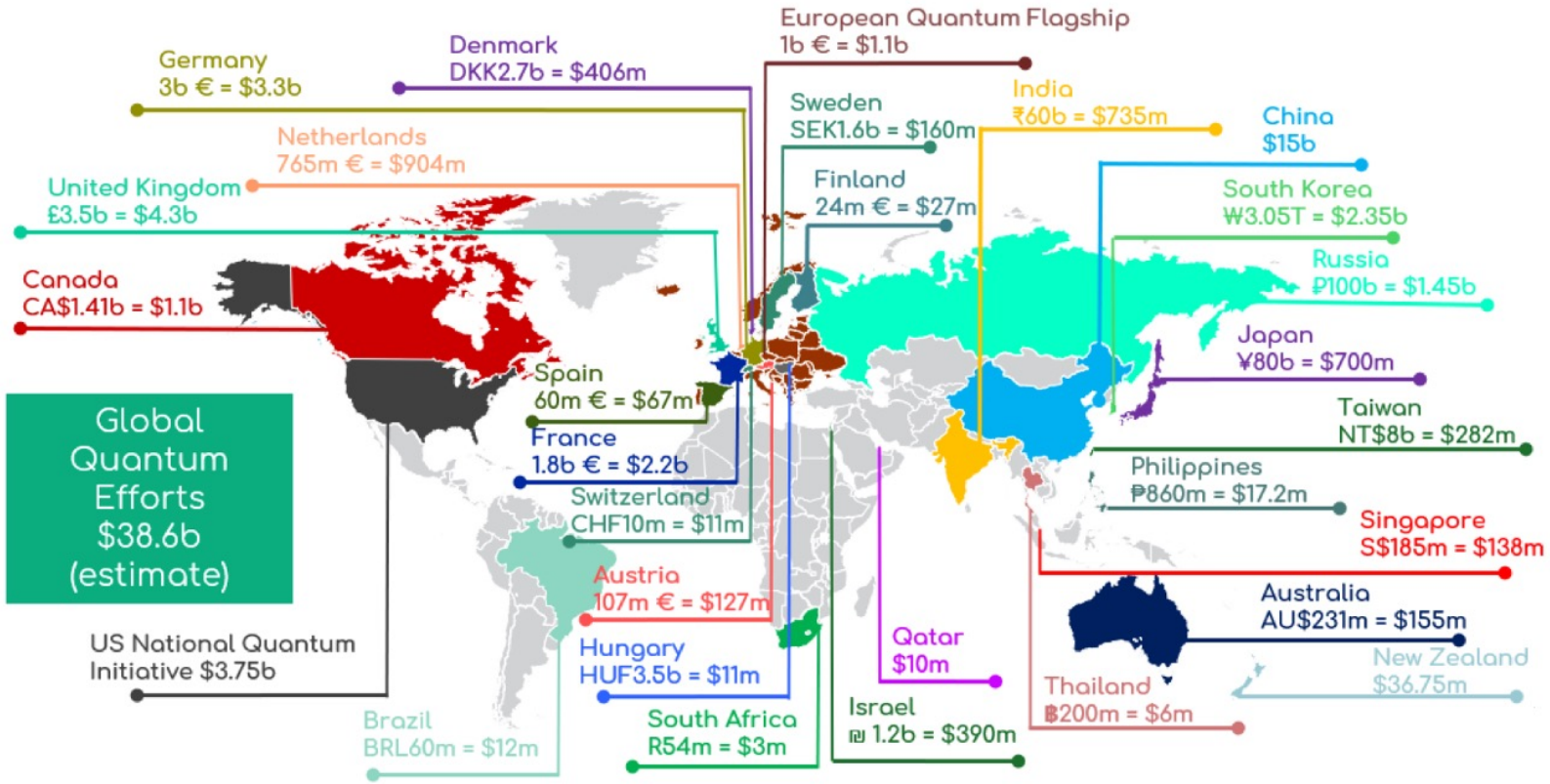


Leaders in Photonic QC

Xanadu (🇨🇦)
PsiQuantum (🇺🇸)
ORCA Computing (🇬🇧)
QuiX Quantum (🇳🇱)
Quantum Computing Inc. (🇺🇸)

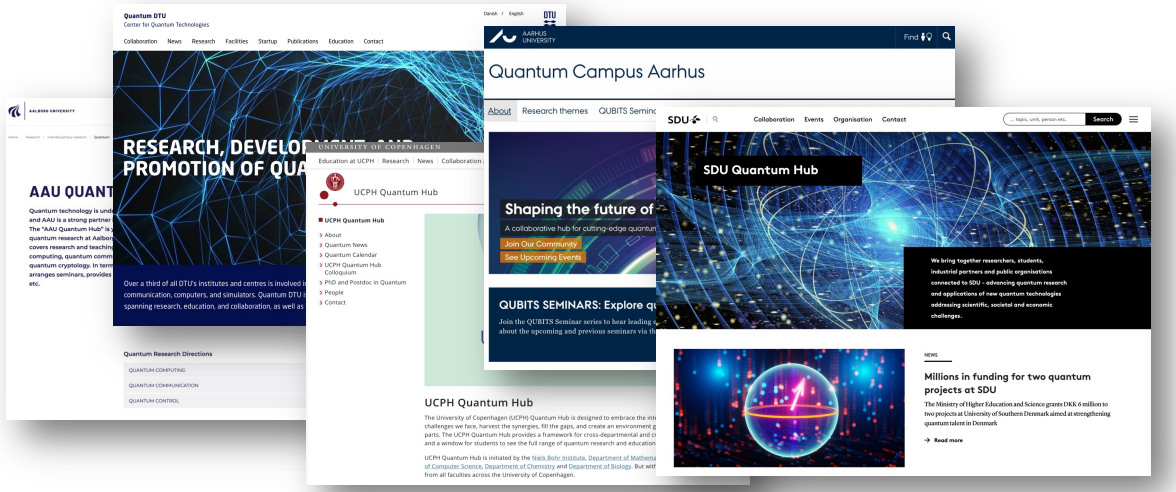
Quandela (🇫🇷)
OptQC (🇯🇵)
TuringQ (🇨🇳)
eleQtron (🇩🇪)
NQCG (🇳🇴)

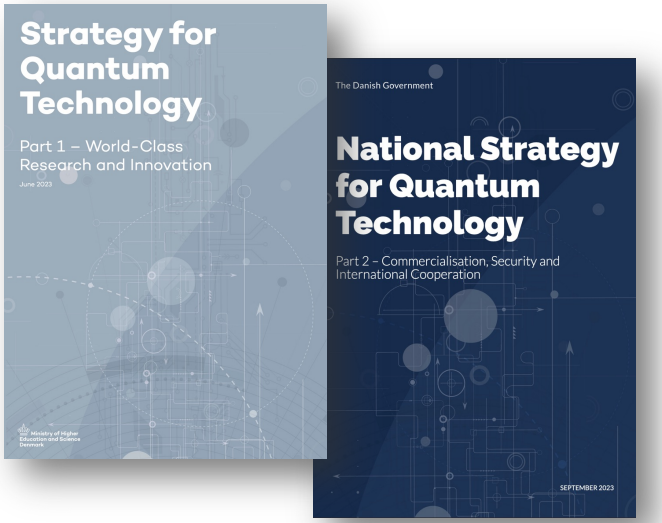
Global Landscape of Quantum Computing



Denmark's National Quantum Strategy

- The Danish government has committed to invest 1.000.000.000 DKK into quantum research and innovation from 2023 to 2027.
- **Quantum Hubs** have been established at 5 of the Danish research universities: KU, DTU, SDU, AU, AAU





Innovationsfonden

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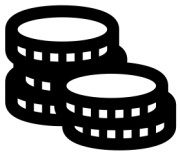
4. Overview of DeiC's Q-Access Initiative

a. Two-mode Access Strategy
b. Consulting Service with Quantum Experts

Two-Mode quantum access

Roadshow purpose



Yearly budget –2027: 12 million DKK

- Est. 1 million kr for Mode 1
- Est. 11 million kr for Mode 2

Mode 1: Microsoft Azure Quantum - cloud computing platform

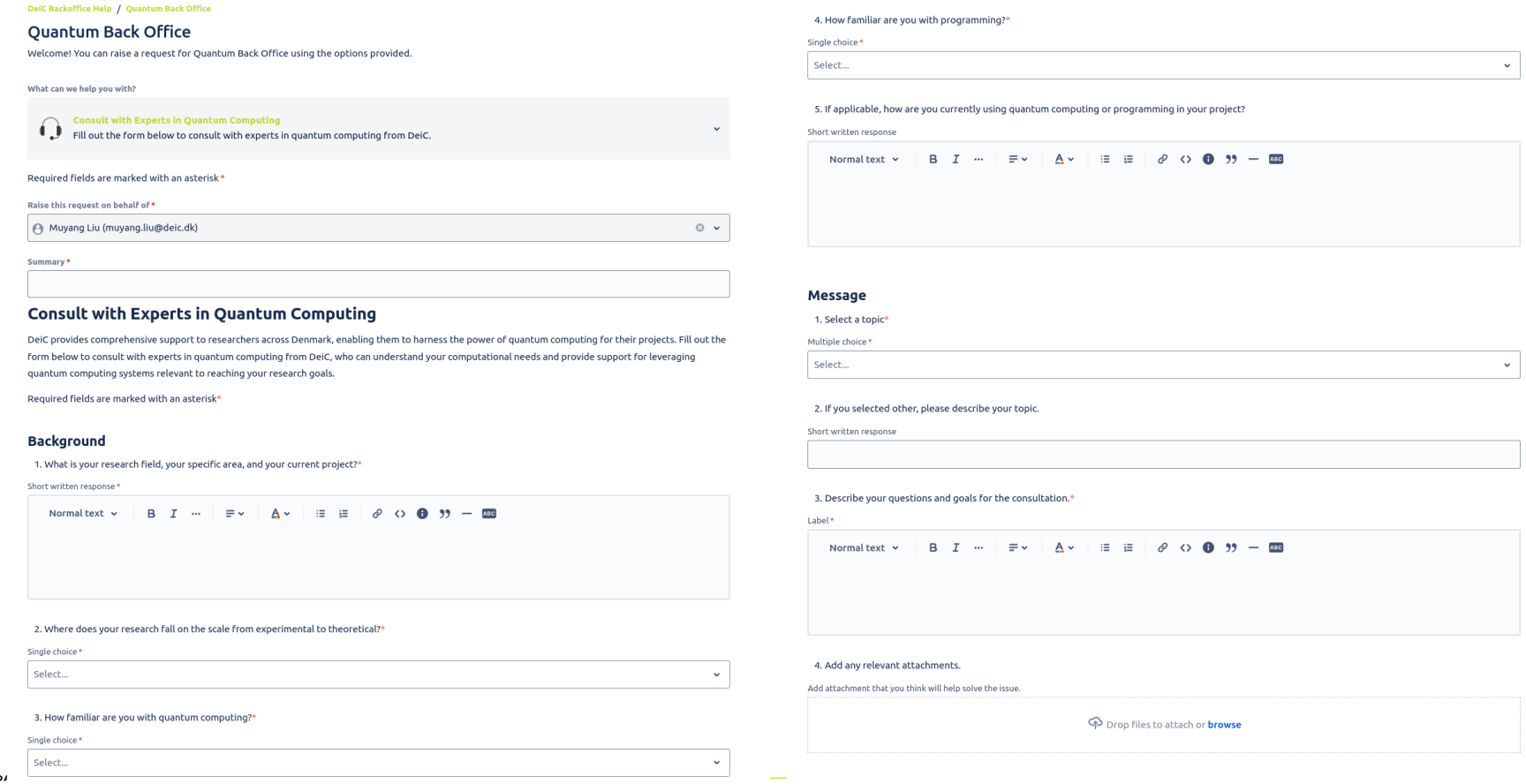
- **Simple online request** form with quick response
- Access to quantum simulator and hardware from IonQ, Quantinuum and Rigetti
- Access **worth of up to 25.000 kr**. (can be requested multiple times)

Mode 2: Selected quantum computers for specialized research needs

- Evaluation by international scientific committee
- Two annual calls for research project proposals
- Apply for access worth of up to est. 7 milion Kr

Q-Access consulting service

- Fill out the form below to consult with experts in quantum computing from DeiC
  - https://deic-backoffice.atlassian.net/servicedesk/customer/portal/3/group/4/create/34



DeiC Backoffice Help / Quantum Back Office

Quantum Back Office

Welcome! You can raise a request for Quantum Back Office using the options provided.

What can we help you with?

Consult with Experts in Quantum Computing
Fill out the form below to consult with experts in quantum computing from DeiC.

Required fields are marked with an asterisk *

Raise this request on behalf of *

Muyang Liu (muyang.liu@deic.dk)

Summary *

Consult with Experts in Quantum Computing

DeiC provides comprehensive support to researchers across Denmark, enabling them to harness the power of quantum computing for their projects. Fill out the form below to consult with experts in quantum computing from DeiC, who can understand your computational needs and provide support for leveraging quantum computing systems relevant to reaching your research goals.

Required fields are marked with an asterisk*

Background

1. What is your research field, your specific area, and your current project?*

Short written response *

Normal text

2. Where does your research fall on the scale from experimental to theoretical?*

Single choice *

Select...

3. How familiar are you with quantum computing?*

Single choice *

Select...

4. How familiar are you with programming?*

Single choice *

Select...

5. If applicable, how are you currently using quantum computing or programming in your project?

Short written response

Normal text

Message

1. Select a topic*

Multiple choice *

Select...

2. If you selected other, please describe your topic.

Short written response

3. Describe your questions and goals for the consultation.*

Label *

Normal text

4. Add any relevant attachments.

Add attachment that you think will help solve the issue.

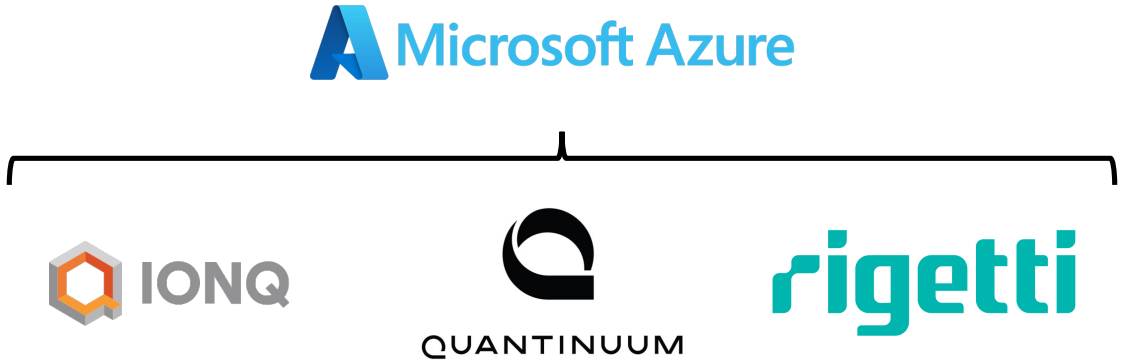
Drop files to attach or browse

5. Q-Access via Microsoft Azure

a. Application and Evaluation Process
b. Step-by-step Demo
c. Provider Status Updates

Q-Access via Azure

- Access to Azure for testing worth up to **25.000 DKK** can be applied for by filling out a simple form at: https://deic-backoffice.atlassian.net/servicedesk/customer/portal/3/group/4/create/35



- **Evaluation process – within a week**

Application form

- Fill a simple online form as below (+ accept the term of service) !

DeiC Backoffice Help / Quantum Back Office

Quantum Back Office

Welcome! You can raise a request for Quantum Back Office using the options provided.

What can we help you with?

Request Access to Microsoft Azure Quantum
Using the below form, you can apply for a quota to use Microsoft Azure Quantum.

Required fields are marked with an asterisk *

Raise this request on behalf of *

Muyang Liu (muyang.liu@deic.dk)

Summary *

DeiC provides access to the Microsoft Azure Quantum cloud service to Danish academia, industry, and the public sector (see the FAQ for more information on eligibility). This access is intended to allow users to explore and test a variety of quantum platforms. Users requiring more significant access to a specific platform can apply for such access from one of the DeiC Q-Access calls.

Through Microsoft Azure Quantum, users have access to a diverse portfolio of quantum simulators and quantum computers from Quantinuum, IonQ, Quantum Circuits Inc., Rigetti, and Pasqal. Because this access is intended for testing, we strongly encourage users to start with testing the various free simulators (from Microsoft and their backend providers) before moving on to actual hardware tests.

Using the below form, you can apply for a quota to use Microsoft Azure Quantum (see Azure Quantum pricing for more information). The standard initial resource quota is 10.000 DKK in Azure Quantum Credits. However, it is possible to apply for up to 25.000 DKK. Moreover, it is possible to apply for more credits multiple times once your quota has been used up.

Allocated resources can be used up until 30/06/2025, at which point unused resources will be returned to the pool, and a new usage period will begin. Users will be asked to fill out a short report on their usage, which will be required for future allocations of resources.

Background

Full Name *

What area are you in? *

Select...

Describe the project that the access will be used for and who will be using it. *

If you are in academia and applying for access for a project involving a Postdoc, PhD or Master's student who will be using the access, please provide their details. If you are in industry or the public sector, please describe how the project is new and different from current activites.

Normal text

Access Usage

Describe your intended use for the access. *

Normal text

Have you applied for Microsoft Azure Quantum access from DeiC in the past? *

- Yes
- No

Required Resources

Does the standard initial resource quota of 10.000 DKK suffice for your needs? *

- Yes
- No

Customized user group in DeiC plan

Why split the user groups

a) It can take up to 24 hours for Microsoft to update a resource group's real cost, rendering it ineffective for limiting user spending based on usage.
b) Currently, Azure does not offer adequate controls to limit user spending.

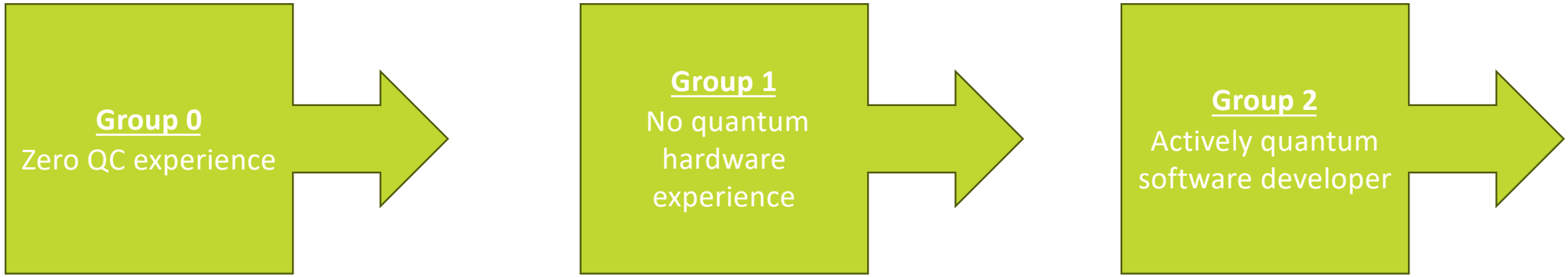
Intermediate solution

a) Users will be split into two(three) groups, each with different levels of access to Azure (see next slide).
b) The separation of multiple groups is especially important for mitigating risk.
c) Most of the development and testing should take place on simulators due to high cost of QPU.

DeiC's Support

a) Actively developing a set of supporting materials.
b) Share regular updates on the status of Azure's quantum providers .

Customized user group in DeiC plan



- Recommend to use a free browser interface simulator https://quantum.microsoft.com/en-us/tools/quantum-coding
- Can get access to quantum simulators from Microsoft and Quantinuum

- Indirectly access to allocated QPU resources on Azure
- Submit requests to DeiC via an online form
- DeiC performs submitted jobs

- Direct access to allocated QPU resources on Azure
- Responsible to cover the cost if significantly exceeding allocation

How to submit a job for users in Group 1

Fill out an online form with the following information

a) User's name and e-mail address
b) Script to be executed on Azure + A Brief description
c) Confirmation that the script fits the standards outlined below
    - The file has been successfully tested on a simulator (along with the values of the parameters used)
    - The output from the simulator
    - Specific QPU to be used for the job
    - Parameters of the script to be used for the job
    - Cost estimate for resources necessary to complete the job (e.g, unit of HQC on Quantinuum system)

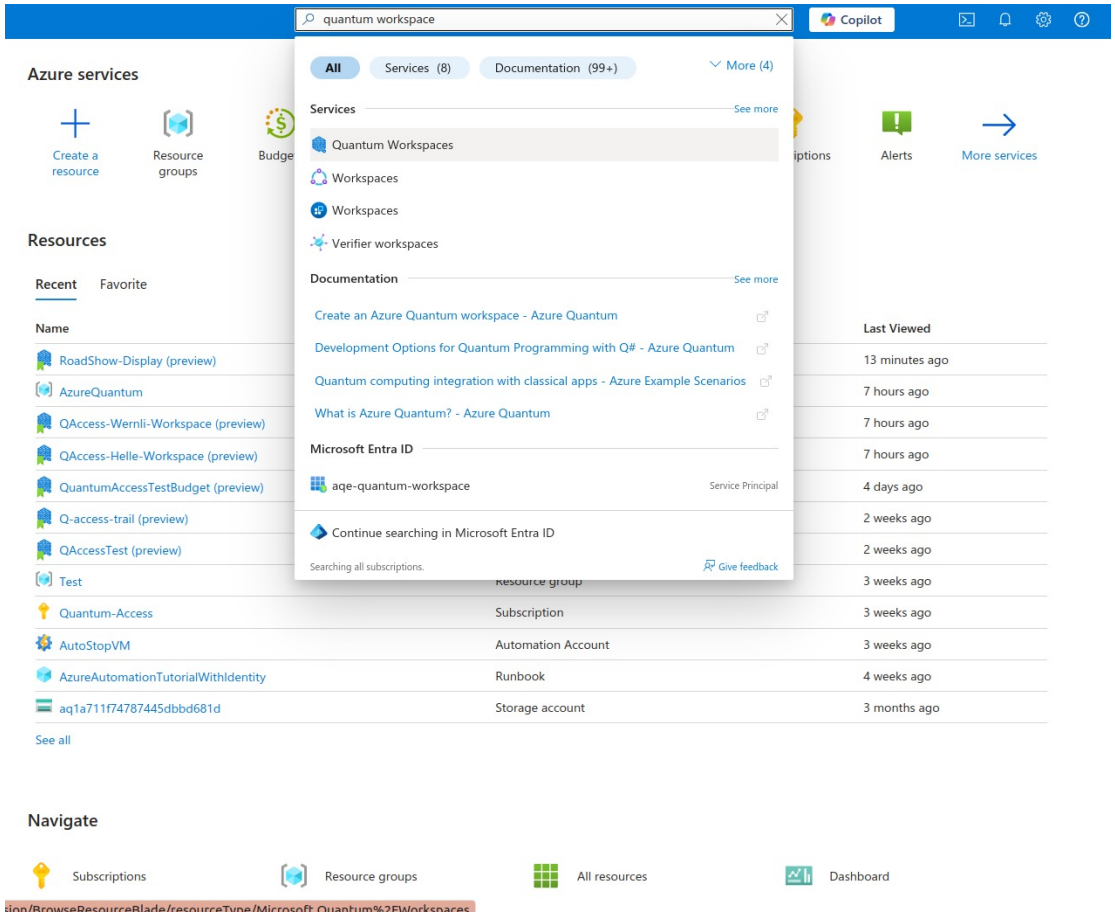
After submitting the form, a DeiC quantum expert will

a) Follow up and resolve any questions, execute the job on a QPU
b) Return the output of the job to the user
c) The job output follows Azure's format; users must handle their own post-processing

Step-by-step Demo of Using Azure – Group 2 Users

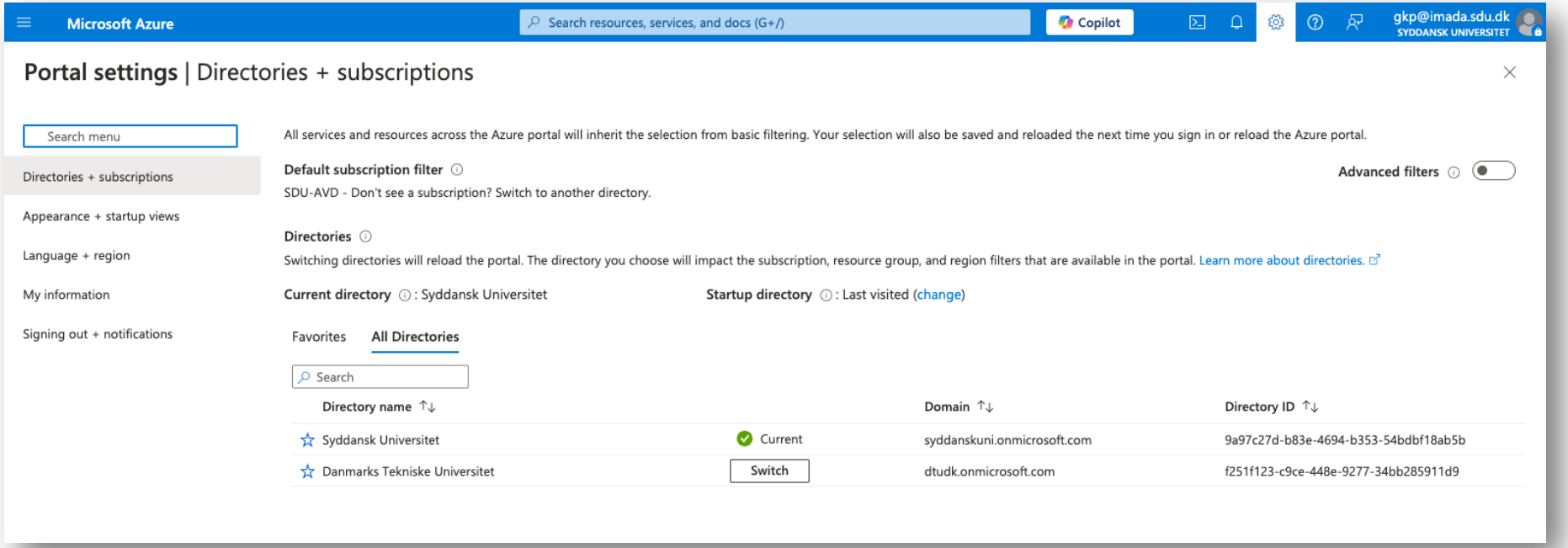
1) **Log in to Azure**
   - Go to https://portal.azure.com
   - Use the credentials associated with your organization or Microsoft account

2) **Navigate to your Quantum Workspace**
   - Use the search bar at the top to find “Quantum Workspaces.
   - You must be in the DTU directory to access resources allocated from DeiC’s Q-Access initiative.



Accessing Allocated Resources for Users in Group 2

Note: You must be in the DTU directory to access resources allocated from DeiC's Q-Access initiative.



The Quantum Workspace Overview

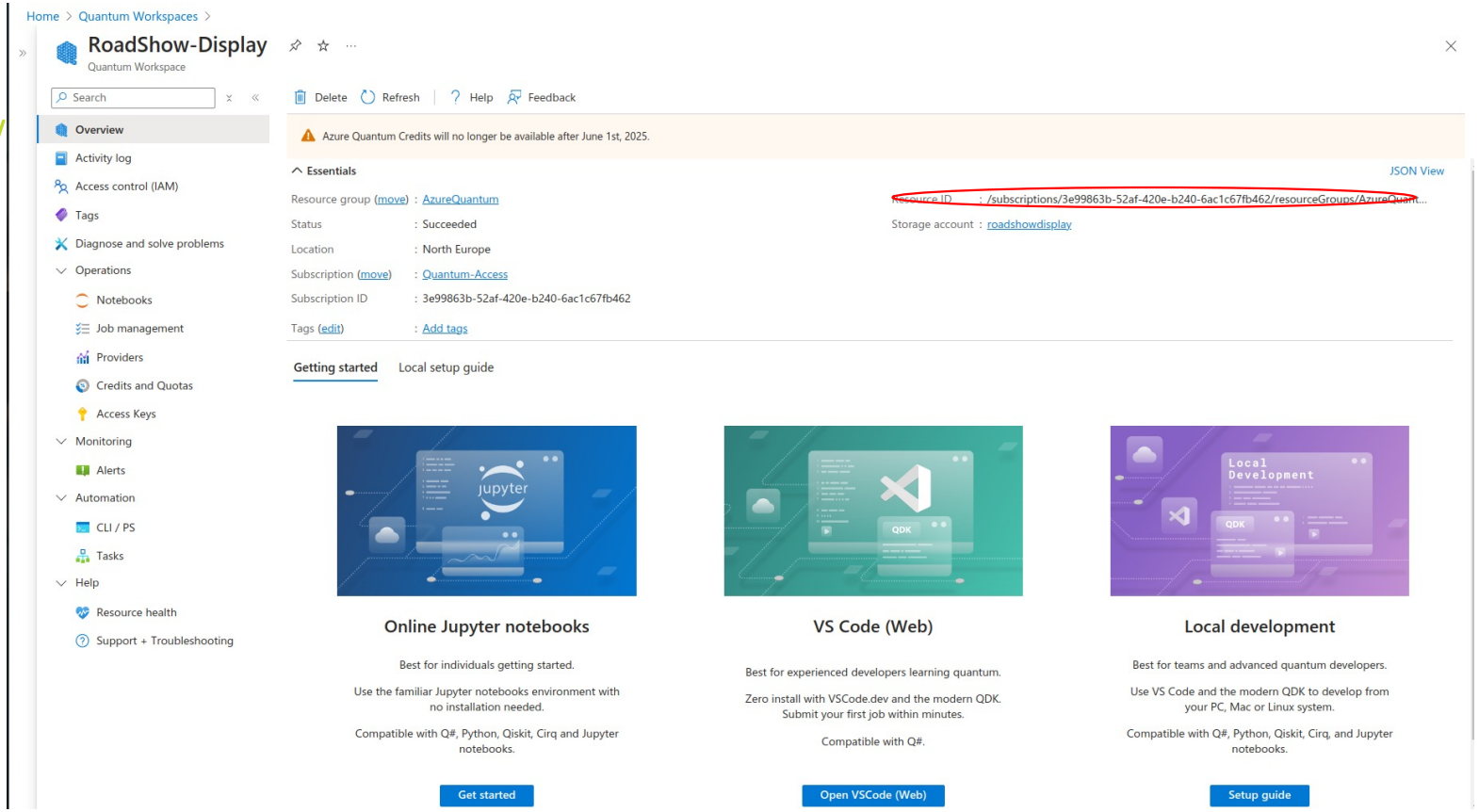
Workspace Essentials:

- **Displays general workspace info:**

  Subscription ID, status, resource group, region.

- **Contains key inputs to job initiative:**

  resource_id, location

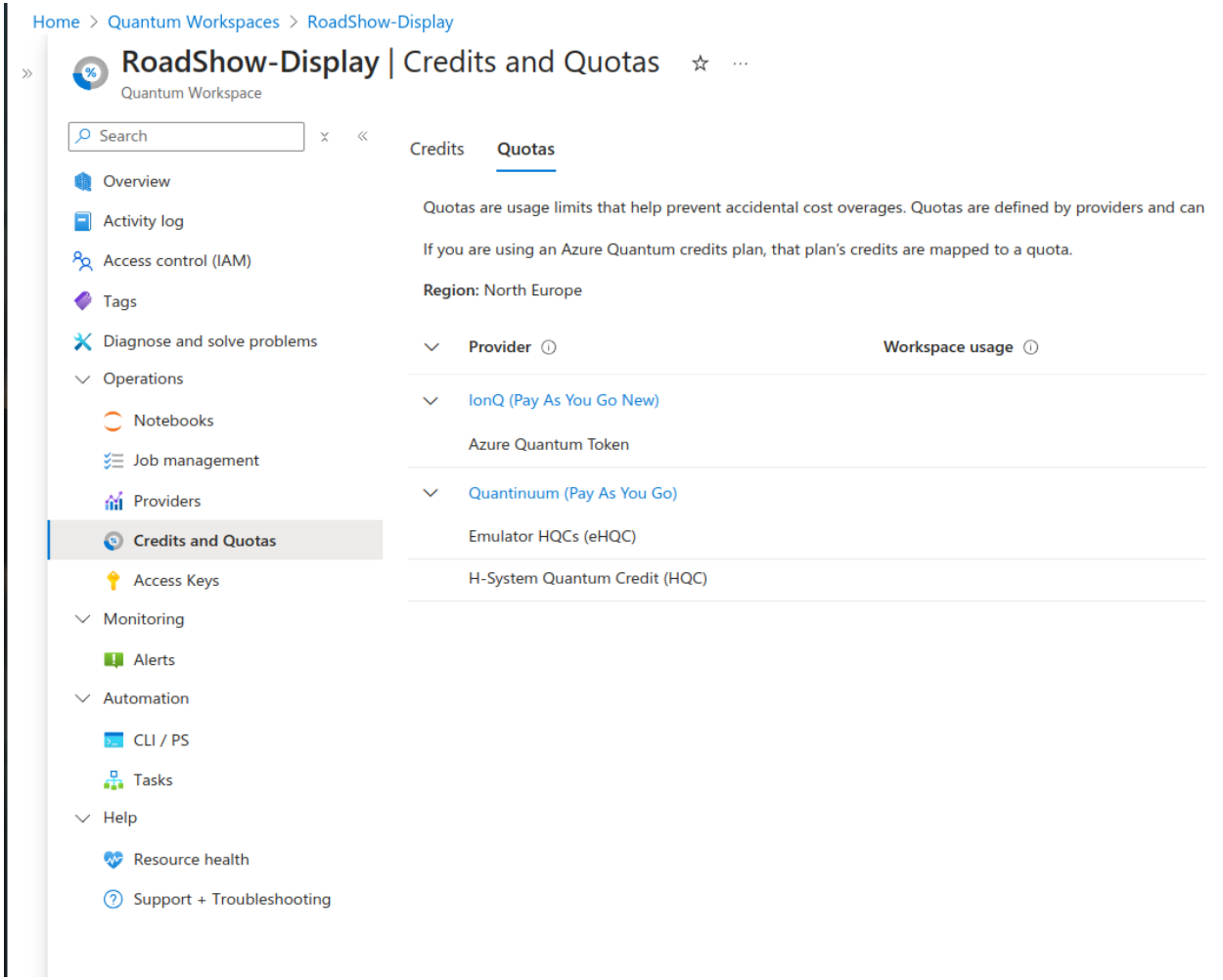



```
from azure.quantum import Workspace
from azure.quantum.qiskit import AzureQuantumProvider

workspace = Workspace(
            resource_id = "/subscriptions/3e99863b-52af-420e-b240-6ac1c67fb462/resourceGroups/AzureQuantum/providers/Microsoft.Quantum/Workspaces/RoadShow-Display",
            location = "northeurope")

provider = AzureQuantumProvider(workspace)
```

The Providers Tab

1. **List of Allocated Providers**
   - Status of providers (see next slides).
   - Management of providers (done by DeiC).

2. **Credits & Quotas**
   - Shows the whole DeiC's plan usage (not your personal allocation), because quota allocation happens at the subscription level.



Azure Provider Status Updates

- DeiC's quantum department will give **monthly updates** on the status of Azure's quantum providers, as well as communicate with Microsoft and the providers to ensure full transparency on QPU availability.

Azure Status Update: February 2025

IonQ

Aria-1 and Aria-2 are unavailable due to "planned and unplanned maintenance" and are expected to be down until February 13 and March 28 respectively, but the IonQ simulator is still available.

Quantinuum

H1-1, the syntax checker, and emulator are all available. Note that reported average queue times are unreliable due to Quantinuum's uptime schedule of 1:00 – 10:00 am UTC+1 for running jobs.

Rigetti

Ankaa-9q-3, Ankaa-3, and the simulator are all available. However, Ankaa-3 will not show up as a target unless you are running the latest version of the Azure Quantum Python library (https://pypi.org/project/azure-quantum/2.3.0/).

Pasqal

Pasqal is still in private preview and is not currently available through DeiC's provided access.

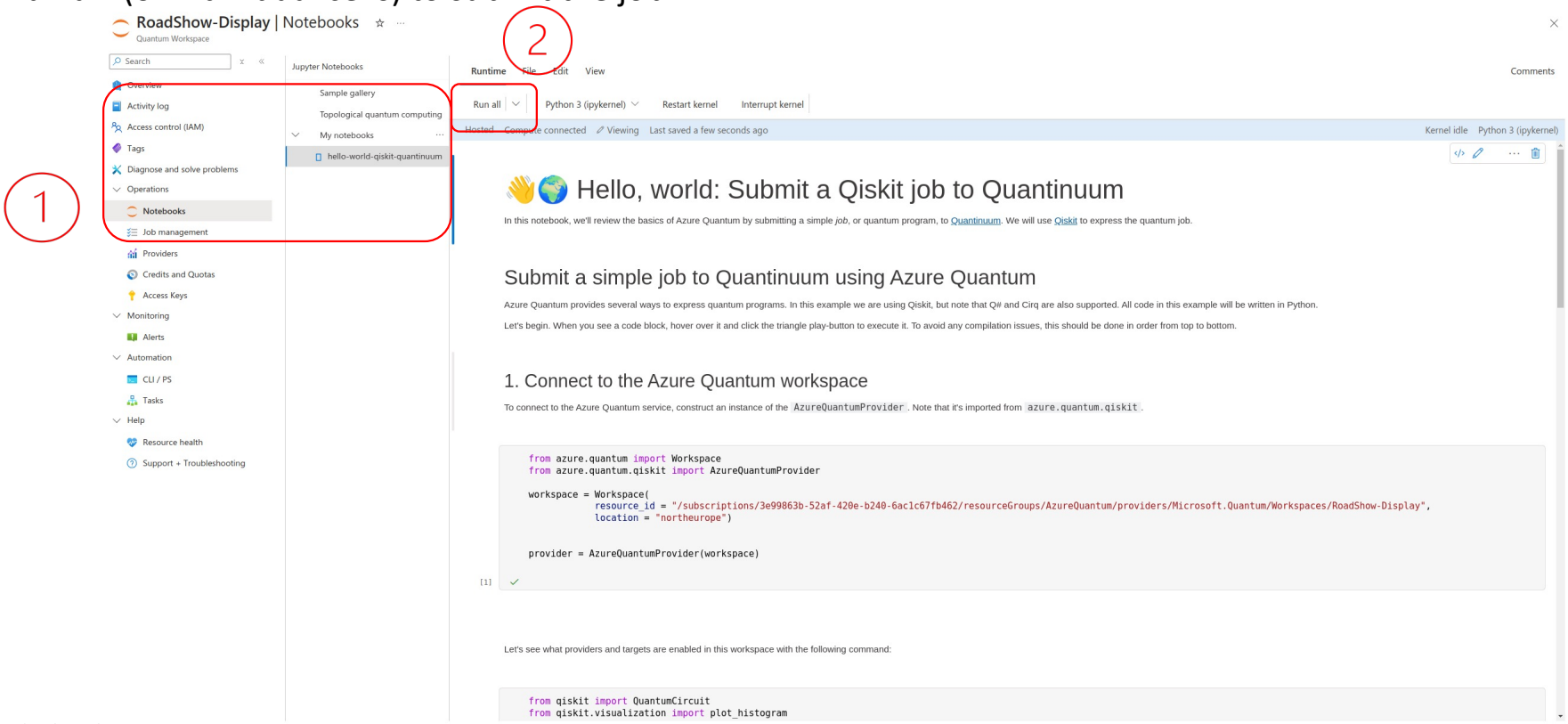
Azure Provider Status Updates – March 4, 2025

IonQ IonQ	Quantum Computing	Pay As You Go New	✓	Available	
ionq.qpu.aria-1				Available	3m
ionq.qpu.aria-2				Unavailable	N/A
ionq.simulator				Available	<1m
Quantinuum Quantinuum	Quantum Computing	Pay As You Go	✓	Available	
quantinuum.qpu.h1-1				Available	13h 2m
quantinuum.sim.h1-1sc				Available	<1m
quantinuum.sim.h1-1e				Available	1h 23m
Rigetti Quantum Rigetti Computing	Quantum Computing	Pay As You Go	✓	Available	
rigetti.sim.qvm				Degraded	<1m
rigetti.qpu.ankaa-3				Available	<1m

Submitting Job – online Jupyter notebook

In the left-hand panel of the workspace, click on **“Operations”**

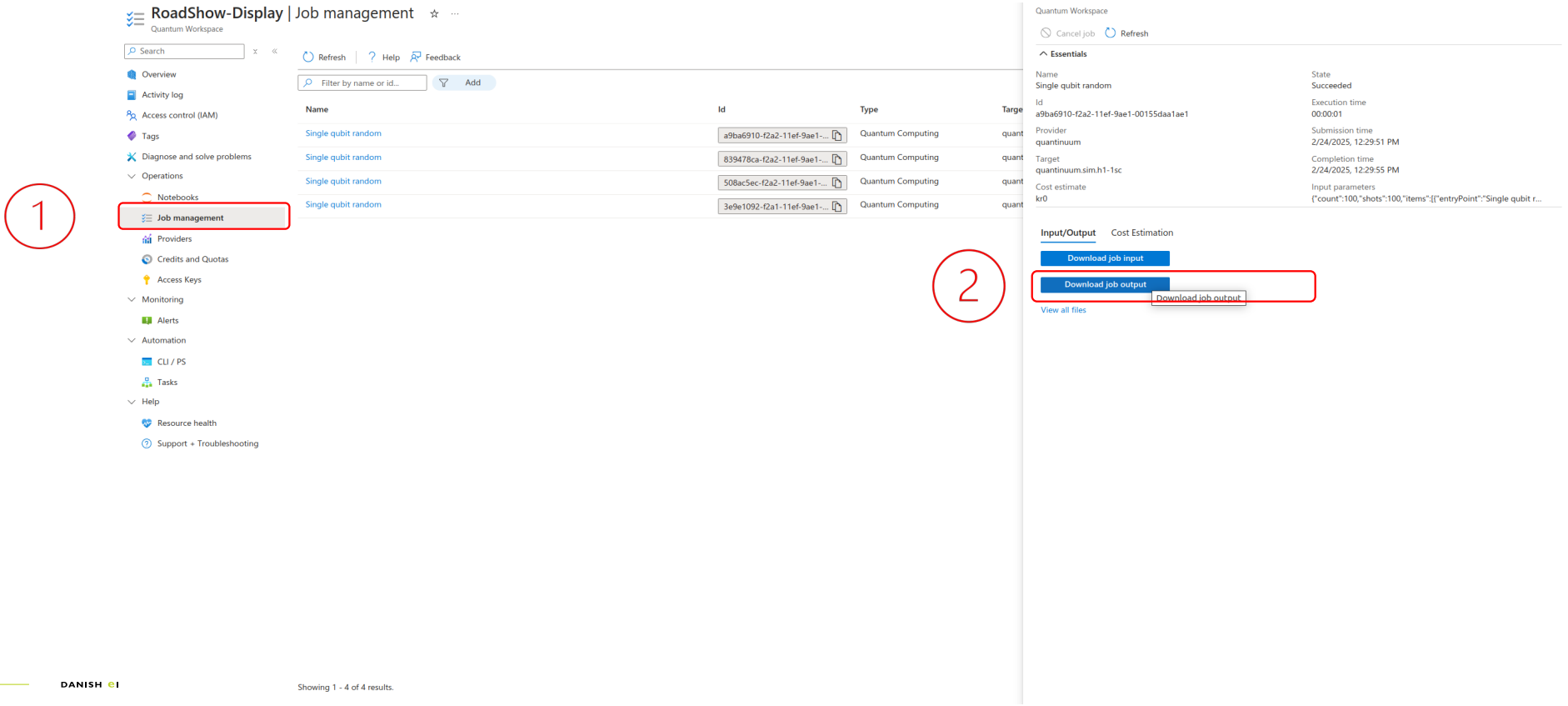
1) Click 'Notebook' on the scroll down menu
   a. Provide necessary parameters of the script to be used for the job
2) Click 'Run all' (or individual cells) to submit the job



Viewing Job Results

1) Select Your Job in the “**Job management**” list.

2) Download Button: Allows you to **export** results locally as JSON format



Pricing plans for Azure Quantum providers

- **Price Model 1 - usage unit** counted by an explicit formula depends on number of operations and shots

QUANTINUUM $HQC = 5 + C(N_{1q} + 10N_{2q} + 5N_m)/5000$ • 1 HQC = $ 12.5 (15)

IONQ $AQT = m + 0.000220 \cdot (N_{1q} \cdot C) + 0.000975 \cdot (N_{2q} \cdot C)$

- N_{1q} is the number of single-qubit operations in a circuit.
- N_{2q} is the number of native two-qubit operations in a circuit. Native gate is equivalent to CNOT up to several single-qubit gates.
- N_m is the number of state preparation and measurement (SPAM) operations in a circuit including initial implicit state preparation and any intermediate and final measurements and state resets.
- C is the shot count.

For IonQ:
- $ 0.000220 / 1-qubit-gate shot
- $ 0.000975 / 2-qubit-gate shot

m is the minimum price per program execution

- $ 97.50 if error mitigation is on
- $ 12.4166 if error mitigation is off

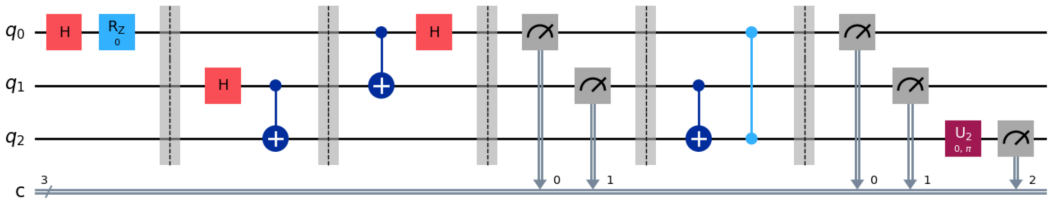
- **Price Model 2 - charges for job execution time** on their quantum processors

rigetti

- USD 0.013 per 10-millisecond increment of job execution time

Example: Quantum Teleportation

- Designing circuits
- Estimating cost
- Submitting jobs
- Interpreting results




```python
from qiskit import QuantumCircuit

def initialize_state(theta):
    qc = QuantumCircuit(1, name='initialize_state')
    qc.h(0)
    qc.rz(theta, 0)
    return qc

def create_Bell_pair():
    qc = QuantumCircuit(2, name='create_Bell_pair')
    qc.h(0)
    qc.cx(0,1)
    return qc

def entangle_with_Bell_pair():
    qc = QuantumCircuit(2, name='entangle_with_Bell_pair')
    qc.cx(0,1)
    qc.h(0)
    return qc

def measure_and_communicate_classically():
    qc = QuantumCircuit(2, 2, name='measure_and_communicate_classically')
    qc.measure([0,1], [0,1])
    return qc

def quantum_teleportation():
    qc = QuantumCircuit(3, name='quantum_teleportation')
    qc.cx(1,2)
    qc.cz(0,2)
    return qc
```

Azure Local Development using VS Code

See our DeiC quantum consultant's screen.

DeiC Q-Access Roadshow

March 5, 2025

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Resources

- Q-Access Website: https://deic.dk/da/q-access

- IBM Quantum Learn: https://learning.quantum.ibm.com/
- Qiskit Documentation: https://docs.quantum.ibm.com/
- Microsoft Azure Documentation: https://learn.microsoft.com/en-us/azure/quantum/
- Quantinuum TKET Documentation: https://docs.quantinuum.com/tket/

- Xanadu's Strawberry Fields: https://strawberryfields.ai/
- Tensorflow Quantum Machine Learning: https://www.tensorflow.org/quantum

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Thank you all for listening!

Stick around for a Q&A session and hands-on support
with the Q-Access Team and Microsoft.