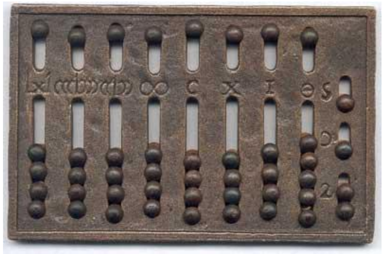
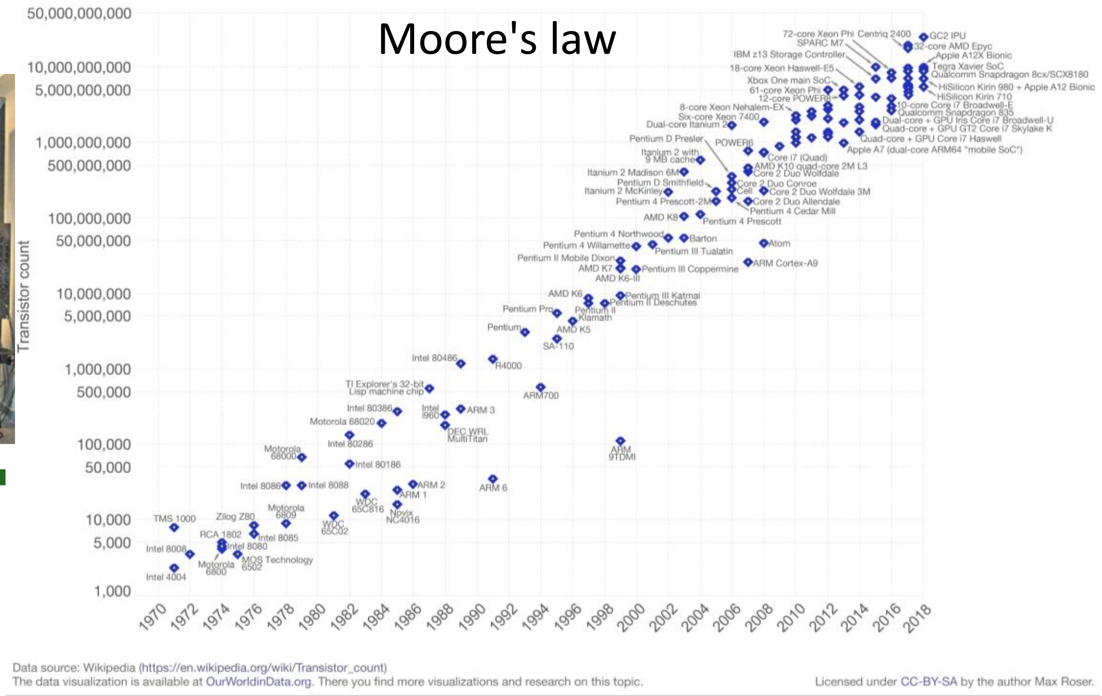
Quantum Computing at KFUPM
Present and Future

History of Computing





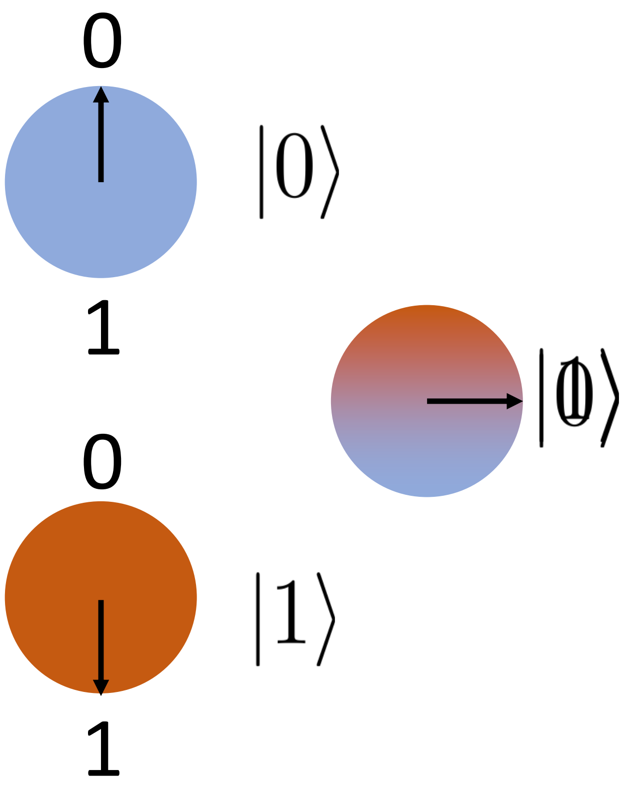
Why..

Simulating Physics with Computers

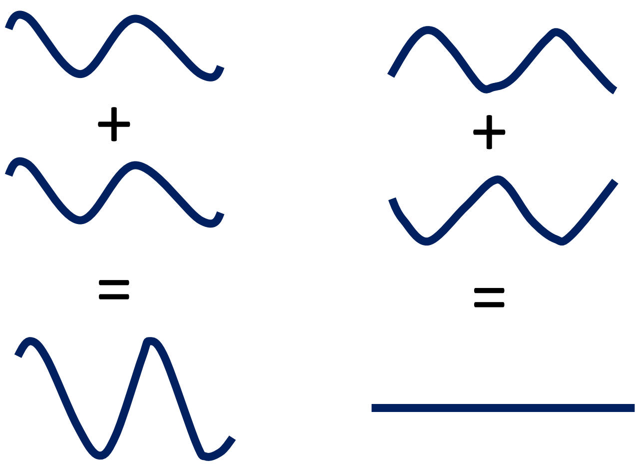
“The first question is, What kind of computer are we going to use to simulate physics?
….
Therefore my question is, Can physics be simulated by a universal computer? “

How..

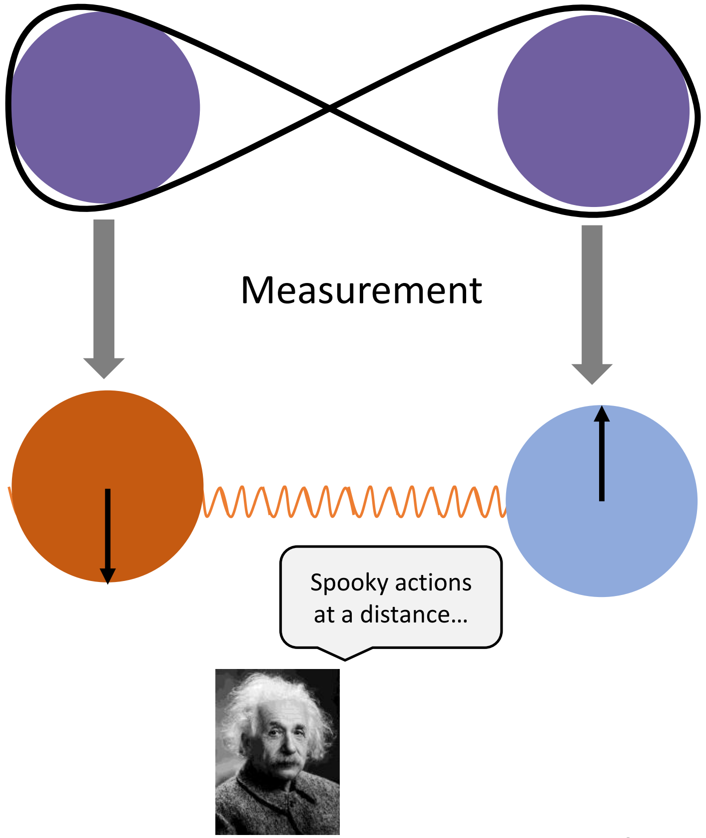
Superposition



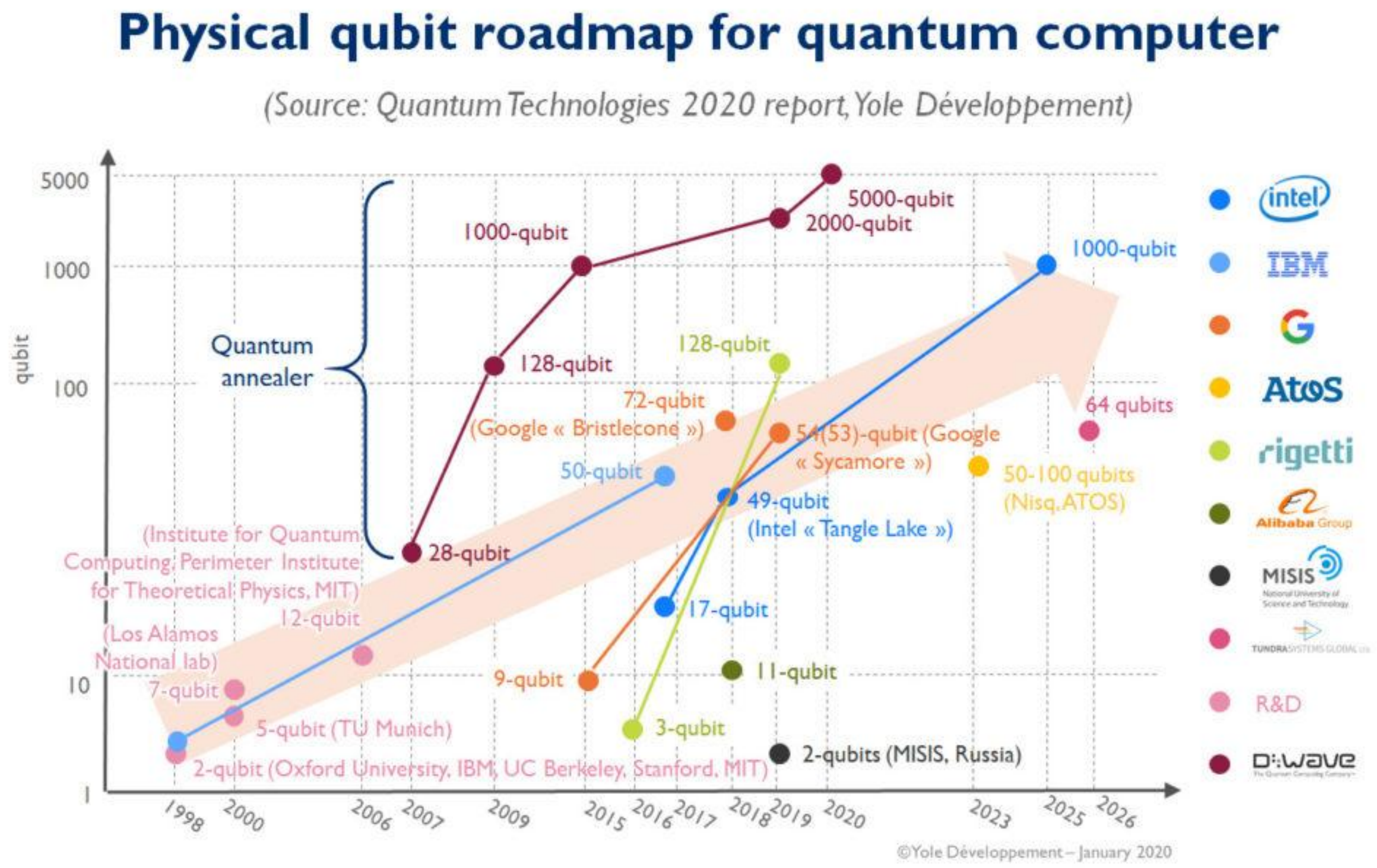
Interference



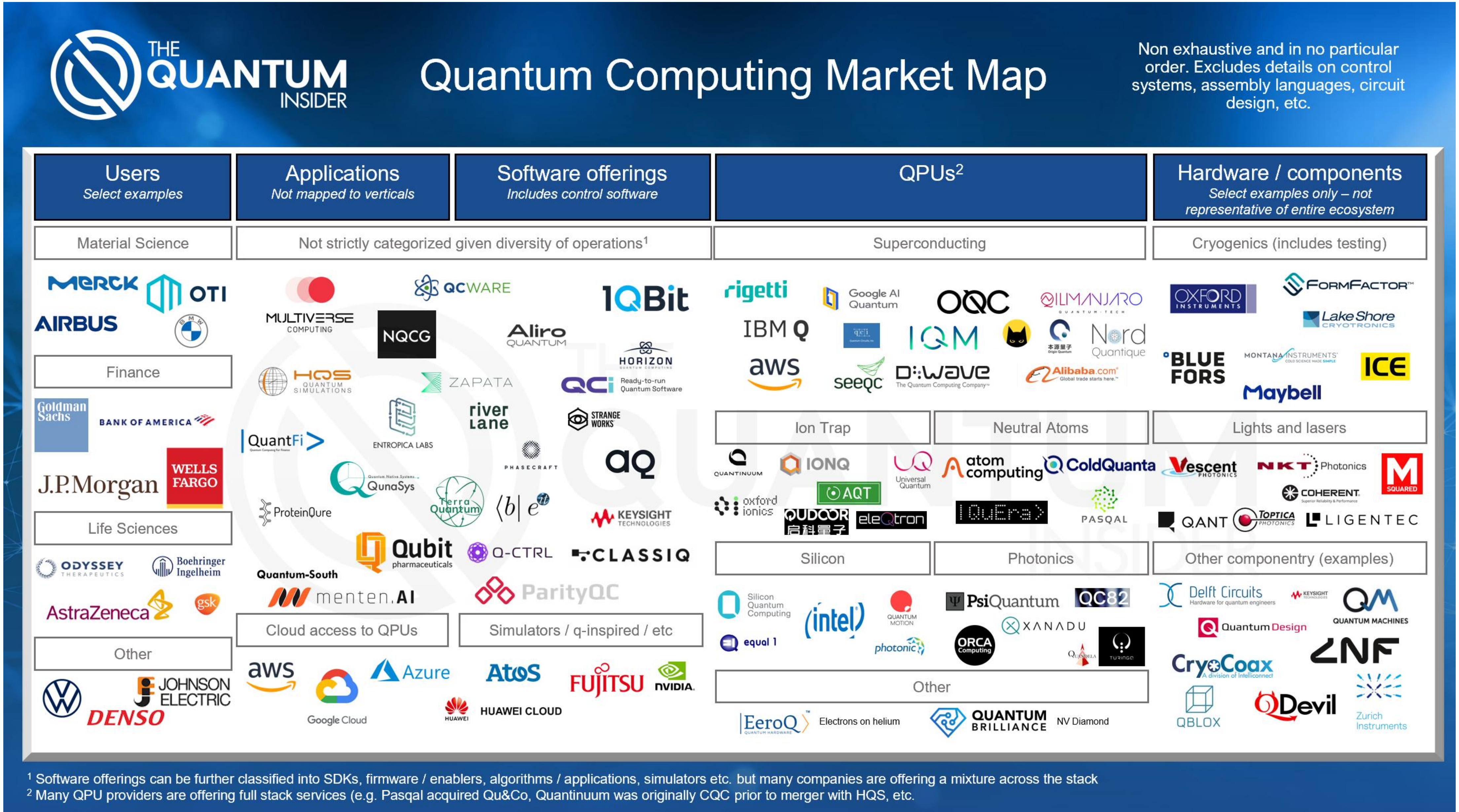
Entanglement



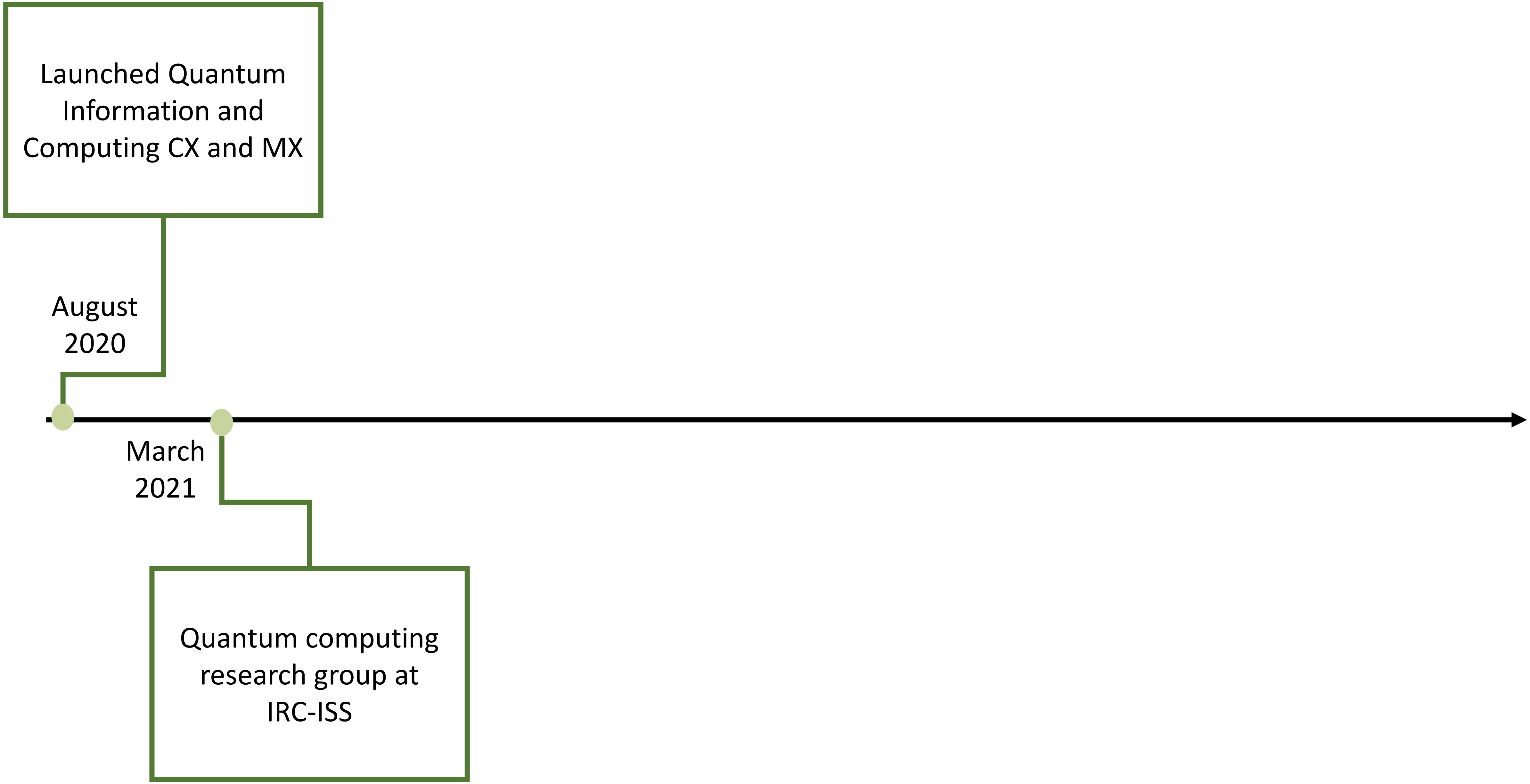
Between Hope and Hype



Quantum Computing Landscape



Quantum Computing at KFUPM


Launched Quantum Information and Computing CX and MX
August 2020
March 2021
Quantum computing research group at IRC-ISS

Quantum Computing and Technology Group in IRC-ISS

PHYSICS COMPUTING


Dr. Saleem Rao


Dr. Burhan Saifaddin


Dr. Adel Abbout


Dr. Khalil Harrabi


Dr. Raditya Weda


Dr. Saeed Al-Marzoog


Dr. Sabre El-Atrash

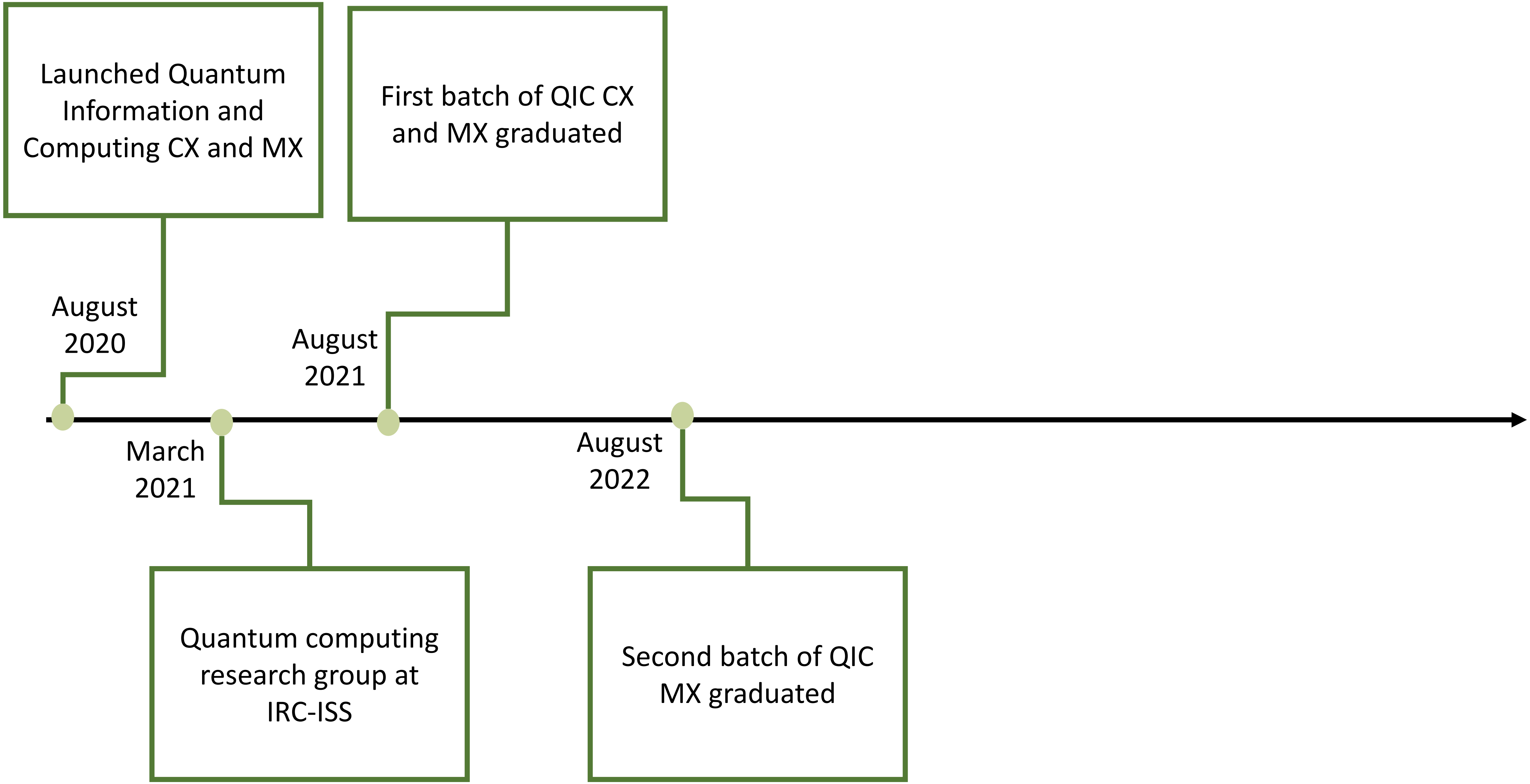
Dr. Abdulwahab Alluhaibi

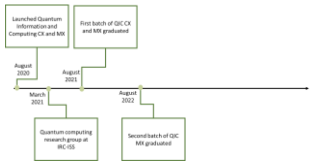

Dr. Sultan Al-Muhammadi


Dr. Muhamad Felemban


Dr. Abdulaziz Tabbakh

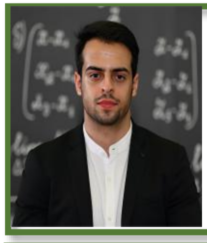
Dr. Alawi Alsaggaf


Launched Quantum Information and Computing CX and MX
First batch of QIC CX and MX graduated
August 2020
August 2021
March 2021
August 2022
Quantum computing research group at IRC-ISS
Second batch of QIC MX graduated



Quantum Computing CX/MX Alumni

Muhammad Al-Saiyari
Team Lead, Quantum Valley
Saudi Aramco



Mohammed Alghadeer
PhD Candidate (Rhodes Scholar)
University of Oxford

Sarah Alwadaah
Quantum Computing Group
Saudi Aramco

Shuroog Alogbi
Lab Engineer, IR-ISS
KFUPM

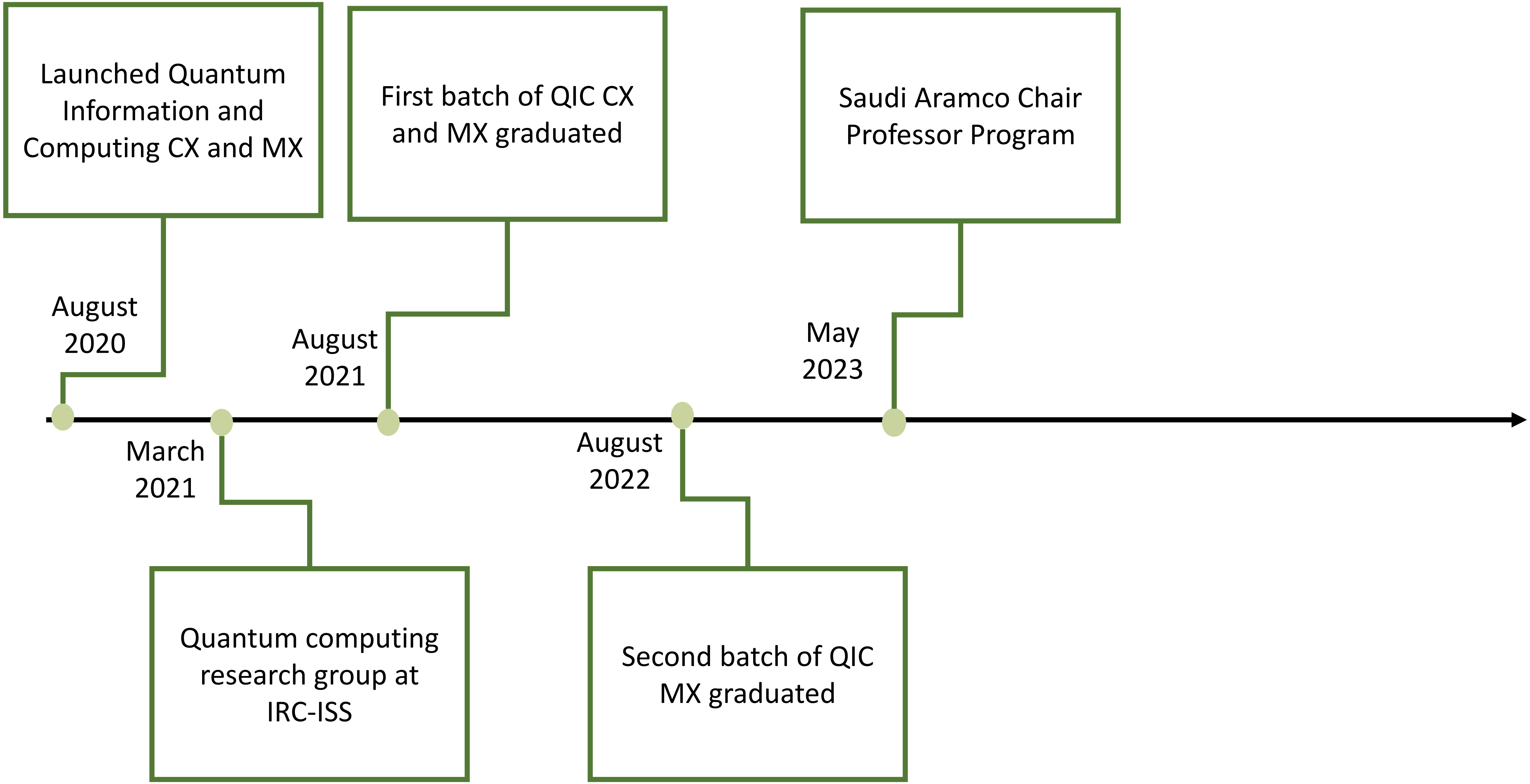
Rawan Eraqi
Technical Business Developer
PASQAL

Hajar Almutairi
Cryptography Specialist
(Confidential Government)

Fahad Almunif
Quantum Computing Group
Saudi Aramco

Abdulelah Almimoni
Cryptography Researcher, KSU

*Total number of graduates from CX and MX programs is 35
**Alumni studying or working in jobs related to quantum computing


Launched Quantum Information and Computing CX and MX
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First batch of QIC CX and MX graduated
August 2021
Second batch of QIC MX graduated
August 2022
Saudi Aramco Chair Professor Program
May 2023

Chair Professor Program Objectives

Chair Professor

Academic

- Build educational capacity
- Teaching and developing courses
- Develop local talent

Community

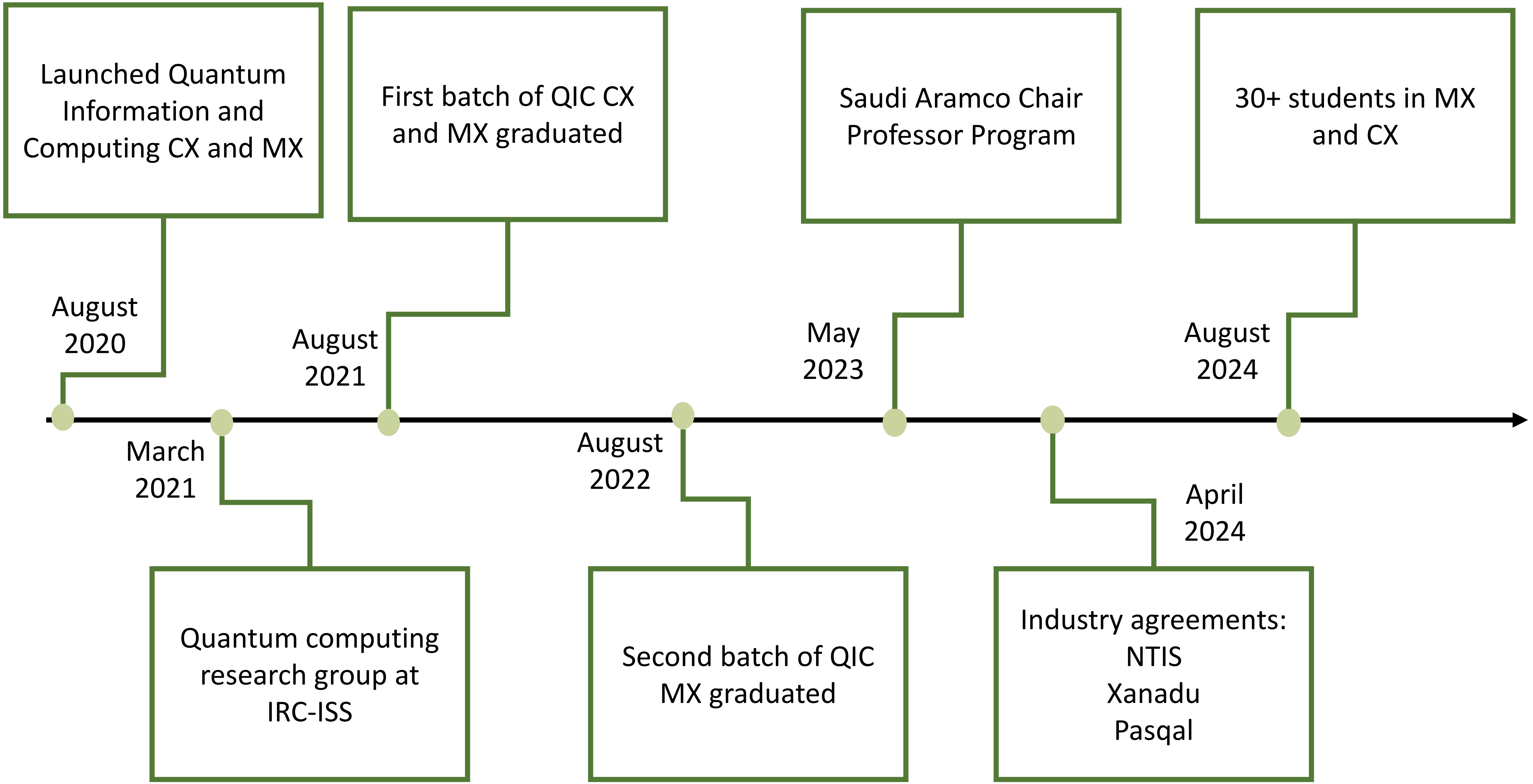
- Seminars, conference, and professional development programs and short courses
- Introductory and advance short courses

Research

- Establish and lead research group
- Advance the global knowledge in QC

Industry

Steer R&D in solving problems related to Saudi Aramco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First batch of QIC CX and MX graduated
August 2022
Second batch of QIC MX graduated
May 2023
Saudi Aramco Chair Professor Program
April 2024
Industry agreements:
NTIS
Xanadu
Pasqal
August 2024
30+ students in MX and CX

MX Program

Foundation

First semester

- PHYS 512 Introduction to Quantum Information and Computing
- ICS 560 Foundations of Quantum Computing

Hardware

Second semester

- PHYS 514 Quantum Hardware
- COE 530 Quantum Computers & Architecture

Software and applications

Third semester

- ICS 561 Quantum Algorithms
- COE 531 Advanced Quantum Computing and Communication

Advanced topics

Fourth semester

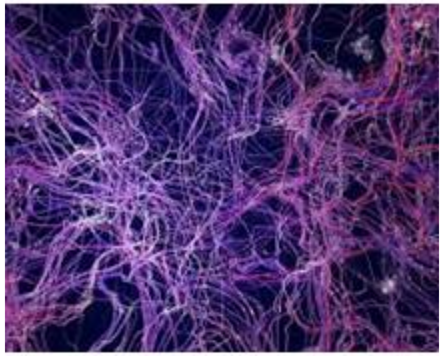
- ICS 562 Quantum Cryptography
- COE 532 Emerging Quantum Technolgies

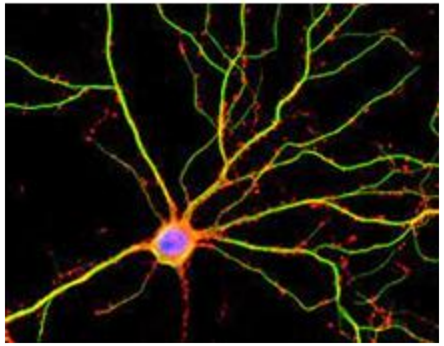
Third and Fourth semesters

- COE 619 Project

Ongoing Projects

Artificial Superconducting Neuron

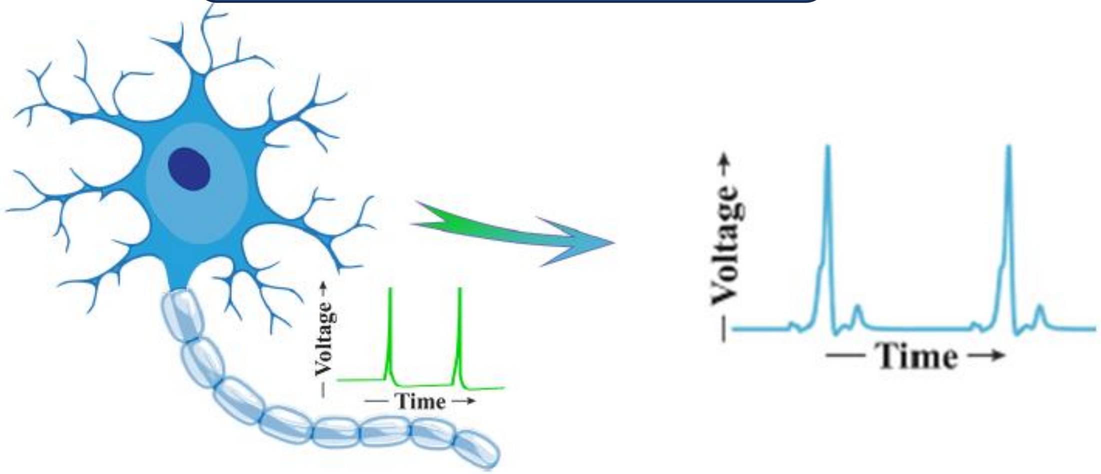




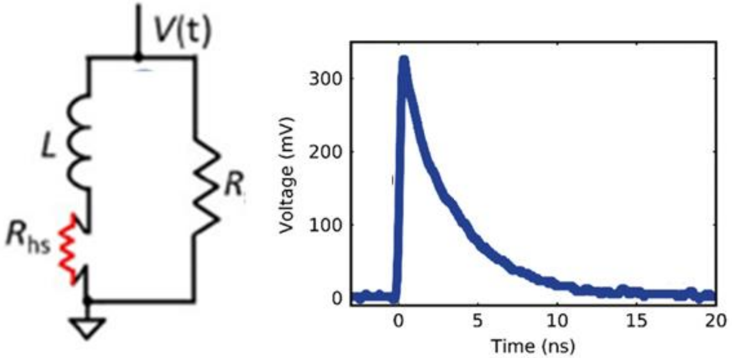
Neurons in the human brain transmit information through electrical impulses, optimizing energy use. Similarly, superconducting wires transmit electrical signals without resistance, minimizing energy loss during conduction.

Neurons transmit and process signals in networks, enabling complex computations in the brain. Similarly, superconducting wires can form networks in quantum computing systems, facilitating complex information processing and computations.

Biological Neuron



Superconducting Wire



PI: Prof. Khalil Harrabi

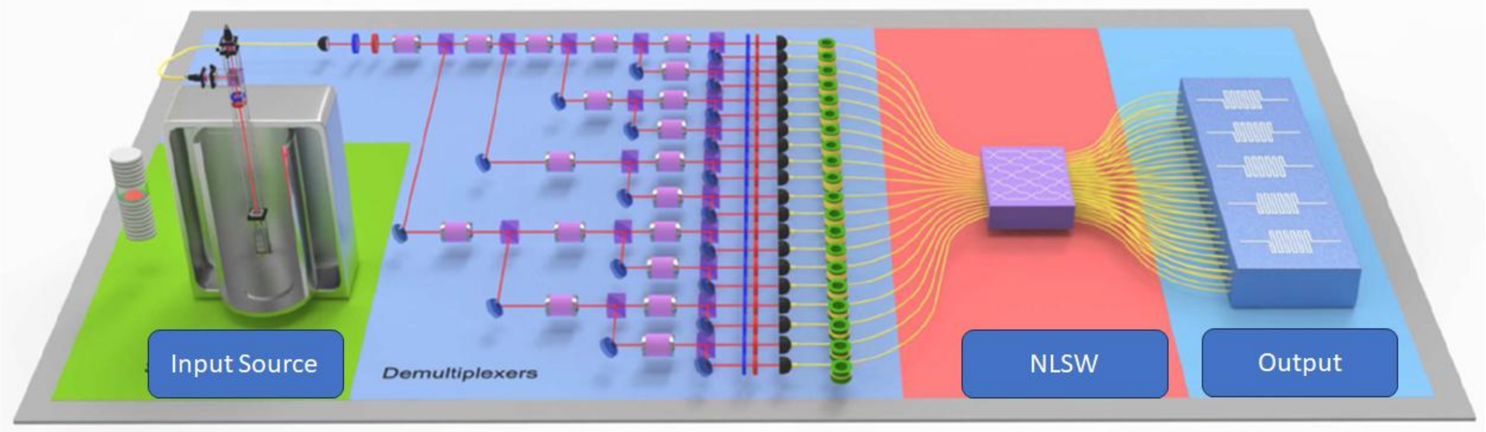
Future Directions:
Quantum Design

Aim to develop a prototype for:

Quantum Computing: Superconducting artificial neurons can be integrated into quantum computing networks, providing fast, energy-efficient processing for quantum machine learning and quantum neural networks. This could accelerate tasks like pattern recognition and optimization in quantum systems

Neuromorphic Computing: Superconducting neurons can mimic the behavior of biological neurons, enabling the development of neuromorphic computing systems. These systems aim to replicate the efficiency and adaptability of the human brain, offering improvements in AI, machine learning, and real-time decision-making tasks.

Quantum cryptography: Quantum cryptography using the nonlinear inductance of superconducting wires enables secure communication by controlling quantum states. This allows for tamper-proof encryption, as any eavesdropping attempt alters the quantum states, ensuring secure quantum key distribution (QKD). Superconducting circuits, like Josephson junctions, enhance the sensitivity and reliability of this process.



PI: Prof. Khalil Harrabi

Mitigation of Coherent Losses in Superconducting Quantum Circuits

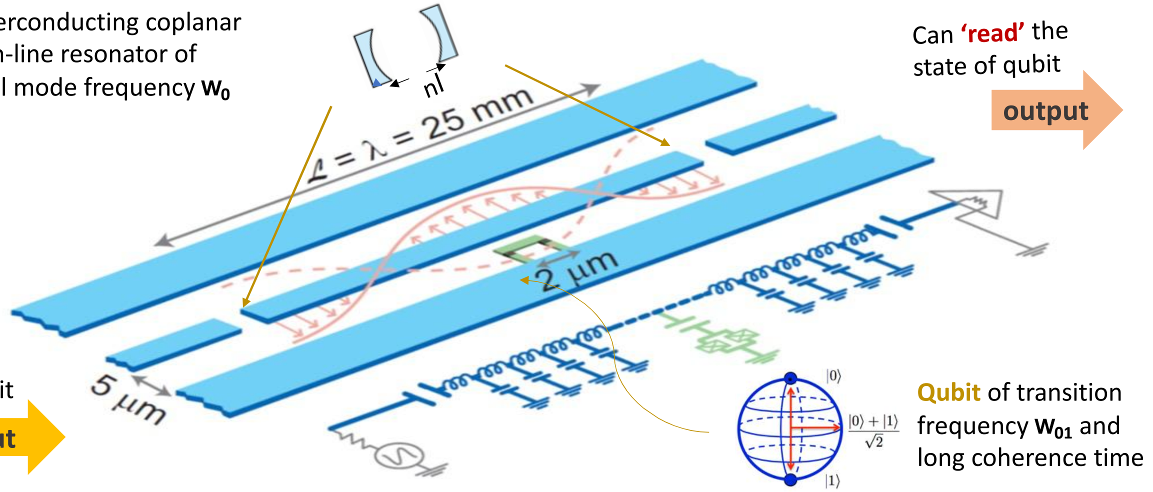
'**Cavity**' superconducting coplanar transmission-line resonator of fundamental mode frequency $\mathbf{W_0}$

Can **'read'** the state of qubit

output

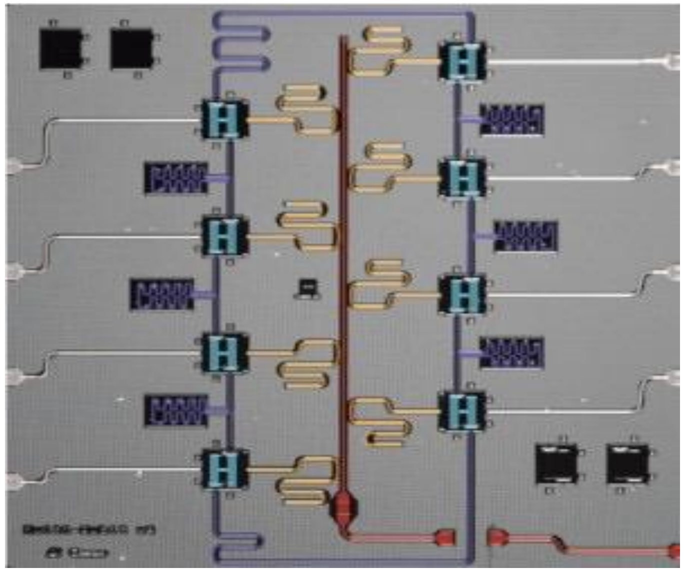
Can **flip** the state of qubit

Input



Qubit of transition frequency $\mathbf{W_{01}}$ and long coherence time

Figure. 1 Coupling between Qubits and CPW resonators



- **8 - Transman Qubits (Charge Qubit)**
- CPW resonators :
  - **Qubit-Qubit coupling bus resonators**
  - **Single-Qubit readout resonators**
- **Microwave drive lines**
- **Feedline resonators**

Figure. 3 8-Qubits connected to superconducting resonators for controlling their quantum states that allow direct processing of information

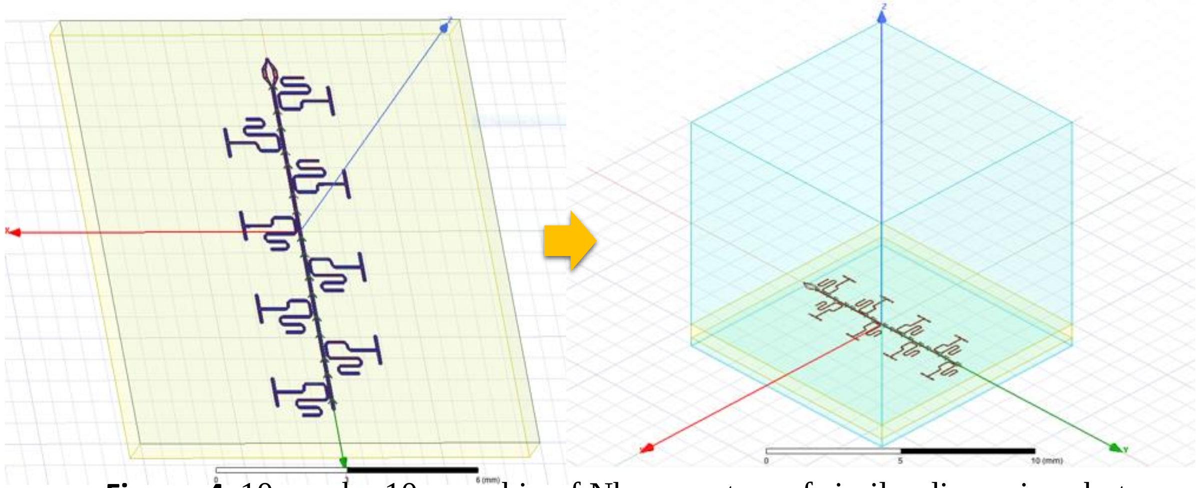
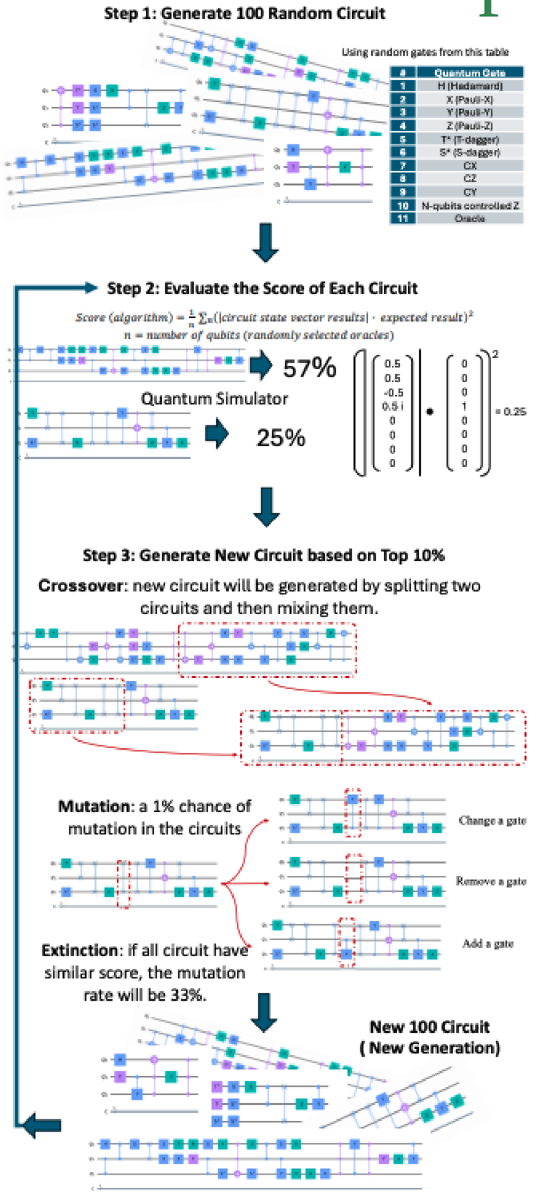


Figure. 4 10 mm by 10 mm chip of Nb resonators of similar dimensions but different positions on 674 µm thick Si substrate same as used in the 8-Qubit chip

PI: Dr. Saleem Rao

Discovery of Quantum Algorithms Using Genetic Algorithms: Exponential Speedup via Random Sampling*

Methodology



Results

Our experiments used a genetic algorithm to discover oracle-based quantum algorithms in circuits with 3 to 8 qubits. By reducing evaluation time complexity from $O(2^n)$ to $O(n)$, we efficiently optimized larger circuits.

•**Grover's Algorithm Discovery**: The genetic algorithm identified the first iteration of Grover's algorithm in multiple experiments, proving the effectiveness of our approach. Sample of found circuits is shown in **Figure 1**.

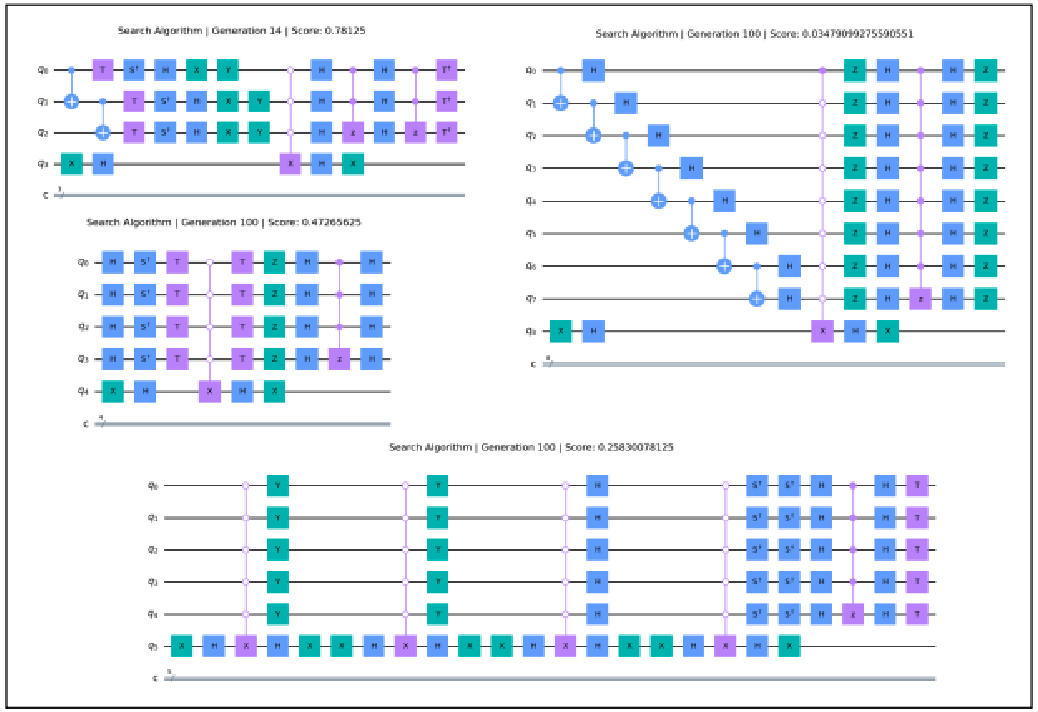


Figure 1: Sample of the best circuits found

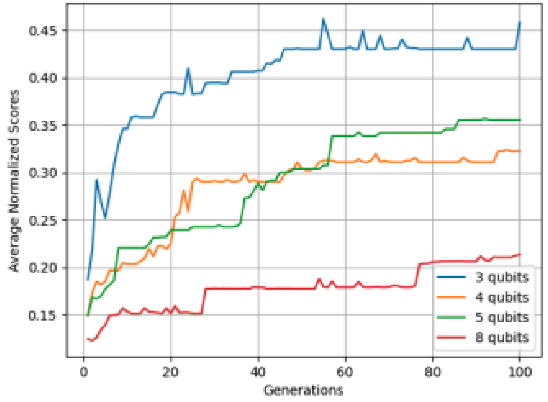


Figure 2: Average Normalized Scores Over Generations

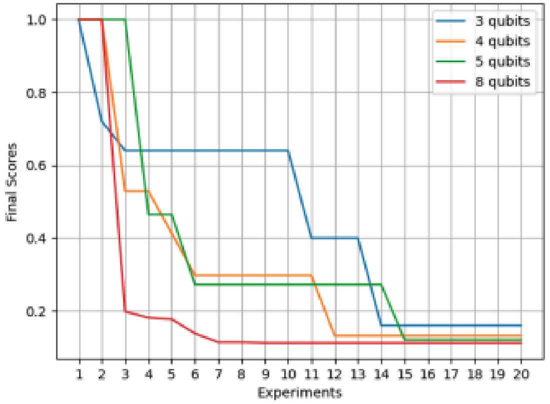


Figure 3: Final Normalized Scores of Each Experiment

PI: Tariq Almuqbil – MX Student

*Demo paper – IEEE QCE 2024

Quantum-speedup for Non-linear Partial Differential Equations

Problem Formulation

Governing Equations

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x}(\rho v) = 0$$

$$\frac{\partial}{\partial t}(\rho v) + \frac{\partial}{\partial x}(\rho v^2 + p - r) = 0$$

$$\frac{\partial}{\partial t}\left[\rho\left(e + \frac{v^2}{2}\right)\right] + \frac{\partial}{\partial x}\left[\rho v\left(e + \frac{v^2}{2}\right) + pv - \tau + \frac{\kappa \partial T}{\partial x}\right] = 0$$

After conservation → non-linear partial form:

$$\frac{\partial U}{\partial t} + \frac{\partial F[U, \frac{\partial U}{\partial x}]}{\partial x} = J[U]$$

Mathematical methods → non-linear ordinary form:

$$\frac{dU}{dt} = f(U)$$

By integrating over N_k intervals:

$$y_{i+1}(j) = y_i(j) + N_k \sum_{l=1}^{N_k - 1} \frac{h}{N_k} \int_0^1 \boldsymbol{f}\left(I_{i,l}(j,u)\right) du$$

Task: compute a bounded function $I(j,t)$ to approximate the exact solution $U(j,t) \approx y_{i+1}$ for a specific interval $0 \leq t \leq T$ with respect to the initial condition $I(j,0) = U(j,0) = U_0(J)$.

Experiments: Mean-Value Estimating Using QAEA

Initialize a quantum state that's in superposition → Define the probability distribution of measuring the target state → Measure and extract the estimated value

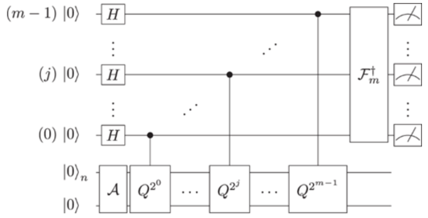


Fig. 1: QAEA circuit

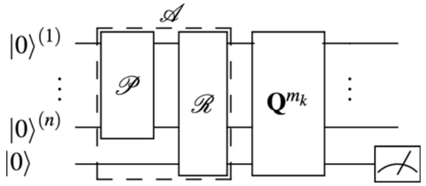


Fig. 2: Decomposed QAEA circuit

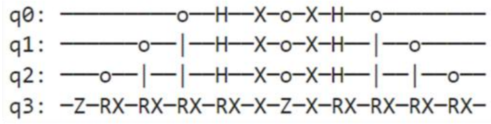


Fig. 3: 4-qubit quantum circuit implementing f

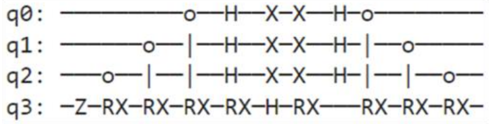


Fig. 4: Circuit Fig. 3 after applying gate merging technique

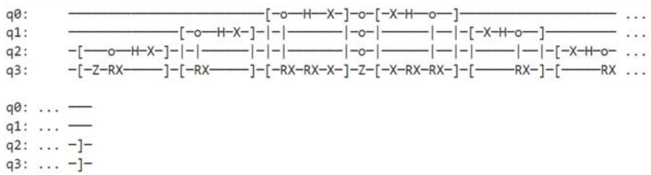


Fig. 5: Circuit Fig. 3 after applying gate fusing technique

***Qibo* Original Circuit**	
Number of Qubits	4
Circuit Depth	12
Number of Gates	24
Estimated Value	**0.27**
***Qibo* Optimized Circuit using Gate Merging**	
Number of Qubits	4
Circuit Depth	11
Number of Gates	22
Estimated Value	**0.27**
***Qibo* Optimized Circuit using Gate Fusing**	
Number of Qubits	4
Circuit Depth	7
Number of Gates	7
Estimated Value	**0.27**
***Qibo* Optimized Circuit using Both Methods**	
Number of Qubits	4
Circuit Depth	5
Number of Gates	5
Estimated Value	0.27
***Pennylane* Original Circuit**	
Number of Qubits	7
Number of Gates	842
Estimated Value	0.30

Table 1: Results of Simulation on Qibo and Pennylane platforms

PI: Shuroog Al-Ogbi – Researcher, IRC-ISS

Moving Forward

Phase I: Building Capability

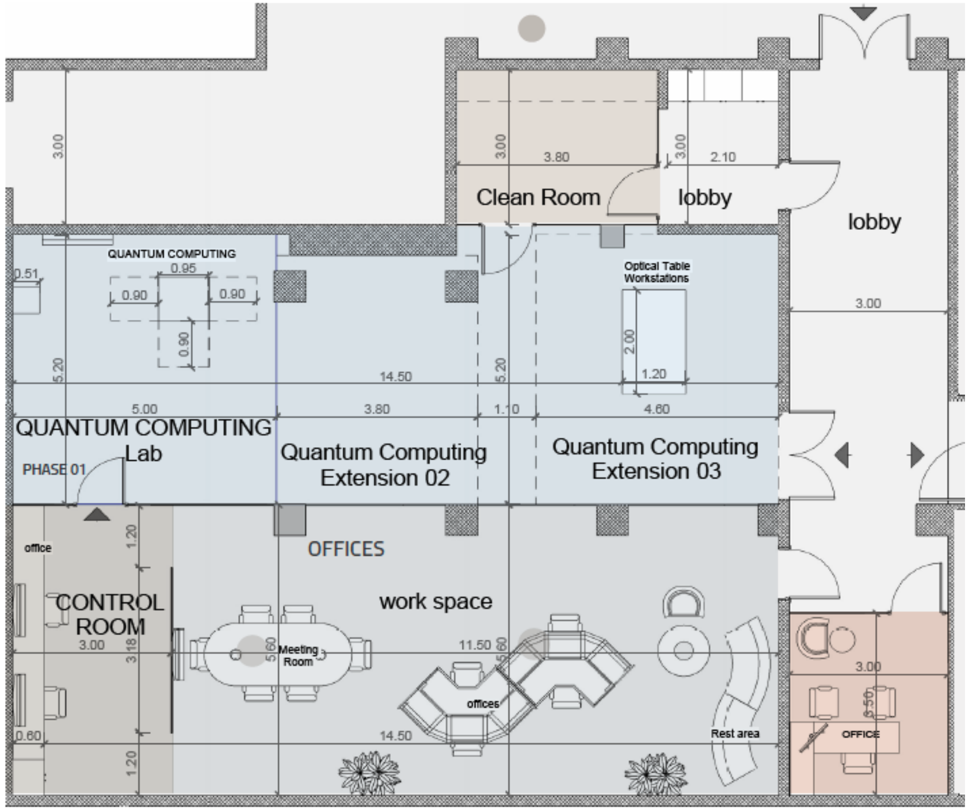
Faculty and Researchers

Graduate (PhD) Students

Facilities (Labs and infrastructure)

Superconducting Quantum System Lab

- This lab will be for research in superconducting based quantum systems
- The lab will used to characterize superconducting quantum chips, i.e., control and measure qubits



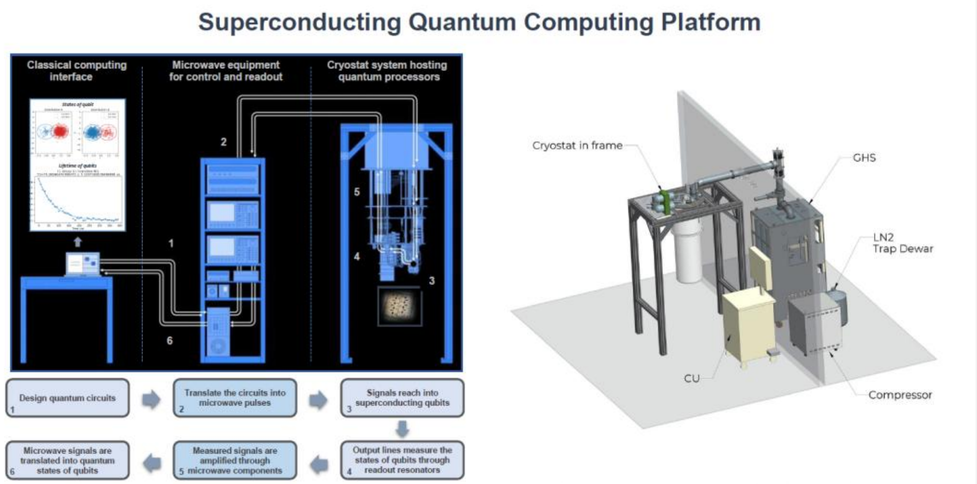


Figure: The general cycle for running a quantum experiment based on superconducting circuits. Classical interface is used to communicate with microwave equipment for control and readout. The measured signal is received back at the classical interface and analyzed.

Source: part of images is from IBM website

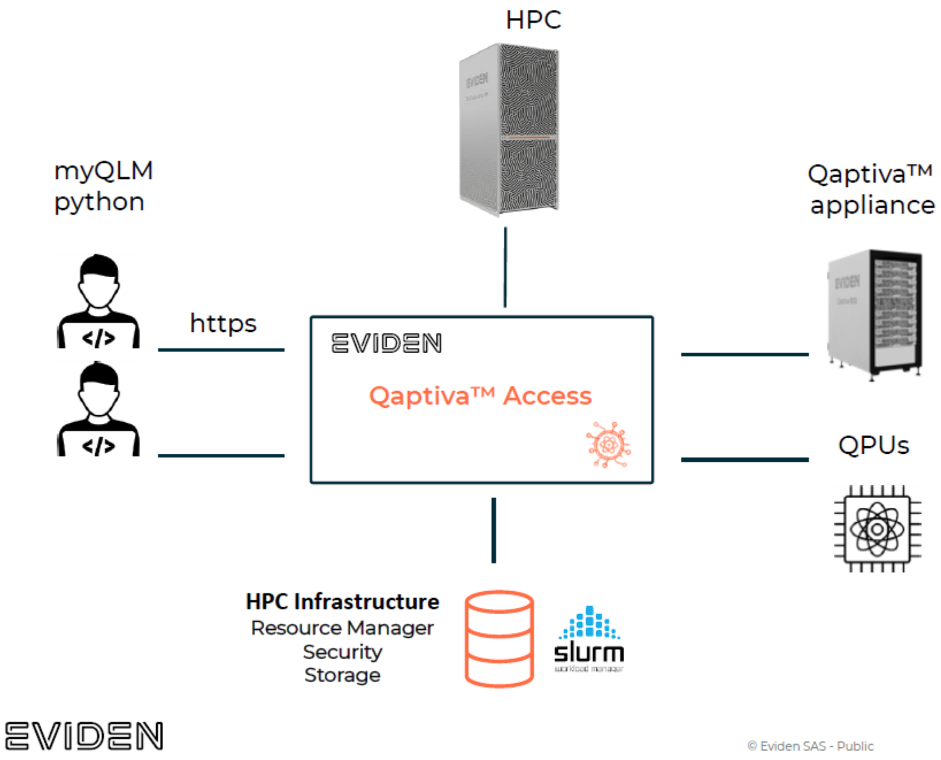
Figure: Standard layout system from BlueFors. CU is the control unit, GHS is the gas handling system and LN2 Trap Dewar where liquid Nitrogen need to be filled. The compressor requires water supply, and the cryostat frame holds the system and minimizes unwanted mechanical vibrations.

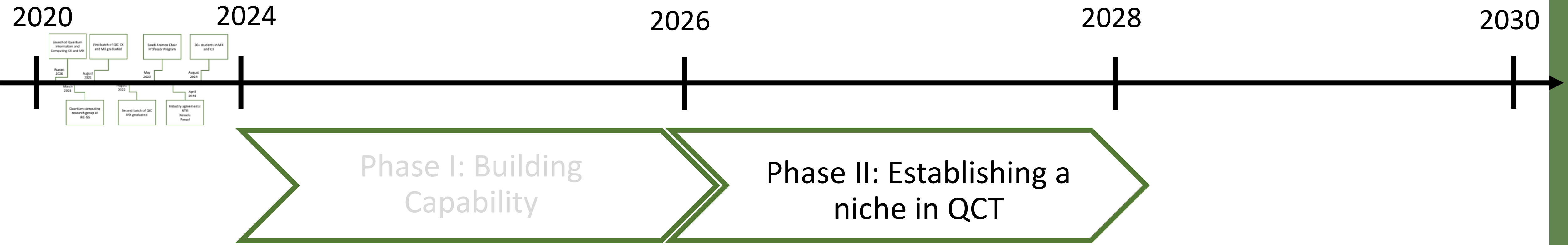
Source: part of images is from BlueFors website

Superconducting Quantum System Lab

Quantum Computing Lab

- The lab will be used to emulate quantum circuits for developing and testing quantum algorithms and applications
- Eventually, the emulators will interface with the superconducting quantum system to execute quantum algorithms on our own quantum superconducting chips





- Collaboration with national universities and research institutes

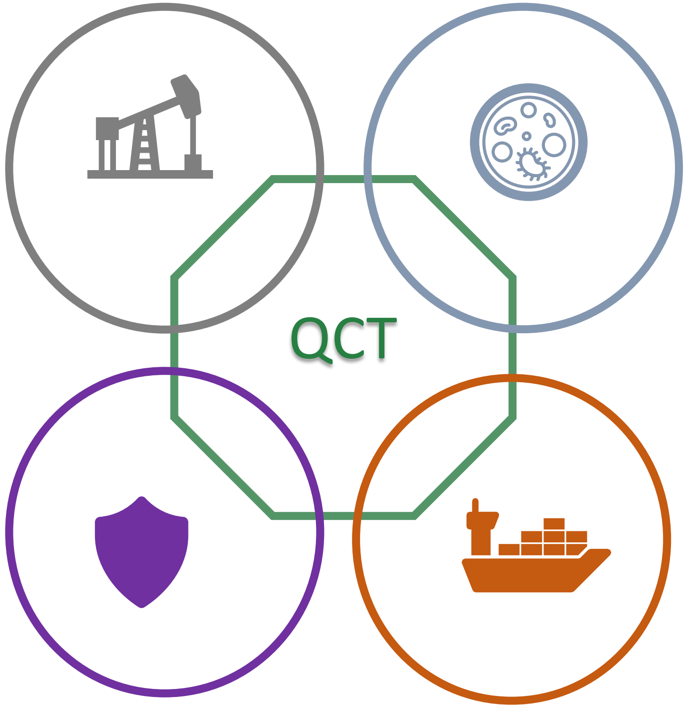
KACST, King Abdullah University of Science and Technology, King Saud University, Jazan University

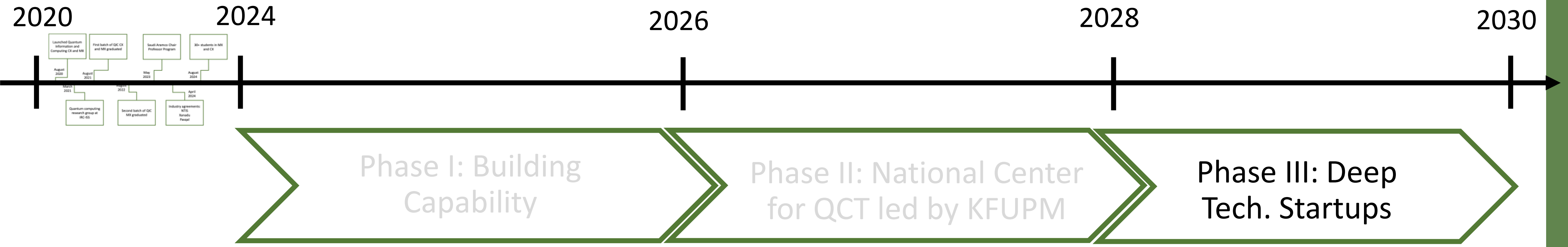
- Collaboration with International Universities

NC State University, Purdue University, Berkeley University of California, University of Oxford, University of Waterloo, University of Antwerp

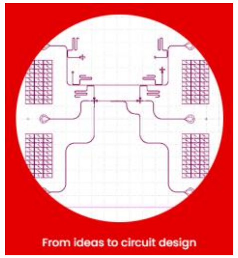
- Industry

NTIS National company of Telecommunications & Information security, Pasqal, Quantinuum, Saudi Aramco, IBM, Xanadu, Enowa Neom

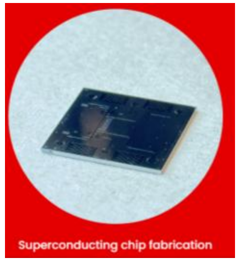




Quantum Foundry



Circuit design



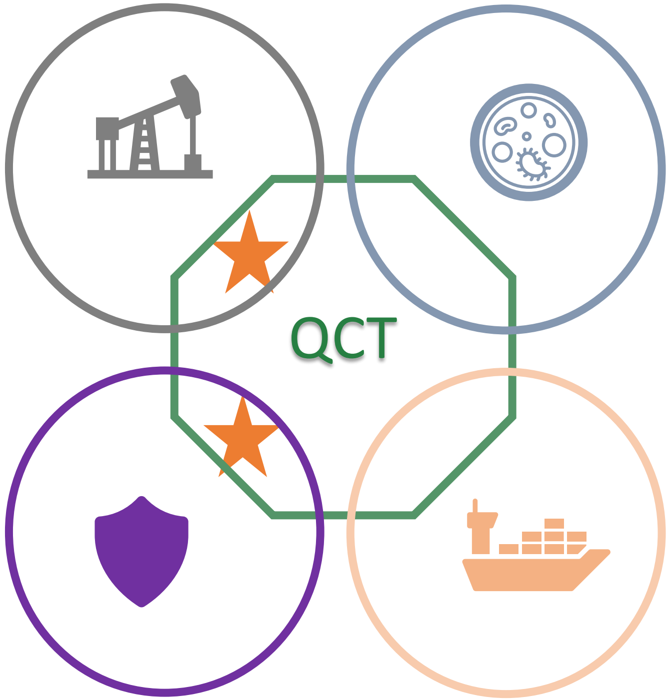
Chip fabrication

Cryogenic characterization

Quantum Software

Quantum Middleware

Quantum Hardware



https://www.rbquantum.com/

What's next

Solving real-world problems that will impact 100% of humans requires a combination of ..

Technology

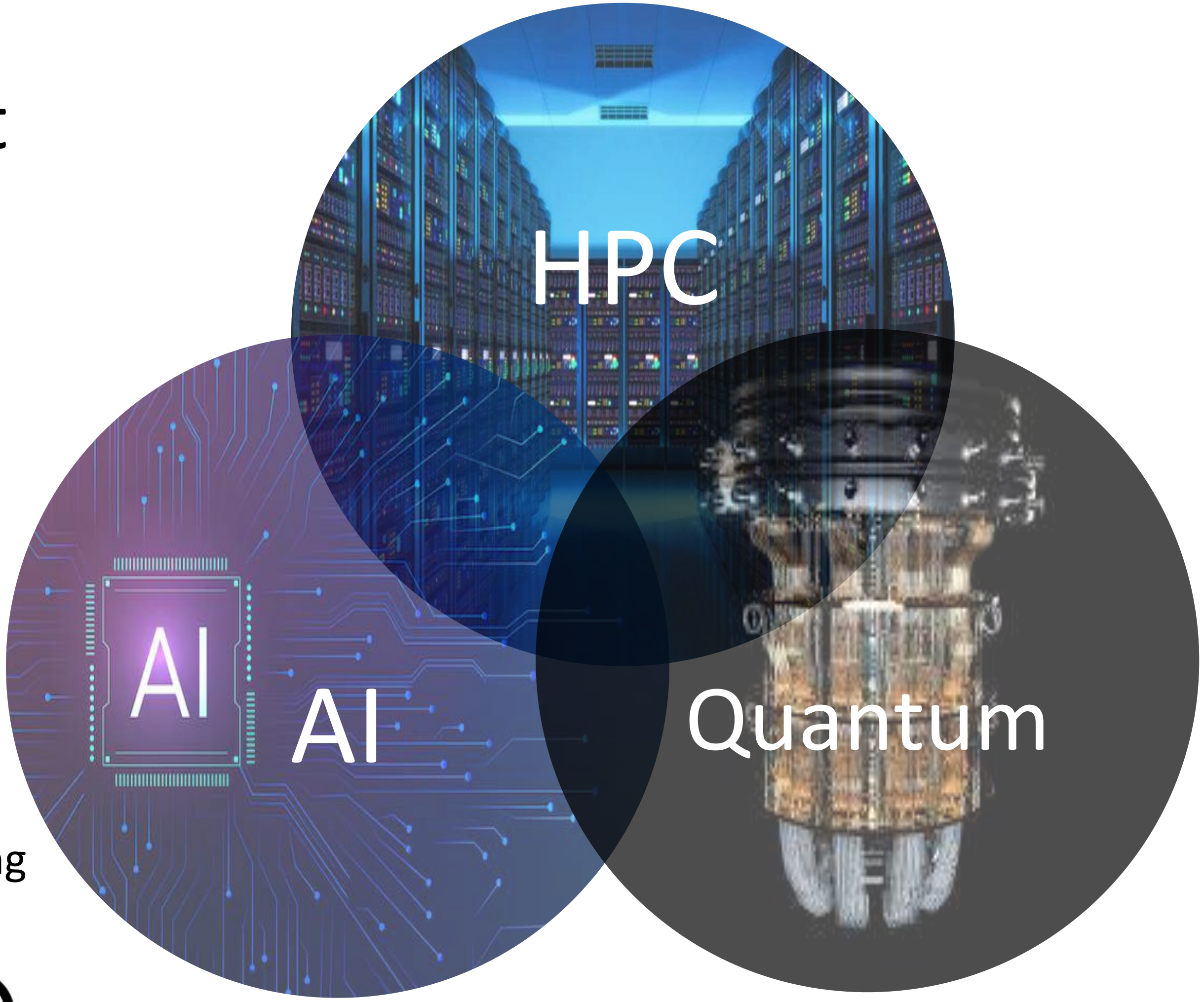
Quantum ~~Computing~~

Computing

Simulation

Communication

Sensing



Thank you