PSI Center for Photon Science

Cyber Alp Retreat, Sachseln, 21 June

Quantum Computing Technologies at PSI

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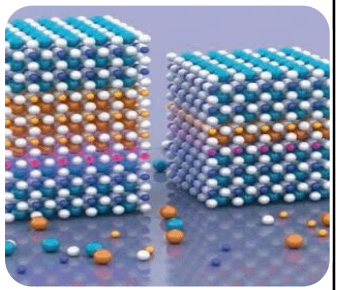
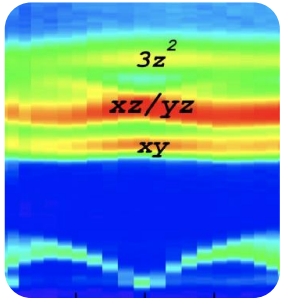
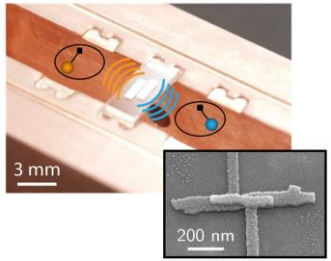
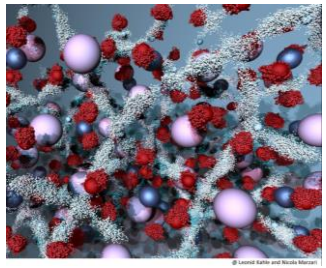
Cyber Alp Retreat, Sachseln, 21 June

Paul Scherrer Institut – ETH Domain

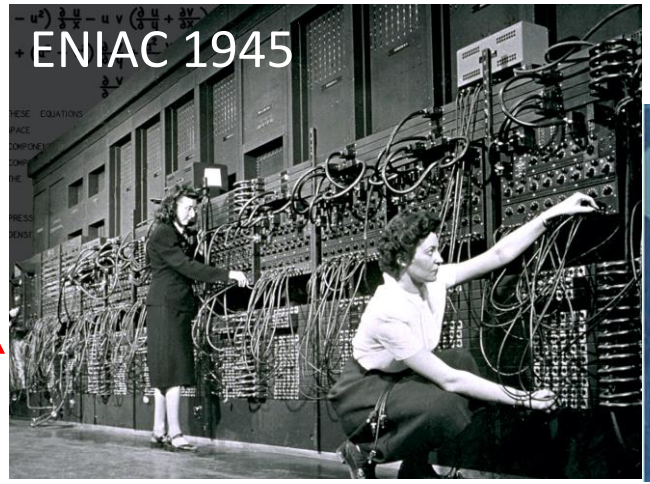
Establishing the span from comprehending Quantum Materials (QM) to fabricating devices at PSI

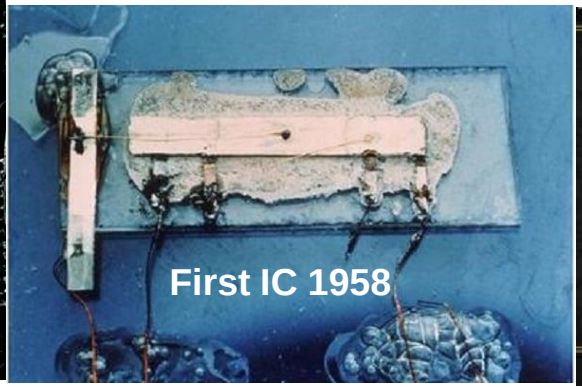
Quantum Materials	X-ray spectroscopy	Quantum Computing	Technology platform	Simulation
				
PLD, MBE, AFM@ SLS, Cleanroom	RIXS, SX-Arpes, HX-Arpes, UV-ARPES, XPS, XAS, IR, SwissFEL	QC-Hub (PSI-ETHZ), Individual Labs	Cleanroom and characterization infrastructure	Division of Scientific Computing, Theory and Data
Superconductors, non-conventional heterostructures, 2D, topological materials	Spectral Function and Low excitation States in Quantum System, Operando Devices, 3D materials and interfaces	Superconducting qubits (bosonic and digital), ion-trap, neutral atoms. Supporting photonic and electronic technology	Establishing process technology geared towards quantum applications	Modelling and computing resources for PSI science and accelerator programmes.

Quantum computing today

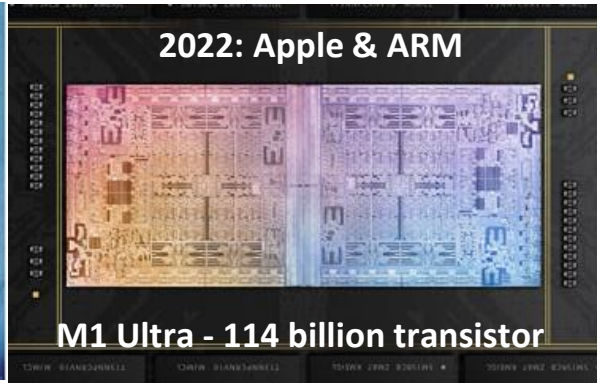
(doesn’t look like this)

Classical Computer Technologies

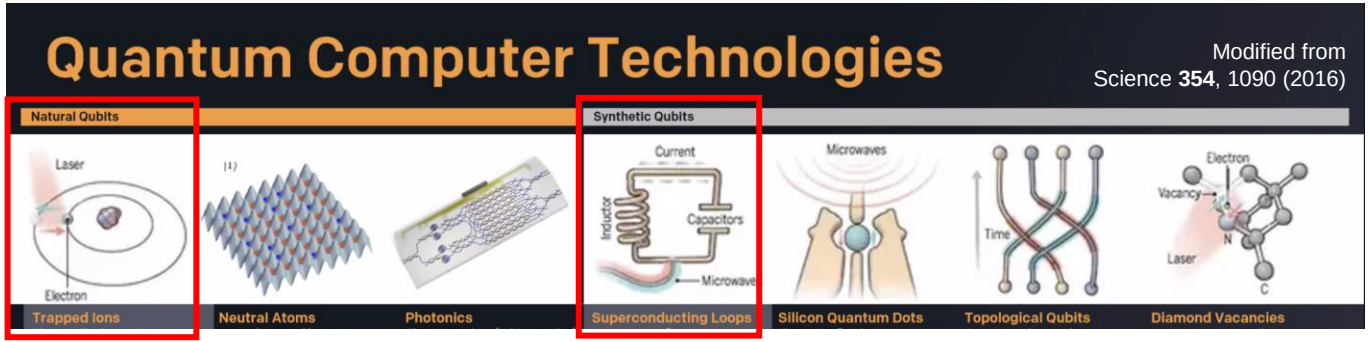




today



Quantum hardware is here in 2022 (analog, not digital)



Today:

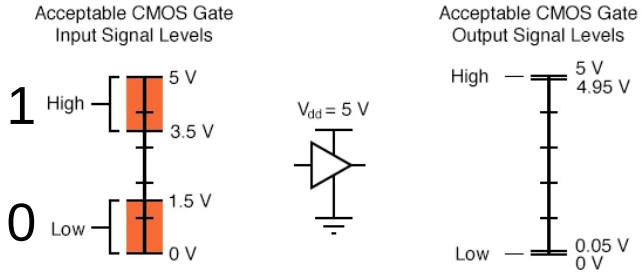
Noisy intermediate-scale (NISQ) quantum computers

“Tomorrow”:

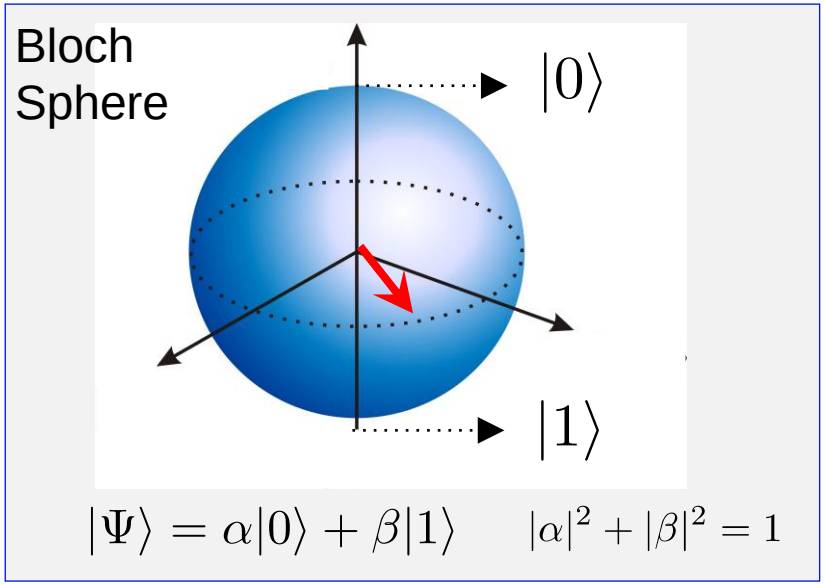
Error corrected, digital quantum computers

Classical computer vs. Quantum Computer

(classical) *binary digit* **(bit)**



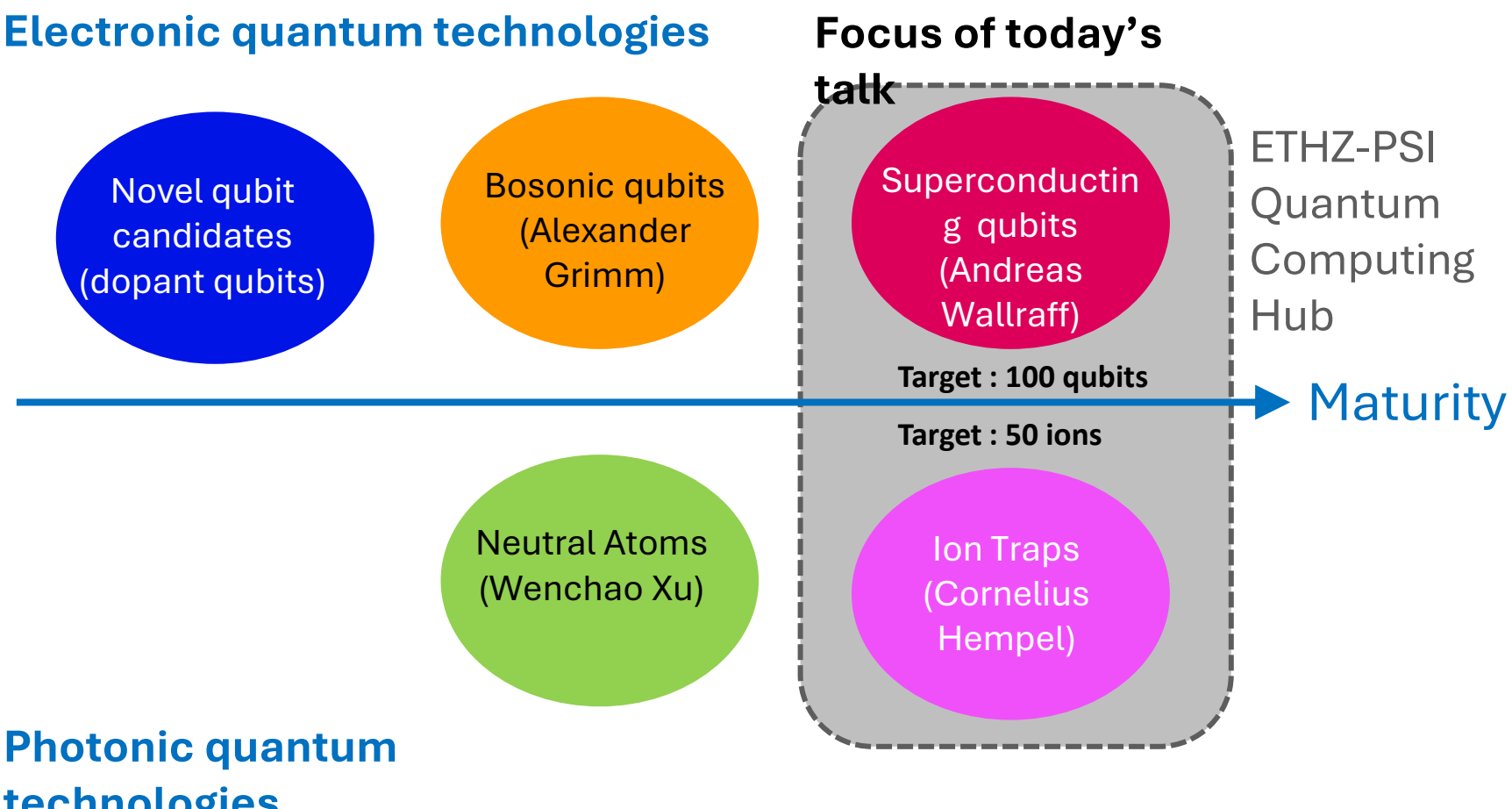
„Qu(antum) bit“



The discrete levels and relatively large energies in digital CMOS makes it more robust to errors

superposition → analog, continuous during computation

Quantum computing platforms at PSI



Motivation: Building applications of quantum technology

University

- ☑ Deep knowledge of quantum physics
- ☑ Blue skies research, ”wherever it takes us“
- ☒ Not “built” (for external users)
- ☒ No “scaling” (high turn-over)

?

Industry

- ☒ Not familiar with quantum physics
- ☒ Focus on product, not science
- ☑ Engineering and manufacturing expertise
- ☑ Reliability in “scaling”

National Lab

- ☑ Familiar with quantum physics
- ☑ Engineering and manufacturing at scale
- ☑ Science **and** applications
- ☑ Interface to industrial partners

Partners to advance large scale Quantum Computing

ETH Zurich and PSI found Quantum Computing Hub

03.05.2021 | Press release

Andreas Wallraff

Jonathan Home

ETH zürich

PAUL SCHERRER INSTITUT PSI

Gabriel Aeppli

Cornelius Hempel

- World-leading quantum computing research
- Short term projects (students, postdocs,…)
- Special purpose experiments (internal only)

- Operation of large-scale experiments
- Long term operation
- Platforms with external users

Goal: **Establish multi (50-100) qubit** systems in the two technologies

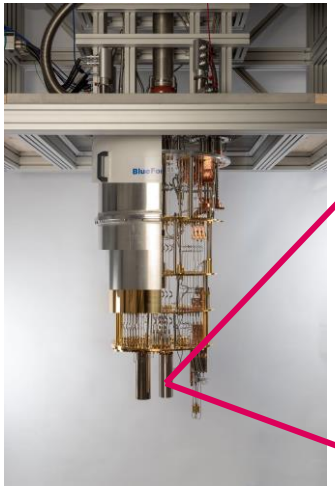
A scientific and technological challenge … that can be solved together.

Quantum bits

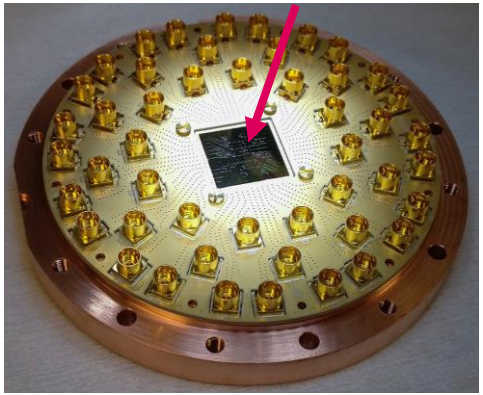
PSI

Made by humans

17 SC qubits



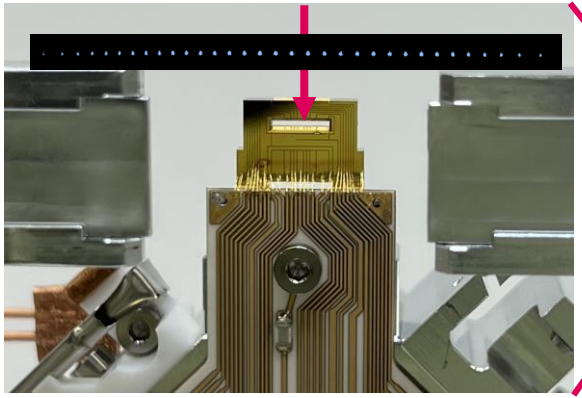
0.01 K
-273.14 C



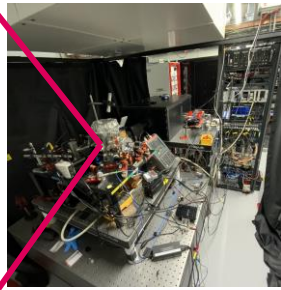
Superconducting circuit with quantumbits sourrounded by electrical connections

Taken from nature

33 ion qubits



Charged atoms (ions) as quantum bits in an ion trap (+ camera picture)



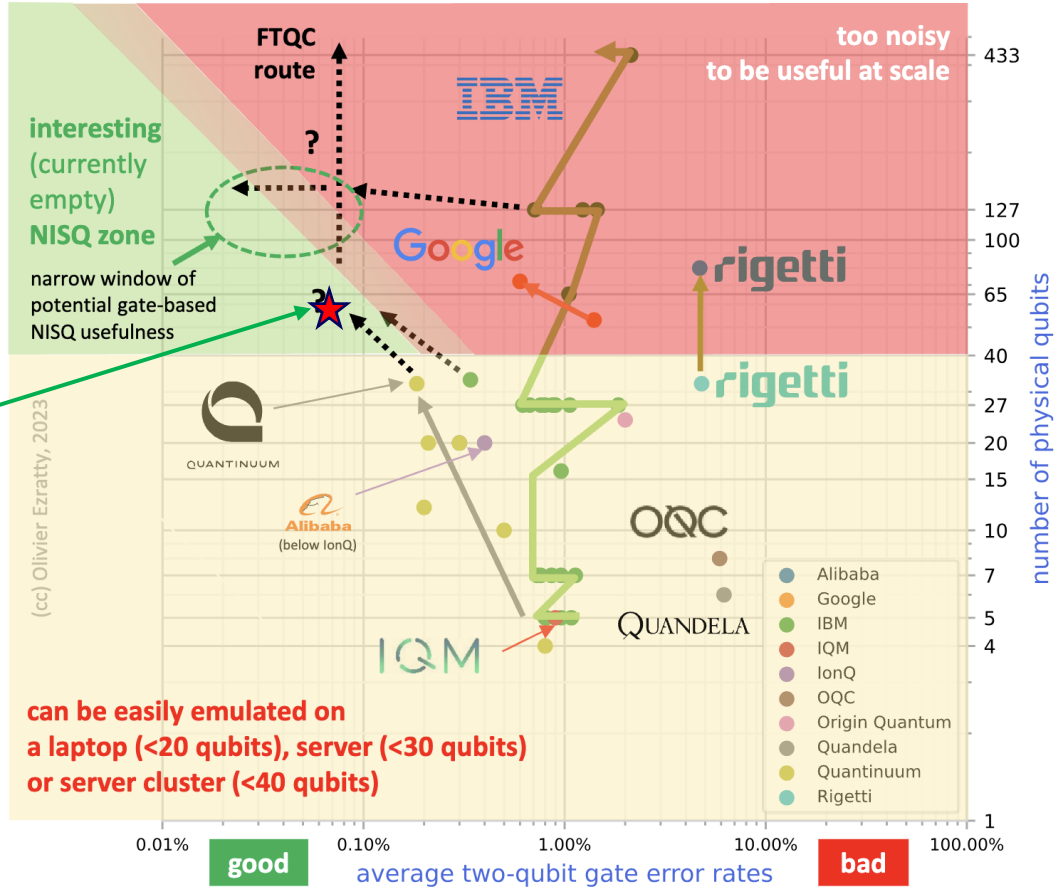
293 K
laser cooling to
0.0005 K

challenge is not the #qubits, but having them work together!

The state of the art in industry

The road towards Fault Tolerant Quantum Computing (FTQC)
Noisy Intermediate Scale Quantum (NISQ)

Quantinuum/Honeywell
First to enter the “green zone”- with 0.1% error across all 56 qubits
June 5th 2024



Graphic: Ezratty, O. Where are we heading with NISQ? *arXiv* (2023) doi:10.48550/arxiv.2305.09518.

Developing quantum simulation fameworks

Laboratory for Theoretical and Computational Physics
Andreas Läuchli

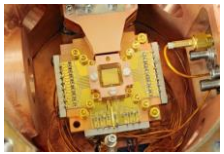
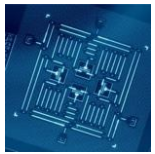
Ion Trap Quantum Computing Group
Cornelius Hempel

QuCoS²

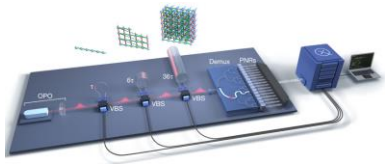
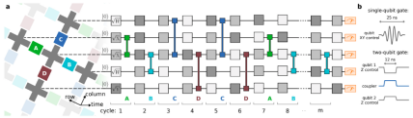
Benchmarking quantum simulation packages

PENNYLANE
QuEST
ProjectQ
QIBO

Quantum Algorithm Templates for HPC and QC Hub* Hardware

Exploring the regime of Quantum Advantage

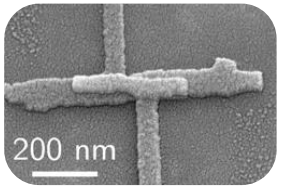
*ETH Zurich - PSI Quantum Computing Hub


ETH zürich
PAUL SCHERRER INSTITUT
PSI
March 2022
Innosuisse collaboration
Zurich Instruments

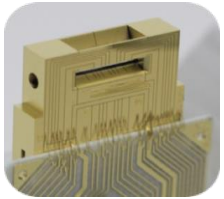
PICO - Park InnovAaRE Cleanroom for Optics and Innovation

New opportunities to upgrade and to expand the capabilities

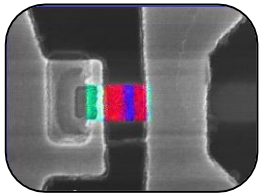
- New tools – focused on quantum applications, superconductors
- Doubling the cleanroom space area: Total: ~1000 m^2.
- 8-inch wafer capability, state-of-the art semiconductor fabrication capability
- Advanced lithography: two 100 kV E-Beams, grey-scale lithography, X-ray analysis



Josephson junctions

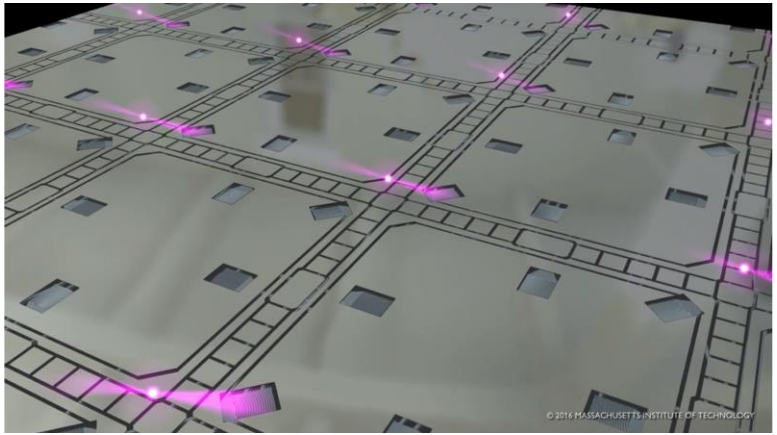


Ion trap development

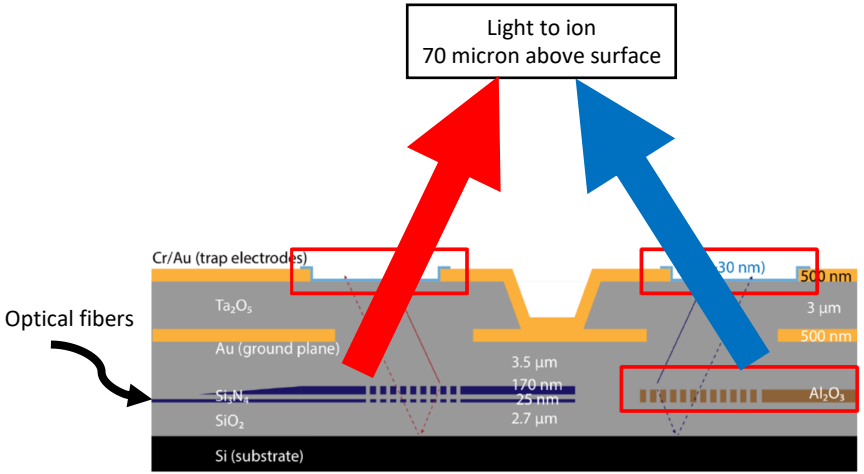


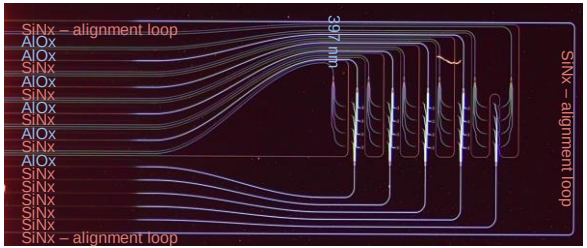
Integrated photonics

Surface ion traps with integrated photonics

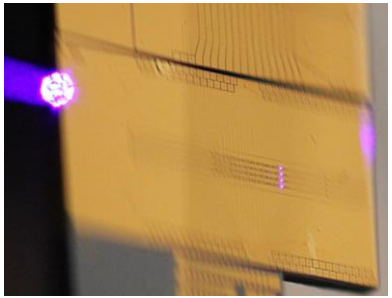


Concept illustration (MIT-LL)





First integrated chip with UV and VIS photonics

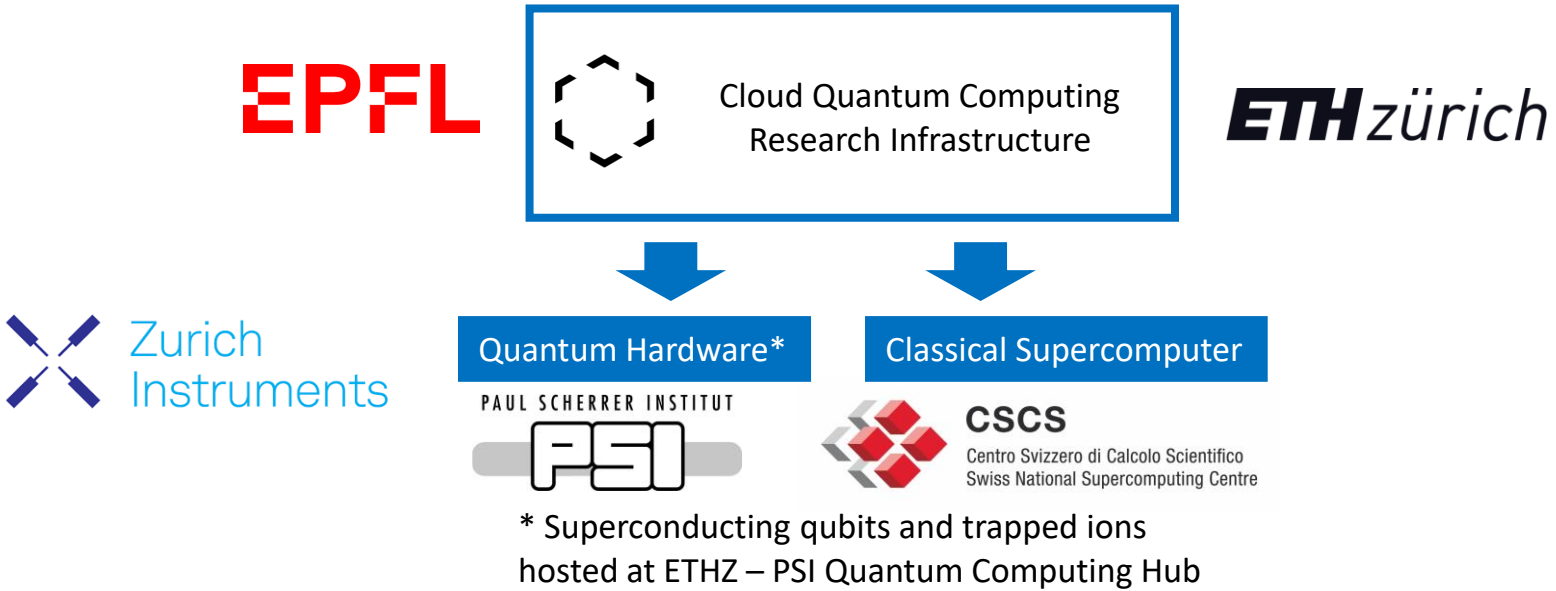


Photonics tests successful

- Key to scalability of the QCCD architecture
- Chip design by ETH group
- Deployment and photonics integration at PSI

Whats's next? - Cloud Quantum Computing Research Infrastructure

Vision: Create a cloud accessible quantum computing research infrastructure available to the Swiss community



* Superconducting qubits and trapped ions hosted at ETHZ – PSI Quantum Computing Hub

- Low level hardware access – physical qubits
- Linked high performance computing platform in one portal

Proposal for a Swiss full-stack quantum pl

PSI

Vision of future capability

Industrial

Quantum cloud access

- Software on real qubits
- Develop applications

Swiss Quantum Computing Cloud

- Development of Swiss quantum cloud test-bed
- Access to mature physical hardware
- Benchmarking

Research Usecase

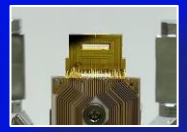
Academic ecosystem

- Develop novel algorithms based on physical qubits

Equipment

- Swiss manufacturing value chain

ETHZ-PSI QC-Hub

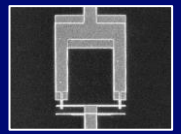


Research

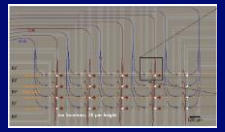
Testbed for exploratory quantum technologies & error correction codes

Established today

Quantum Technology Backbone



Qubit development



Integrated photonics

Materials

Embedded software

In development


Thank you for your attention !
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ETH zürich
PSI
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IARPA
BE THE FUTURE
ELQ
Innosuisse
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