The Entanglement Fabric

Enabling distributed quantum computing with quantum networks

Simone Eizagirre Barker
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QT4HEP25, CERN

QUANTUM

Building the networking infrastructure for quantum computing scale-out

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Building the networking infrastructure for quantum computing scale-out

Founding year 2018	Pre-A funding £8.5M
People ~60 FTE	Nationalities 20
Female 40%	LGBTQ 10%
Tech disciplines 9	PhDs 28

Locations
Cambridge, UK
Harwell, UK
Los Angeles, USA

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At QT4HEP

Simone Eizagirre
Product Manager

Ed Wood
VP Product

Romerson Oliveira
Senior FPGA Engineer

Quantum computing represents an exponential increase in computing power to address some of the world's biggest challenges

1.3 trillion in value by 2035

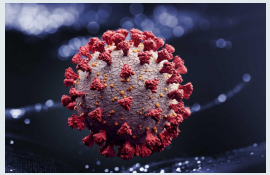
Reference **McKinsey**

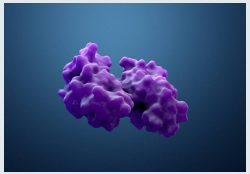
Life Sciences	Transport Market	Energy Market
$20B	$21B	$30B

10x
Qubit Quality

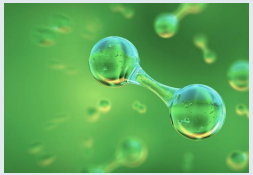
10x
Code Efficiency

Plateauing:
Qubit Numbers


Viruses


Enzymes

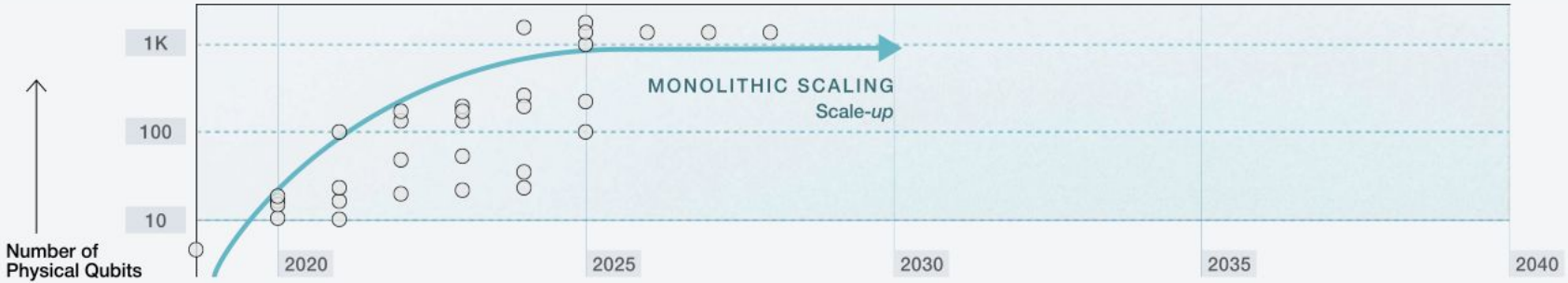
Decarbonisation


Batteries


Global food systems

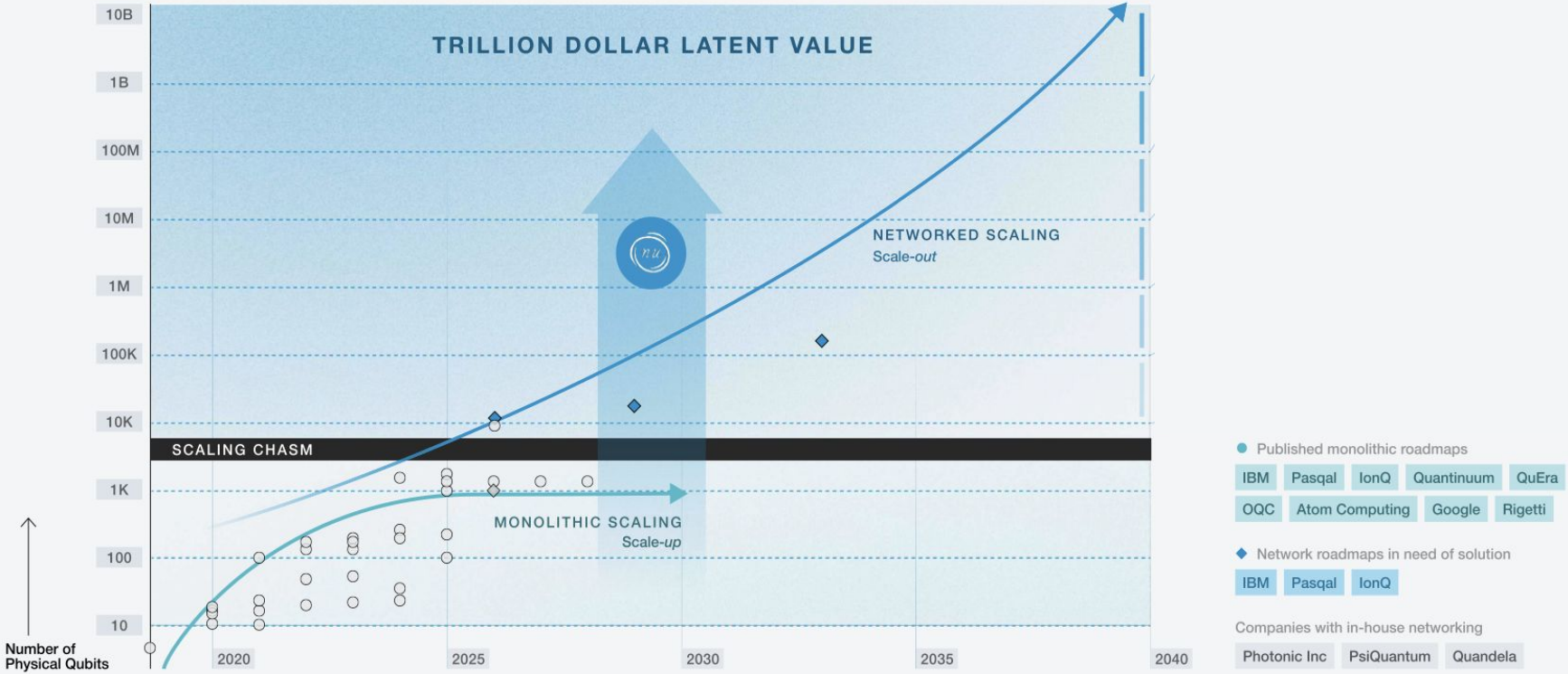

AI

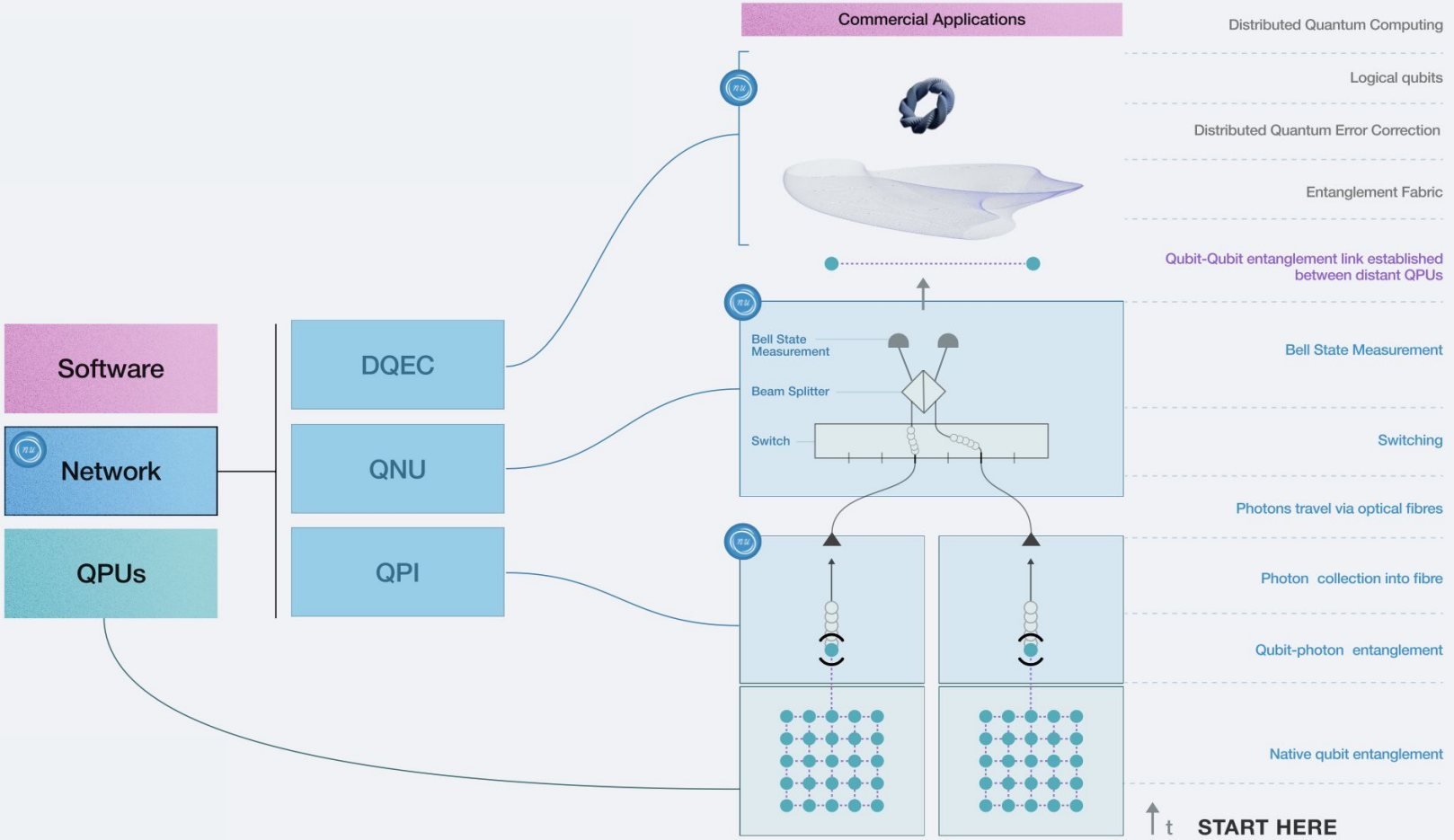
A Scaling Challenge: the ‘monolithic’ approach to scaling qubit numbers is hitting a wall



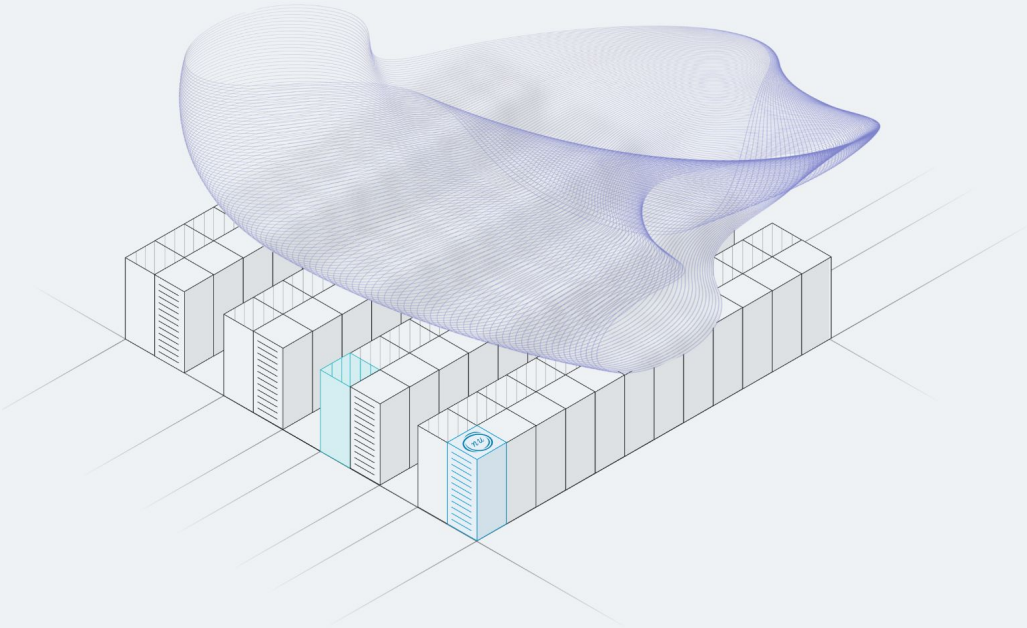
IBM Pasqal IonQ Quantinuum QuEra
OQC Atom Computing Google Rigetti

Network-enabled scale-out accelerates the timeline to larger quantum computers




Commercial Applications
Distributed Quantum Computing
Logical qubits
Distributed Quantum Error Correction
Entanglement Fabric
Qubit-Qubit entanglement link established between distant QPUs
Bell State Measurement
Switching
Photons travel via optical fibres
Photon collection into fibre
Qubit-photon entanglement
Native qubit entanglement
t
START HERE
Bell State Measurement
Beam Splitter
Switch
Software
Network
QPUs
DQEC
QNU
QPI

Our network architecture: the **Entanglement Fabric,**
to weave multiple processors into a larger, more powerful
distributed quantum computer



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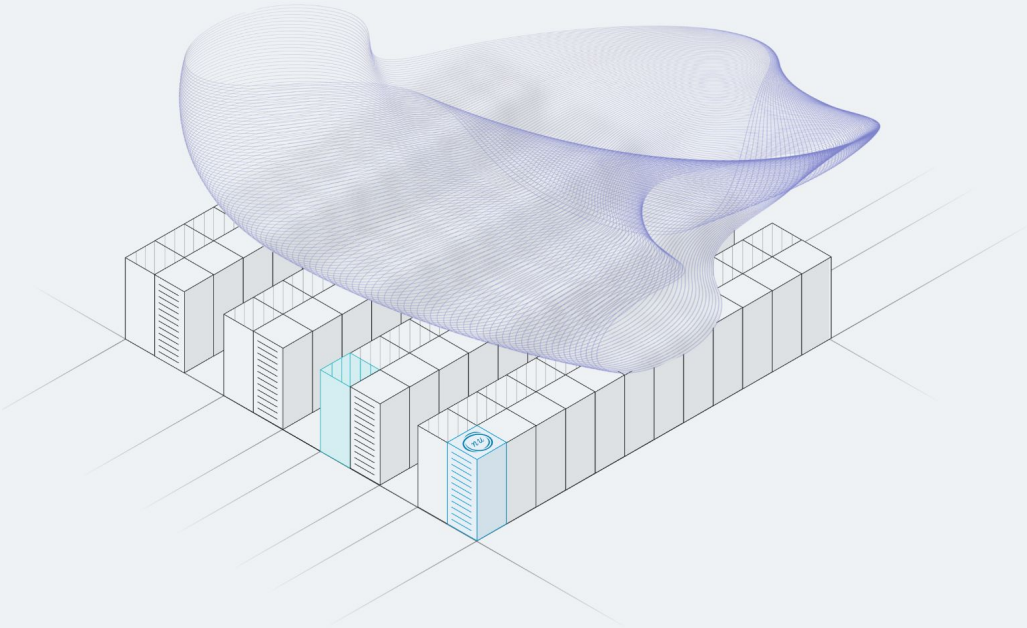

Can we extract light efficiently from qubits?

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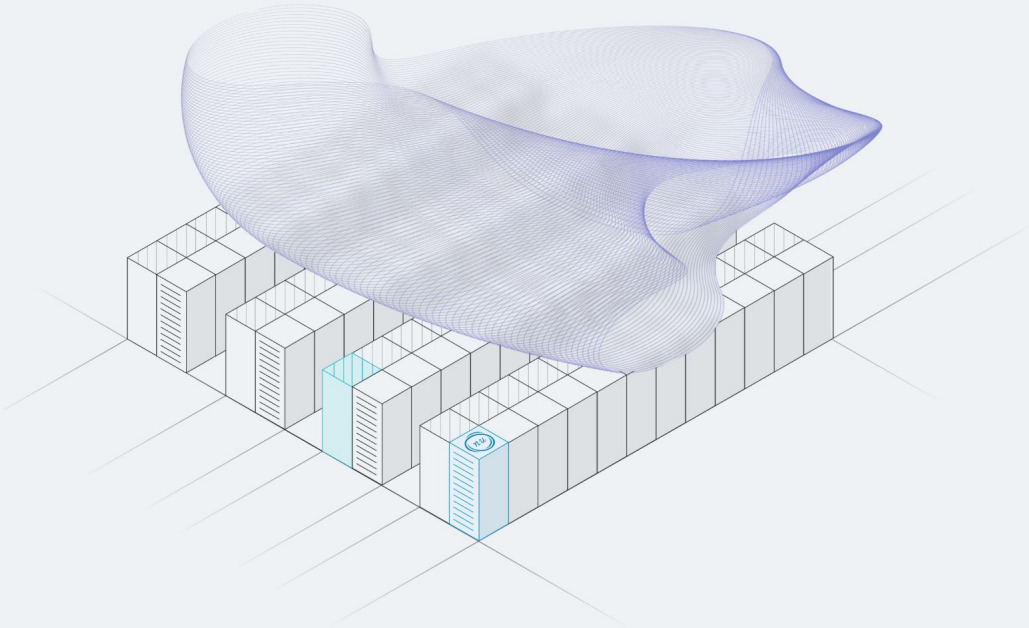

Can we build the networking hardware to entangle processors together?

Can we extract light efficiently from qubits?

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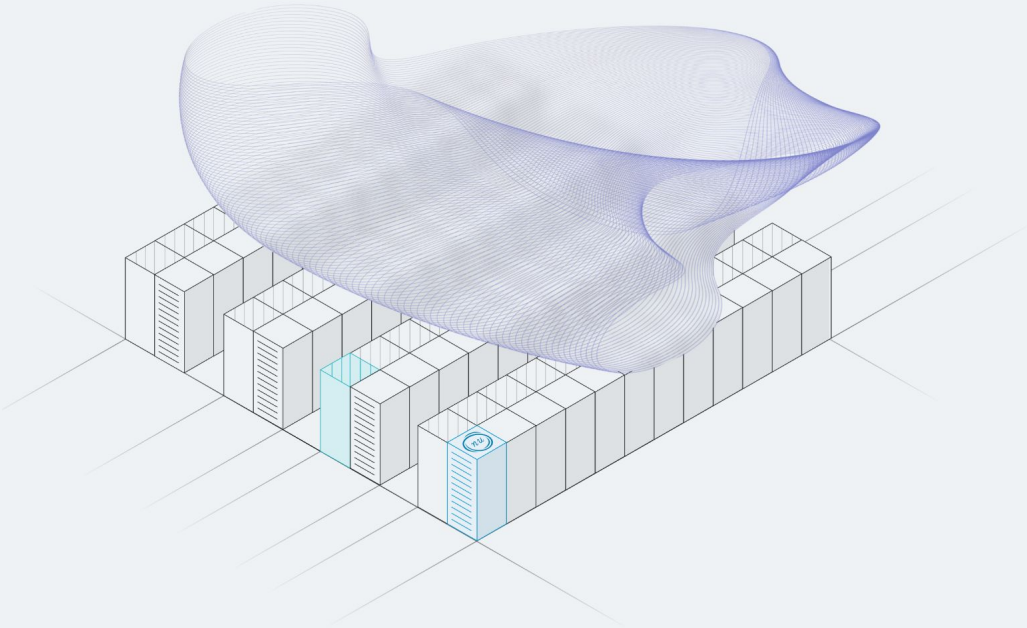

Can quantum error-correction codes be implemented on a distributed machine?

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The Qubit Photon Interface: extracting light from qubits

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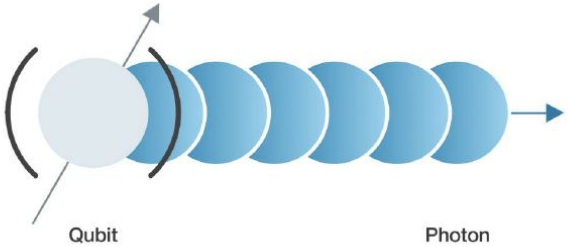
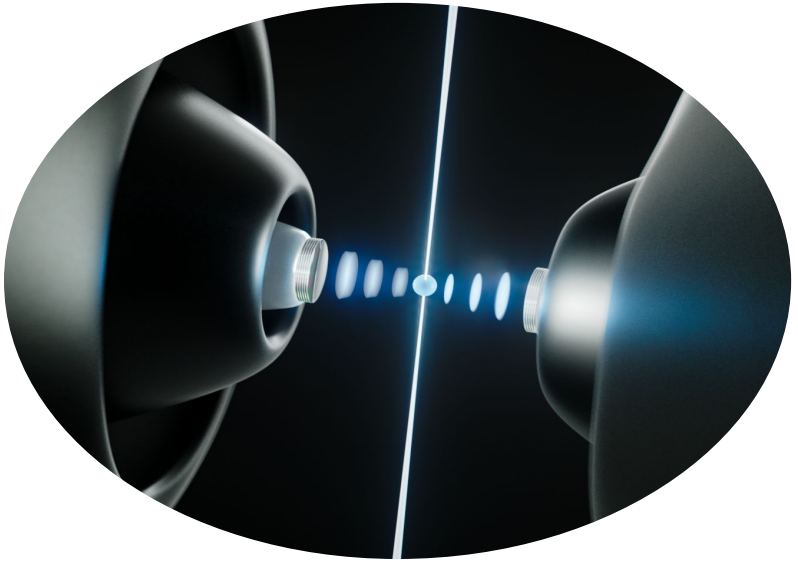


The Qubit Photon Interface: extracting light from qubits



Optical microcavity QPI

- Enhances qubit transition
- Boosts emission rates
- Emission into cavity mode

The Qubit Photon Interface: extracting light from qubits

FIGURES OF MERIT

- Probability of photon extraction into cavity mode
- Probability of photon collection into fibre

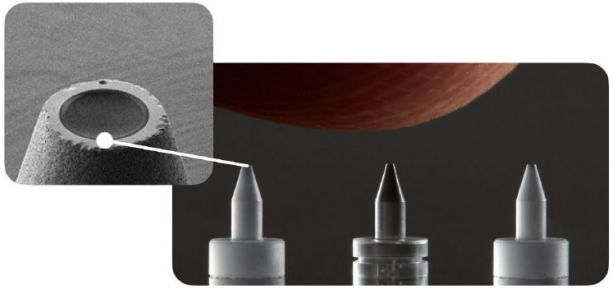
TECHNICAL REQUIREMENTS

- Ultra smooth cavity mirrors (<nm)
- High-precision cavity locking
- Photon collection optics
- Ultra-high vacuum compatibility

The Qubit-Photon Interface: in-house proprietary design and fabrication

Cavity finesse

200,000



Cavity locking resonance tunability

1 MHz- 6 GHz

Cavity length locking precision

80 pm

The Qubit-Photon Interface: adaptable to different qubit types

QPI for neutral atoms

In collaboration with Infleqtion

Infleqtion

QPI for trapped ions

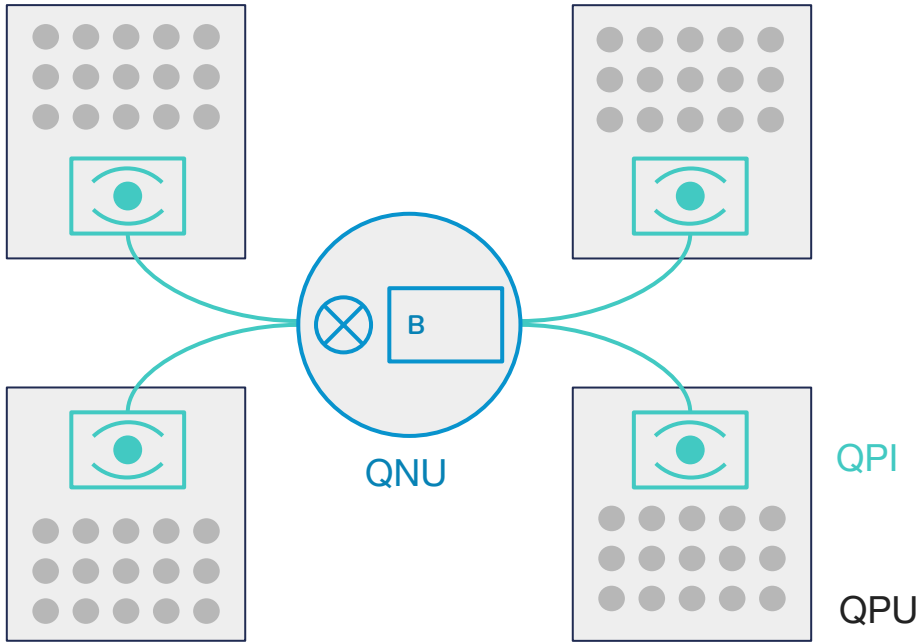
In collaboration with NQCC

National Quantum Computing Centre

Can we build the networking hardware to entangle processors together?

The Quantum Networking Unit

hosts photonic technology to distribute entanglement across processors



Project LYRA:

delivering a world-first Quantum Networking Unit product prototype

Innovate UK

SBRI contract

“from the lab to the data centre”

- scalable
- industrialised
- modular

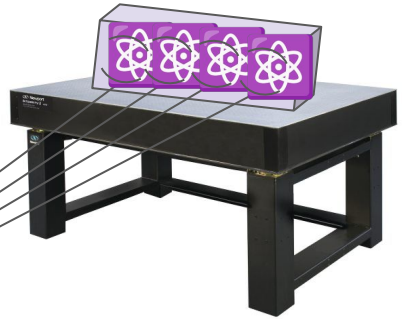
Project LYRA:

delivering a world-first Quantum Networking Unit product prototype

Control Module

Optical Module

Test Harness



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Prospective end-user

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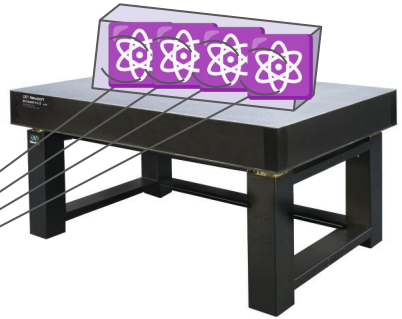

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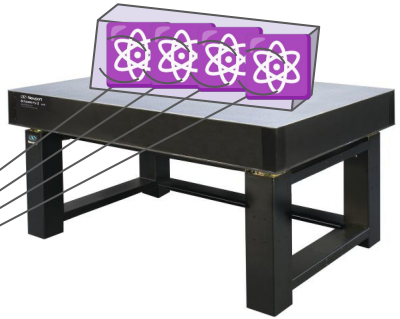

Prospective end-user

Customer Requirements Council (including ion, atom & superconducting qubits)

The Quantum Networking Unit: control and orchestration

Control Module

TECHNICAL REQUIREMENTS

- Low latency
- Scalability
- Fast feedforward
- Distribution of precise timing

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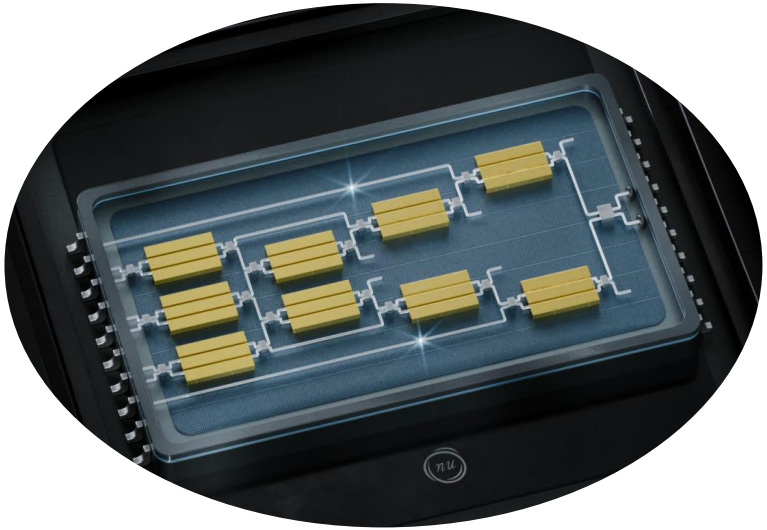
CURRENT APPROACH

- **ARTIQ** control system
  - Developed for ion traps
  - FPGA-based
  - 8 ns time resolution
  - 250 ns fast feedforward

- **White Rabbit** Technology
  - Ethernet for timing distribution
  - Sub-nanosecond accuracy
  - Scalable (1000+ nodes)

The Quantum Networking Unit: switching light to weave entanglement

Optical Module



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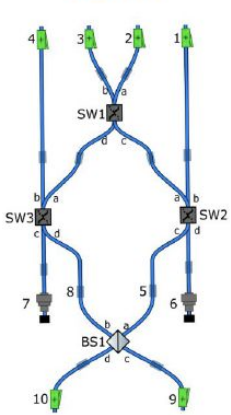
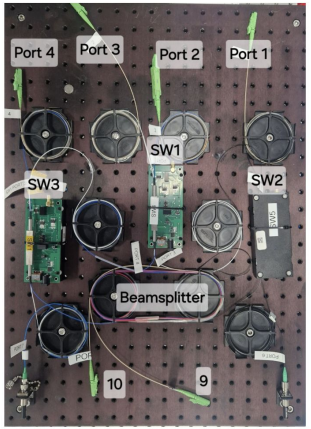
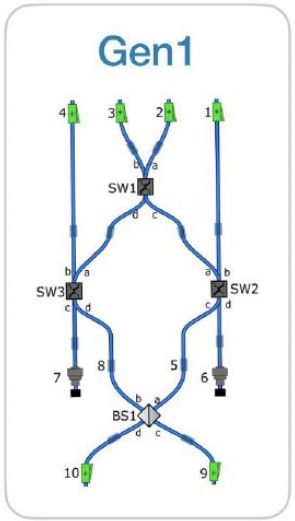




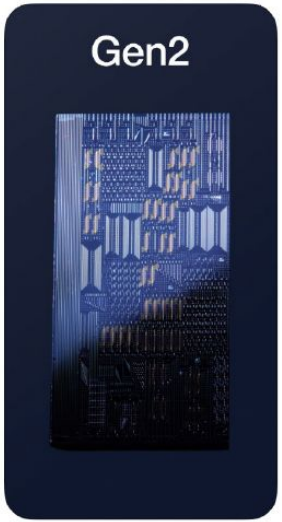
- Gen1: commercial off-the-shelf components (COTS)
- Limited entanglement fidelity (97-8%)

The Quantum Networking Unit: switching light to weave entanglement

Optical Module

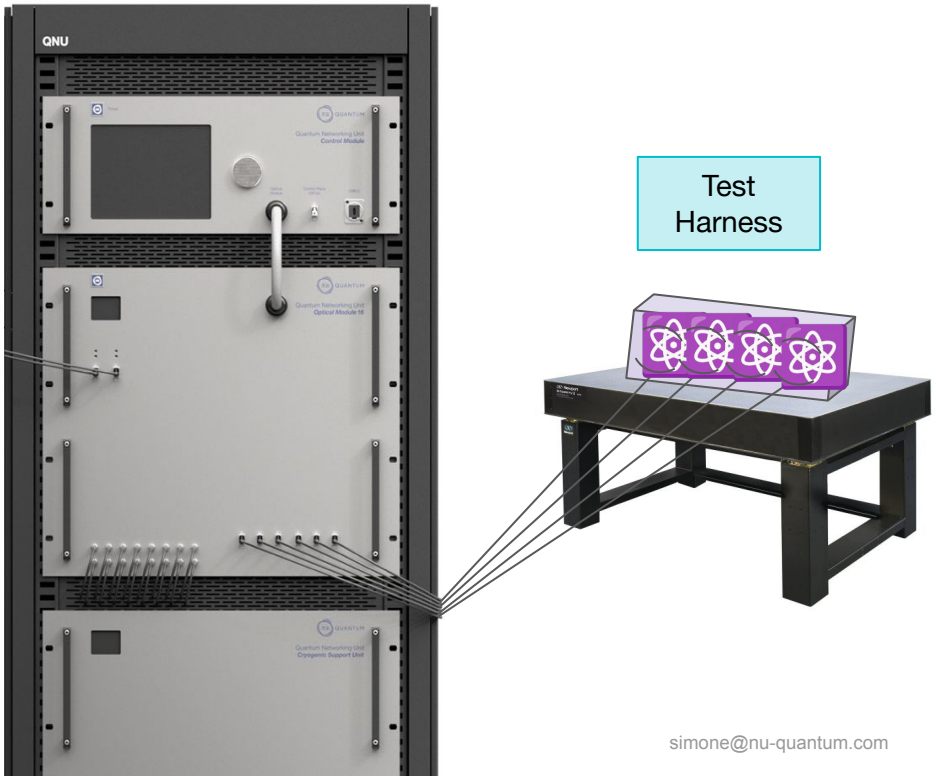


COTS
97% E.F.



integrated photonics
99.5% E.F.

The Quantum Networking Unit: entangling quantum processors

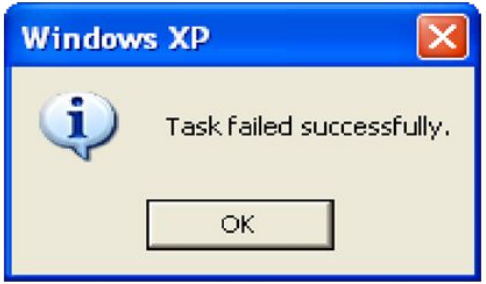


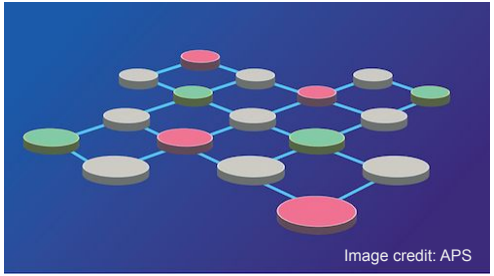
- Ion QC emulator
- Benchmarking capability
- Upgradeability
- Next: integration with **real ion nodes** in Nu Quantum networking testbed

Can quantum error-correction codes be implemented on a distributed machine?

Building a modular **fault-tolerant** quantum computer

- Computing operations are susceptible to hardware and environmental noise
- Quantum Error Correction (QEC) enables the creation of *logical* qubits out of multiple *physical* qubits
- Are QEC codes compatible with a modular architecture?





Distributed Quantum Error Correction: a pathway to modular fault-tolerant QCs

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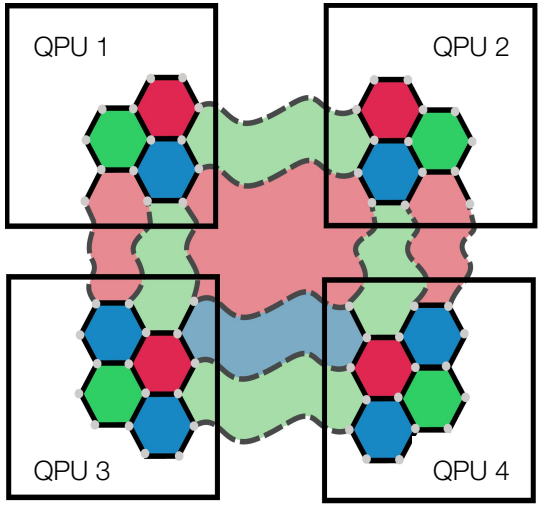

Logical qubits formed by physical qubits
in different processors

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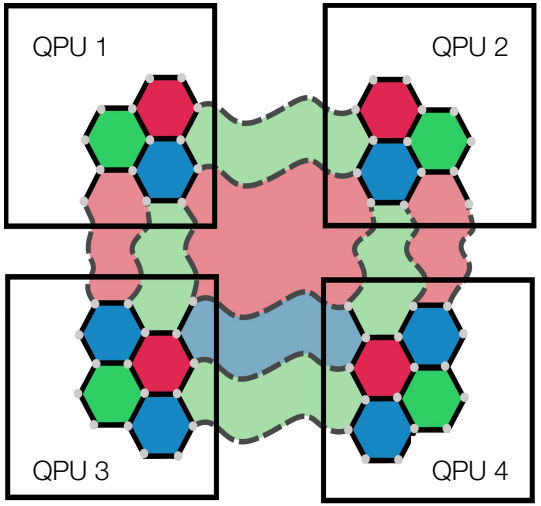

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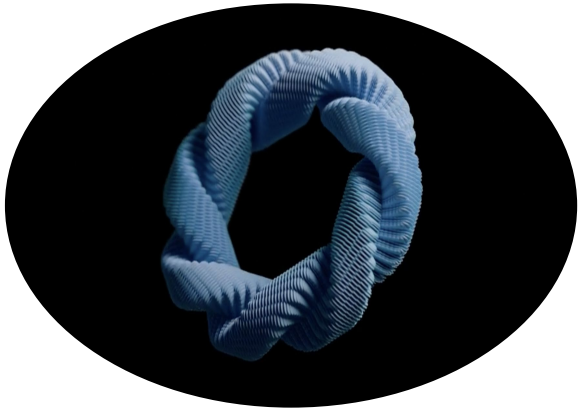
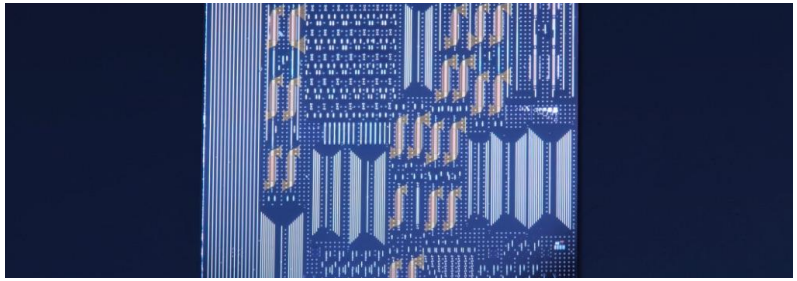


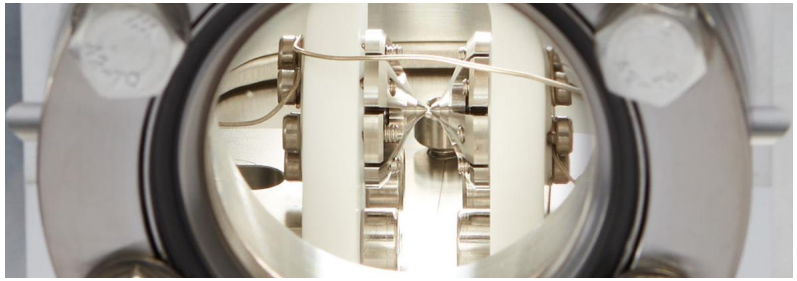
Distributed architecture unlocks application of new families of QEC codes

What’s next?

Pioneering an optically connected multi-node system at the NQCC



R&D into the next-generation of our QPI & QNU technology



Integrating our solutions with real quantum computers

Thank you to everyone at Nu Quantum & shout-out to CERN!

White Rabbit COLLABORATION

CERN

White Rabbit Collaboration, December 2024 (image:CERN)

Thank you for your attention and *#StayEntangled!*

Interested in collaborating?
simone@nu-quantum.com

We're hiring!
AMO Engineer
Lab Software Engineer