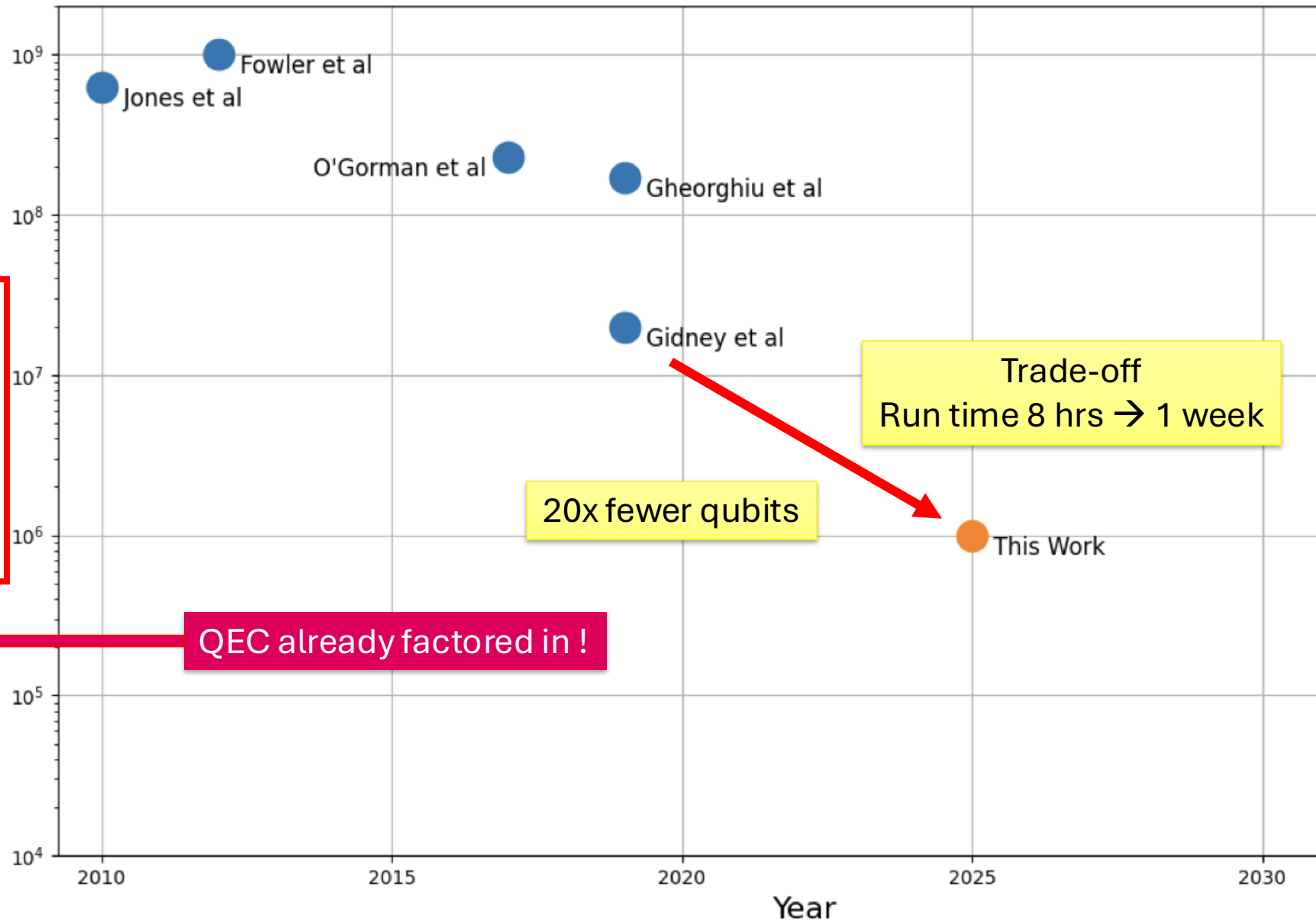


The packaging challenge in laser-based
trapped-ion quantum computing
Cornelius Hempel :: SwissPIC opening :: 2025-11-24

Shor's algorithm – projection of required resources



“How to factor 2048 bit RSA integers in 8 hours using 20 million noisy qubits”
Quantum 5, 433 (**2021**)

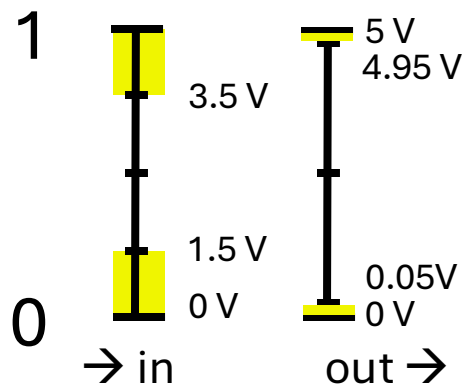
“How to factor 2048 bit RSA integers with less than a million noisy qubits”
arXiv:2505.15917
May 2025



Craig Gidney

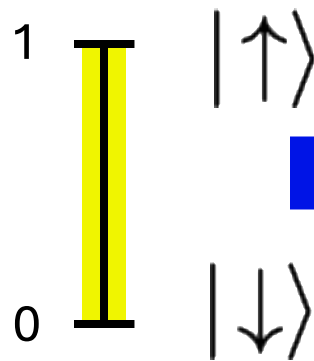
A sense of scale

Classical information



Digital / robust

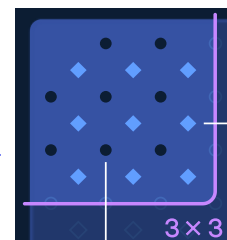
Quantum Information



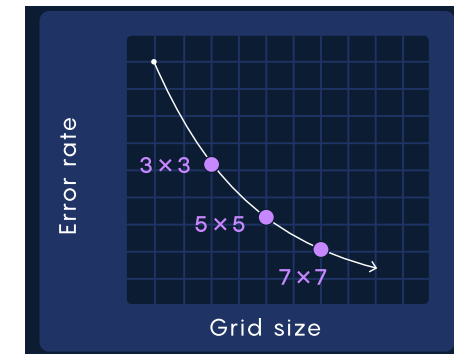
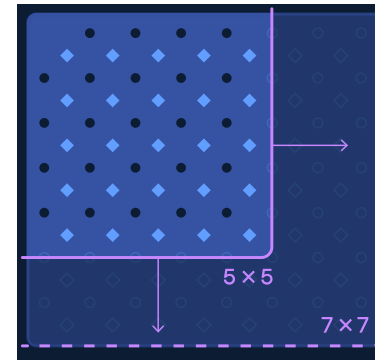
Analog & cannot be copied

needs

Many physical qubits + algorithm = 1 logical qubit



Quantum Error Correction

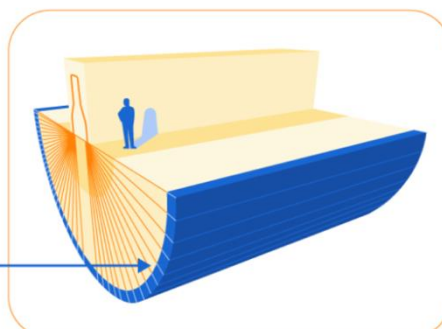
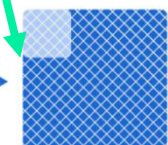
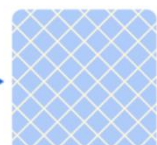


2023/2024 experiments show it's working 

3720 physical qubits for 1 logical qubit (currently 105 qubits)



Google Quantum AI



54

Beyond classical

M1 (2019)

10²

Logical qubit prototype

M2 (2023)

10³

1 long-lived logical qubit

M3 (2025+)

10⁴

Tileable module (logical gate)

M4

10⁵

Engineering scale up

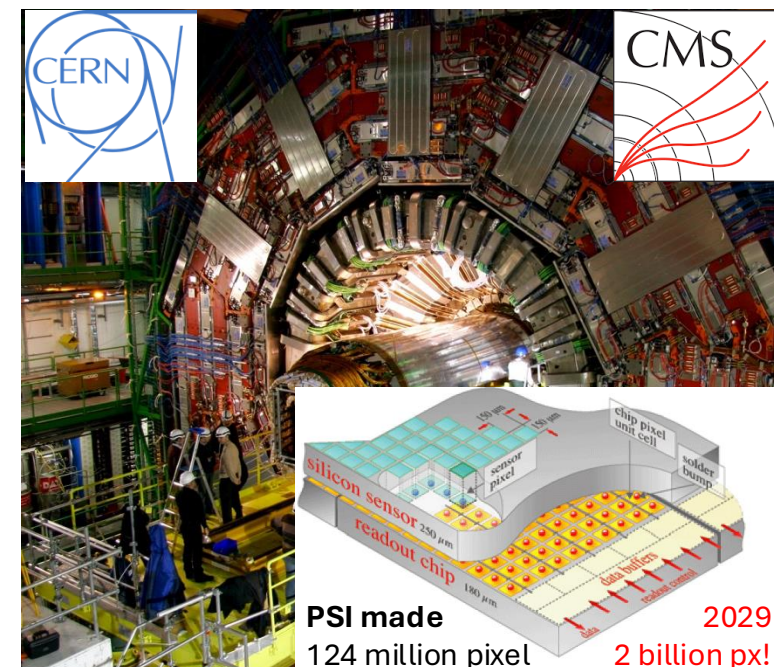
M5

10⁶

Error-corrected quantum computer

M6

physical qubits

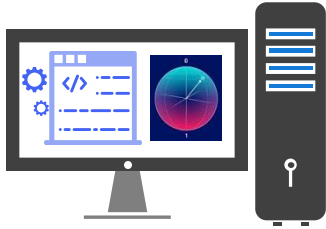


PSI made 124 million pixel

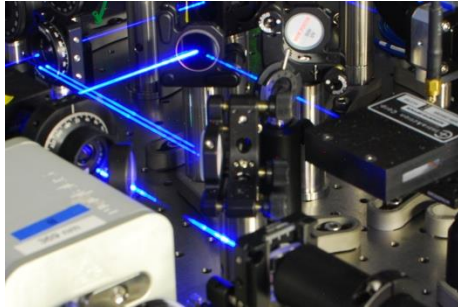
2029 2 billion px!

Trapped ion quantum processors in a nutshell

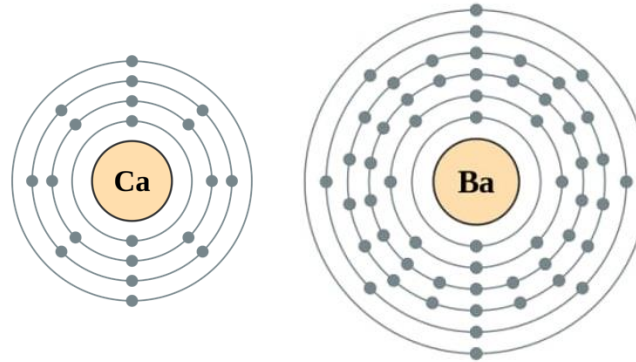
Encoding



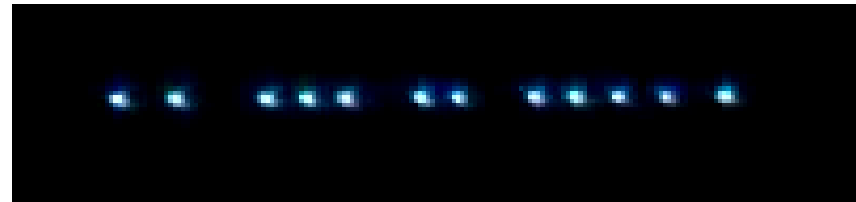
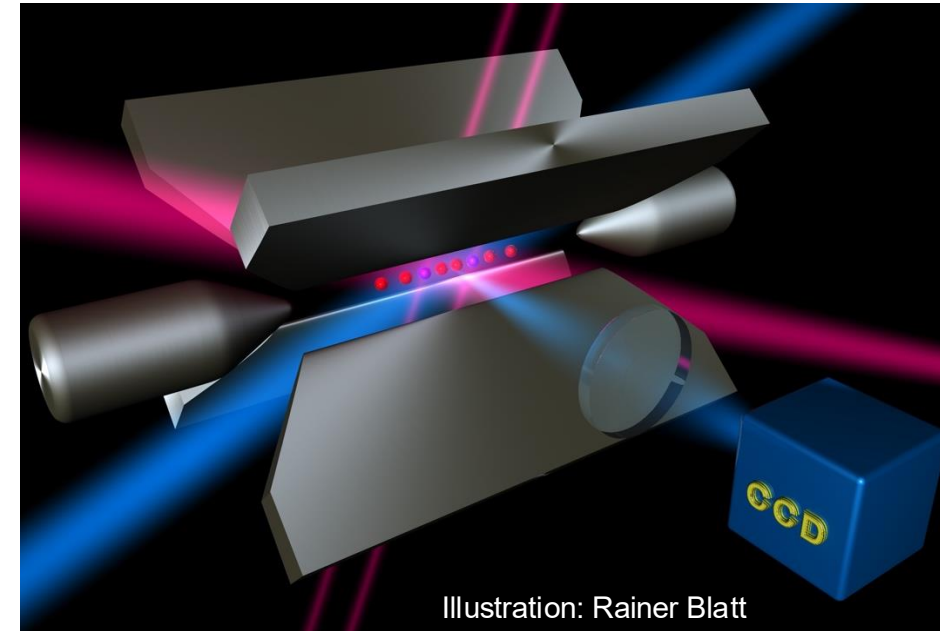
+ Laser(s)



+ Atoms (-> Ions)

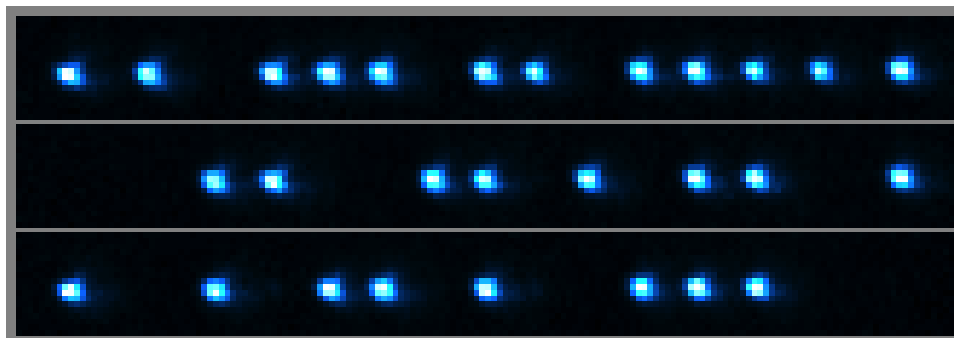


+ Ion trap



Camera

Single shot
"samples"



a $|110111011011111\rangle$
b $|001100110101101\rangle$
c $|101011010011100\rangle$

Result

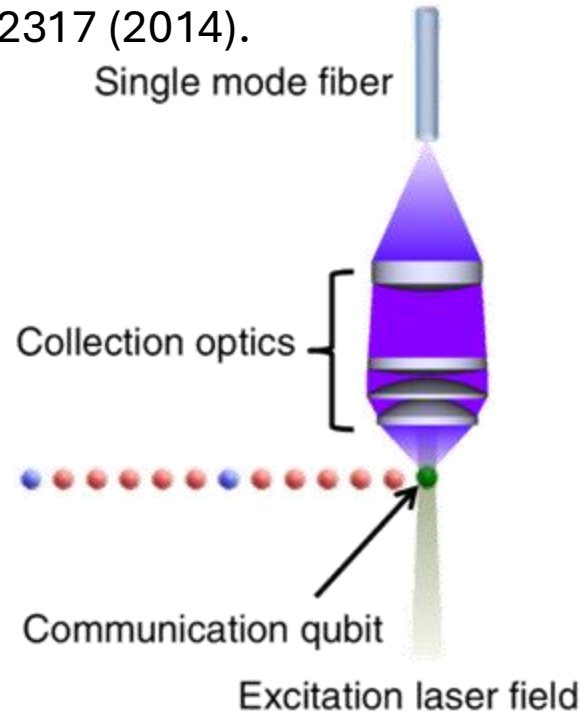
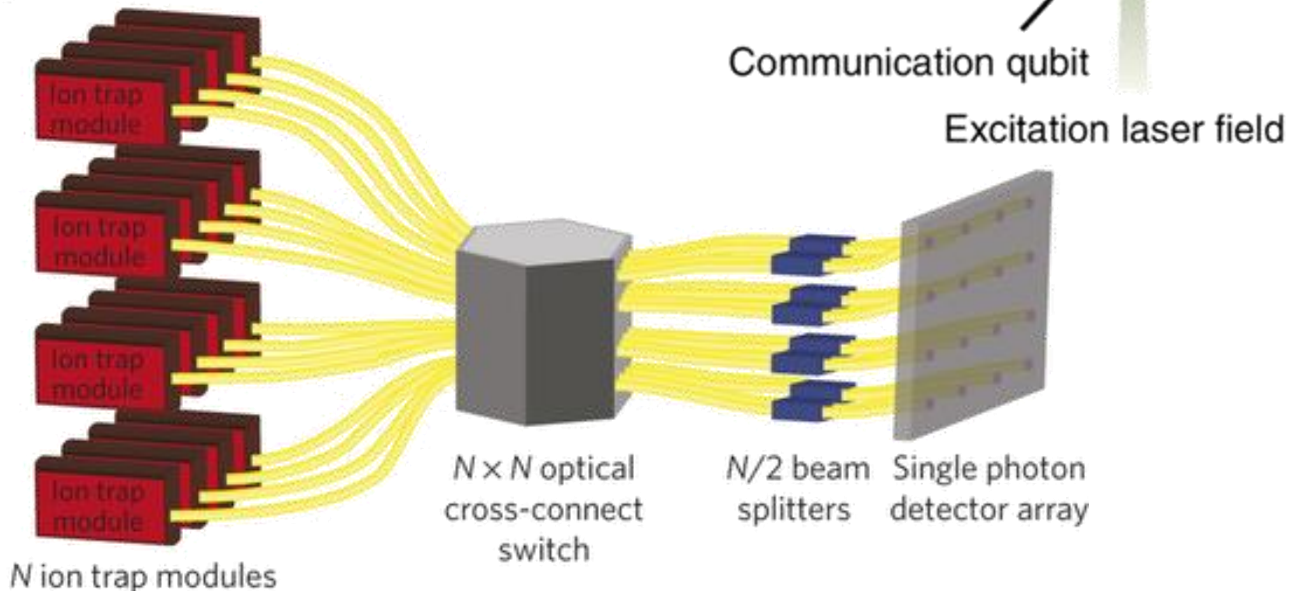
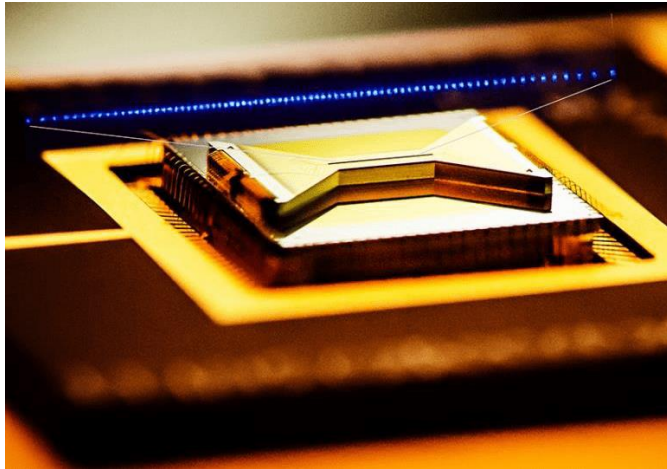


Two ways to scale up



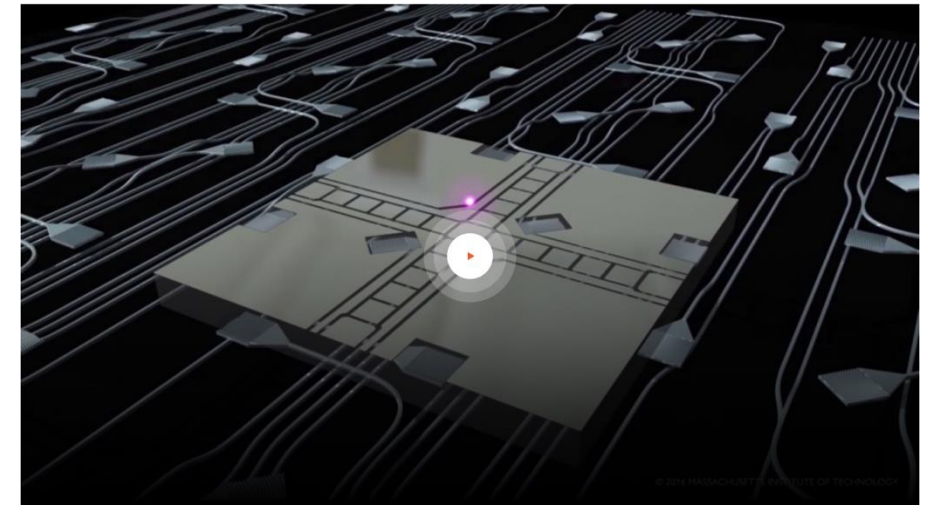
Photonic interconnects

Monroe *et al.* *Phys. Rev. A* **89**, 022317 (2014).



Q(uantum)CCD

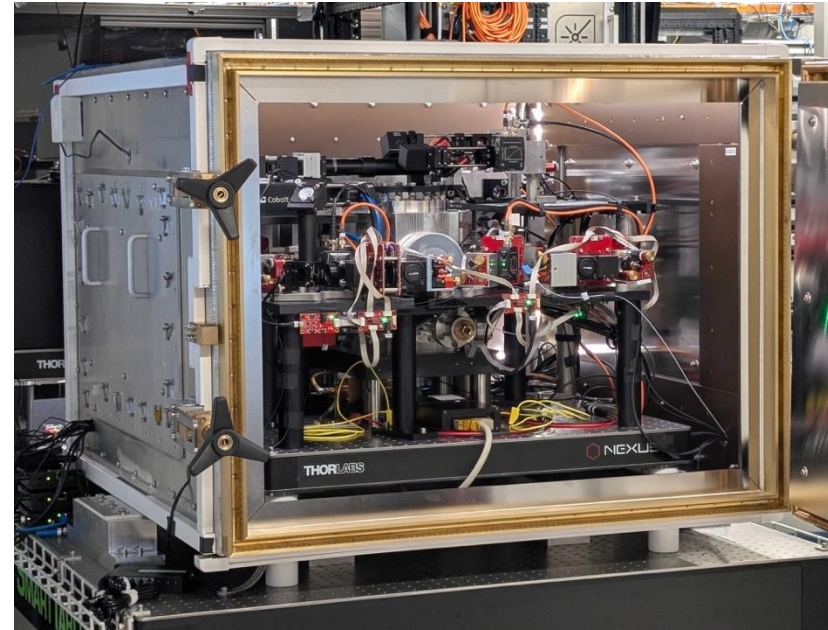
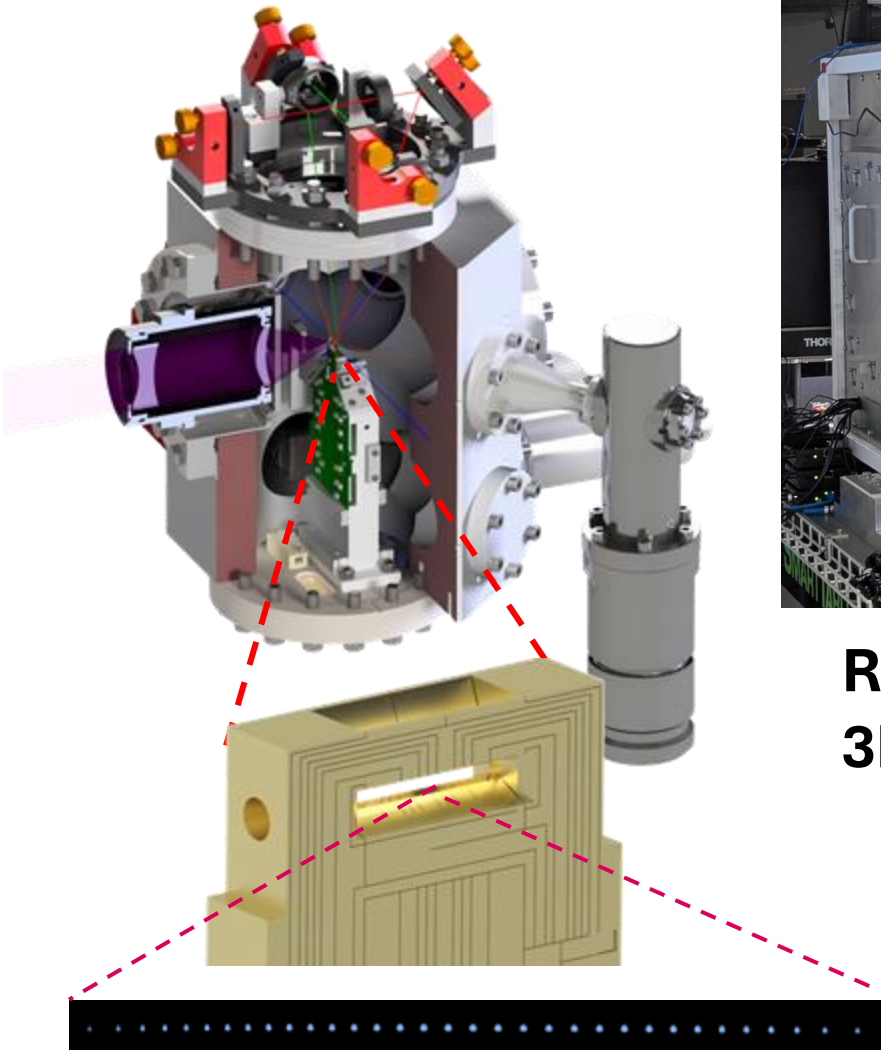
Kielpinski *et al.*, *Nature* **417** 709 (2002).



MIT Lincoln Lab (2016)

<https://www.youtube.com/watch?v=UT3ev9OgkmY>

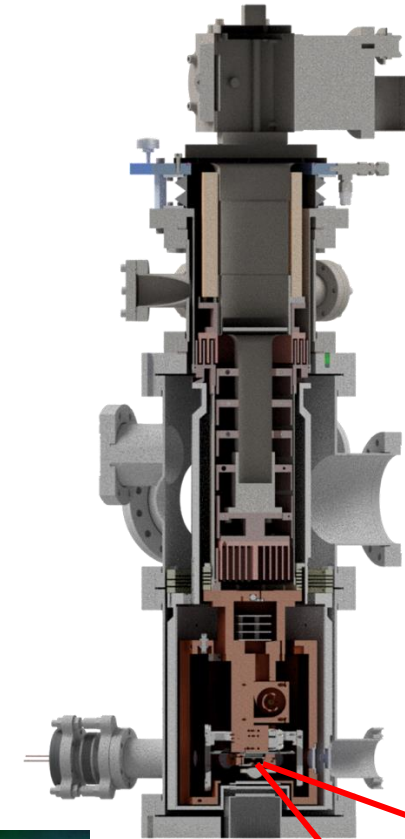
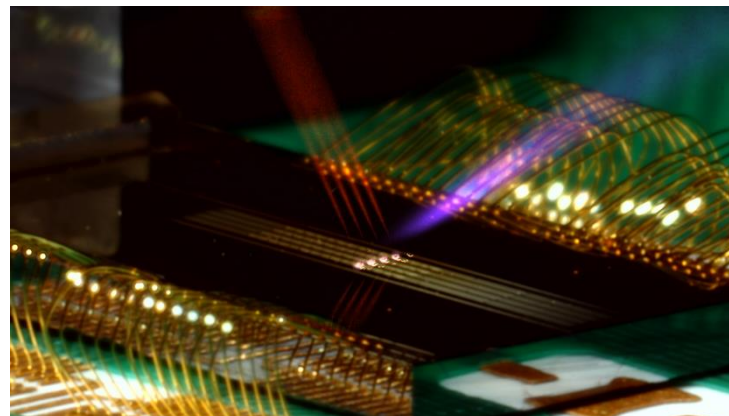
Trapped ions at the Quantum Computing Hub



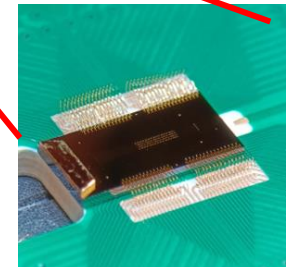
**Room temperature
3D trap**

33 Ca^+ (supports up to 50 physical qubits)

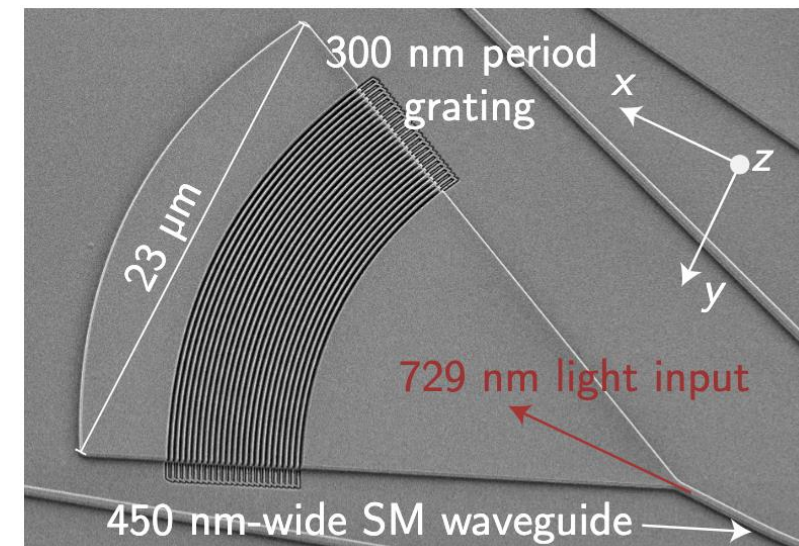
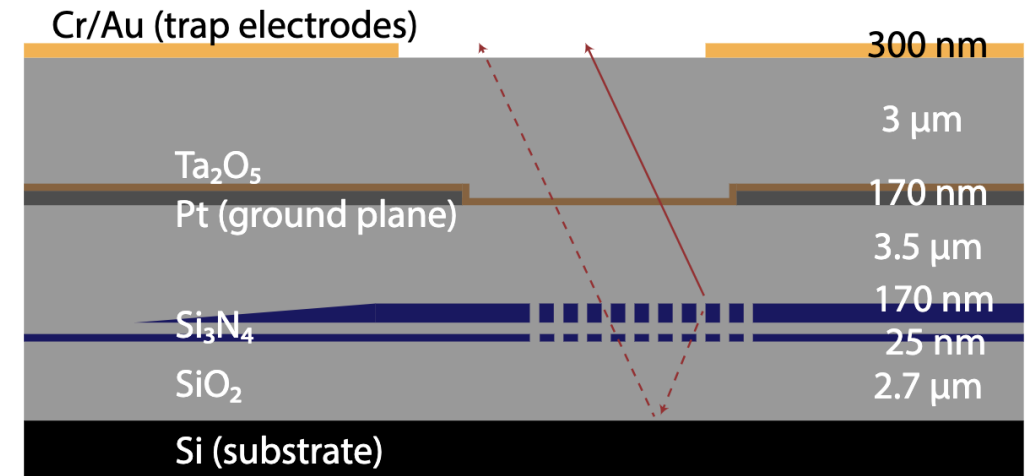
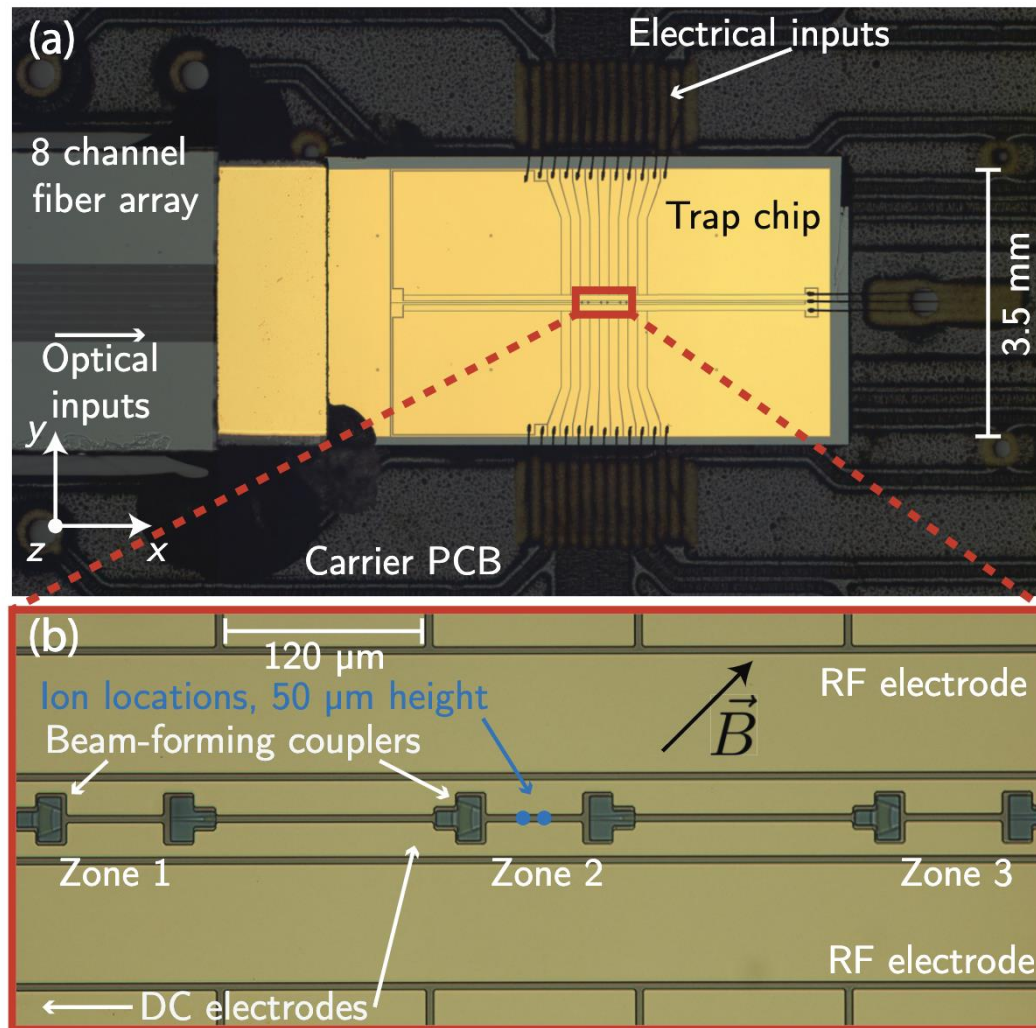
Autonomous runs + remote operation



**Cryogenic
2D chip trap**
**Integrated
photonics**



First demo of 2Q-gate operations with integrated photonics @ **ETH** zürich



K. K. Mehta, C. Zhang, M. Malinowski, T.-L. Nguyen, M. Stadler, and J. P. Home, *Nature* **586**, 533-537 (2020).

Challenges: *transmissivity in near IR and UV, fabrication process (multi-layer, materials)*

Scaling up to 20 zones @ ETHZ-PSI QC Hub



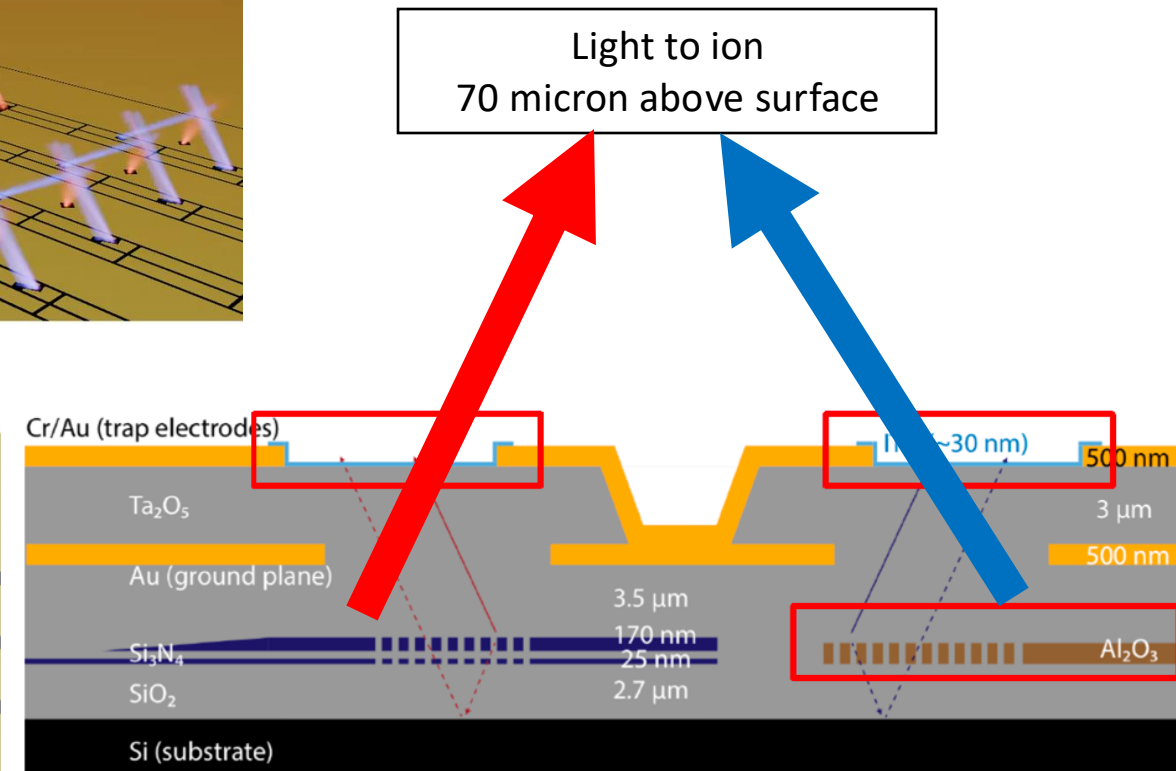
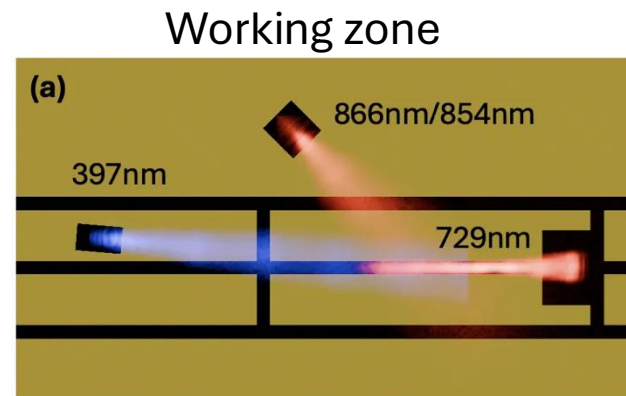
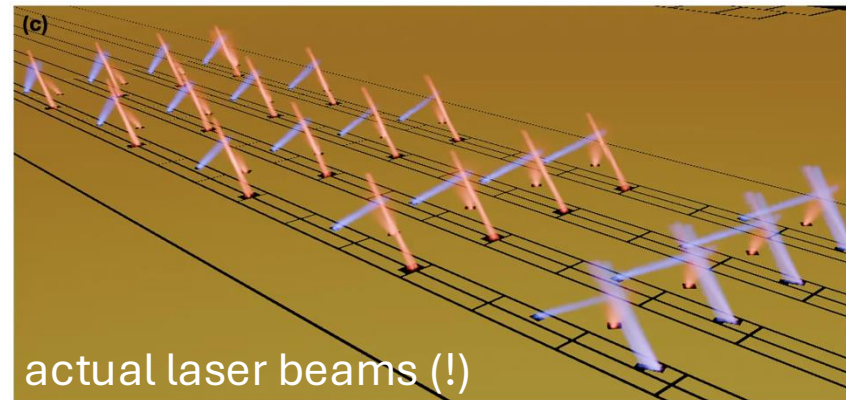
joint work with TIQI @ ETH Zurich

Current chip:

- 60 output gratings
- 15 fibers
- 120 DC electrodes

Cryostat (ColdEdge)

- 1.5 W cooling power
- System supports up to 400 DC channels



design: Karan Mehta (now Cornell)

fab: **LIONIX**
INTERNATIONAL

\$: **ETH zürich**



Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

What's hard about scaling this up?

6 zones  384 zones



Many DC connections (6 per zone \rightarrow 2'304)

- Recent work from Quantinuum, Oxford Ionics on multiplexing, MIT-LL on trap-integrated DACs

arXiv:2403.00756 (2024) ; PRX Quantum **4**, 040313 (2023) ; PR Applied **11**, 024010 (2019)

Site-resolved readout

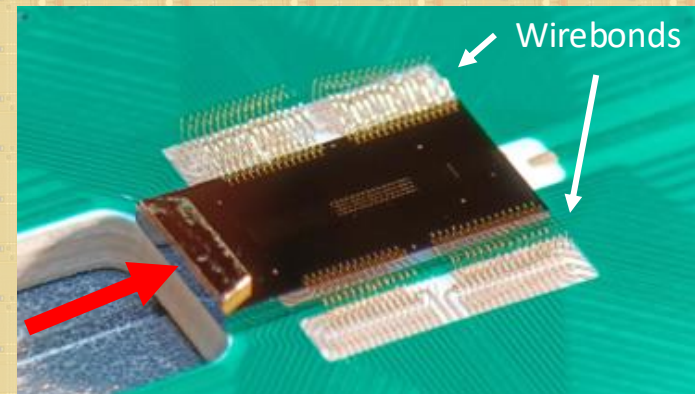
- Integrated detectors (see work from NIST, MIT-LL, Sandia)

APL **119**, 154002 (2021) ; PRL **126**, 010501 (2021) ; PRL **129**, 100502 (2022)

- Lens arrays

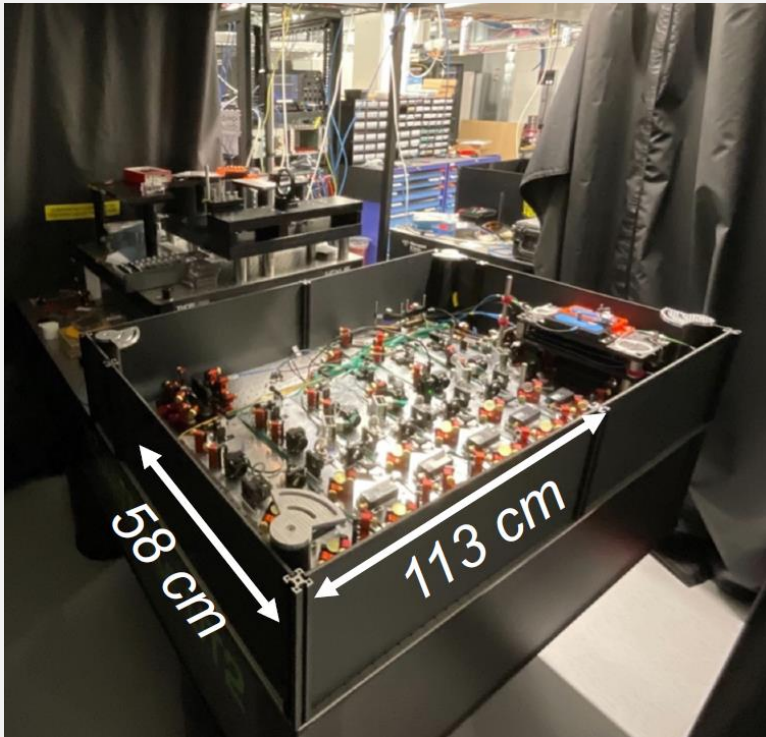
Many individually controlled laser beams (3 per zone \rightarrow **1152 beams**)

- wavelengths from 397nm to 866nm (or 493nm to 1762nm with Ba⁺)
- > 60 dB on-off extinction ratio**
- Amplitude, frequency, phase control

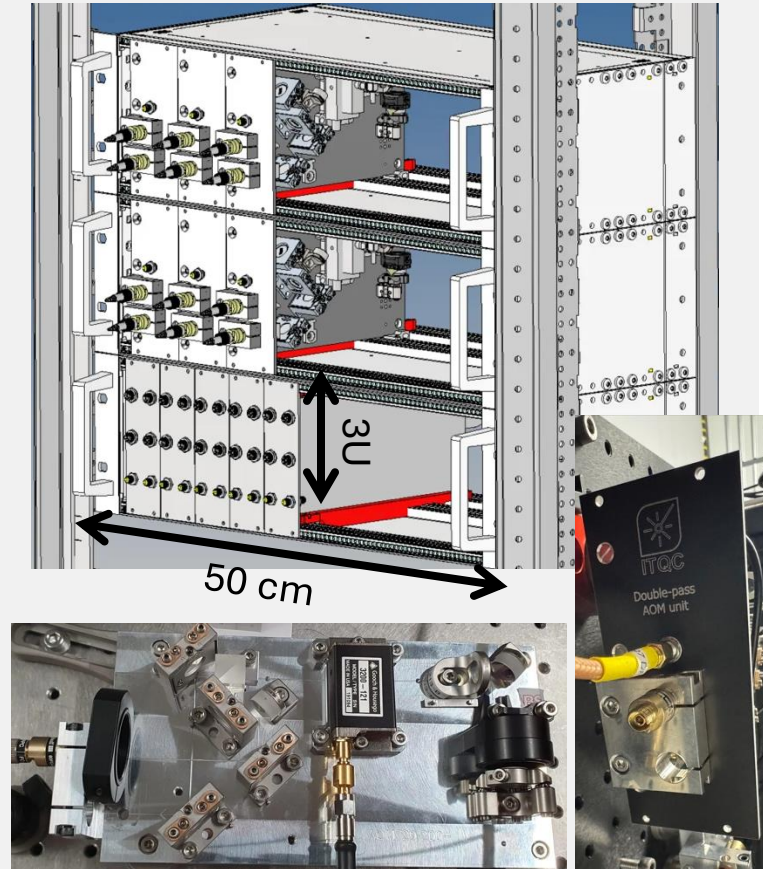


PSI-ITQC: shrinking the optical table

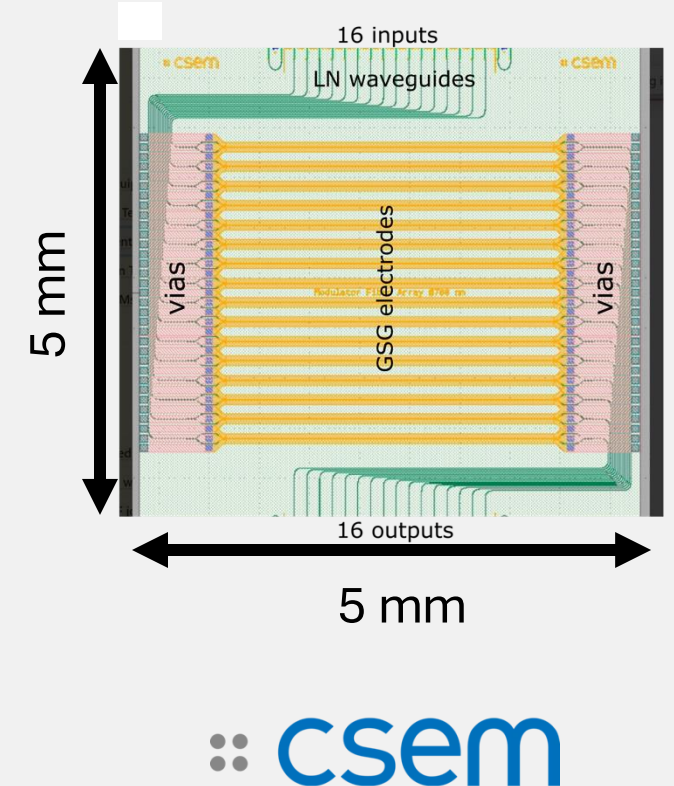
6 outputs / optical table
(1" optics)



10 outputs / rack unit
(1/2" optics, modular)



~16 channels in 25 mm²



“An integrated photonic engine for programmable atomic control”,
Nature Communications 16:82 (2025)

First tests of TFLN

(Devices from R. Grange group at ETHZ)



No photos, please.

Powell et al. Opt. Express **32**, 44115-44122 (2024)

More actives and more passives



No photos, please.



Thank you!

Cornelius.Hempel@psi.ch