quantum computing with photons

science, technology, industry

olivier ezratty

⟨ … | quantum engineer | QEI cofounder | … ⟩

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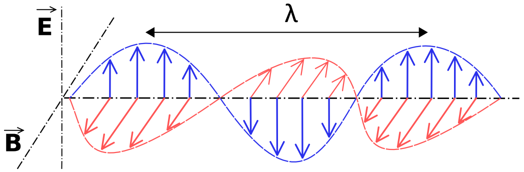
Minalogic Quantum Day

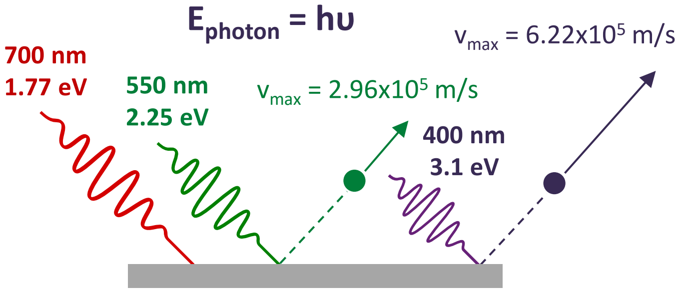
Lyon, November 18th, 2025

what is a photon?

$$\nabla \cdot \mathbf{D} = \rho$$
$$\nabla \cdot \mathbf{B} = 0$$
$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$
$$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$$



EM “wave” – Maxwell - 1865



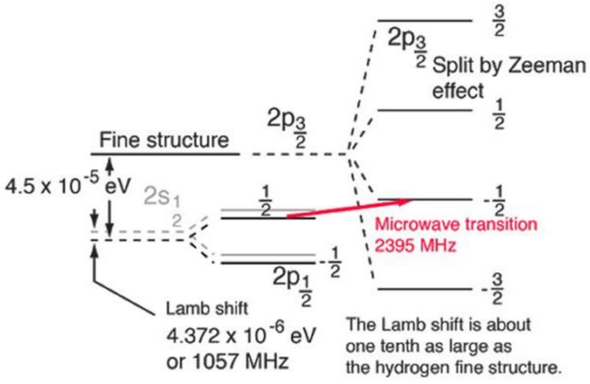
“particle” – Einstein - 1905

quantized electromagnetic field

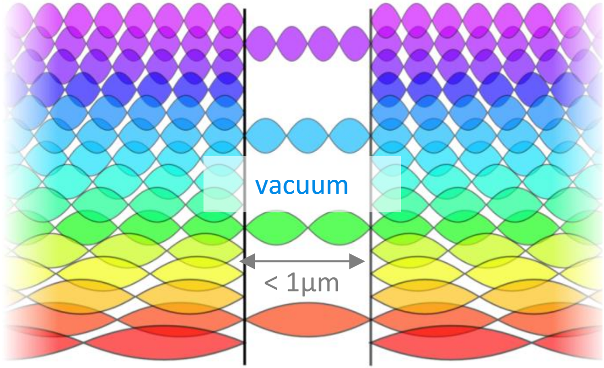
quantum vacuum fluctuations

according to quantum field theory and Heisenberg indetermination principle, vacuum contains harmonic oscillators with zero-point energy:

$$E = \frac{1}{2} h\upsilon \qquad \Delta E . \Delta t \geq \frac{\hbar}{2}$$



Lamb shift
1947



Casimir effect
1948-1997

What is a photon?

Anti-photon

W.E. Lamb, Jr.

Optical Sciences Center, University of Arizona, Tucson, AZ 85721,

Received: 23 July 1994 / Accepted: 18 September 1994

Abstract. It should be apparent from the title of this article that the author does not like the use of the word "photon", which dates from 1926. In his view, there is no such thing as a photon. Only a comedy of errors and historical accidents led to its popularity among physicists and optical scientists. I admit that the word is short and convenient. Its use is also habit forming. Similarly, one might find it convenient to speak of the "aether" or "vacuum" to stand for empty space, even if no such thing existed. There are very good substitute words for "photon", (e.g., "radiation" or "light"), and for "photonics" (e.g., "optics" or "quantum optics"). Similar objections are possible to use of the word "phonon", which dates from 1932. Objects like electrons, neutrinos of finite rest mass, or helium atoms can, under suitable conditions, be considered to be particles, since their theories then have viable non-relativistic and non-quantum limits. This paper outlines the main features of the quantum theory of radiation and indicates how they can be used to treat problems in quantum optics.

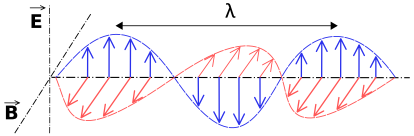
PACS: 12.20.–m; 42.50.–p

Ambiguous term "photon"

- ☒ Wave-particle duality
- ☒ Light "particle"
- ☑ Discrete energy E=hf
- ☑ Non-classical statistics

https://www.youtube.com/watch?v=xteuqbb-bdU

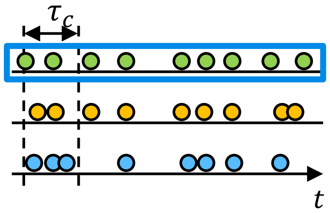
photon modes encode information



spatial mode
where is the photon in space

spectral mode
frequency or wavelength

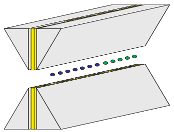
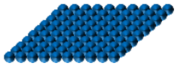
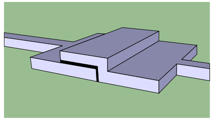
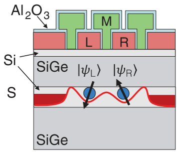
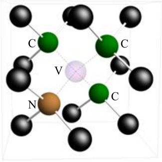
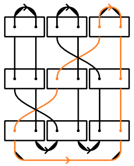
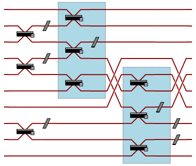
orbital angular momentum
twisted light modes with
helical phase fronts



temporal mode
when the photon was emitted

a mode describes one property of a photon

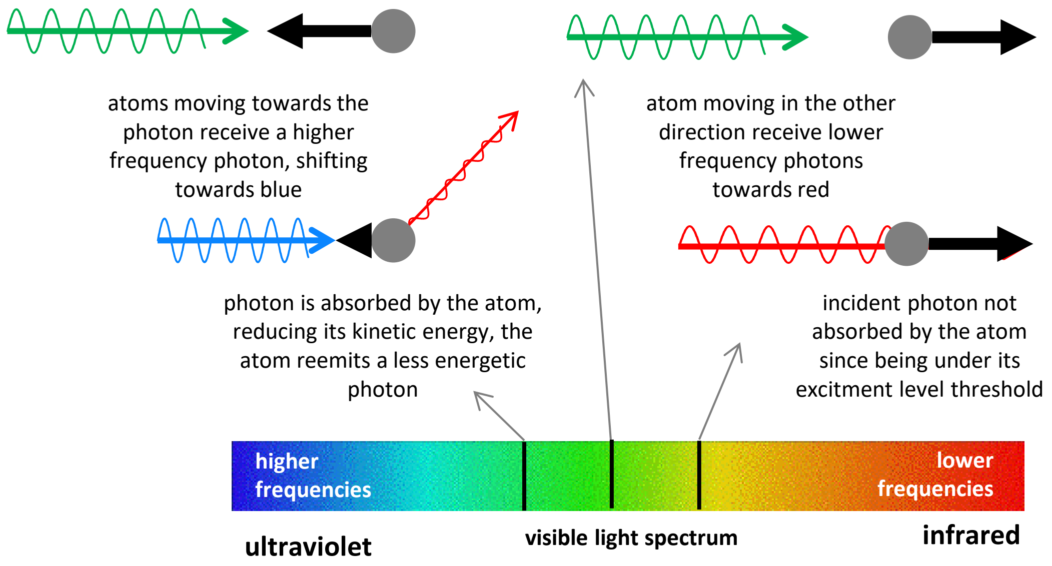
photons in quantum computing

	atoms		electrons *controlled spin and microwave cavities*				photons
							
	trapped ions	**cold atoms**	**superconducting**	**silicon**	**vacancies**	**topological**	**photons**
initialization	optical or electromagnetic tweezers		microwave pulses		optical	DC current	single photon sources and polarizers
quantum gates	laser pulses microwaves RF signals		microwave pulses and/or DC current		optical and/or microwaves	microwave reflectometry and quadrature analysis	interferometers, polarizing beam splitters, ...
readout	laser and CCD detected fluorescence		microwave reflectometry and quadrature analysis		laser and CCD detected fluorescence		single photon detectors

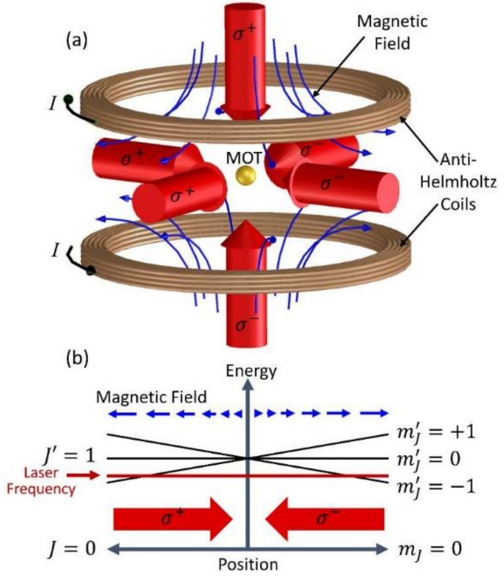
microwave photons
optical photons
other signals

Guillaume de Giovanni – Viqthor

slowing down atoms

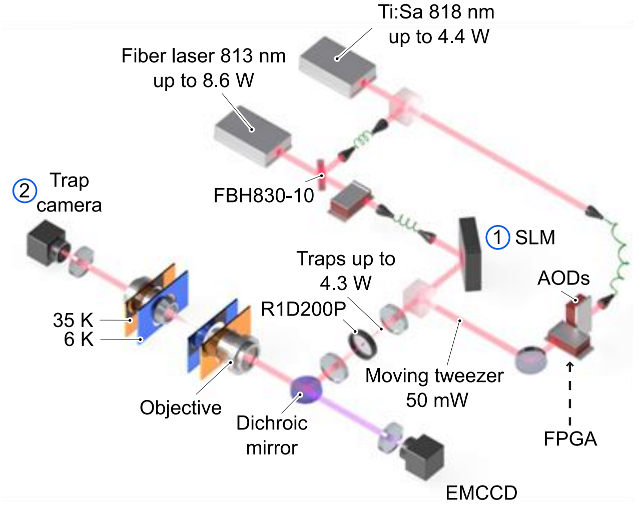


Doppler effect

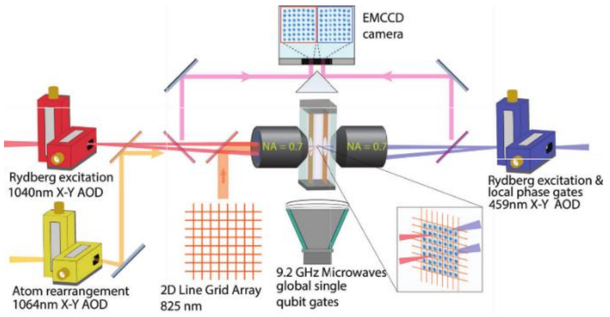


Magneto Optical Trap

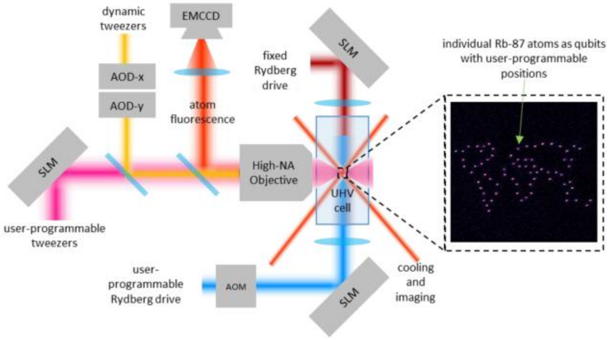
controlling cold atoms with lasers “tweezers”



Pasqal



Infleqtion

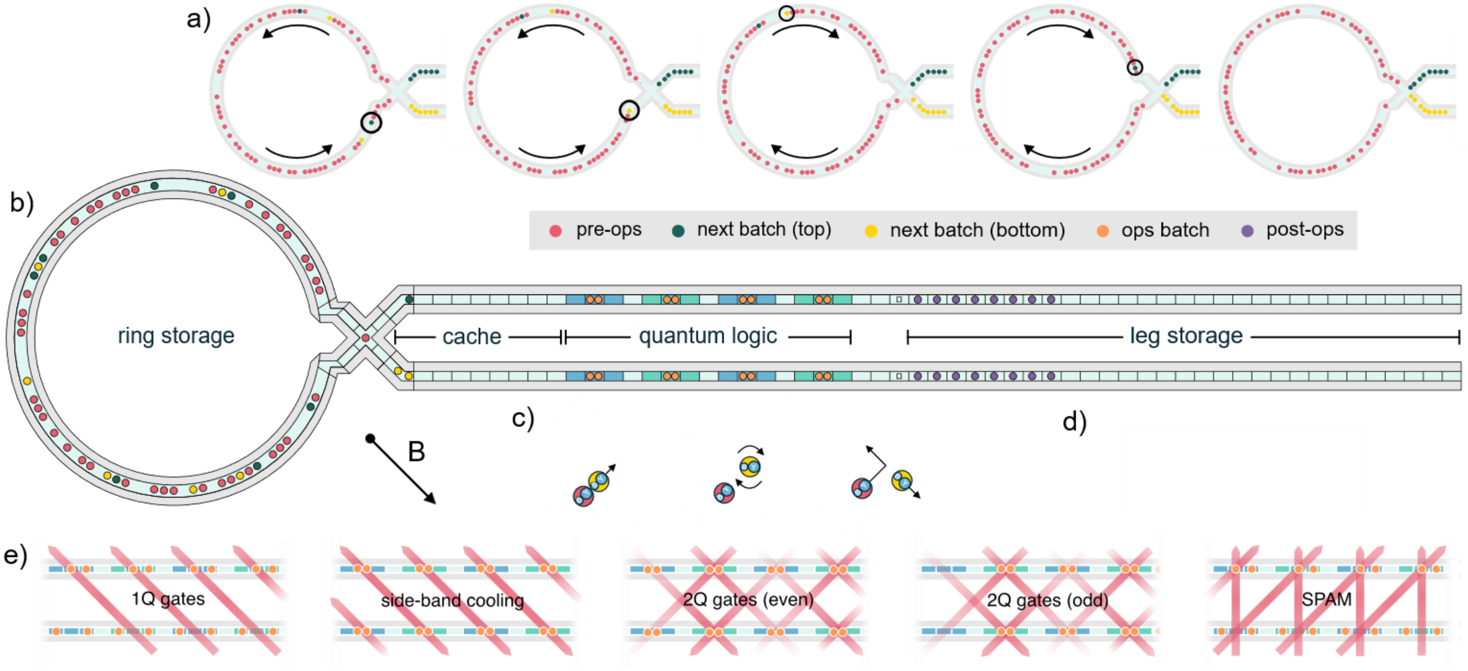


|QuEra>

Tiphaine Delsalle – Menlo Systems

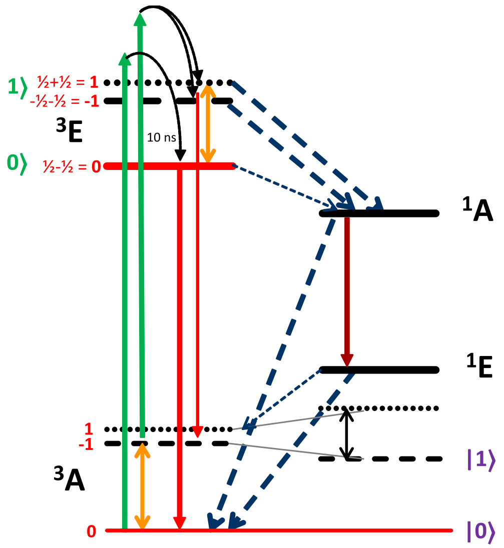
P. Laygues / Johan Boullet – Toptica

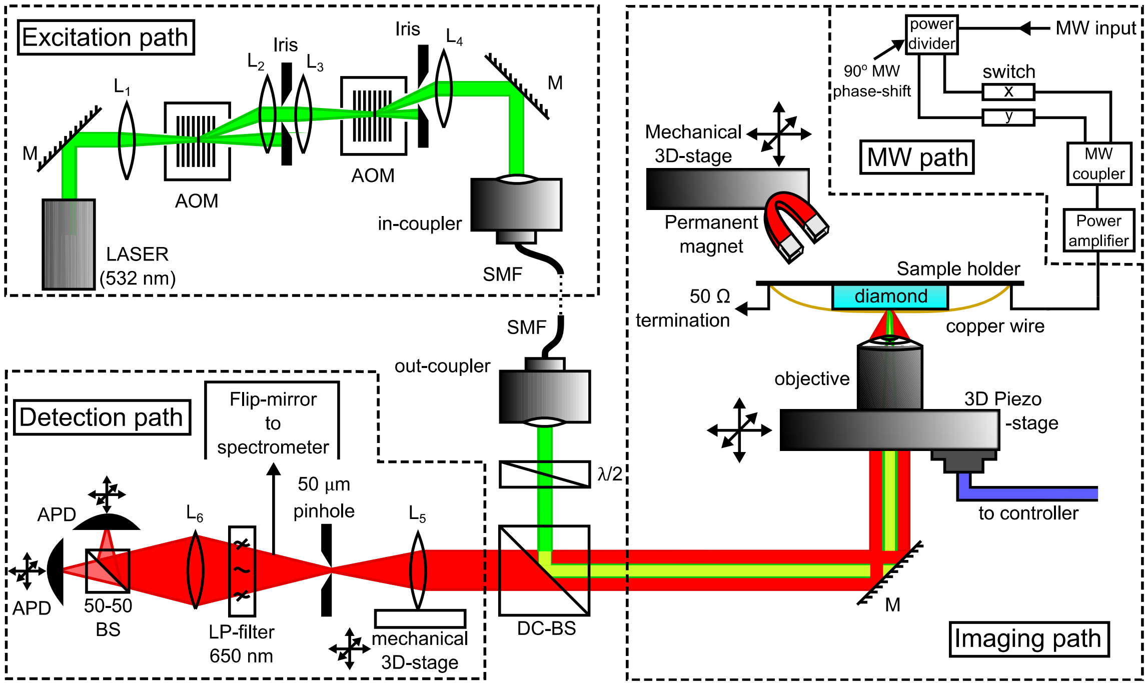
controlling trapped ions with lasers



Helios: A 98-qubit trapped-ion quantum computer by Anthony Ransford, M.S. Allman et al, arXiv, November 2025 (25 pages)

controlling NV centers with lasers





Jean-François Roch – ENS Paris Saclay

Matthieu Munsch – Qnami

quantum photonics enabling techs

laser sources

- TOPTICA PHOTONICS
- exail
- FOCUSLIGHT Never stop exploring
- AUREA TECHNOLOGY
- Stable Laser Systems
- THORLABS
- MenloSystems
- FEMTUM
- LUMIBIRD MORE THAN LASERS
- FREEDOM PHOTONICS
- FISBA Innovators in Photonics
- VECTOR PHOTONICS
- Chromacity
- VEXLUM
- UNIKLASERS

photon sources and detectors

- QUANDELA
- Sparrow Quantum
- Pixel Photonics
- SINGLE QUANTUM Excellence in photon detection
- Qontrol Systems
- Quantum Opus
- FIFTEEN INSTRUMENTS
- SCONTEL SUPERCONDUCTING NANOTECHNOLOGY
- MPD MICRO PHOTON DEVICES
- EXCELITAS TECHNOLOGIES
- HAMAMATSU PHOTON IS OUR BUSINESS
- Qubitekk
- ARTILUX
- Photon Spot

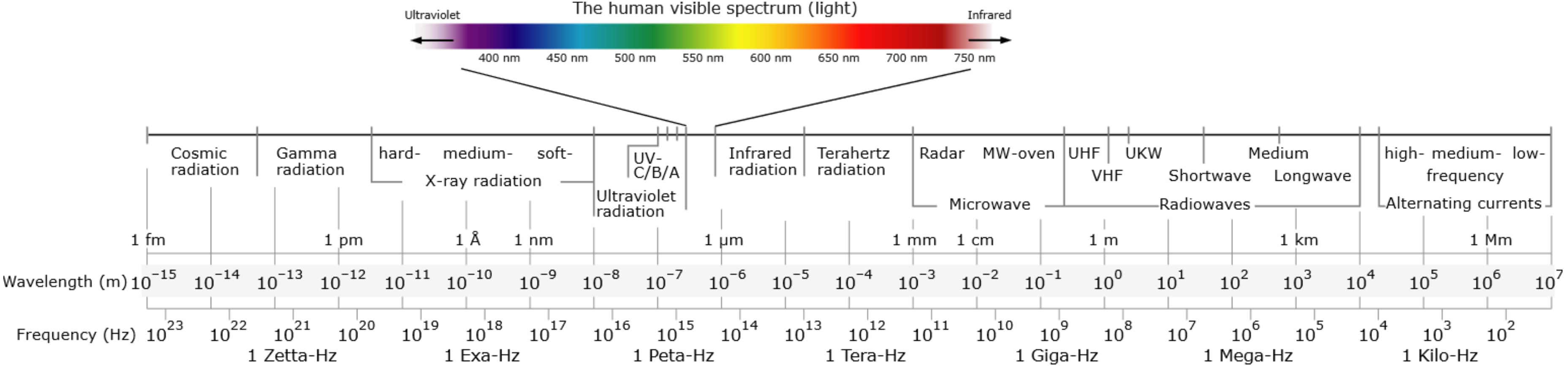
interconnect

- Welinq
- SilQ Connect
- NanoQT Nanofiber Quantum Technologies
- nu QUANTUM
- QPHOX
- IONQ

other

- SCINTIL PHOTONICS
- SILENTSYS ultralow noise systems
- HYPERLIGHT
- VLC PHOTONICS
- Qlibri Cavity enhanced science
- Alcyon PHOTONICS
- g2-Zero
- aresis

electromagnetic spectrum

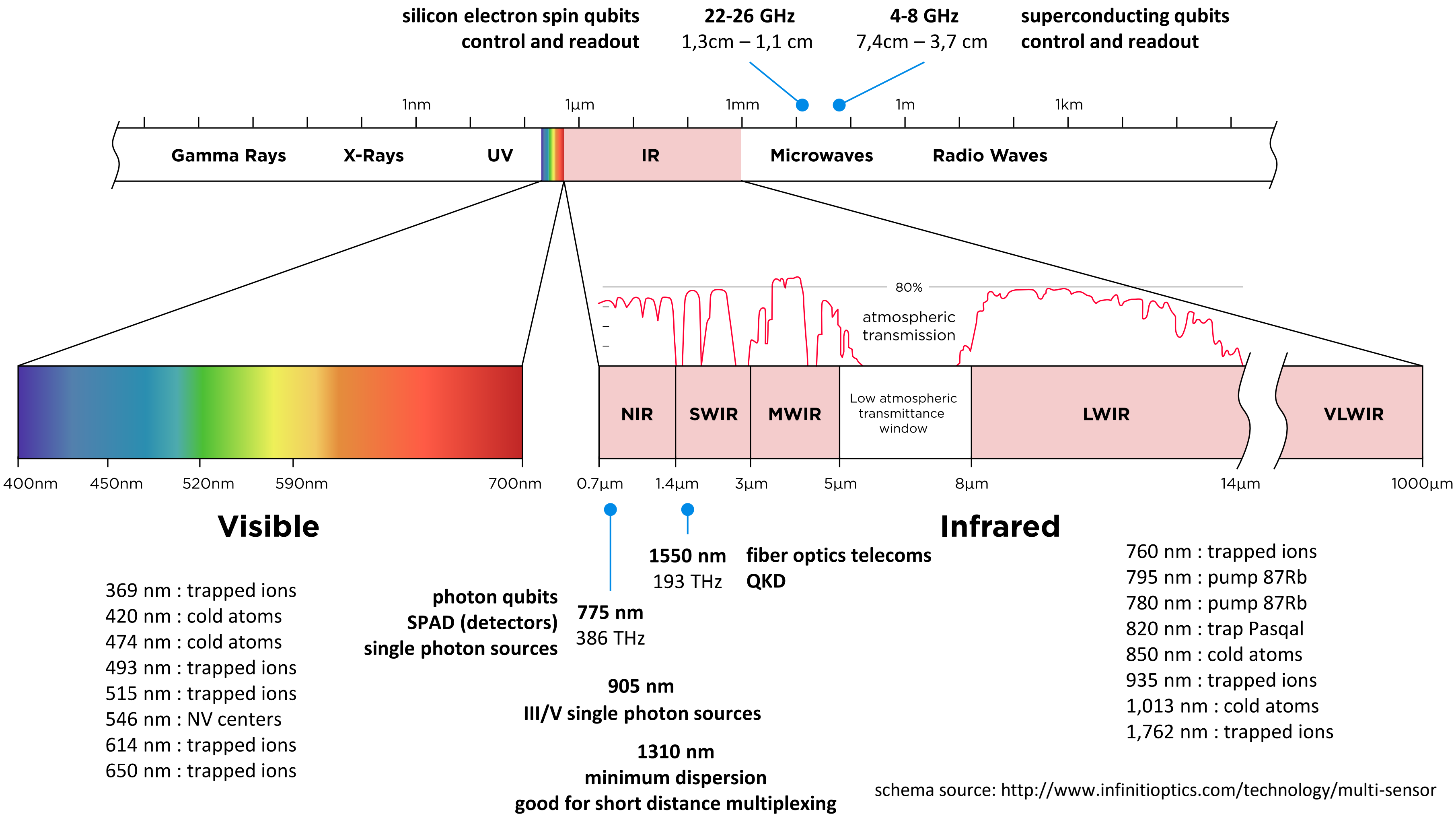


Rydberg trapped ions

photon qubits computing and quantum communications

solid state qubit control

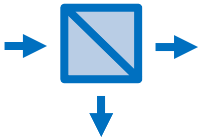
source: Wikipedia + edits


silicon electron spin qubits
control and readout
22-26 GHz
1,3cm – 1,1 cm
4-8 GHz
7,4cm – 3,7 cm
superconducting qubits
control and readout
1nm
1µm
1mm
1m
1km
Gamma Rays
X-Rays
UV
IR
Microwaves
Radio Waves
80%
atmospheric
transmission
NIR
SWIR
MWIR
Low atmospheric
transmittance
window
LWIR
VLWIR
400nm
450nm
520nm
590nm
700nm
0.7µm
1.4µm
3µm
5µm
8µm
14µm
1000µm
Visible
Infrared
369 nm : trapped ions
420 nm : cold atoms
474 nm : cold atoms
493 nm : trapped ions
515 nm : trapped ions
546 nm : NV centers
614 nm : trapped ions
650 nm : trapped ions
photon qubits
SPAD (detectors)
single photon sources
775 nm
386 THz
1550 nm
193 THz
fiber optics telecoms
QKD
905 nm
III/V single photon sources
1310 nm
minimum dispersion
good for short distance multiplexing
760 nm : trapped ions
795 nm : pump 87Rb
780 nm : pump 87Rb
820 nm : trap Pasqal
850 nm : cold atoms
935 nm : trapped ions
1,013 nm : cold atoms
1,762 nm : trapped ions
schema source: http://www.infinitioptics.com/technology/multi-sensor

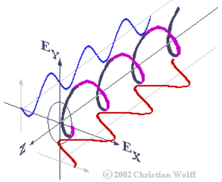
photons qubits types and tools

qubits

path

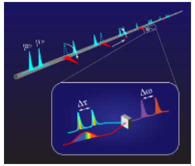


polarization

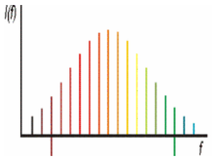


angular orbital moment

time

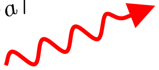


frequency



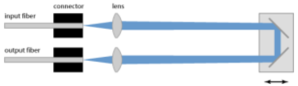
photon number

$$\sqrt{p_0}|0_a\rangle + \sqrt{p_1}e^{\imath\alpha_1}|1_a\rangle$$

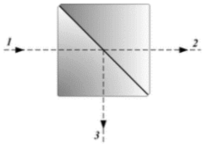


instrumentation

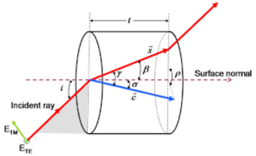
light guides
optical fibers of guides integrated in nanophotonic components



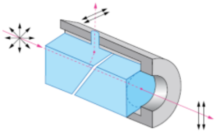
optical delay line
used to synchronize photons phase after going through various lengths fibers



splitters
split a light beam in two identical beams



birefringent filters
filters with two refracting index



polarizers
keep only one polarity

dephasers
modifies photons (circular) polarity or (linear) phase
delay lines of Pockels celles

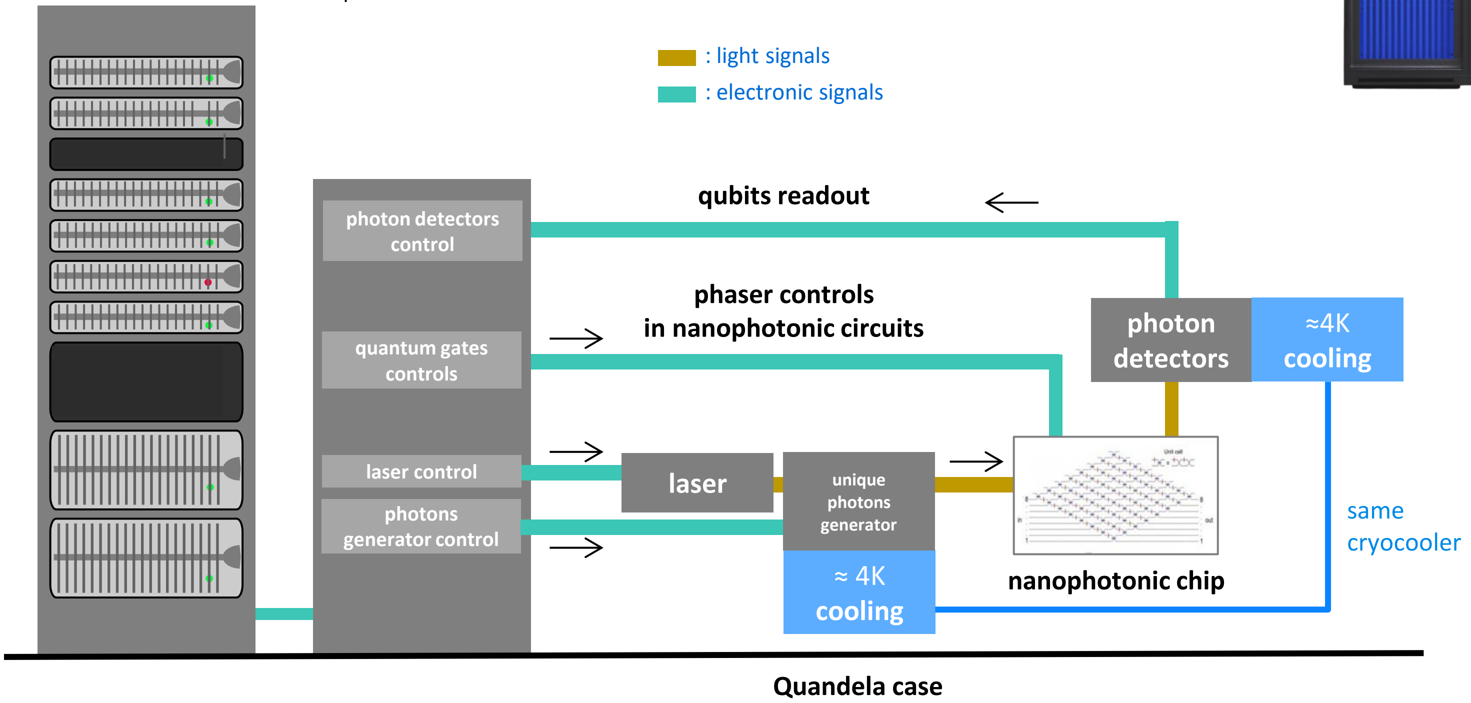
inside a photon qubit QPU

QUANDELA

computing
servers, network, software, data

qubits control electronics
laser, unique photon generator, quantum gates, photons readout

nanophotonic chipset
where quantum computation is done



indistinguishable photons generation

<10K

QUANDELA

Sparrow Quantum

integrated photonic circuits

300K

leti cea tech

SMART PHOTONICS
Independent InP Foundry

VLC PHOTONICS

QuiX

LIGENTEC

BRIGHT Integrated PHOTONICS

unique photons detectors

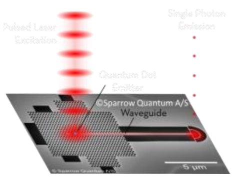
2K

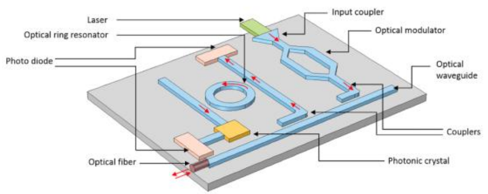
SINGLE QUANTUM
Excellence in photon detection

Photon Spot

IDQ

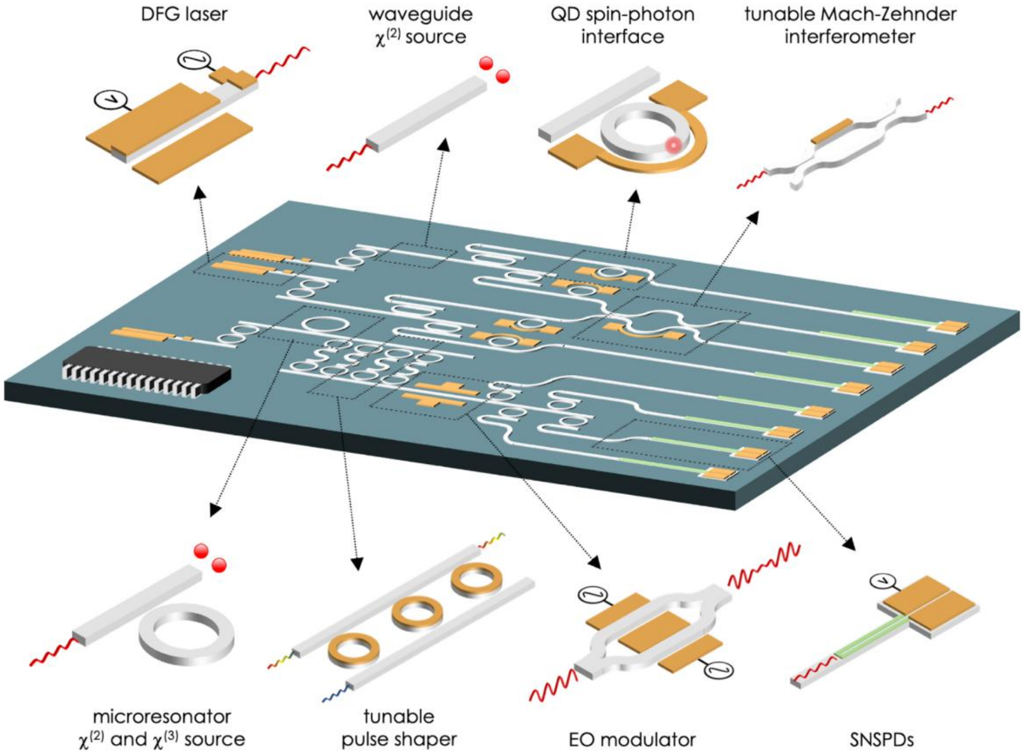
Quantum Opus





source : adapted from Photonic quantum bits by Pascale Senellart, june 2019 (31 slides)

nanophotonic circuits



wafer substrates
silicon
silicon on insulator (SOI)
gallium nitride (GaN)
gallium arsenide (GaAs)
sapphire (Al_2O_3)
silicon carbide (SiC)
quartz (SiO_2)

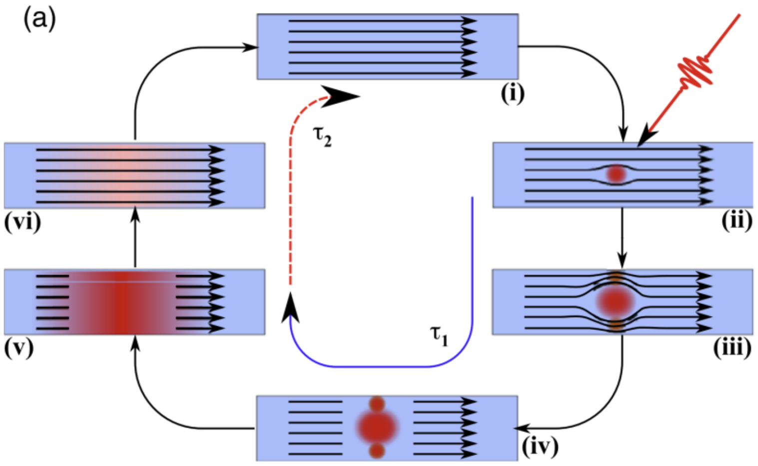
added materials
lithium Niobate ($LiNbO_3$ on SiO_2)
barium Titanate (BTO) on SOI
hexagonal Boron Nitride (hBN)
erbium-doped Silica ($Er{:}SiO_2$)
InAs/GaAs and AlAs/GaAs Quantum Dots

Ségolène Olivier – CEA-Leti

Michael Geiselmann – Ligentec

single photon detectors

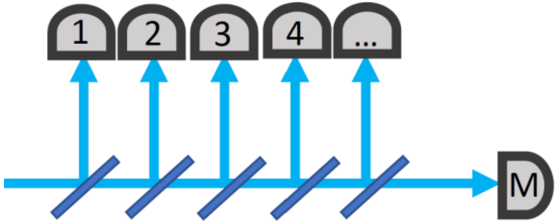
SNSPD



+TES

+ homodyne detection

PNRD



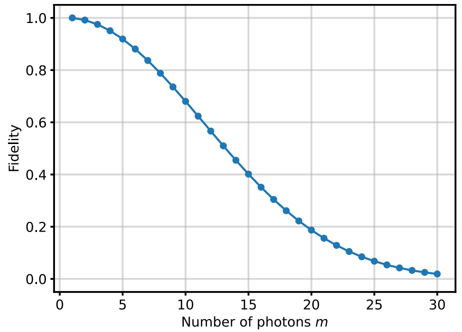


Fig. 2. Fidelity versus the number of incoming photons m (blue points) with $N = 120$ single-photon detectors. This plot was obtained by a second order Stirling expansion of Eq. 6.

Andreas Fognini – Single Quantum

key figures of merit

photon sources

- purity $g^2(0)$
- indistinguishability (HOM)
- brightness
- clock rate
- timing jitter
- coupling
- tunability
- mode purity

photon detectors

- efficiency
- dark count rates
- timing jitter
- timing resolution
- dead time
- memory effect
- latency
- electronics jitter
- spectral response

fibers and waveguides

- total losses
- coupling efficiency (fiber to PIC)
- insertion loss
- attenuation
- chromatic dispersion
- noise

DV and CV photon qubits

	discrete variables	continous variables	boson sampling
quantum information	**discrete degree of freedom of a photon** Fock states: $\|0\rangle, \|1\rangle, \|2\rangle$ … single or many photon properties	**quadrature of a light field** coherent states, qumodes, spectral and time modes	**multimode photons**
photon sources	**single indistinguishable photon sources**	**entangled photons sources** **squeezed states, …**	**unique photons source**
representation	**density matrix**	**Wigner function**	**permanent**
gates	**KLM model, MZI (Mach-Zehnder Interferometer) gates, measurement based**	**determinist gates** modes measurement gaussian and non gaussian gates	**MZI and interferometer**
photon detectors	**photon counters /detectors** APD, SNSPD, VLPC, TES	**homodyne and heterodyne detectors**	**single photons detectors**
players	PsiQuantum ORCA Computing QUANDELA DUALITY QUANTUM PHOTONICS	XANADU	QUANDELA XANADU

the KLM model

QUANDELA

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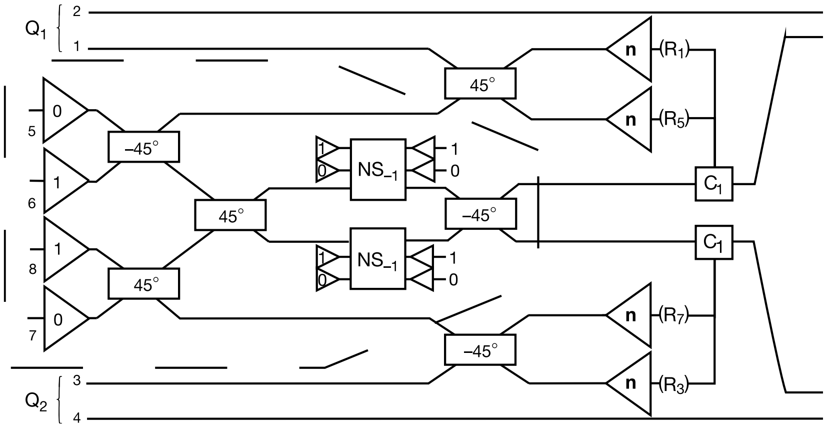
Article | Published: 04 January 2001

A scheme for efficient quantum computation with linear optics

E. Knill, R. Laflamme & G. J. Milburn

Nature **409**, 46–52 (2001) | Cite this article



Daphné Wang - Quandela

boson sampling

The computational complexity of linear optics

Authors: Scott Aaronson, Alex Arkhipov | Authors Info & Claims

STOC '11: Proceedings of the forty-third annual ACM symposium on Theory of computing
https://doi.org/10.1145/1993636.1993682

Published: 06 June 2011 Publication History

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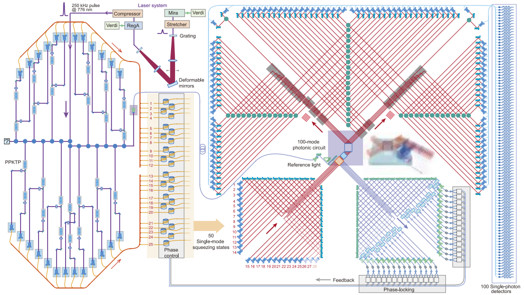
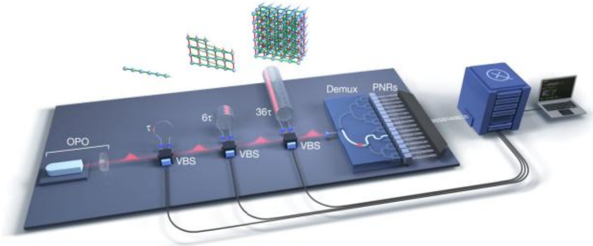


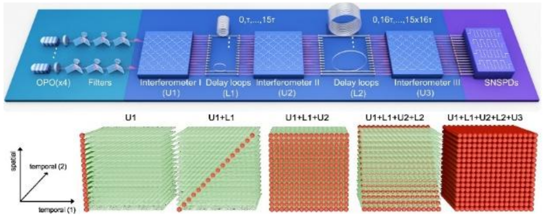
Quantum computational advantage using photons by Han-Sen Zhong, Jian-Wei Pan et al, arXiv, December 2020.

100 photon modes and detectors



Quantum computational advantage with a programmable photonic processor by lars S Madsen et al, Nature, June 2022.

216 squeezed photon modes
still a sampling task, not a real computational task



Robust quantum computational advantage with programmable 3050-photon Gaussian boson sampling by Hua-Liang Liu, Jian-Wei Pan et al, arXiv, August 2025.

8,176 modes photon and 16 detectors

Using Gaussian Boson Sampling to Find Dense Subgraphs

Juan Miguel Arrazola* and Thomas R. Bromley†
Xanadu, 372 Richmond Street W, Toronto, Ontario M5V 1X6, Canada

Boson sampling devices are a prime candidate for exhibiting quantum supremacy, yet their application for solving problems of practical interest is less well understood. Here we show that Gaussian boson samplin[...] the NP-hard densest k-subg[...]h GBS, which selects dense s[...] graph density and the numb[...]evant quantity determining sampling probabilities in GBS. We test our findings by constructing GBS-enhanced versions of the random search and simulated annealing algorithms and apply them through numerical simulations of GBS to identify the densest subgraph of a 30 vertex graph.

dense subgraphs search

arXiv:1803.10730v2 [quant-ph] 30 Jul 2018

Quantum algorithms are often designed with the assumption that they can access the full power of universal quantum computation. However, presently developing quantum devices have limited resource capabilities and are not fault-tolerant. Their emergence has motivated a reexamination of methods for designing quantum algorithms, with the focus now on harnessing the computational power of small-scale, noisy quantum computers. Candidate algorithms for near-term devices include quantum simulators for many-body physics [1, 2], variational algorithms [3–6], quantum approximate optimization algorithms [7, 8], and machine learning on hybrid devices [9–13].

Boson sampling is a limited model of quantum computation given by passing photons through a linear interferometer and observing their output configurations [14]. Significant efforts have been performed to implement boson sampling [15–18], leading to the proposal of related models such as scattershot boson sampling [19–21] and Gaussian boson sampling [22, 23] that are more suitable for experimental realizations. Moreover, boson sampling devices are in principle capable of performing tasks that cannot be efficiently simulated on classical computers, a feature that has made them a leading candidate for challenging the extended Church-Turing thesis. In fact, the primary objective of implementing boson sampling has so far been to demonstrate quantum supremacy, leaving the real-world application of such devices underdeveloped. A notable exception is the use of Gaussian boson sampling for efficiently calculating the vibronic spectra of molecules, [24–26], which provided the first clue of the usefulness of this platform.

In this work, we show that Gaussian boson sampling (GBS) can be used to enhance classical stochastic algorithms for the densest k-subgraph (DkS) problem. The DkS problem is NP-Hard [27] and defined through the following optimization task: given a graph G with n vertices, find the subgraph of $k < n$ vertices with the largest density. Among subgraphs with a fixed number of vertices, the density and the number of edges are equivalent quantities, and we hence refer to both interchangeably throughout this manuscript. Beyond its fundamental interest in mathematics and theoretical computer science, the DkS problem has a natural connection to clustering problems with the goal of finding highly correlated subsets of data. Clustering has applications in a wide range of fields such as data mining [28–31], bioinformatics [32, 33], and finance [34].

Our approach uses a technique from Ref. [35] to encode a graph into the GBS paradigm. Here, the probability of observing a given photon configuration is proportional to the number of perfect matchings of the corresponding subgraph. We highlight a correspondence between the number of perfect matchings in a subgraph and its density, meaning that a suitably programmed GBS device will prefer to output dense subgrap[...] lowing results in a companion pape[...] is a form of proportional sampling [...] enhance the stochastic element of [...] heuristics for the DkS problem. [...] time approximation schemes are be[...] DkS problem [37], certain worst-[...] ing superpolynomial runtime may [...] stochastic algorithms. Our finding[...] a fixed graph, where we introduce GBS-enhanced hybridizations of random search and simulated annealing algorithms. This approach highlights a general principle of using output samples from a GBS device to enhance approximate solutions to optimization problems.

Applying GBS to the DkS problem.— The important concepts of GBS are first briefly reviewed. In GBS, photon-number detection is performed on a multi-mode Gaussian state [22, 23, 38]. For an n-mode system, we denote the possible outputs of GBS by vectors $S = (s_1, s_2, \ldots, s_n)$, where s_i is the number of photons detected in output mode i. It was shown in Ref. [22] that the probability of observing an output pattern S is

$$P(S) = |\sigma_Q|^{-\frac{1}{2}} \frac{\mathrm{Haf}(\mathcal{A}_S)}{s_1! s_2! \cdots s_n!}, \tag{1}$$

where $\sigma_Q = \sigma + \mathbb{1}_{2n}/2$, σ is the $(2n \times 2n)$-dimensional covariance matrix of the n-mode Gaussian state, and $\mathcal{A}_S$ is a submatrix of $\mathcal{A} = \begin{pmatrix} 0 & \mathbb{1}_n \\ \mathbb{1}_n & 0 \end{pmatrix} \left[\mathbb{1}_{2n} - \sigma_Q^{-1}\right]$ fixed by

useful algorithms based on parameterized gaussian boson sampling

Boson Sampling for Molecular Vibronic Spectra

Joonsuk Huh,* Gian Giacomo Guerreschi, Borja Peropadre, Jarrod R. McClean, and Alán Aspuru-Guzik†
Department of Chemistry and Chemical Biology, Harvard University, Cambridge, Massachusetts 02138, United States

(Dated: December 30, 2014)

Quantum computers are expected to be more efficient in performing certain computations than any classical machine. Unfortunately, the technological challenges associated with building a full-scale quantum computer have not yet allowed the experimental verification of such an expectation. Recently, bo[...]ractable on any classical com[...]tup. Therefore, boson sampli[...] Church-Turing thesis and thi[...]ampling, at least in relation to [...]ful development of a boson sampling apparatus would not only answer such inquiries, but also yield a practical tool for difficult molecular computations. Specifically, we show that a boson sampling device with a modified input state can be used to generate molecular vibronic spectra, including complicated effects such as Duschinsky rotations.

molecular simulation

arXiv:1412[...]ant-ph] 29 Dec 2014

I. INTRODUCTION

Quantum mechanics allows the storage and manipulation of information in ways that are not possible according to classical physics. At a glance, it appears evident that the set of operations characterizing a quantum computer is strictly larger than the operations possible in a classical hardware. This speculation is at the basis of quantum speedups that have been achieved for oracu[...]lems [1, 2]. Particularly significant [...]peed up achieved for the prime fac[...]umbers [3], a problem for which no [...]orithm is currently known. Another [...]uantum computers is quantum sim[...] it has recently been shown that the [...]al reactions [10] as well as molecular [...] [11] are attractive applications for [...]or all these instances, the realization of a quantum computer would challenge the Extended Church-Turing thesis (ECT), which claims that a Turing machine can efficiently simulate any physically realizable system, and even disprove it if prime factorization was finally demonstrated to be not efficiently solvable on classical machines.

At the same time, the realization of a full-scale quantum computer is a very demanding technological challenge, even if it is not forbidden by fundamental physics. This fact motivated the search for intermediate quantum hardware that could efficiently solve specific computational problems, believed to be intractable with classical machines, without being capable of universal quantum computation. Recently, Aaronson and Arkhipov found that sampling the distribution of photons at the output of a linear photonic network is expected (modulo a few conjectures) to be computationally inefficient for any

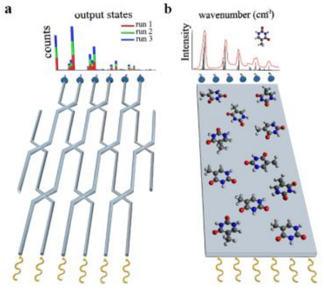


FIG. 1. Pictorial description of boson sampling and molecular vibronic spectroscopy. **a**, Boson sampling consists of sampling the output distribution of photons obtained from quantum interference inside a linear quantum optical network. **b**, Vibronic spectroscopy uses coherent light to electronically excite an ensemble of identical molecules and measures the re-emitted (or scattered) radiation to infer the vibrational spectrum of the molecule. We show in this work how the fundamental physical process underlying **b** is formally equivalent to situation **a** together with a non-linear state preparation step.

classical computer since it would require the estimation of lots of matrix permanents [12]. On the contrary, this task is naturally simulated by indistinguishable photons injected as input of a photonic network (see the pictorial description of boson sampling in Fig. 1a). While several groups have already realized small-scale versions of boson sampling [13–16], to challenge the ECT one also

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another programmable GBS (Gaussian Boson Sampling) in China.

solves graph problems.

comparison made with US DoE Frontier supercomputer.

Solving Graph Problems Using Gaussian Boson Sampling

Yu-Hao Deng,[1,2,*] Si-Qiu Gong,[1,2,*] Yi-Chao Gu,[1,2,*] Zhi-Jiong Zhang,[1,2] Hua-Liang Liu,[1,2] Hao Su,[1,2] Hao-Yang Tang,[1,2] Jia-Min Xu,[1,2] Meng-Hao Jia,[1,2] Ming-Cheng Chen,[1,2] Han-Sen Zhong,[1,2] Hui Wang,[1,2] Jiarong Yan,[1,2] Yi Hu,[1,2] Jia Huang,[3] Wei-Jun Zhang,[3] Hao Li,[3] Xiao Jiang,[1,2] Lixing You,[3] Zhen Wang,[3] Li Li,[1,2] Nai-Le Liu,[1,2] Chao-Yang Lu,[1,2] and Jian-Wei Pan[1,2]

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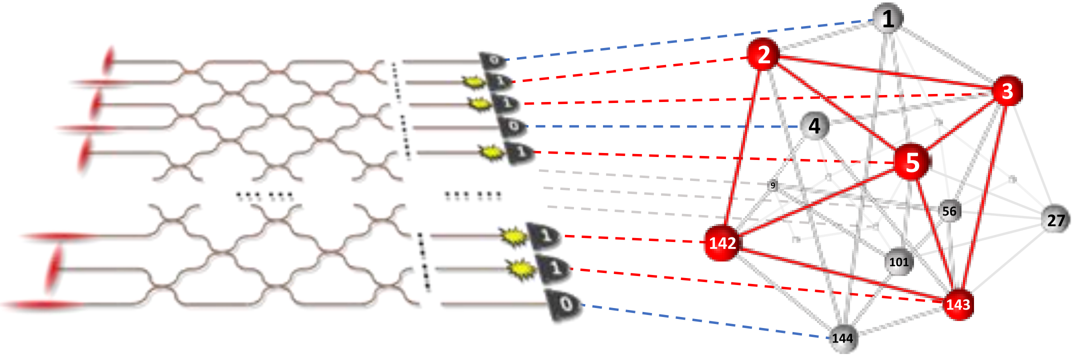
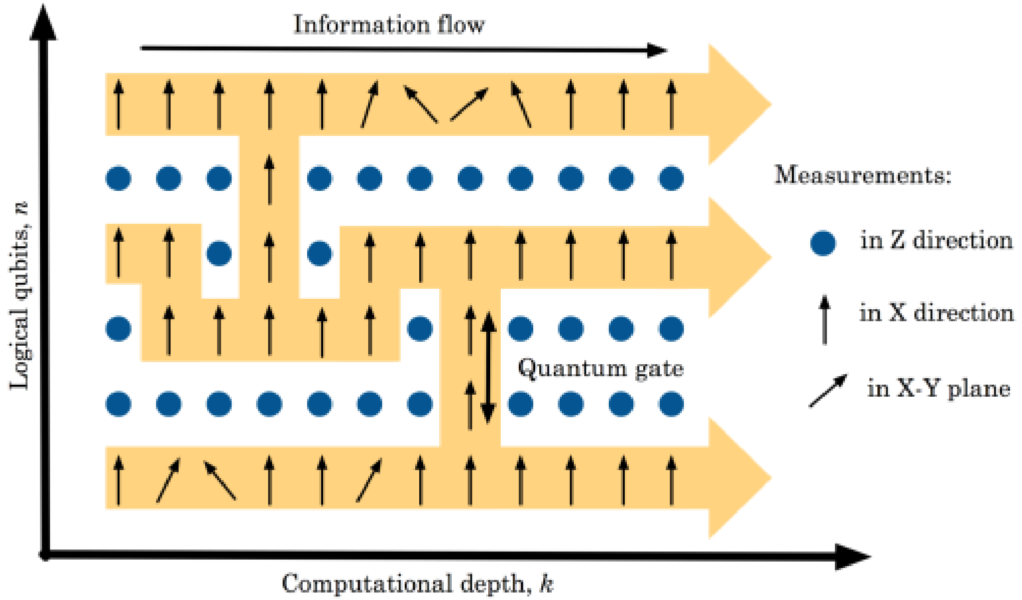
(Dated: February 3, 2023)

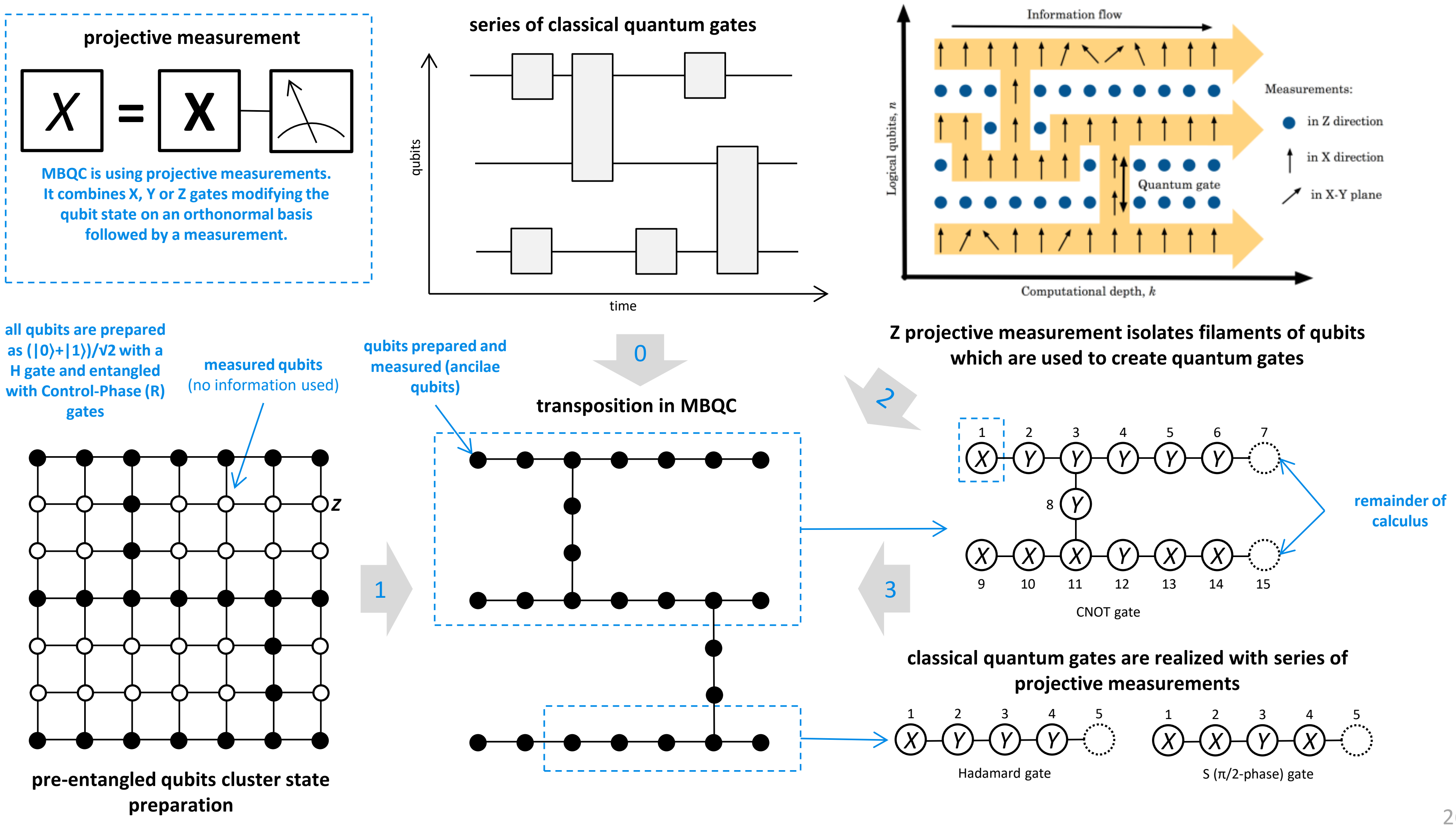
https://arxiv.org/abs/2302.00936 February 2023



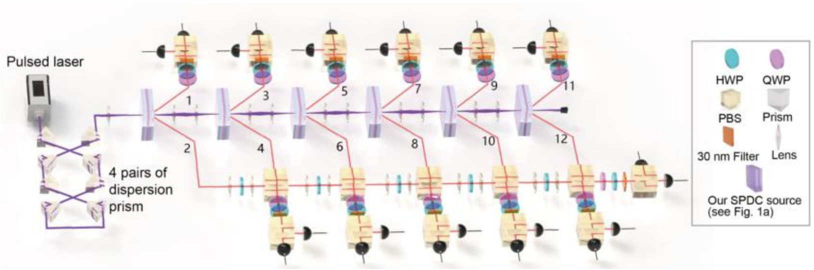
the measurement based model



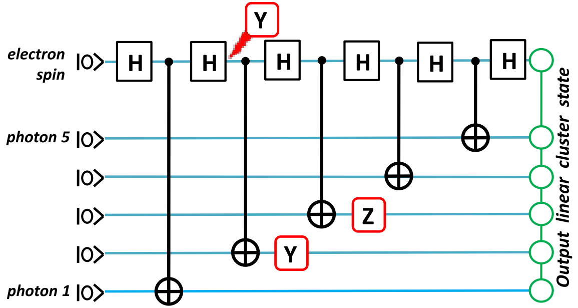
Measurement-based quantum computation by H. J. Briegel, D. E. Browne, W. Dür, R. Raussendorf, M. Van den Nest, Nature Physics, January 2009.


projective measurement
X = X
MBQC is using projective measurements.
It combines X, Y or Z gates modifying the
qubit state on an orthonormal basis
followed by a measurement.
series of classical quantum gates
qubits
time
Information flow
Logical qubits, n
Computational depth, k
Measurements:
in Z direction
in X direction
in X-Y plane
Quantum gate
Z projective measurement isolates filaments of qubits
which are used to create quantum gates
all qubits are prepared
as (|0⟩+|1⟩)/√2 with a
H gate and entangled
with Control-Phase (R)
gates
measured qubits
(no information used)
qubits prepared and
measured (ancilae
qubits)
0
transposition in MBQC
2
1
3
z
remainder of
calculus
CNOT gate
classical quantum gates are realized with series of
projective measurements
Hadamard gate
S (π/2-phase) gate
pre-entangled qubits cluster state
preparation

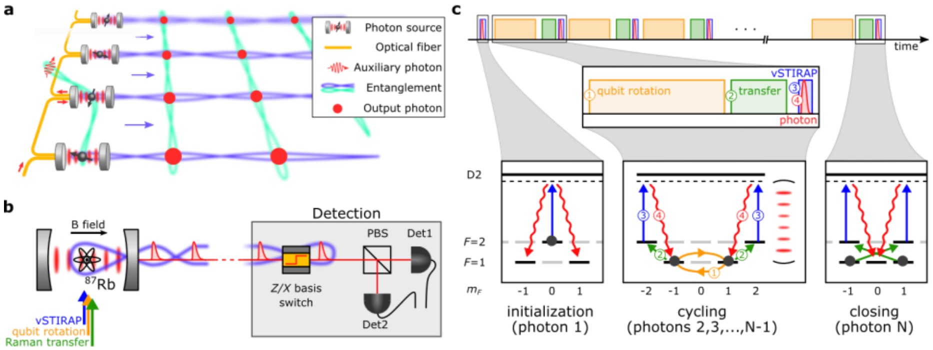
cluster states generation



[12-Photon Entanglement and Scalable Scattershot Boson Sampling with Optimal Entangled-Photon Pairs from Parametric Down-Conversion] by Han-Sen Zhong, Jian-Wei Pan et al, PRL, 2018



[Proposal for Pulsed On-Demand Sources of Photonic Cluster State Strings] by Netanel H. Lindner and Terry Rudolph, PRL, 2009.

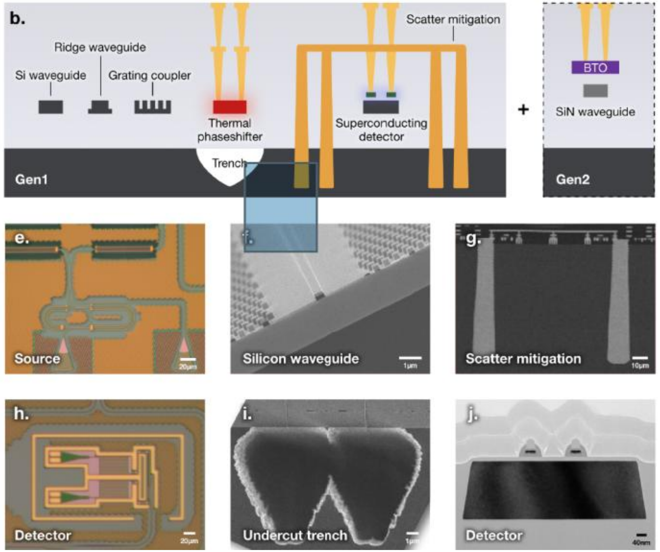


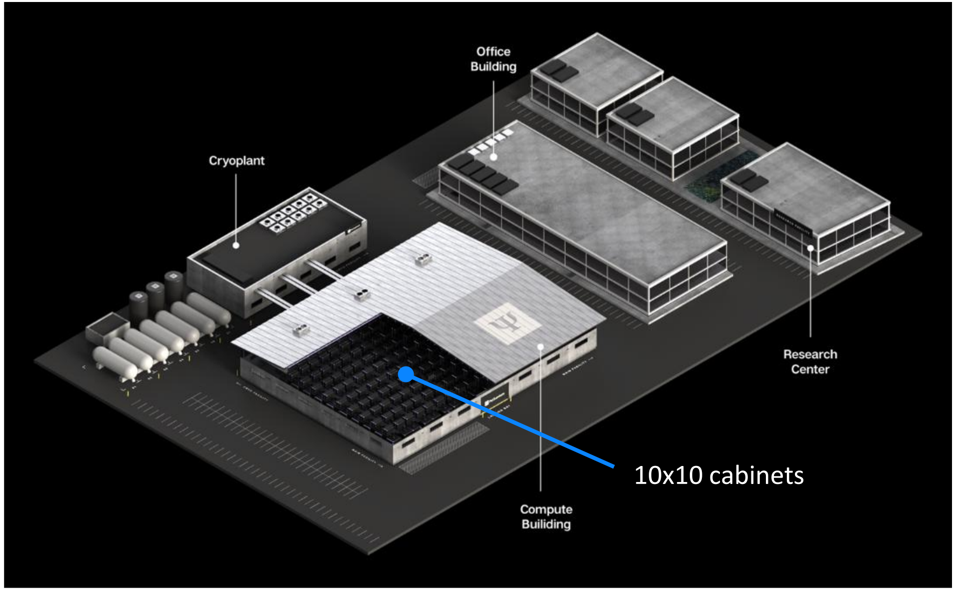
[Efficient generation of entangled multi-photon graph states from a single atom] by Philip Thomas, Leonardo Ruscio, Olivier Morin and Gerhard Rempe, MPI, May 2022

Ψ PsiQuantum

A manufacturable platform for photonic quantum computing
by Koen Alexander et al, PsiQuantum, arXiv, April 2024.

requires 36 kW of cooling power at 4K
for 100 logical qubits





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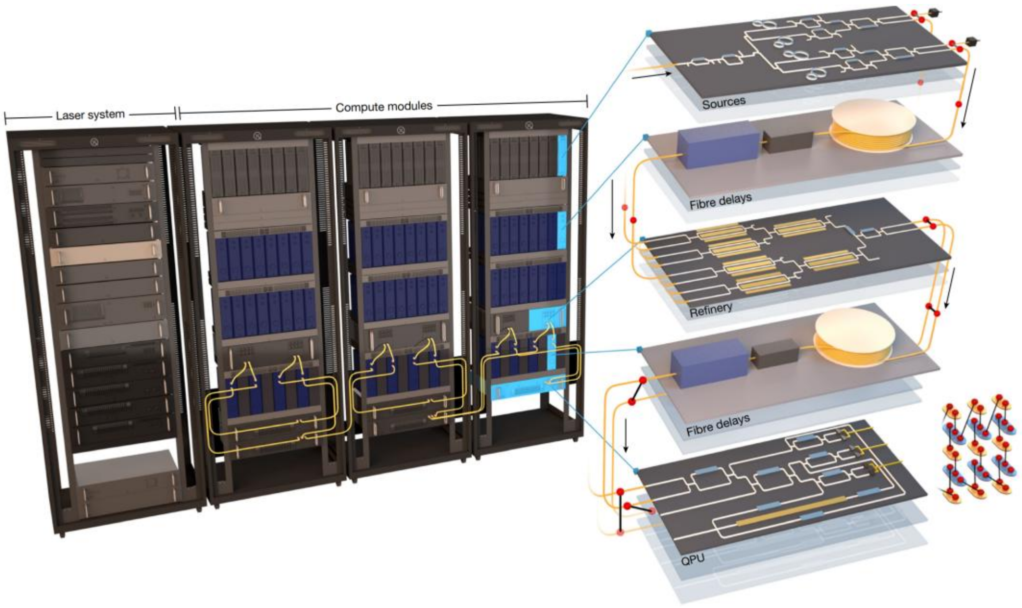
Scaling and networking a modular photonic quantum computer

H. Aghaee Rad, T. Ainsworth, R. N. Alexander, B. Altieri, M. F. Askarani, R. Baby, L. Banchi, B. Q. Baragiola, J. E. Bourassa, R. S. Chadwick, I. Charania, H. Chen, M. J. Collins, P. Contu, N. D'Arcy, G. Dauphinais, R. De Prins, D. Deschenes, I. Di Luch, S. Duque, P. Edke, S. E. Fayer, S. Ferracin, H. Ferretti, ... Y. Zhang + Show authors

Nature 638, 912–919 (2025) | Cite this article



Aurora QPU

distributed QPU with photonic interconnect

GKP qumodes qubits

significant overhead

[quant-ph] 22 Jul 2025

Practical blueprint for low-depth photonic quantum computing with quantum dots

Ming Lai Chan†,[1,2,*] Aliki Anna Capatos,[3,4,†] Peter Lodahl,[1,2] Anders Søndberg Sørensen,[2] and Stefano Paesani[2,4,‡]

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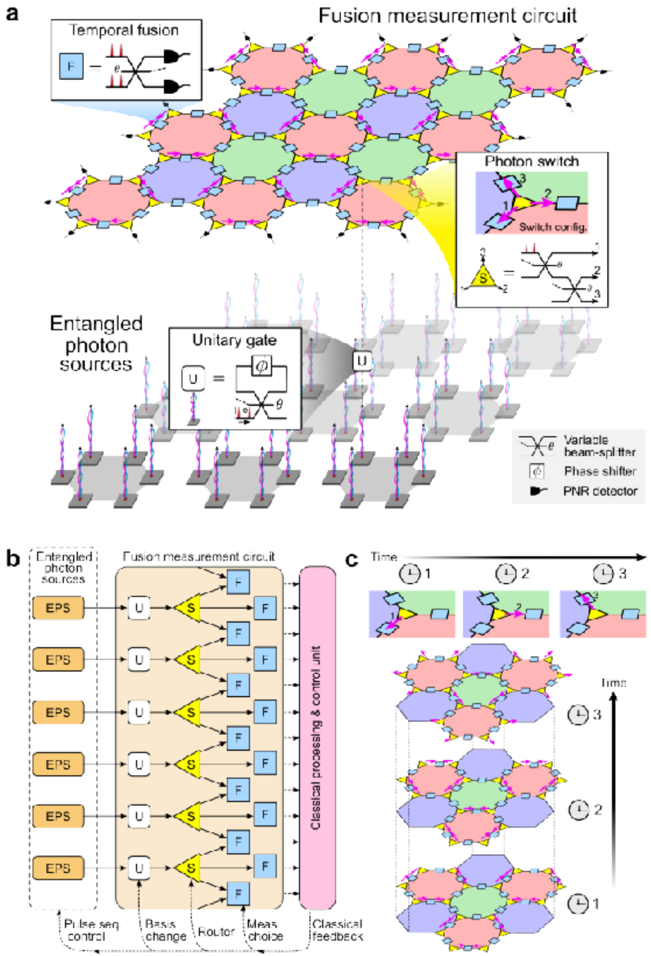
(Dated: July 23, 2025)

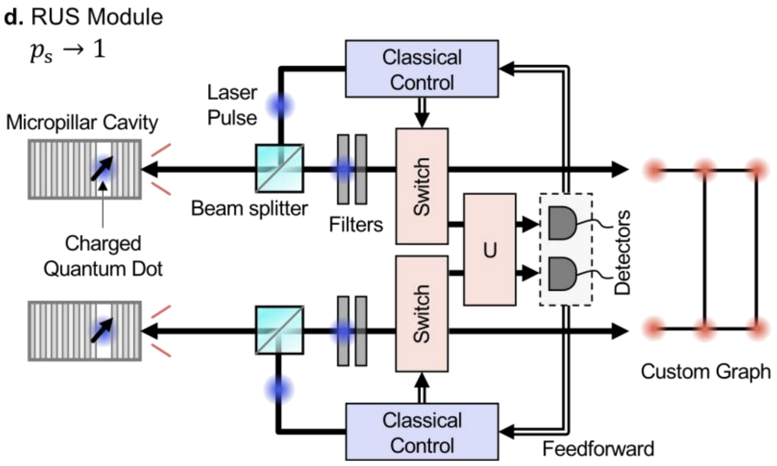
Fusion-based quantum computing is an attractive model for fault-tolerant computation based on photonics requiring only finite-sized entangled resource states followed by linear-optics operations and photon measurements. Large-scale implementations have so far been limited due to the access only to probabilistic photon sources, vulnerability to photon loss, and the need for massive multiplexing. Deterministic photon sources offer an alternative and resource-efficient route. By synergistically integrating deterministic photon emission, adaptive repeat-until-success fusions, and an optimised architectural design, we propose a complete blueprint for a photonic quantum computer using quantum dots and linear optics. It features time-bin qubit encoding, reconfigurable entangled-photon sources, and a fusion-based architecture with low optical connectivity, significantly reducing the required optical depth per photon and resource overheads. We present in detail the hardware required for resource-state generation and fusion networking, experimental pulse sequences, and exact resource estimates for preparing a logical qubit. We estimate that one logical clock cycle of error correction can be executed within microseconds, which scales linearly with the code distance. We also simulate error thresholds for fault-tolerance by accounting for a full catalogue of intrinsic error sources found in real-world quantum dot devices. Our work establishes a practical blueprint for a low-optical-depth, emitter-based fault-tolerant photonic quantum computer.

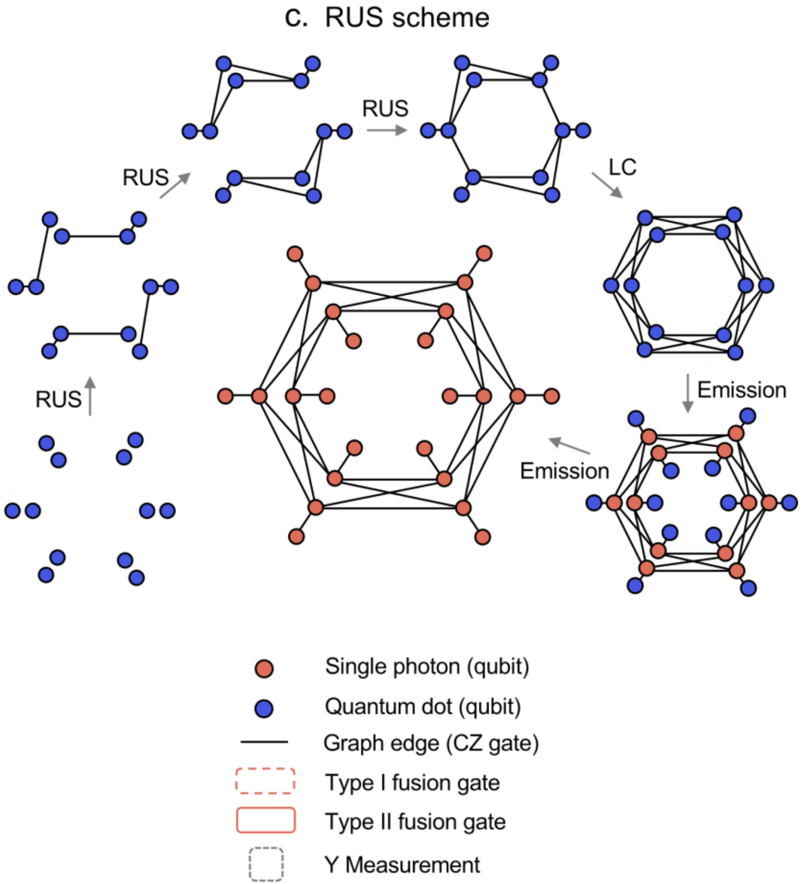


Experimental error source	**Error model**	N	**Maximum tolerable threshold**	**Required experimental benchmark**
General loss	Uncorrelated loss	8	8% [Fig. 8b(i)]	$\eta > 92\%$
Branching (finite cyclicity)	Spin-photon X errors	6	0.174% [Fig. 8b(iii)]	$C > 574$
Emitter-emitter distinguishability (slow spectral diffusion)	Distinguishability	8	4% [Fig. 8b(v)]	$V_{\mathrm{HOM}}^{ee} > 96\%$
Single-emitter distinguishability (fast pure phonon dephasing)	Photon Z errors	8	0.57% [Fig. 8b(vi)]	$V_{\mathrm{HOM}}^{se} > 99.4\%$
Optical excitation errors	Distinguishability	8	4% [Fig. 8b(i)]	$V_{\mathrm{HOM}}^{ee} > 96\%$
Laser-induced spin-flips during spin control	Loss & spin depolarisation errors	7	0.6% [Fig. 8b(ii)]	$\bar{\kappa} < 1.08 \times 10^{-2}$
Finite T_2 (Markovian spin depolarisation)	Spin $X/Z/Y$ errors	7	0.36% [Fig. 8b(iv)]	$T_2 > 417\tau_{\mathrm{rep}}$
Markovian ground-state dephasing (Overhauser noise)	Spin Z errors	10	0.6% [Fig. 8b(ii)]	$T_2^* > 56\tau_{\mathrm{round}}$
Blinking	Correlated loss	8	6.1% [Fig. 8b(vii)]	$P_A/P_D > 15.4$

Practical blueprint for low-depth photonic quantum computing with quantum dots by Ming Lai Chan, Aliki Anna Capatos, Peter Lodahl, Anders Søndberg Sørensen, and Stefano Paesani, arXiv, July 2025.

QUANDELA



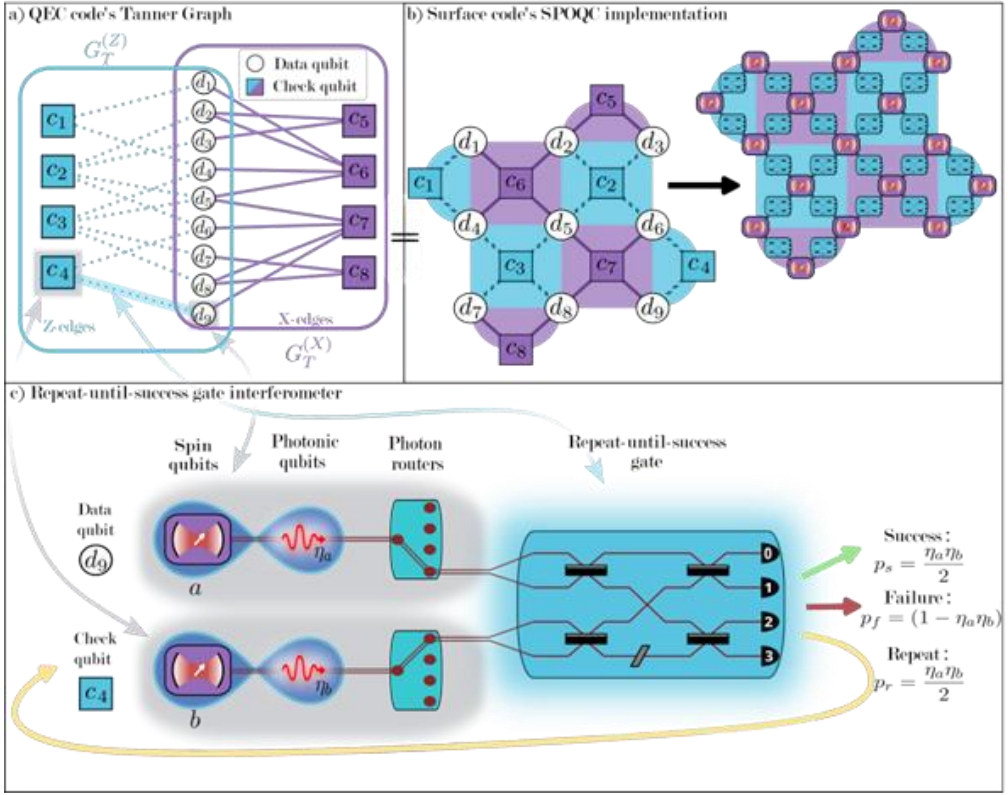


[Minimizing resource overhead in fusion-based quantum computation using hybrid spin-photon devices] by Stephen C. Wein, Timothée Goubault de Brugière, Luka Music, Pascale Senellart, Boris Bourdoncle, and Shane Mansfield, arXiv, December 2024 (22 pages).

QUANDELA

Quandela blueprint for using quantum dots are data qubit and their emitted photons as ancilla qubits for creating CNOT gates between the quantum dots

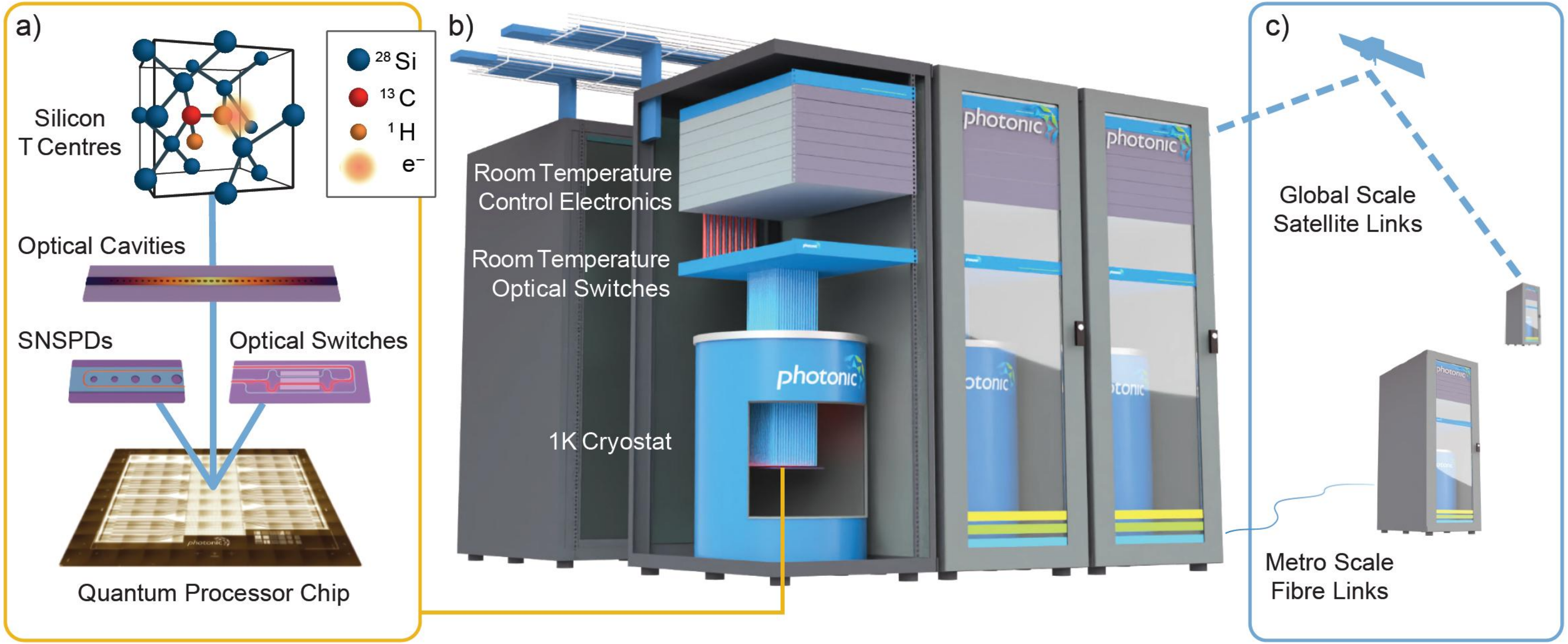
- quantum dots become data qubits.
- emitted photons are used to entangle qubits and measure them.
- quantum dots magnetic control creates single qubit gates.



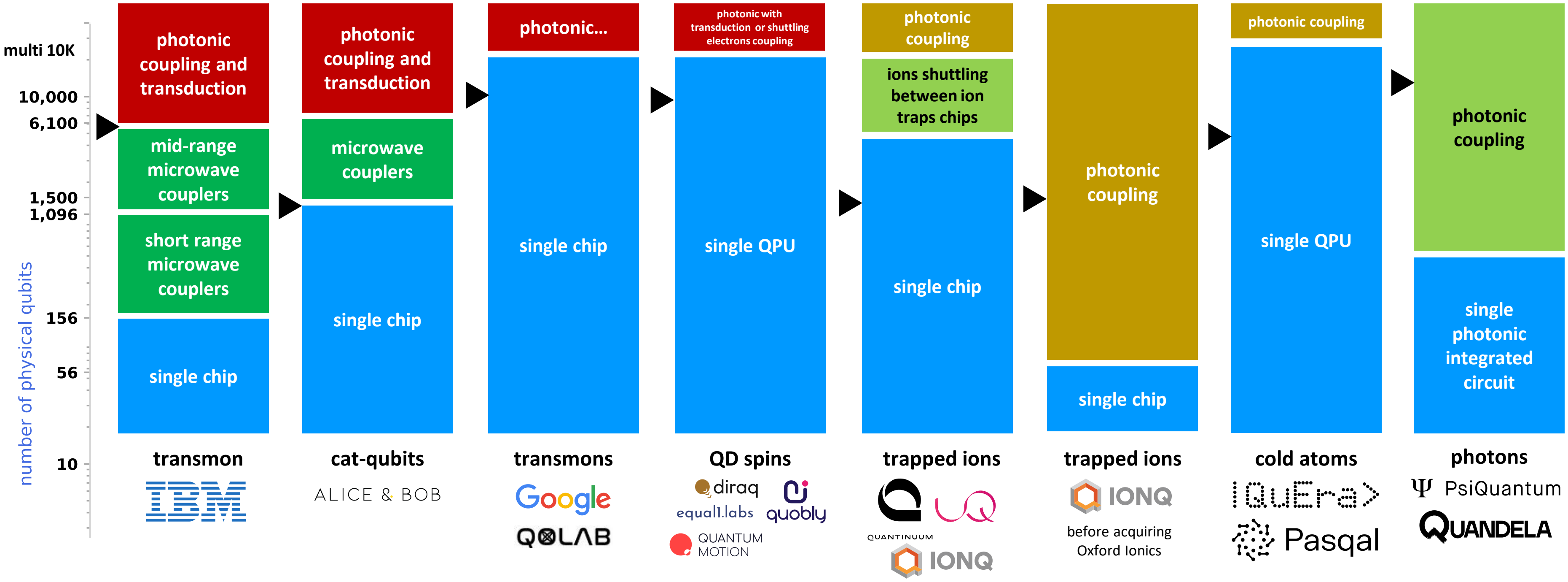
A Spin-Optical Quantum Computing Architecture by Grégoire de Gliniasty, Paul Hilaire, Pierre-Emmanuel Emeriau, Stephen C. Wein, Alexia Salavrakos, Shane Mansfield, Quantum Journal, July 2024.

Daphné Wang - Quandela

Scalable Fault-Tolerant Quantum Technologies with Silicon Colour Centres
by Stephanie Simmons, Photonic, October 2023 (16 pages).



multiple QPUs interconnect options



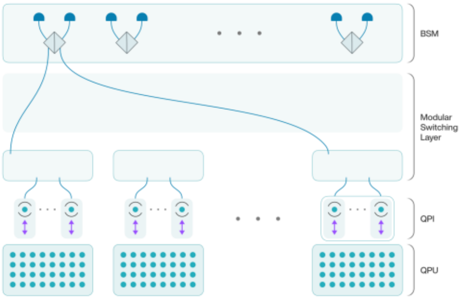
single monolithic chip or QPU | interconnect using same qubit modality | short range or mid-range microwave couplers | direct photonic coupling | photonic coupling with transduction

▶ approximate physical qubits # required to reach 100 logical qubits and 10^{-6} error rate, the lower being the better.

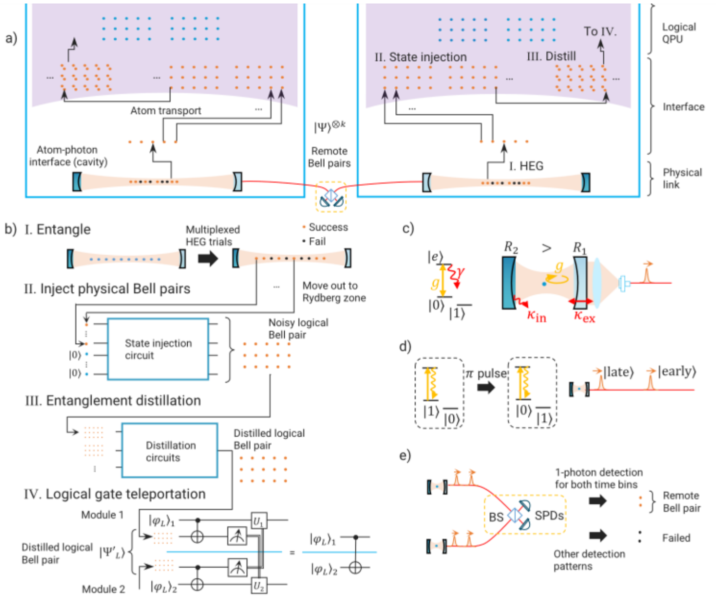
growing complexity with rough estimates thresholds requiring these techniques

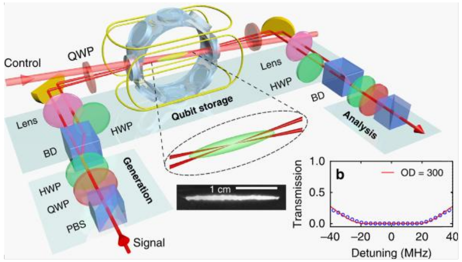
QPU interconnect vendors

Eleni Diamanti – LIP6 and Welinq



nu QUANTUM





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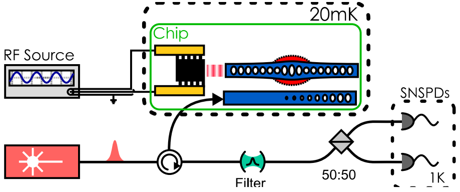
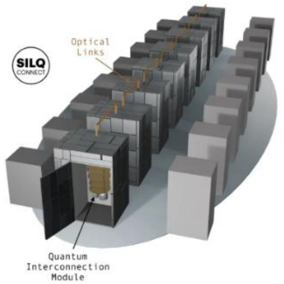


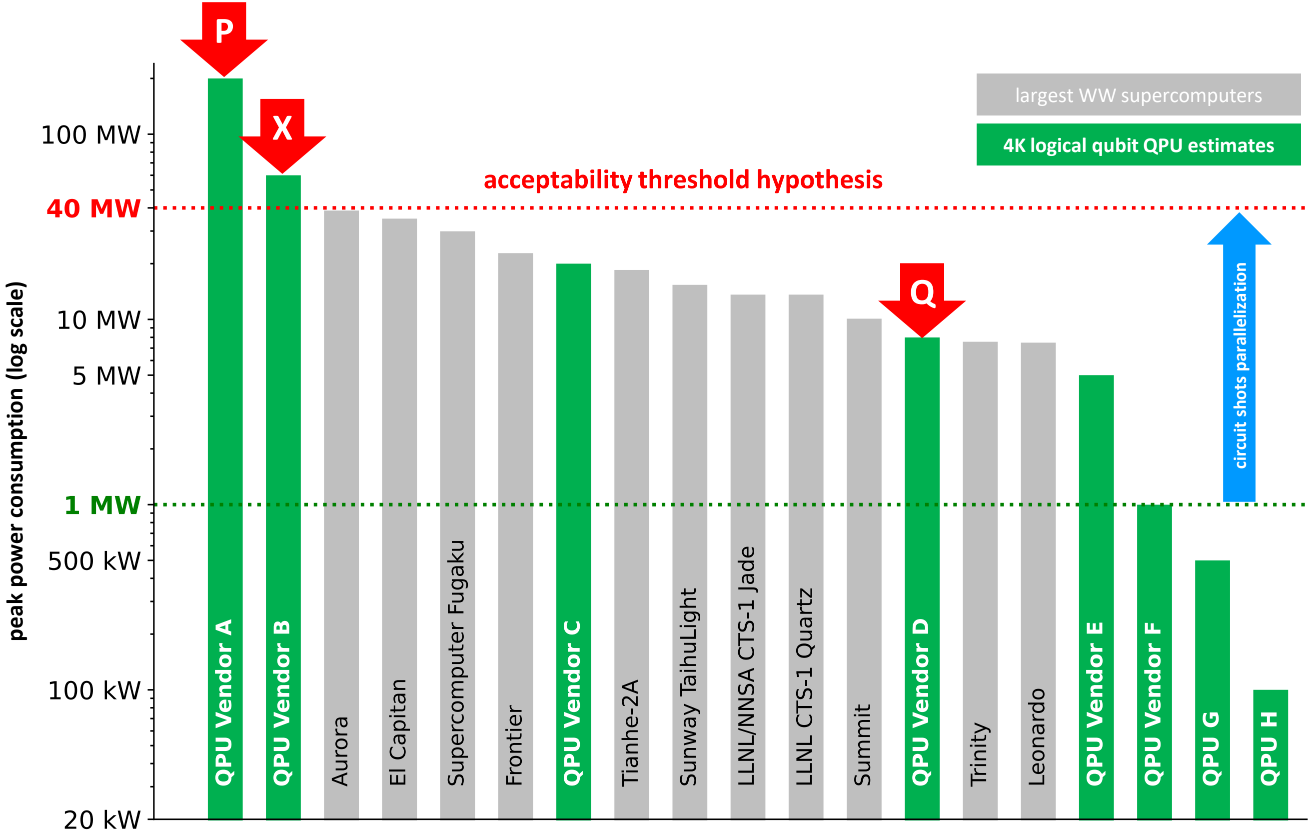


QPHOX

NanoQT
Nanofiber Quantum Technologies

SilQ Connect

QPU vs HPC power scale guesstimates



estimate base power for various QPUs and actual for existing largest HPCs WW. HPC source: https://www.top500.org/lists/top500/2024/06/.

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