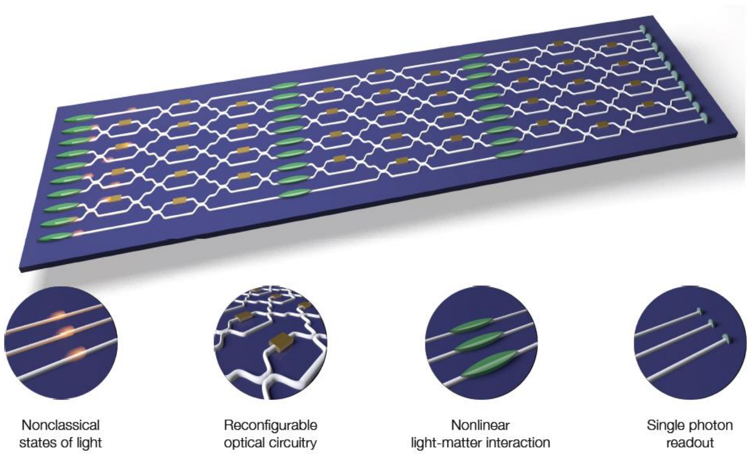
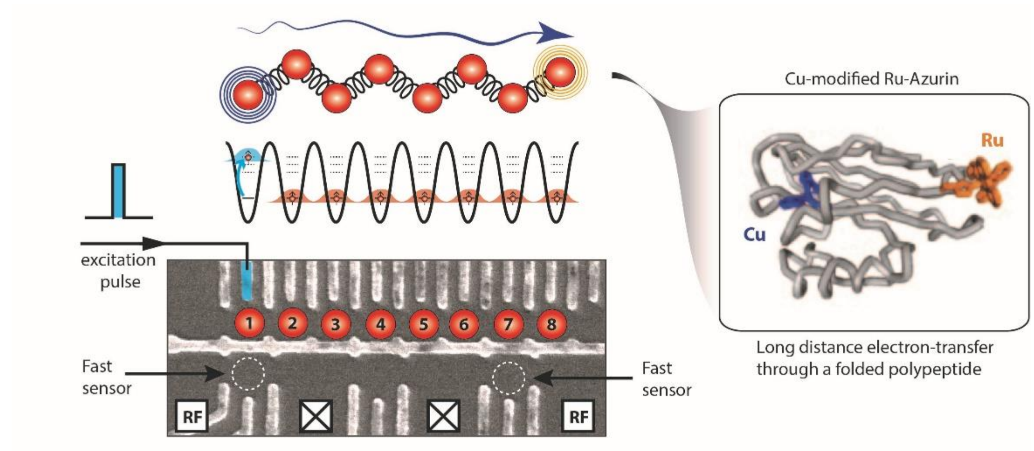
Solid-Q: Solid-State Quantum Simulators for Biochemistry





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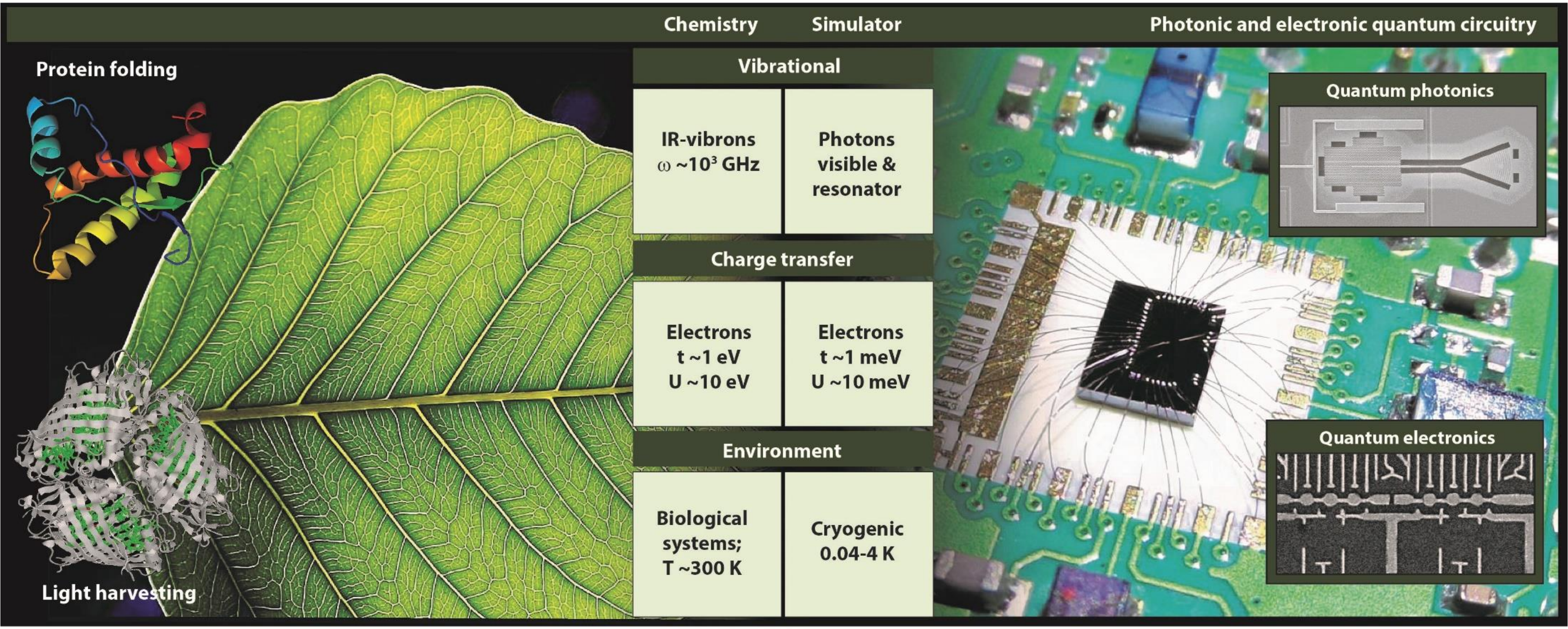
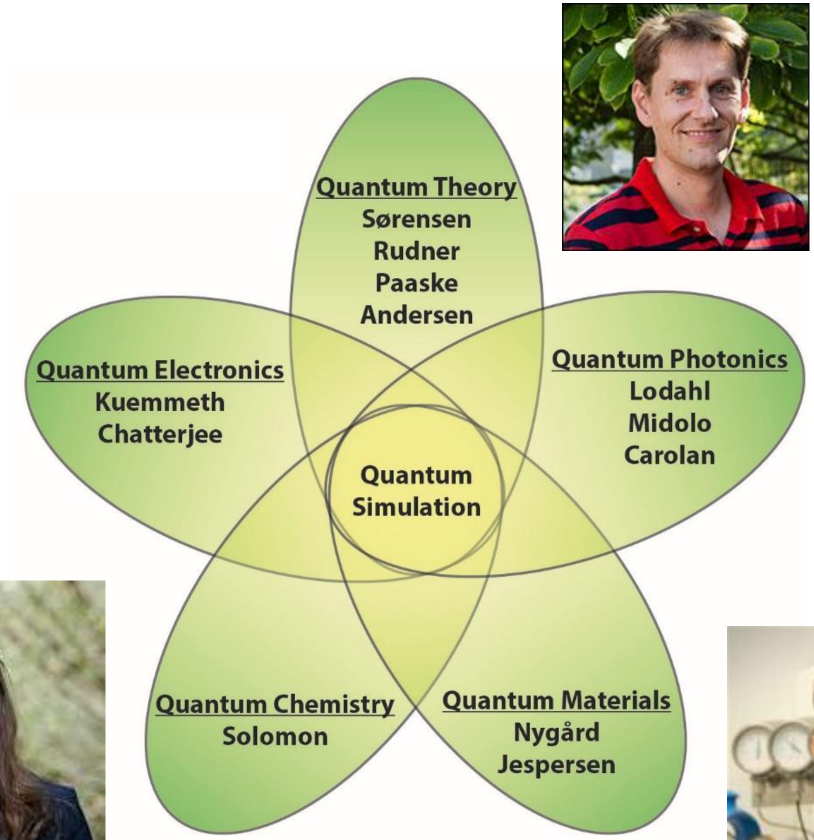
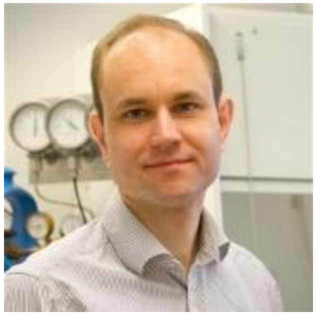
Solid-State Quantum Simulators for Biochemistry

Mission of Solid-Q: apply solid-state quantum hardware in proof-of-concept quantum simulations of protein folding and light harvesting complexes towards the regime of quantum advantage



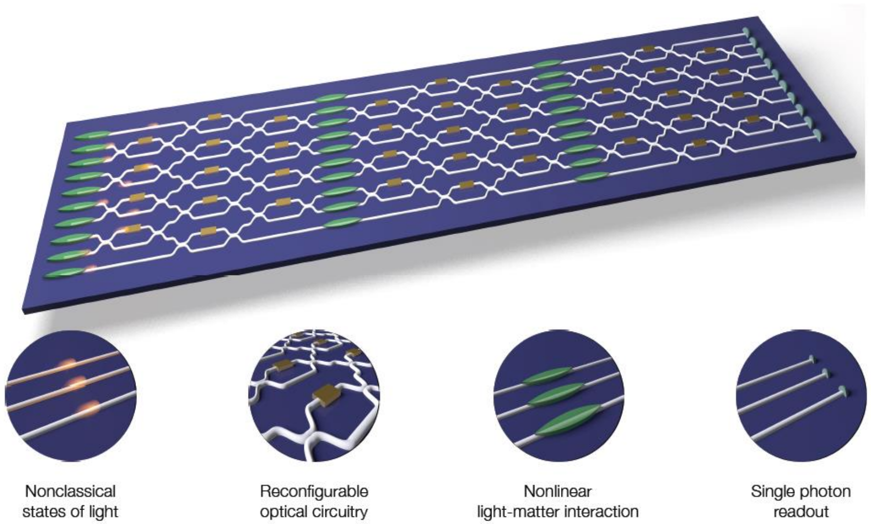
The Solid-Q Team

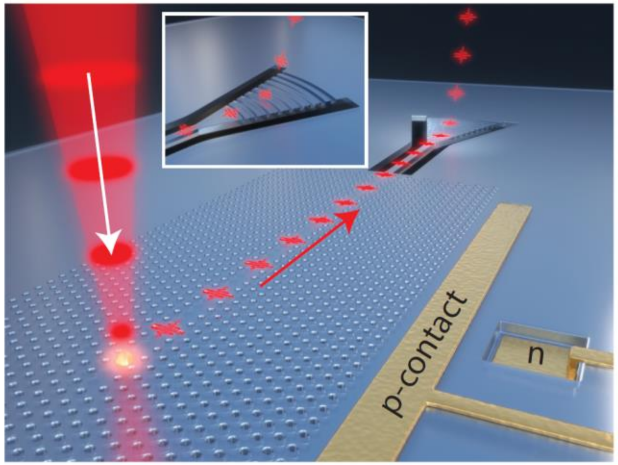




Interdisciplinary research team with expertise in quantum photonics, electronics, chemistry, material science (theory & experiment)

Platform 1: Photonic Quantum Simulators

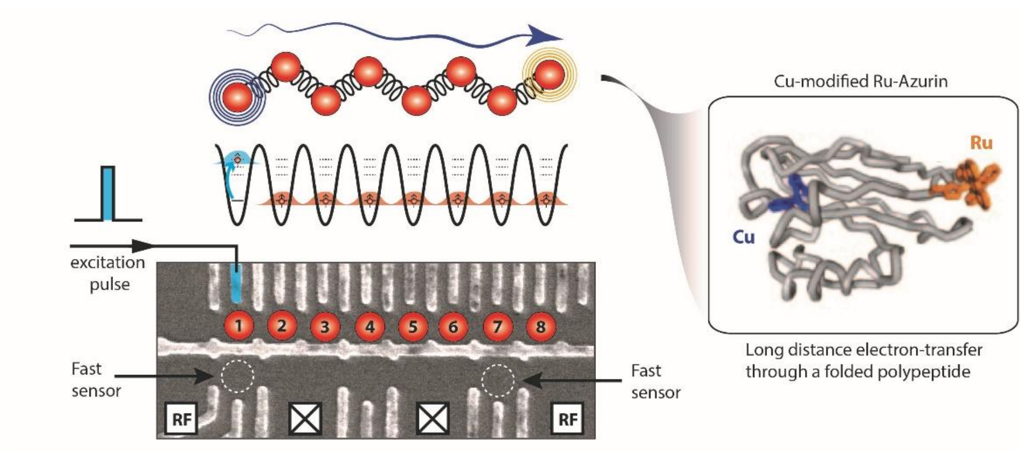


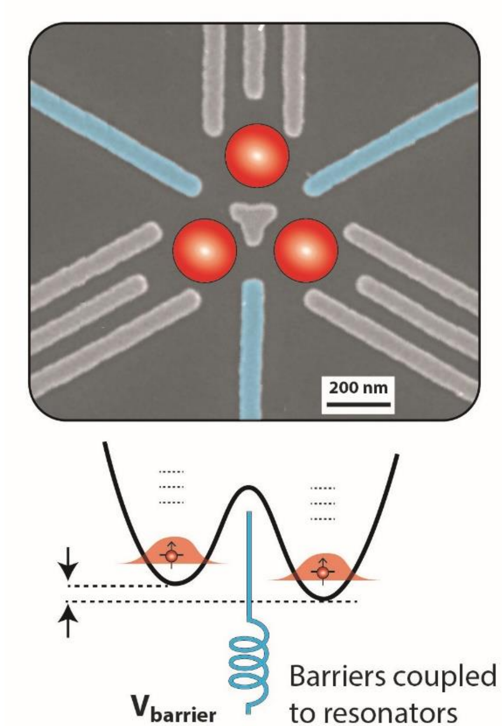


- Mature photonic integrated circuitry can be fully explored
- Scalable single-photon source enabling quantum advantage recently demonstrated*
- Photons in circuits as analog quantum simulator of vibrational dynamics for protein folding problems

*** Uppu et al., submitted, ArXiv: 2003.08919**

Platform 2: Gate-Controlled Quantum Dots



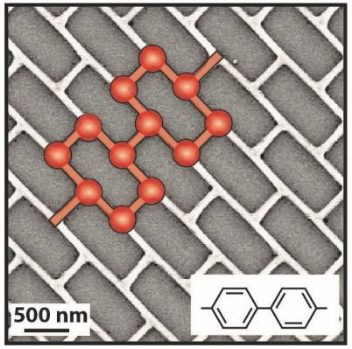


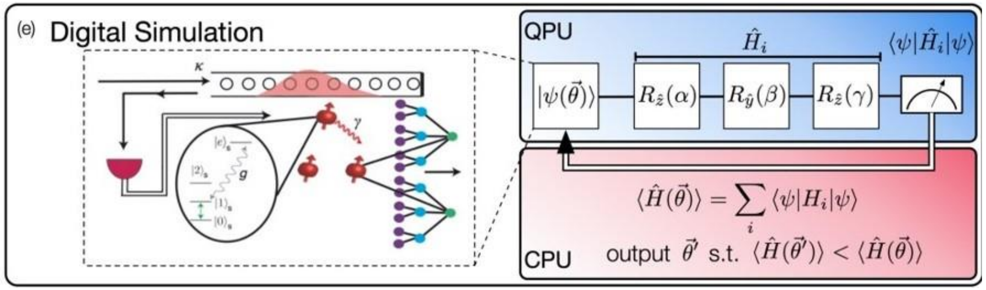
Electrons controlled in quantum dots as qubits

- Exquisite qubit control by in-situ gates
- Fundamental light-harvesting processes directly implementable on solid-state quantum hardware
- Vibrational dynamics simulations achievable by coupling to a superconducting resonator

Solid-Q Synergy

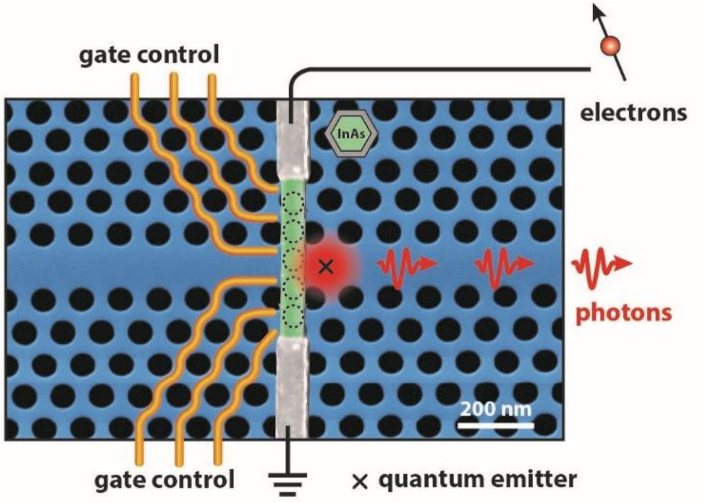
Growth of high-purity III-V semiconductor materials for electronics and photonics



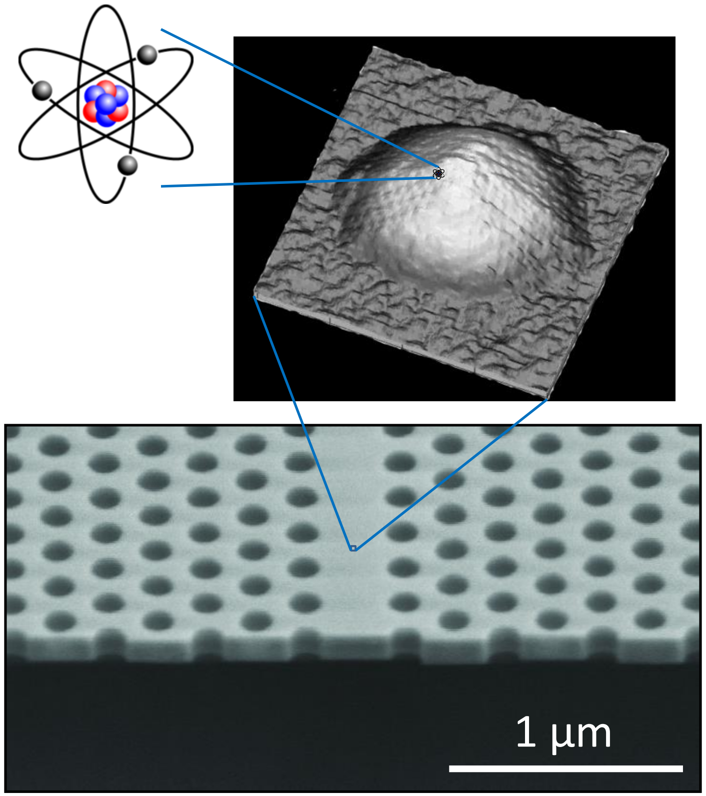


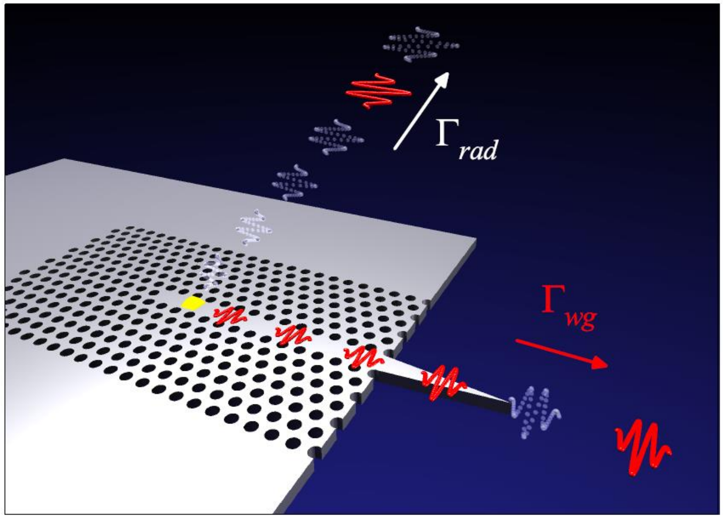
Quantum algorithms for bio-chemistry tailored to the developed hardware

Couple gate-defined quantum dots to photons for scalable quantum computing



The Deterministic Single-Photon Source

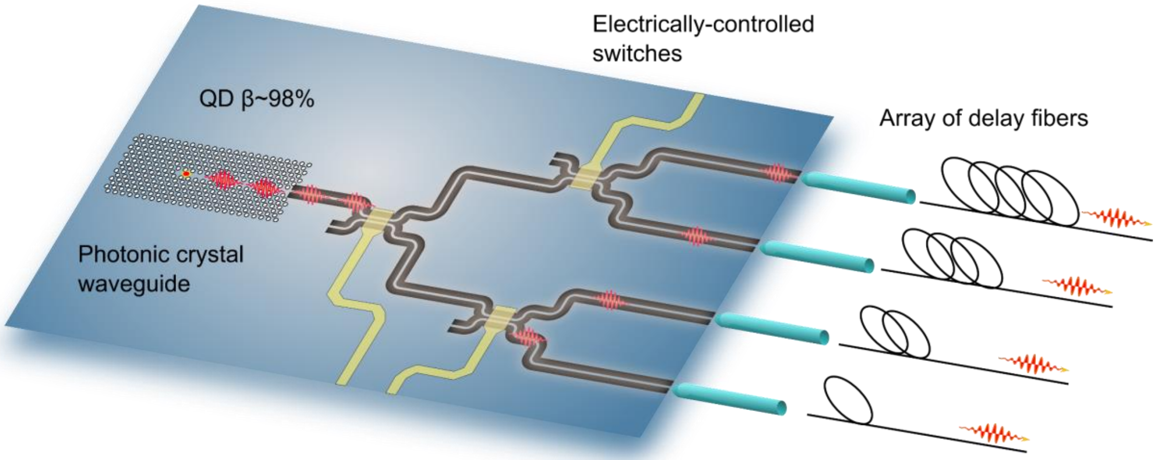




- Photon-emitter coupling efficiency >98.4 %
- Patented technology at NBI
- Commercialized in start-up

Scalable Photonic Resource

A deterministic single-photon source harvested to produce N photonic qubits by highly efficient switching and coupling



η: trans. efficiency

Generation prob.: $P(N) = \eta^N$

Rep. rate: ~1 GHz

η=90 % → R(N=100) ~ 300 Hz

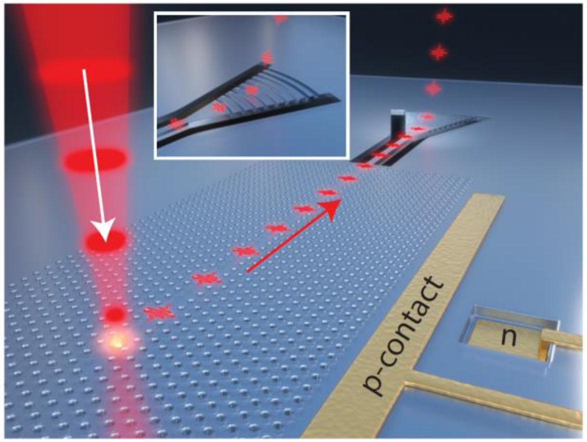
'Quantum advantage' requires N ~ 50 photons

Alternative strategy of multiplexing probabilistic sources is followed by, e.g., Silicon Valley start-up PsiQuantum

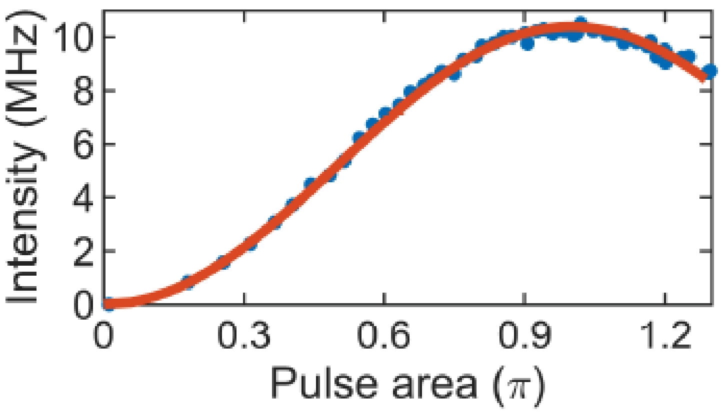
We offer a new and potentially better approach to photonic quantum computing

Lodahl: *Quantum-dot based photonic quantum networks,* Quantum Science & Technology 3, 013001 (2018).

Pulsed Resonant Operation of Single-Photon Source



- 122 million photons/second generated on-chip (84% efficiency) for π-pulse excitation
- Strongly suppressed multi-photon contributions ($g^{(2)}(0) < 1.5\%$)
- Overcome blinking of emission



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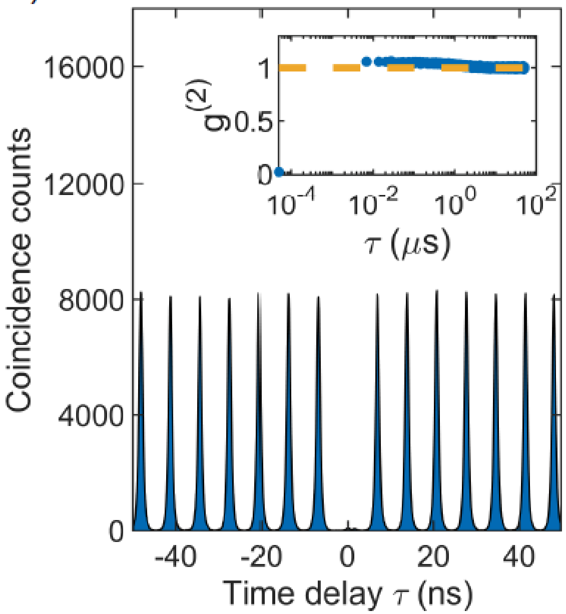
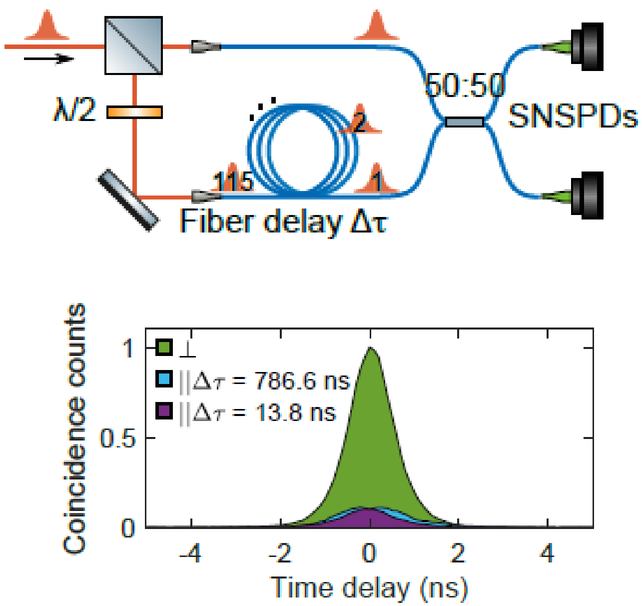
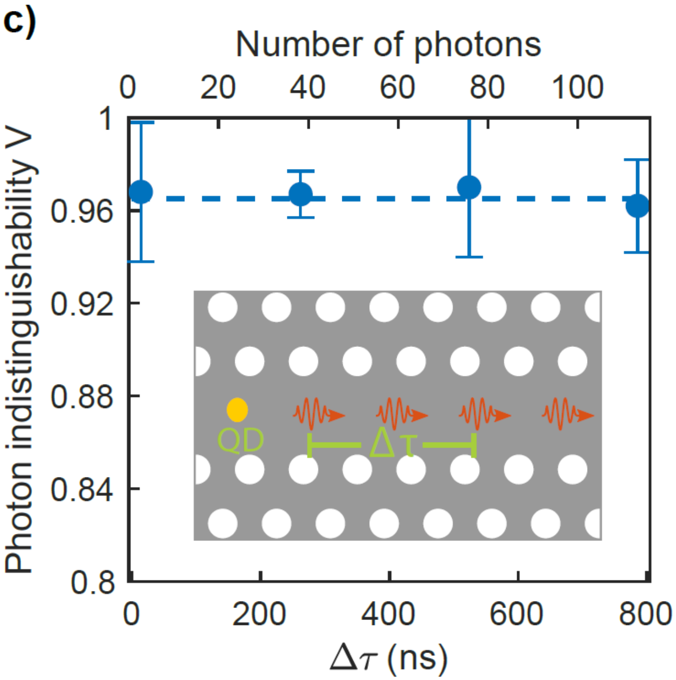


Uppu et al., submitted, ArXiv: 2003.08919

Photon indistinguishability

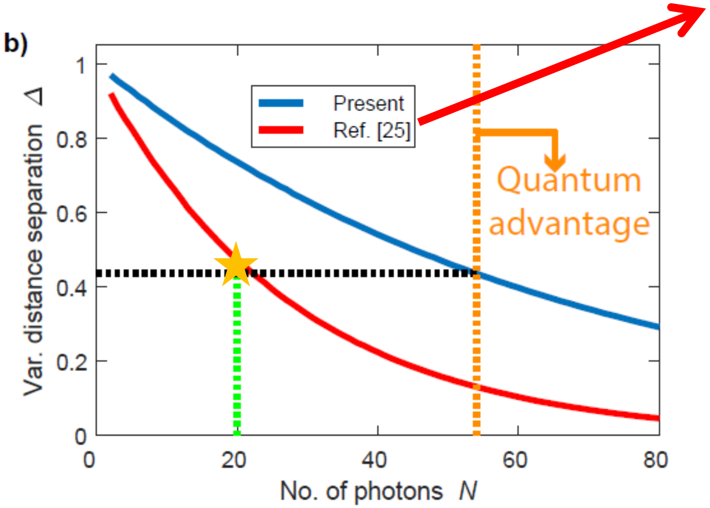




- >96% photon indistinguishability of subsequently emitted photons
- Photon indistinguishability remains unchanged with photon time delay as tested out to strings of 115 photons
- Fundamental limit: phonon decoherence

Uppu et al., submitted, ArXiv: 2003.08919

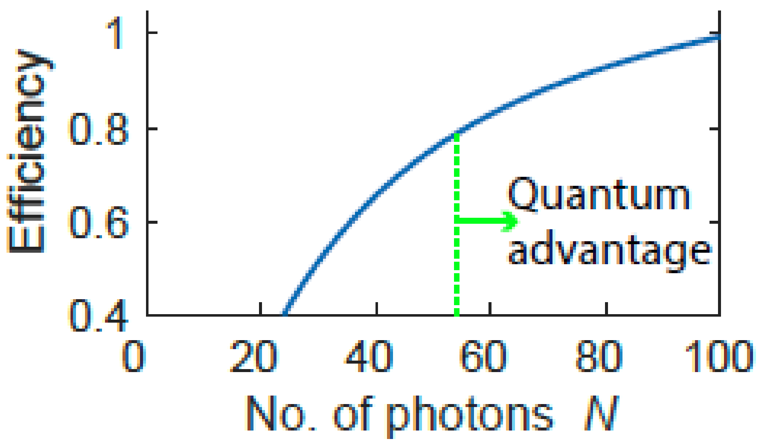
A Resource for Boson Sampling with a Quantum Advantage



Ungated μ-pillar cavity

★ Previous state-of-the-art BS experiment

Variational separation of real boson sampler from ideal case ($\Delta=0$ corresponds to distinguishable photons)



Required source efficiency for running N-photon boson sampler in a fixed runtime of 30 days when accounting for all loss in state-of-the-art boson sampling experiment [Wang et al., PRL 123, 250503 (2019)]

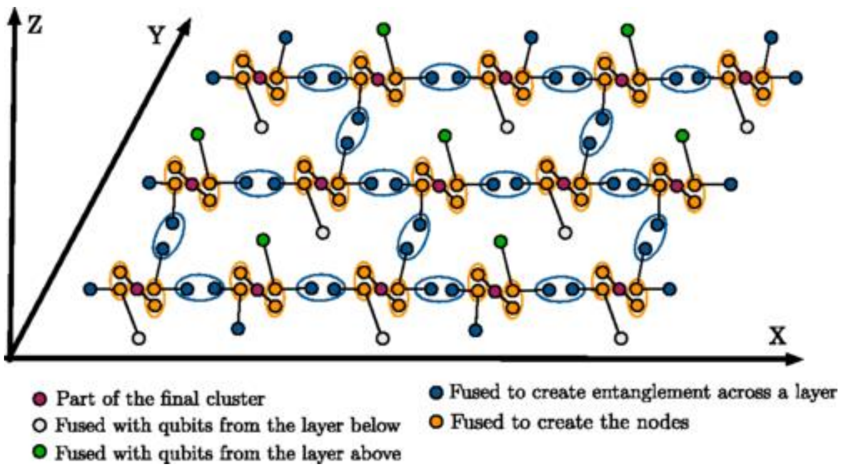
Quantum Advantage ($N > 54$) requires $\eta > 78\%$

Uppu et al., submitted, ArXiv: 2003.08919

Fundamental Building Block of Photonic Quantum Computer

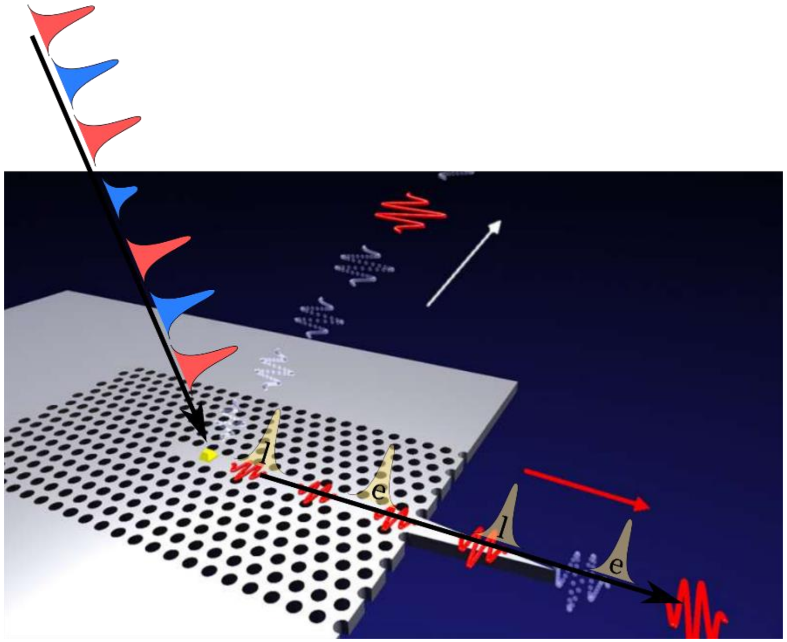
Main challenge: synthesize 3-photon entanglement on-demand
Scaling-up makes use of advanced photonic chips
→ Major 'raison d'etre' for photonics!

Q-computing can be performed based on ballistic scattering of high-fidelity 3-photon entangled states

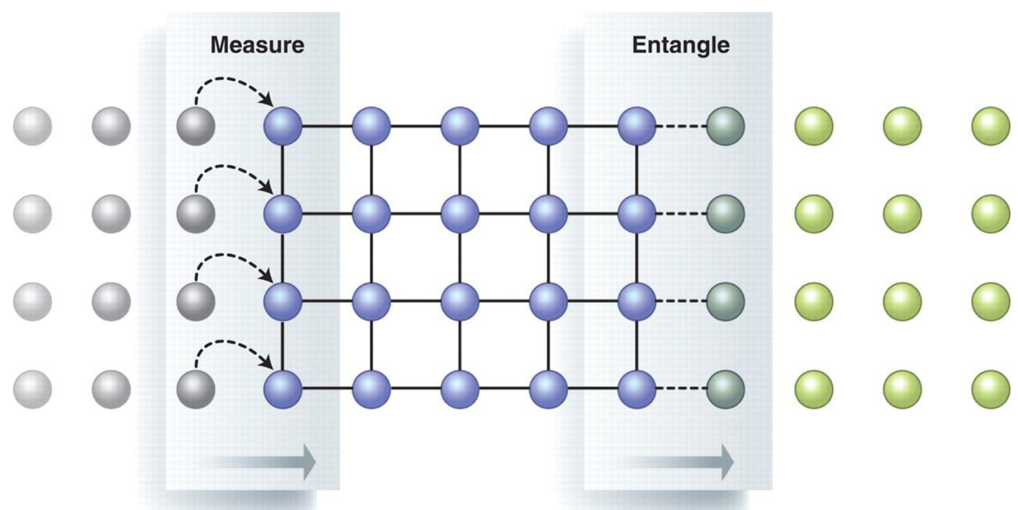


[Gimeno-Segovia,Shadbolt, Browne and Rudolph, Phys. Rev. Lett. 115, 020502 (2015)]

Multi-photon Entanglement for Quantum Simulations



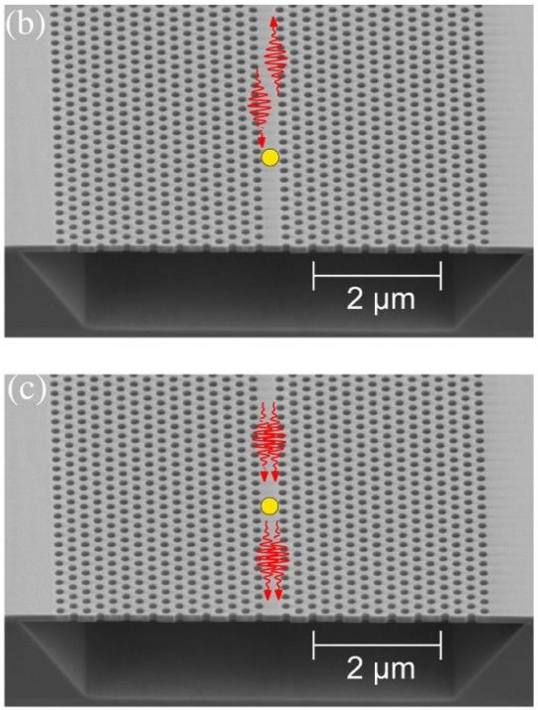
On-demand generation of multi-photon entangled cluster state

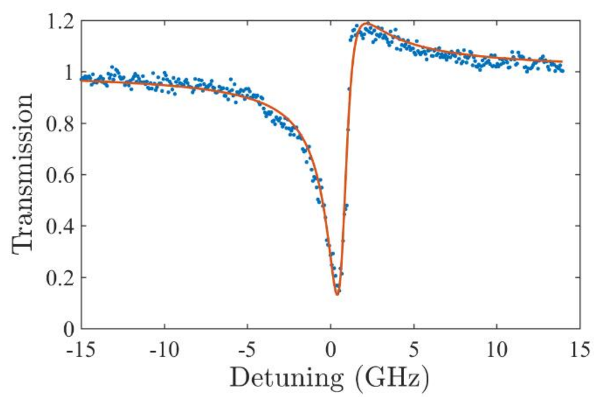


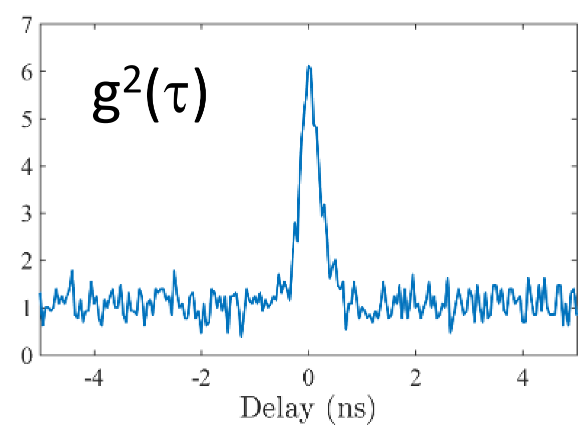
Quantum computing proceeds by measuring on photons in the entanglement cluster

A Single-Photon Nonlinearity

Single quantum dot deterministically coupled to a photonic-crystal waveguide as a nonlinear medium that is saturated by one photon.





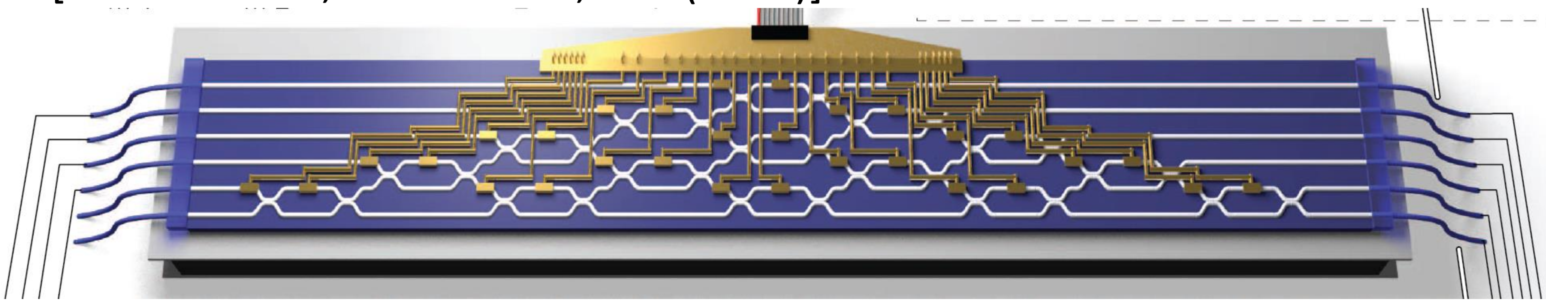


Javadi, et al., Nature Communications 6, 8655 (2015).

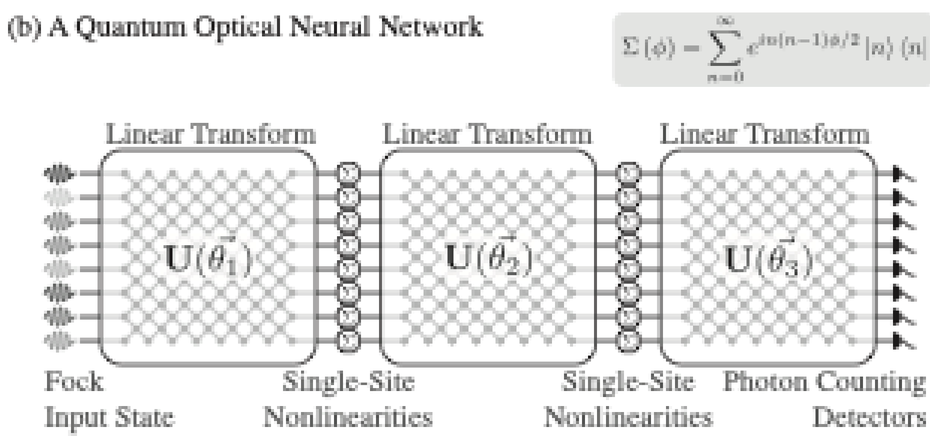
Le Jeannic et al., submitted, arXiv:2006.00258

Advanced Photonic Quantum Circuitry

Reprogrammable universal quantum operations
[Carolan et al., Science 349, 711 (2015)]



Quantum optical neural networks including nonlinear elements
[Steinbrecher, Olson, Englund, Carolan, arXiv: 1808.10047]



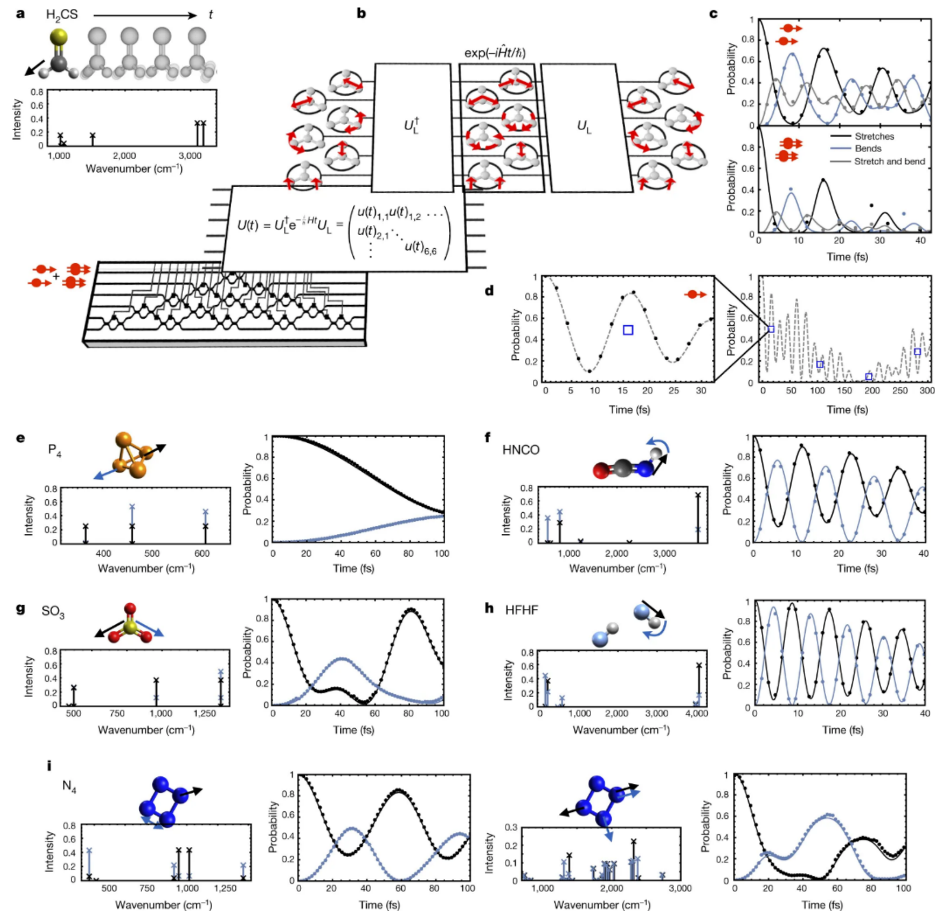
Simulating Molecular Vibrations

ARTICLE

https://doi.org/10.1038/s41586-018-0152-9

Simulating the vibrational quantum dynamics of molecules using photonics

Chris Sparrow[1,2], Enrique Martín-López[3], Nicola Maraviglia[1], Alex Neville[1], Christopher Harrold[1], Jacques Carolan[4], Yogesh N. Joglekar[5], Toshikazu Hashimoto[6], Nobuyuki Matsuda[7], Jeremy L. O'Brien[1], David P. Tew[8] & Anthony Laing[1]*



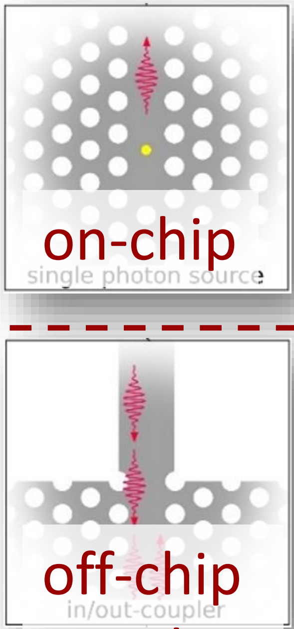
Proof-of-concept simulation of small molecules (~ 10 atoms)

Next: scaling up by implementing advanced photonic hardware and optimized algorithms

Quantum Lego

New devices in the Quantum Photonics / Quantum Electronics Toolbox

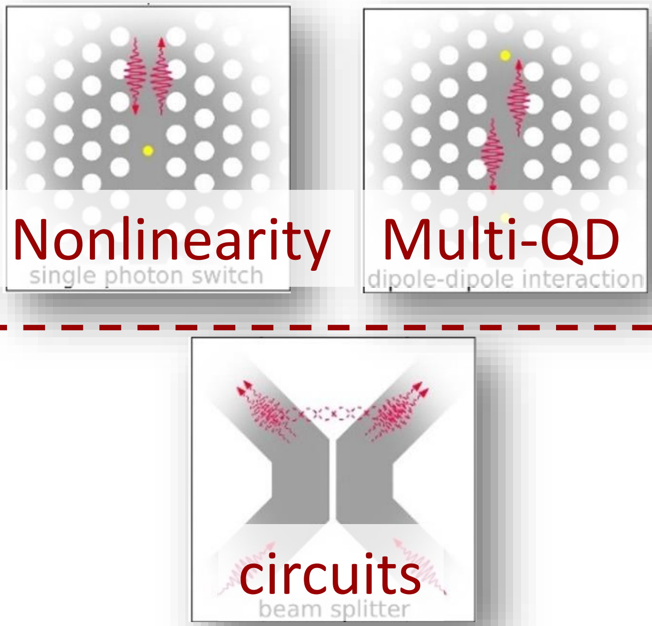
Source



on-chip

off-chip coupling

Processing

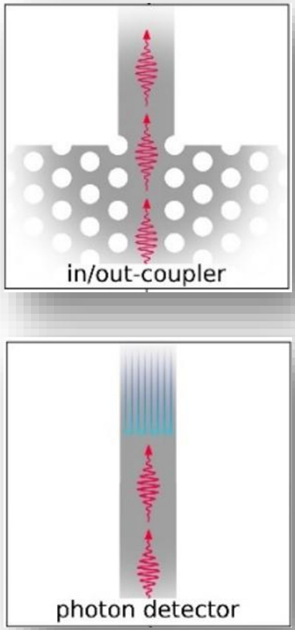


Nonlinearity

Multi-QD

circuits

Out-coupling



Lodahl: ***Quantum-dot based photonic quantum networks,*** **Quantum Science & Technology 3, 013001 (2018).**