Scalable Architectures for Photonic Quantum Computing

MAP-fis essay defense

April 24, 2025

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Supervised by Ernesto F. Galvão (INL)
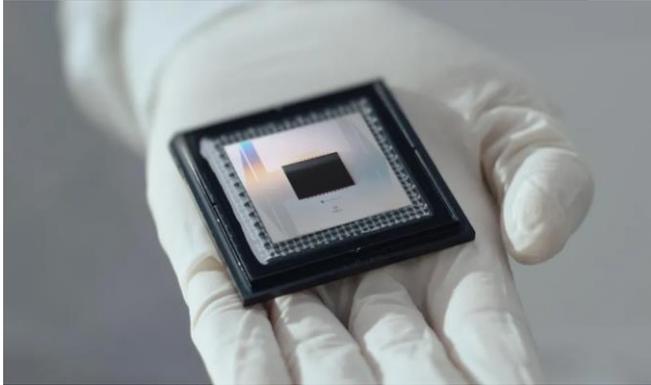Co-supervised by Mikhail Vasilevskiy (Univ. Minho)

Contents

1. Introduction

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Photonic Quantum Computing
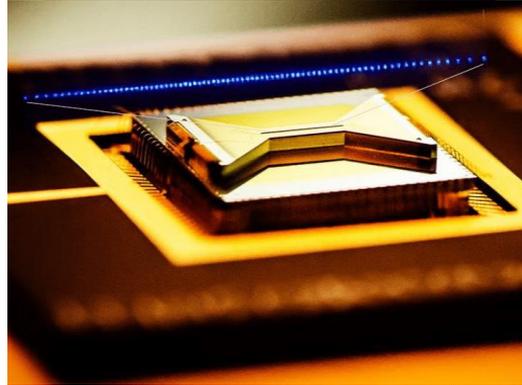
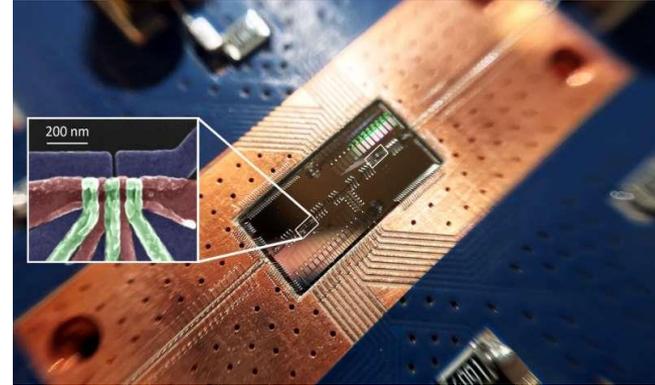# Quantum Computing Platforms

Superconducting circuits

Credit: Google

Trapped ions

Credit: Christopher Monroe

Silicon spins

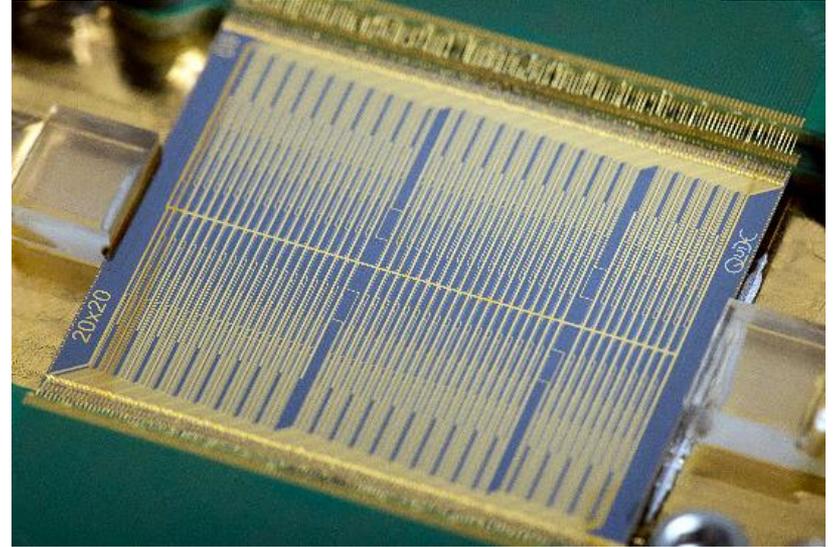Credit: Felix Borjans, Princeton University

Photonic Quantum Computing

Gaussian Boson Sampling

Han-Sen Zhong et al., *Science* **370**,1460-1463 (2020).

Photonic Integrated Circuits

Credit: QuiX Quantum

2. Research Project

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Scalable Architectures for
Photonic Quantum Computing
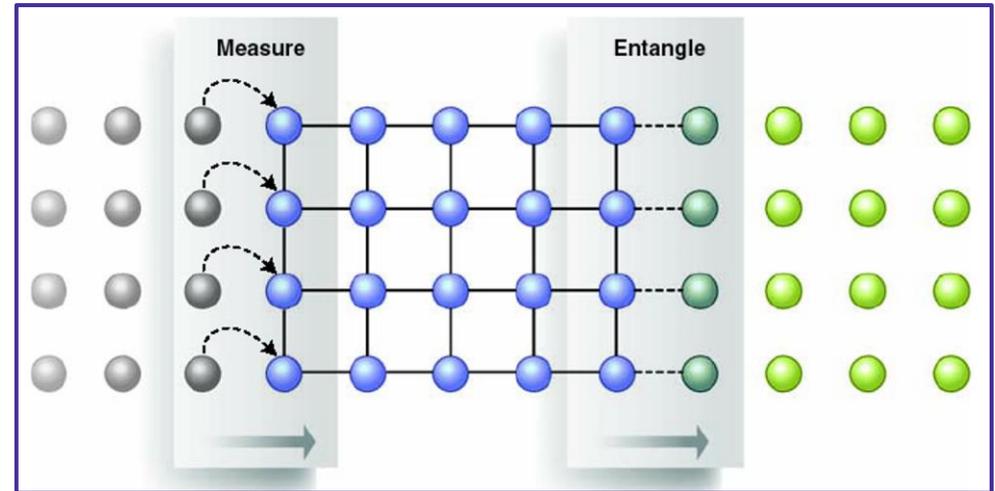
2.1. State-of-the-art architectures

Two recent proposals

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Fusion-based Quantum Computing (FBQC)
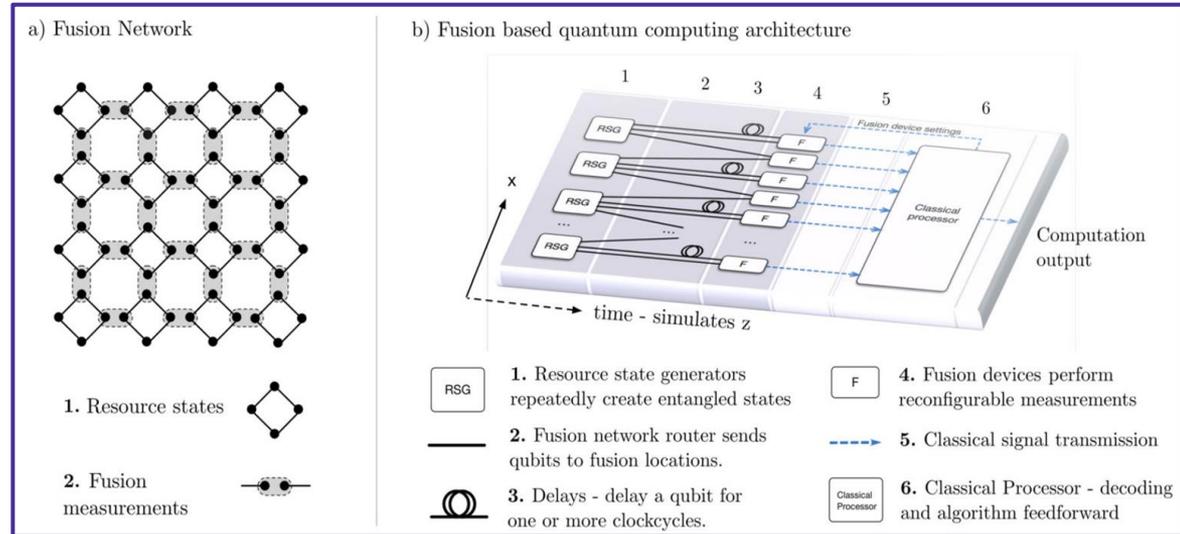
Measurement-based Quantum Computing

- **Cluster state** - large entangled state with regular geometry.

- **Computational steps driven by adaptive single-qubit measurement.**

- **Alternating stages** of measurement and cluster state growth.

J. O'Brien, *Science* **318**,1567-1570 (2007).

Fusion-based Quantum Computing (FBQC)

- **Small entangled resource states** with constant size and structure.

- **Fusions measurements** used to construct **fusion network**.

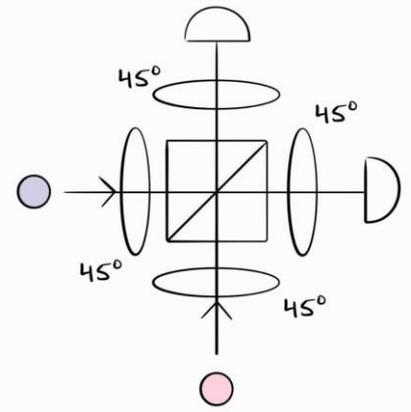- **Constant circuit depth** limits spread of errors.

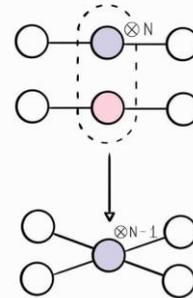- **Limited switching and reconfiguration.**

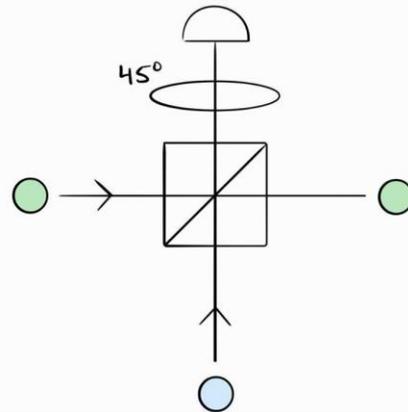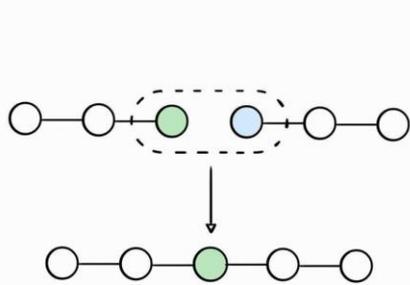S. Bartolucci et al., *Nat. Commun.* **14**, 912 (2023).

Fusion-based Quantum Computing (FBQC)

Fusion Measurements
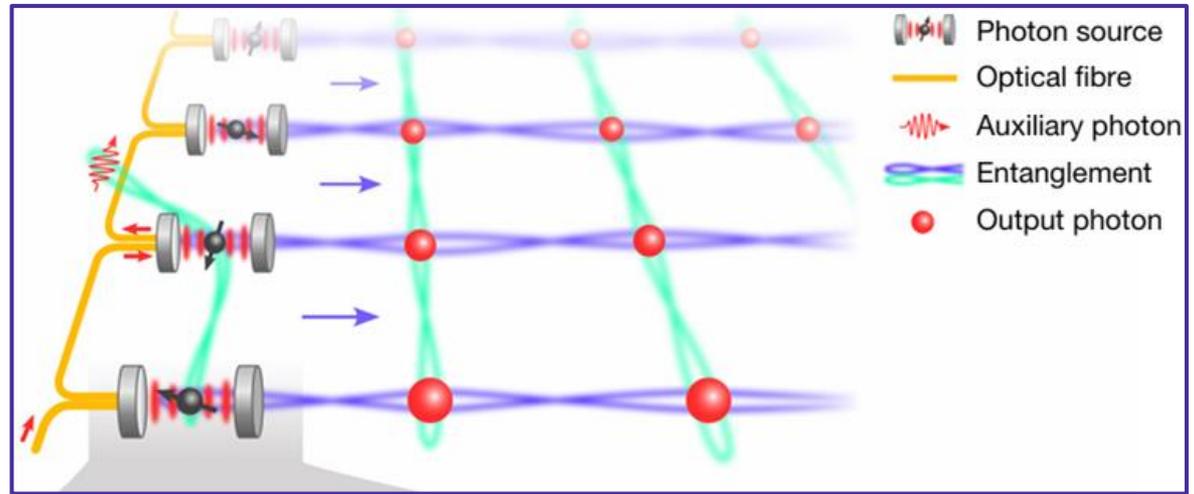
Probabilistic, linear-optical entangling gates

D. E. Browne and T. Rudolph, *Phys. Rev. Lett.* **95**, 010501 (2005).

Spin-Optical Quantum Computing (SPOQC)

Spin quantum emitters

- **"Photonic machine guns"** – On-demand sources of single photons.

- Deterministic, efficient generation of photonic entangled states.

P. Thomas et al., *Nature* **608**, 677–681 (2022).

Spin-Optical Quantum Computing (SPOQC)

- Spin-entangled photons mediate interaction between spins.

- Leverages strengths of both light and matter systems.

G. Gliniasty et al., *Quantum* **8**. 1423 (2024).

2.2. Quantum error-correction

An essential ingredient for fault-tolerance

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Surface and Low-density Parity Check codes

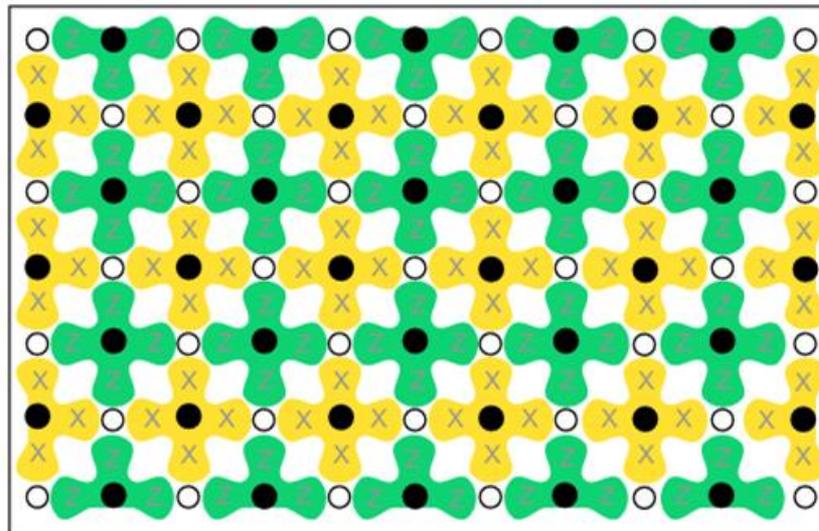- **Surface code** - widely used in the literature.

- **Low-density parity check codes** - **constant encoding rate** and **linear distance**.

A. Fowler et al., *Phys. Rev. A* **86**, 032324 (2021).

Floquet codes

- **"Dynamical" version of surface code** - periodic measurement of low-weight operators.

- **Honeycomb code** - shown to **outperform surface code in SPOQC variant.**

P. Hilaire et al., preprint arXiv:2410.07065 [quant-ph] (2024).

Optimize quantum error-correction strategies

W. Song et al. Phys. Rev. Lett. 133, 050605 (2024).

P. Hilaire et al., preprint arXiv:2410.07065 [quant-ph] (2024).

2.3. Counterfactual quantum gates

A possible scheme for blind quantum computing

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Blind Quantum Computing

Secure client-server setting, where the server is blind to the quantum computation controlled by the client.

J. Fitzsimons, *npj Quantum Information* **23** (2017).

Counterfactual photonic quantum gate

- Bob can **remotely apply an arbitrary single-qubit gate** to a photonic qubit **with a simple classical mechanism, without communicating with Alice**.

H. Salih et al., *New J. Phys.* **23**, 013004 (2021).

3. Summary

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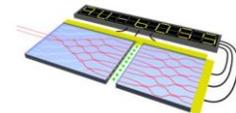
Summary

- **Critical review of FBQC and SPOQC architectures**, with the goal to **improve on their modular building blocks** by considering resource trade-offs in state-of-the-art schemes for photonic entangled state generation.

- **Investigate optimal strategies for implementing quantum error-correction in these architectures**, in terms of the choice of resource and encoded states, error-correction code and fusion mechanisms.

- Assess the security of a protocol for blind quantum computation using Salih et al's counterfactual quantum gate.
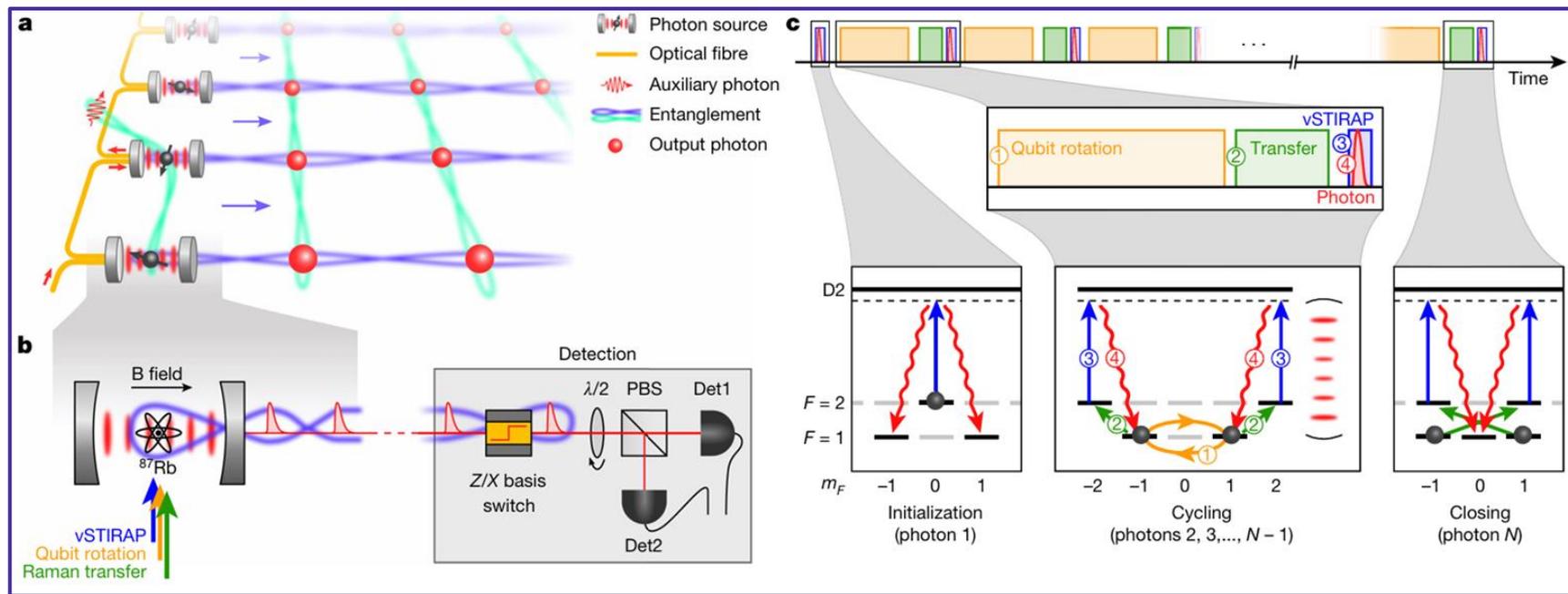
Thank you for your attention

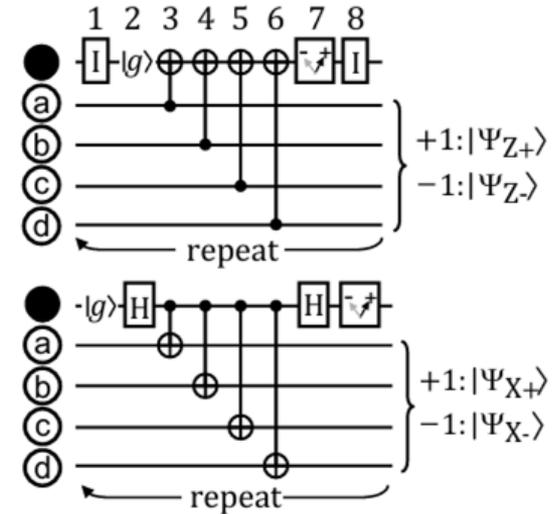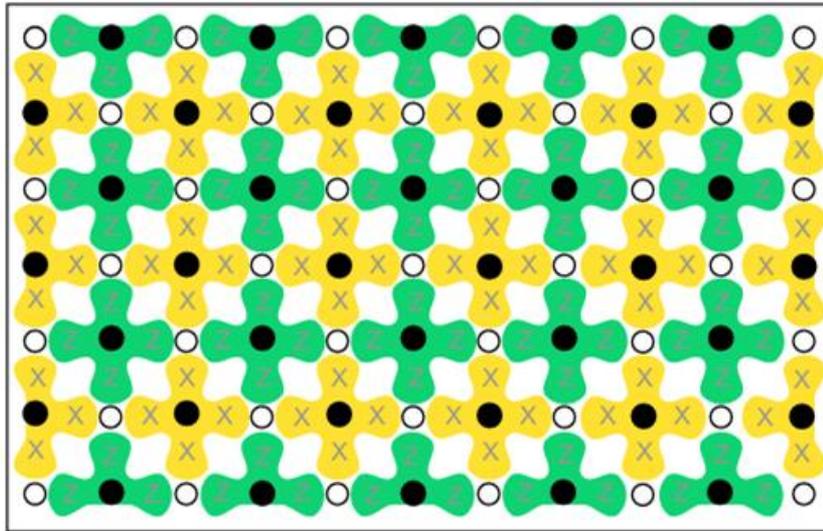sara.franco@inl.int

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- D. E. Browne and T. Rudolph, *Phys. Rev. Lett.* **95**, 010501 (2005).

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- A. Fowler et al., *Phys. Rev. A* **86**, 032324 (2021).

- G. Gliniasty et al., *Quantum* **8**. 1423 (2024).

- P. Hilaire et al., preprint arXiv:2410.07065 [quant-ph] (2024).

- P. Kwiat, Physica Scripta. T76, 115-121 (1998).

- J. O'Brien, *Science* **318**,1567-1570 (2007).

- R. Raussendorf and H. J. Briegel, *Phys. Rev. Lett.* **86**, 5188 (2001).

- H. Salih et al., *New J. Phys.* **23**, 013004 (2021).

- P. Thomas et al., *Nature* **608**, 677–681 (2022).

- Han-Sen Zhong et al., Science 370,1460-1463 (2020).

Spin-Optical Quantum Computing (SPOQC)

P. Thomas et al., *Nature* **608**, 677–681 (2022).

Surface codes

A. Fowler et al., *Phys. Rev. A* **86**, 032324 (2021).

Quantum Error-Correction