



# A Manufacturable Path to Delivering a Silicon Photonics Quantum Computer

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NYCREATES ETSS

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Company mission is:

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To build the world's 1<sup>st</sup>  
large-scale, fault tolerant, error corrected  
quantum computer

Company mission is:

To build the world's 1<sup>st</sup>

*(large-scale, fault tolerant, error corrected)*

**USEFUL**

quantum computer



Prof. Jeremy O'Brien, CEO

25 years in quantum computing  
1<sup>st</sup> photonic logic gate, 2003



Prof. Terry Rudolph, Chief Arch.

World leader in photonic QC theory  
>10,000 citations



Pete Shadbolt PhD, CSO

PhD in experimental photonic QC  
Postdoc in theory of photonic QC



Prof. Mark Thompson, Chief Tech.

20 years in photonic engineering  
Director, CDT in Quantum Engineering

# Quantum computers solve problems that are otherwise *impossible*



## Finance

Portfolio optimization  
Risk management



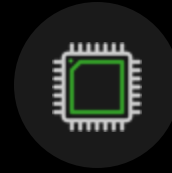
## Healthcare

Drug discovery  
Personalized medicine



## Materials

New solar cells  
Novel superconductors



## Computing

Electronics  
Software



## Security

Cryptanalysis  
Codebreaking



## Transportation

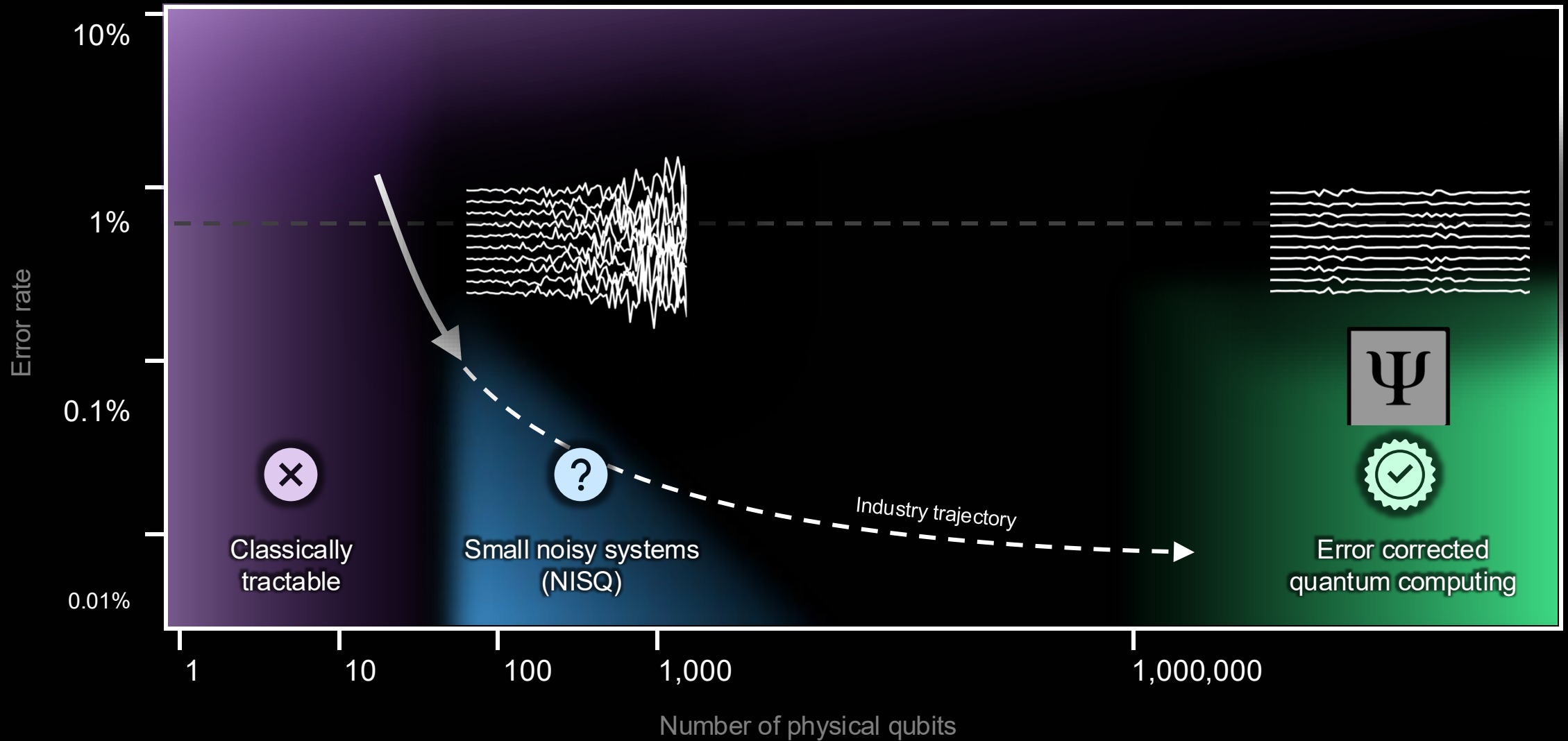
Novel fuels  
New battery materials

Industry leaders are now working with PsiQuantum to prepare for the existence of large-scale quantum computers.

Quantum computing market to reach \$1 trillion by 2035

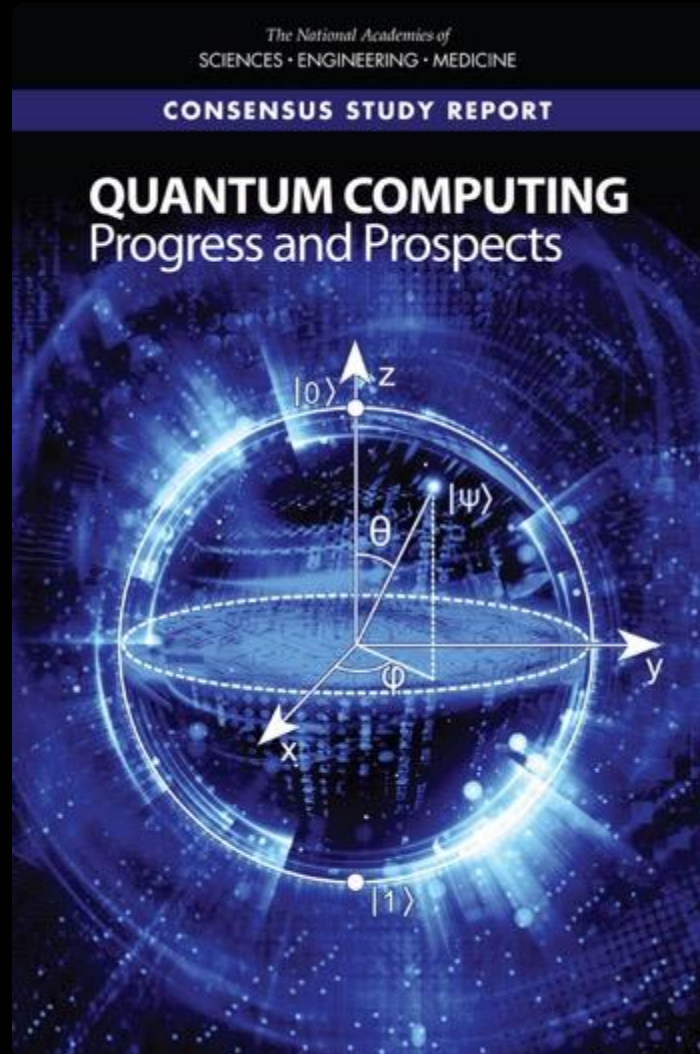
McKinsey

Real applications require ~100 logical qubits = a million physical qubits



*Industries research path to useful quantum computing.*

“...there are at present no known algorithms/ applications that could make effective use of [a NISQ] class of machine.”



“... the number of physical qubits that these devices hold would need to increase by at least a factor of 100,000 in order to create a useful number of effective logical qubits.”

# Qubit Types



Matter-based qubits  
Electrons



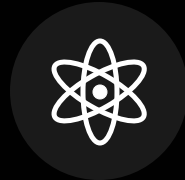
Light-based qubits  
Photons



Superconducting



Quantum dots



Trapped ions



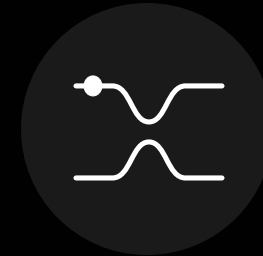
Topological



Annealers



Many others...



Silicon photonics

What do we need to build a useful quantum computer?

1. A fault tolerant architecture
2. A realistic path to scale
3. A manufacturable technology

# Dual-rail photonic qubits

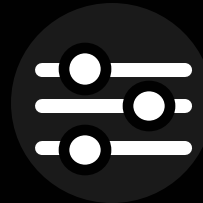


Fixed photon number is a powerful encoding, enabling:



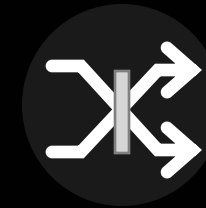
## Heralded Loss

Allows extremely high loss tolerance



## Long delays

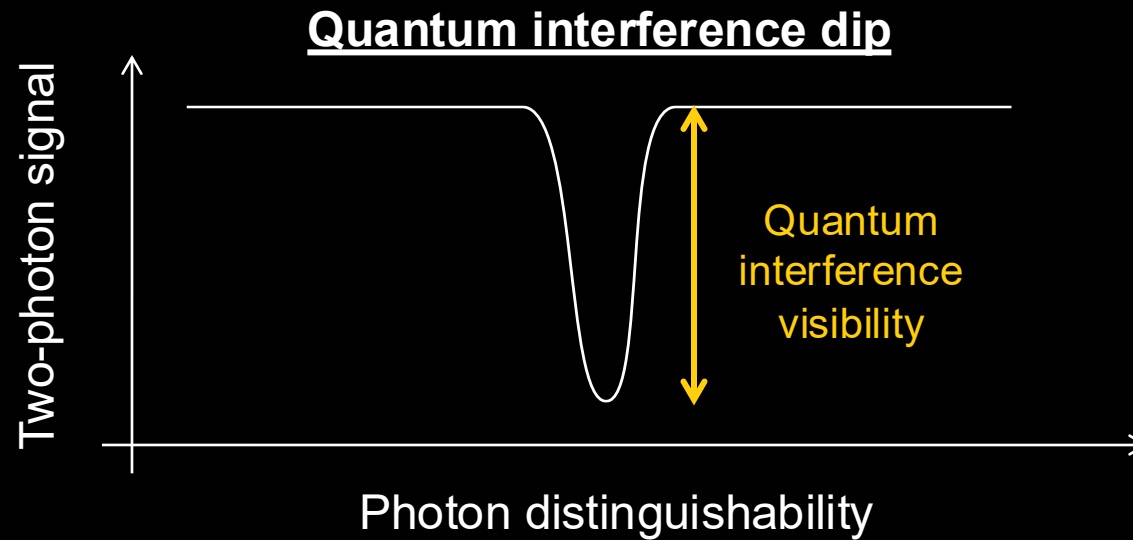
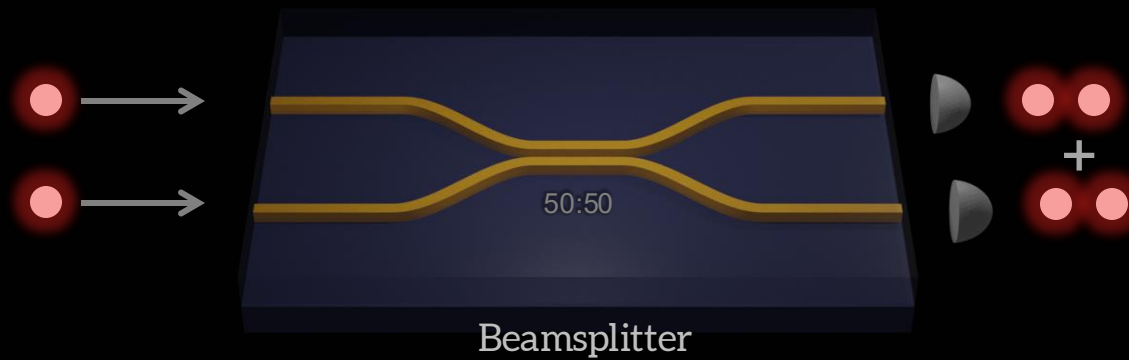
Enabled by relaxed phase stability requirements



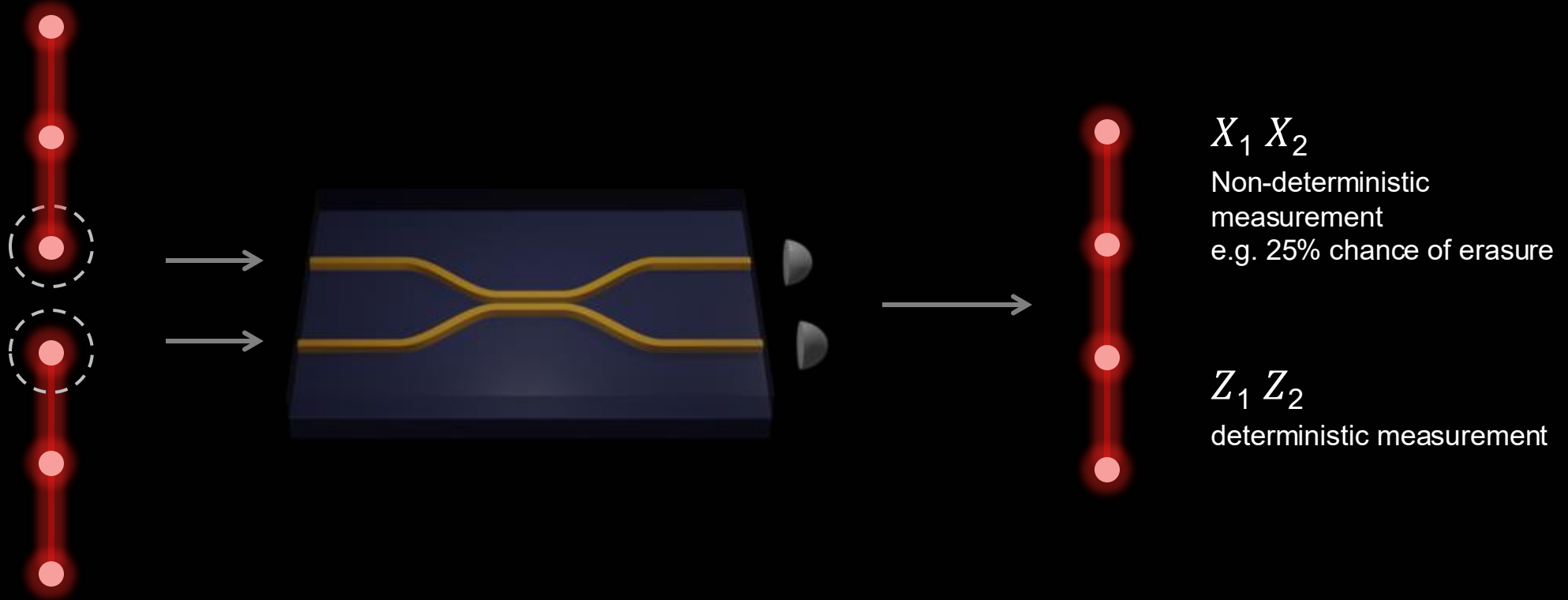
## High fidelity operations

Arbitrary single qubit rotations and Entangling measurements

# Quantum interference for qubit entanglement

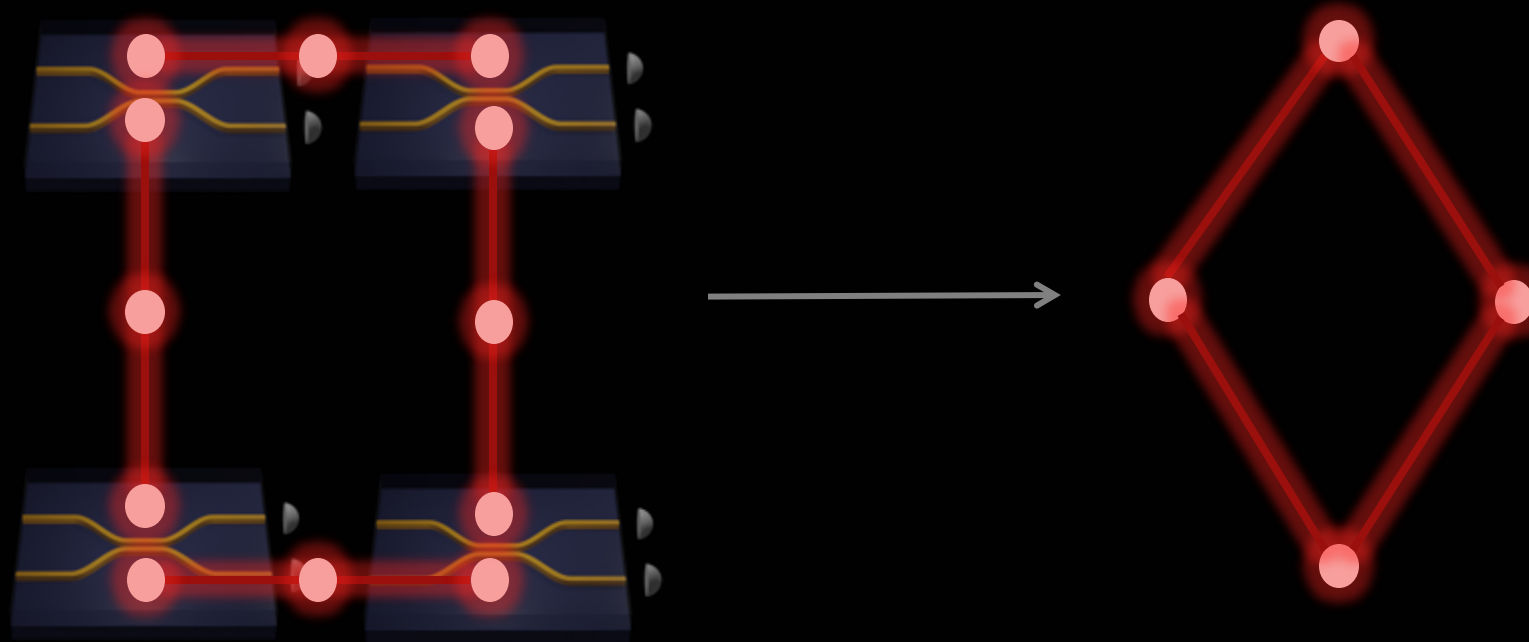


# FUSION gates replace CNOT gates

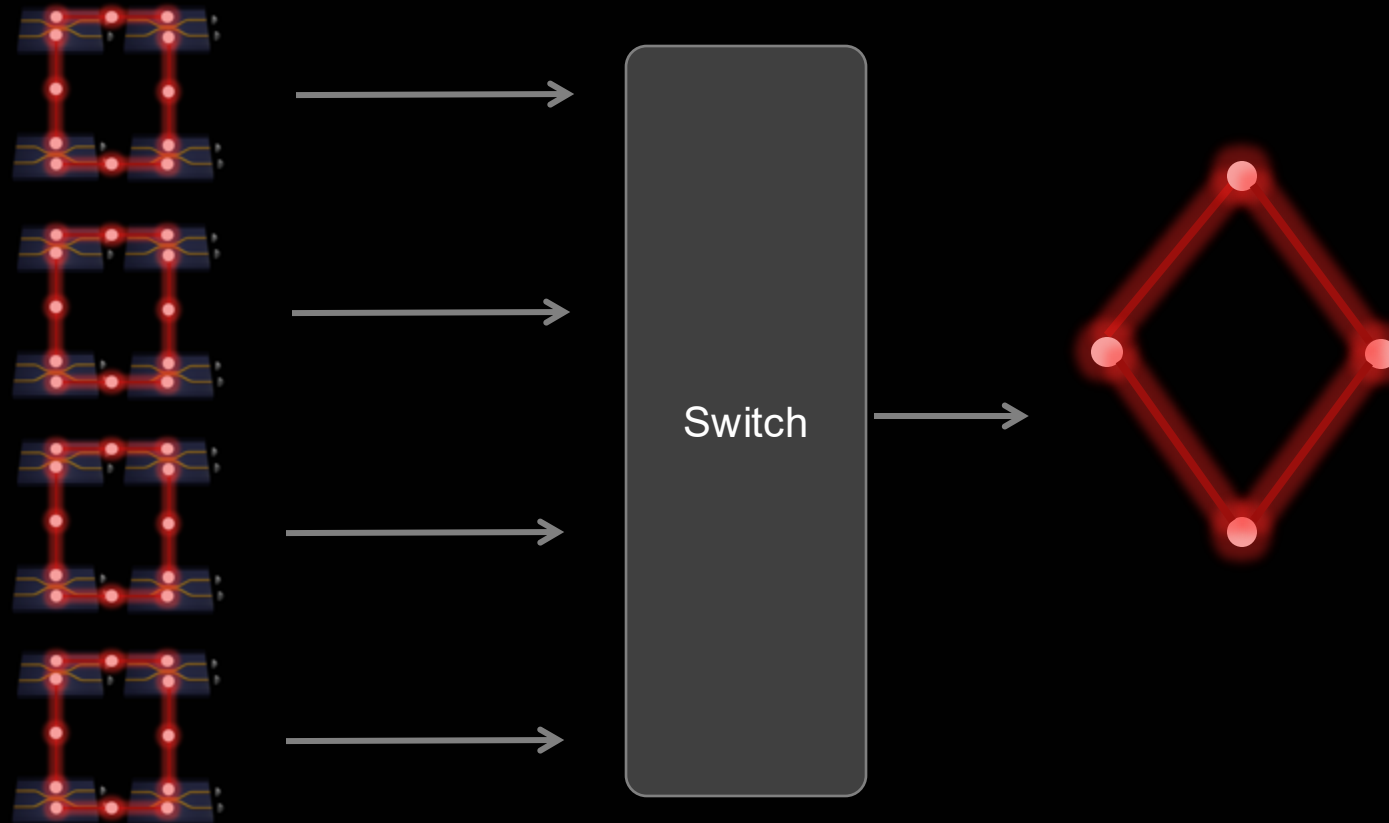


Detection performs an entangling projective measurement on the two incident qubits

Fusion creates larger entangled “Resource States” from smaller ones

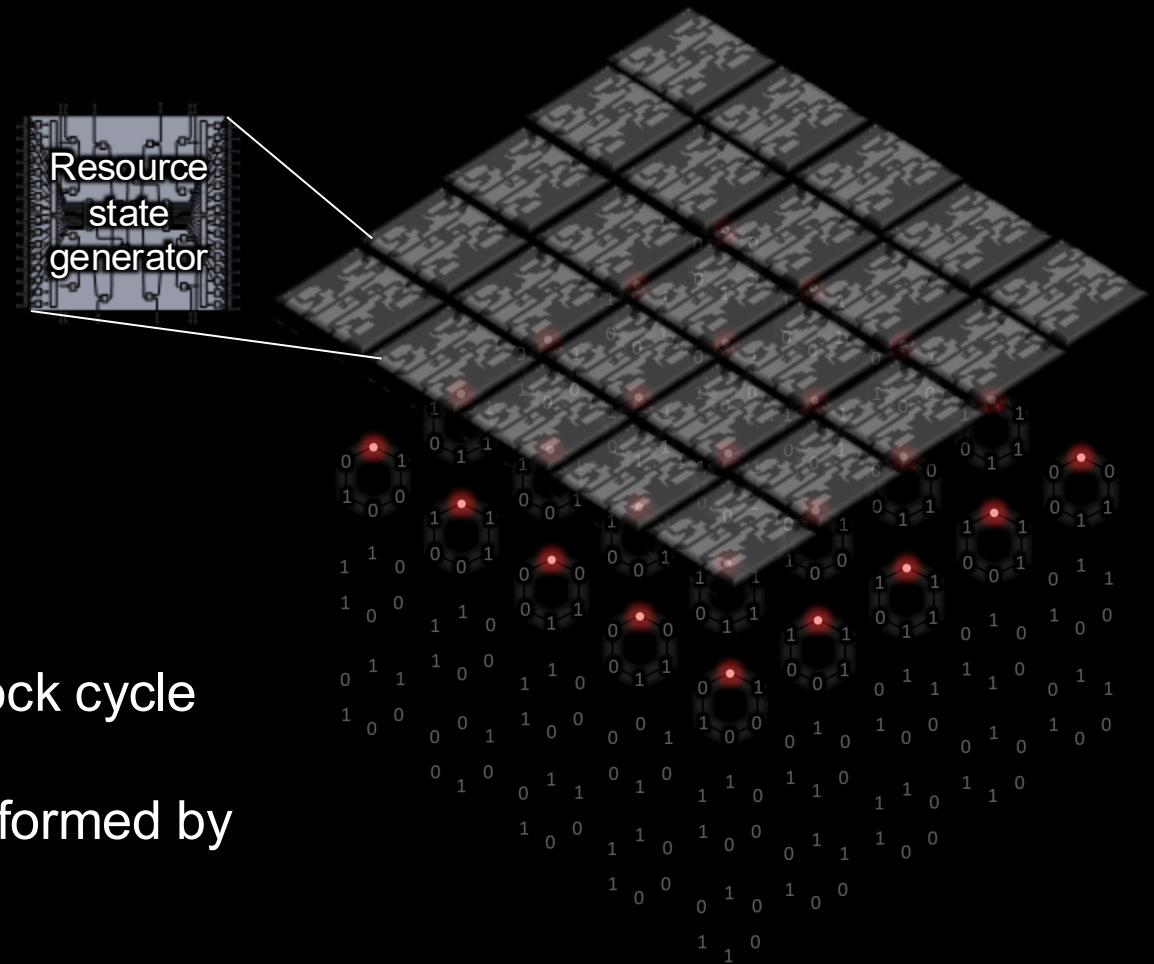


## Boost efficiency by multiplexing



- Each step is probabilistic, but successful events are switched out & multiplexed.
- The states needed are always the same size
- Only constant overhead required for a fixed sized resource state

# Fusion based quantum computation



- Create fixed size resource states on  $\sim 1$ ns clock cycle
- Fusions performed immediately
- Both **error correction** and **computation** performed by the same fusion measurements

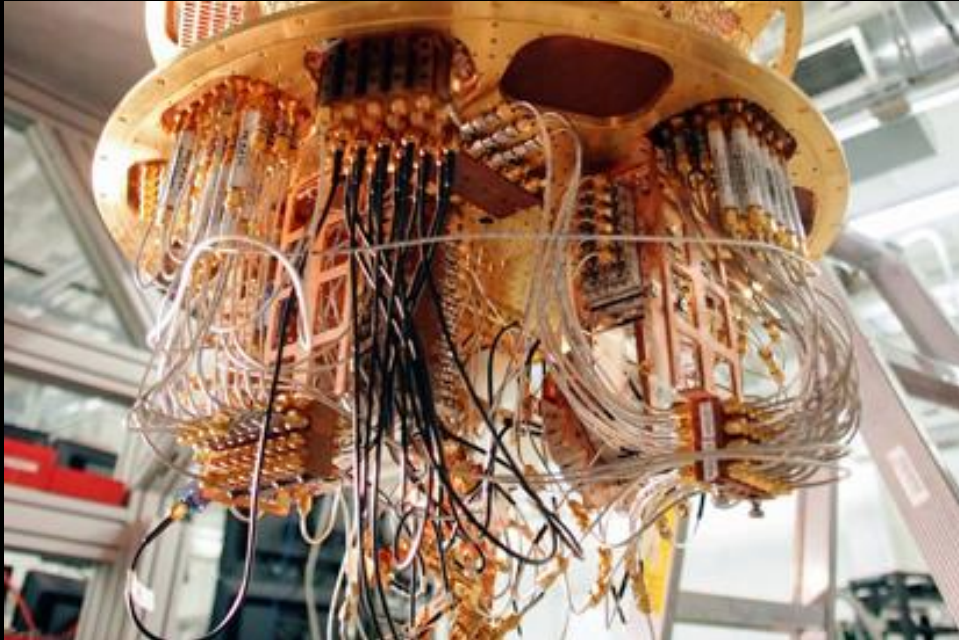
Fusion-based quantum computation

Bartolucci, Sara, et al. *arXiv:2101.09310* (2021).

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# The Essential Distinction



Matter:  
Make a **quantum**  
process **scalable**



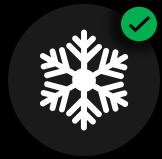
Light:  
Make a **scalable**  
process **quantum**

# PsiQuantum's approach to solve key scaling challenges



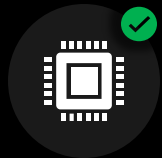
**Connectivity:** Chip-to-chip connections with standard optical fiber

No transducer required; teleportation already demonstrated



**Cooling power:** 1000X more cooling capacity than superconducting qubits

Photons do not feel heat, no need for mK temperatures



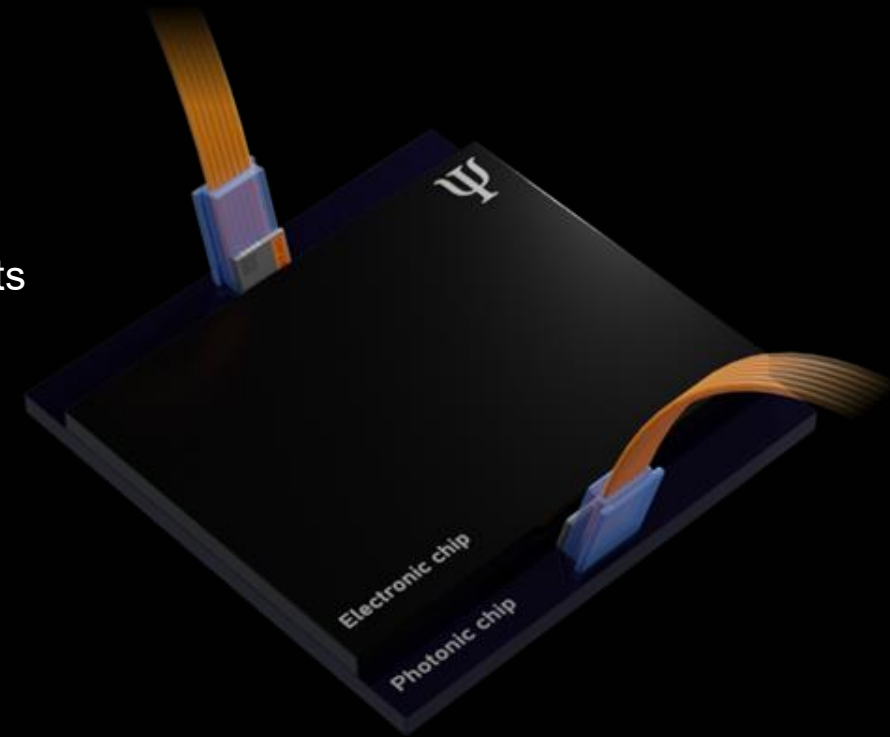
**Control electronics:** Standard CMOS electronics, right by the qubits

Q1 system has 750M transistors



**Manufacturability:** Ability to leverage high-volume chip fabs

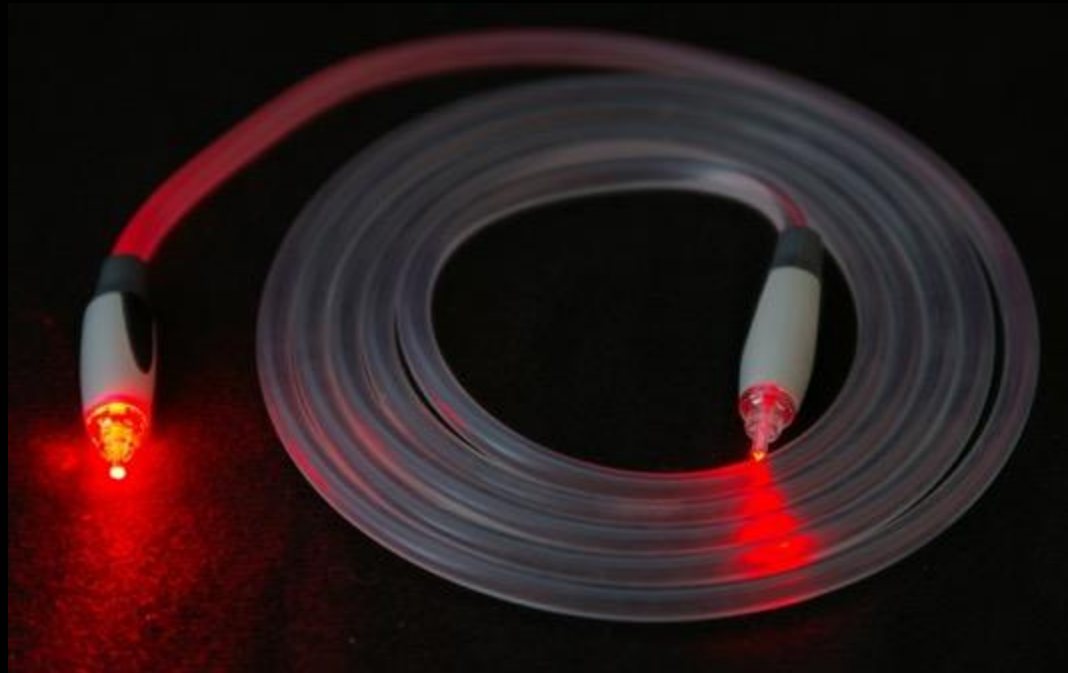
No exotic materials or atomic-scale fabrication, predictable performance



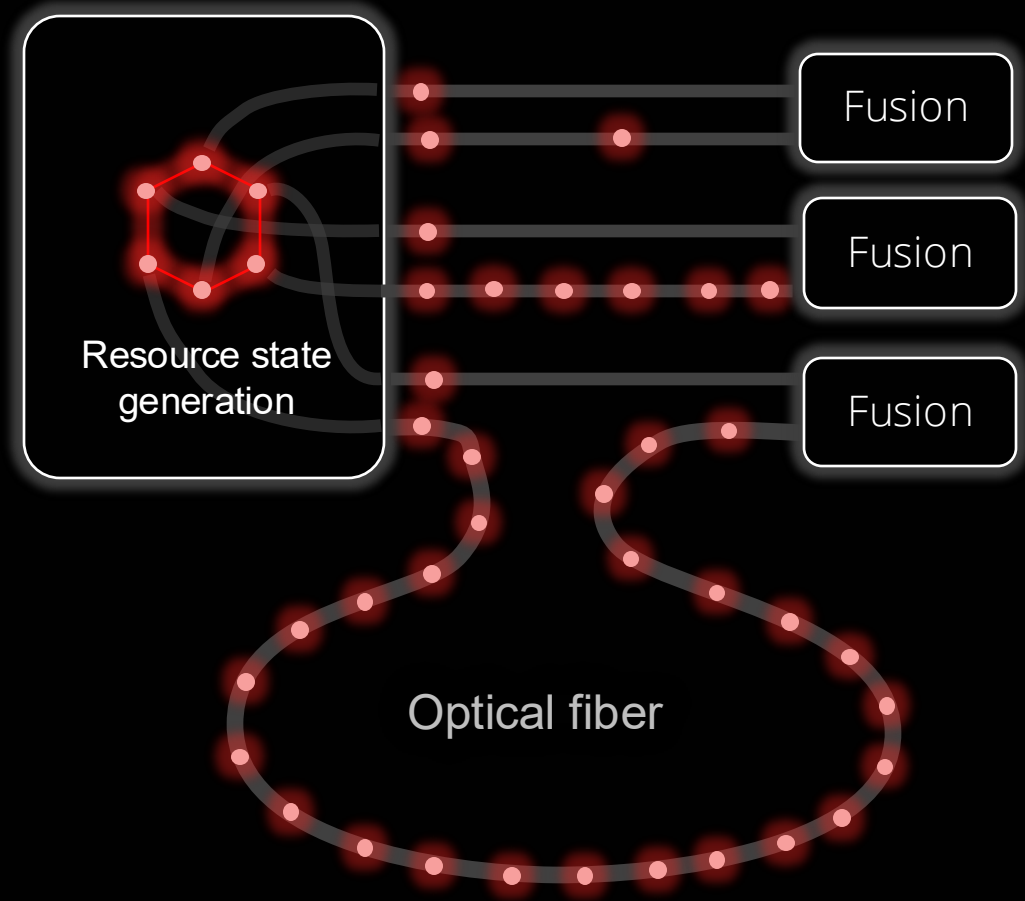


## Connectivity

All approaches to realistic scaling require networking and modularity

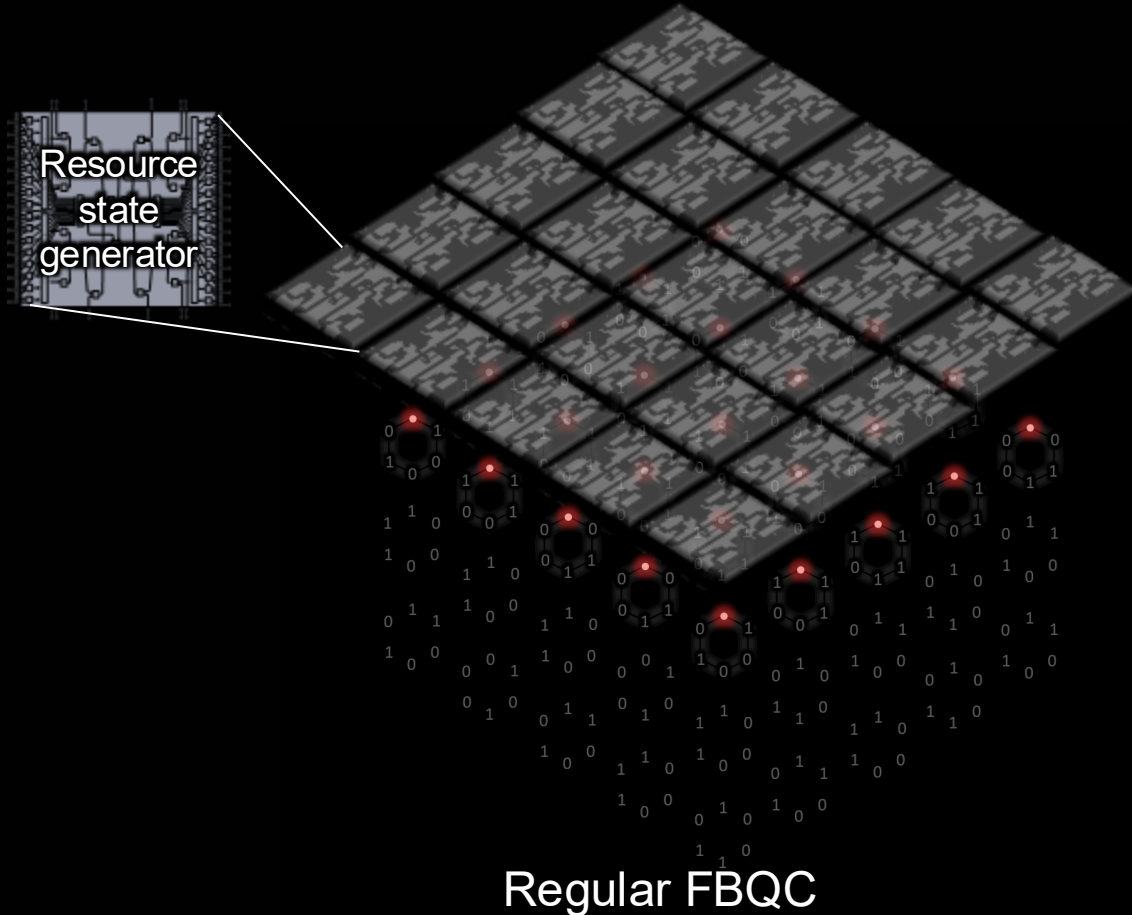


# Snapshot of a full logical qubit using only one resource state generator



# Interleaving: scaling with optical fiber

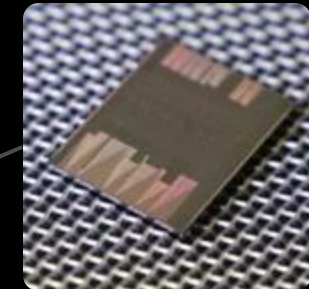
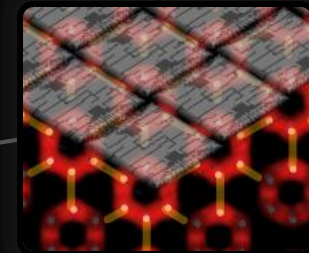
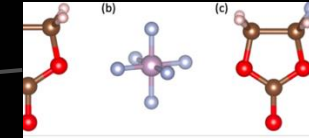
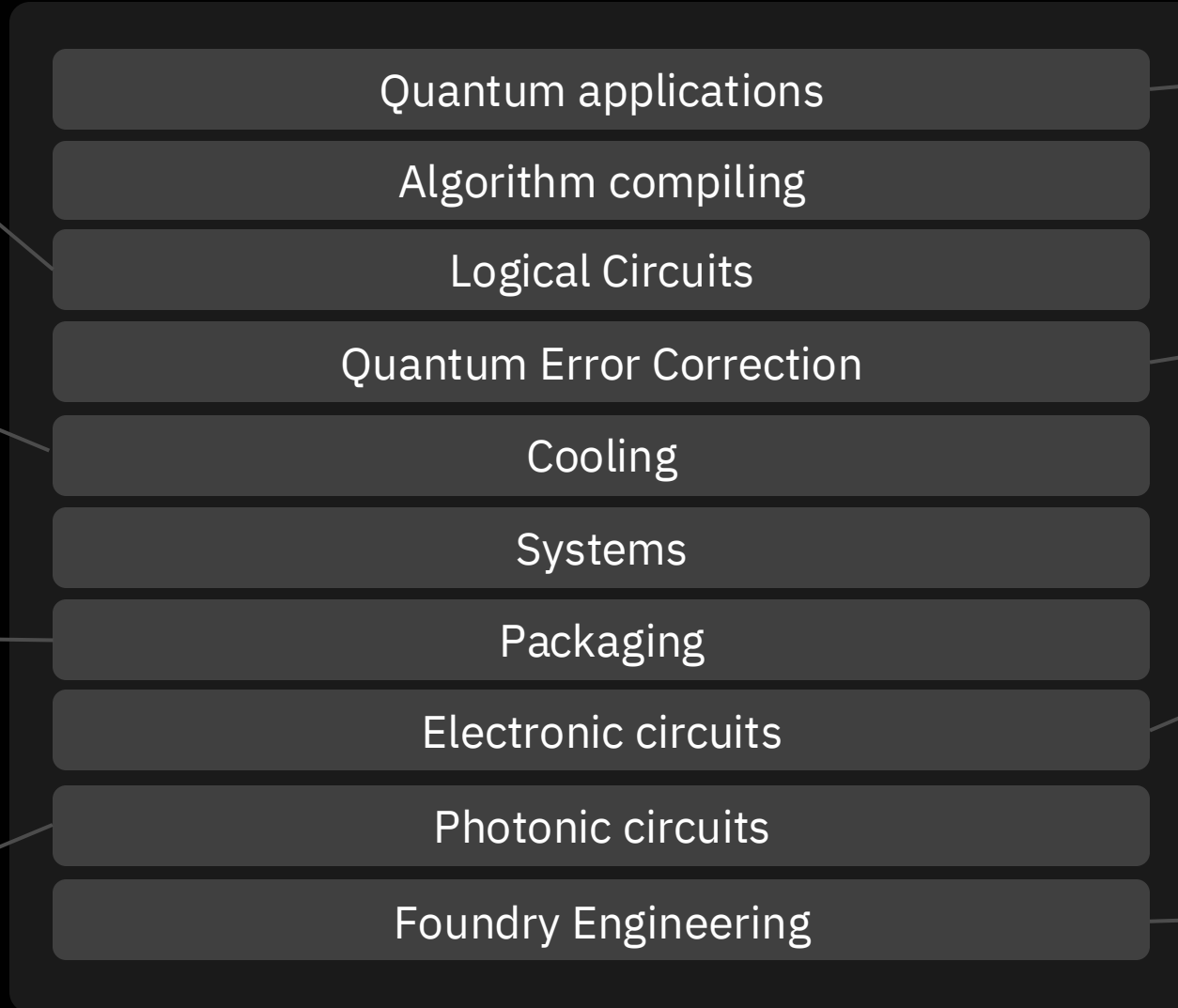
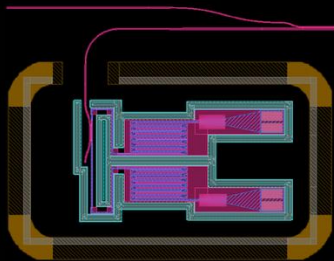
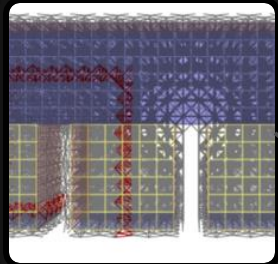
We use a single resource state generator to create an entire logical qubit by rastering to create the 3D fusion network needed for computation

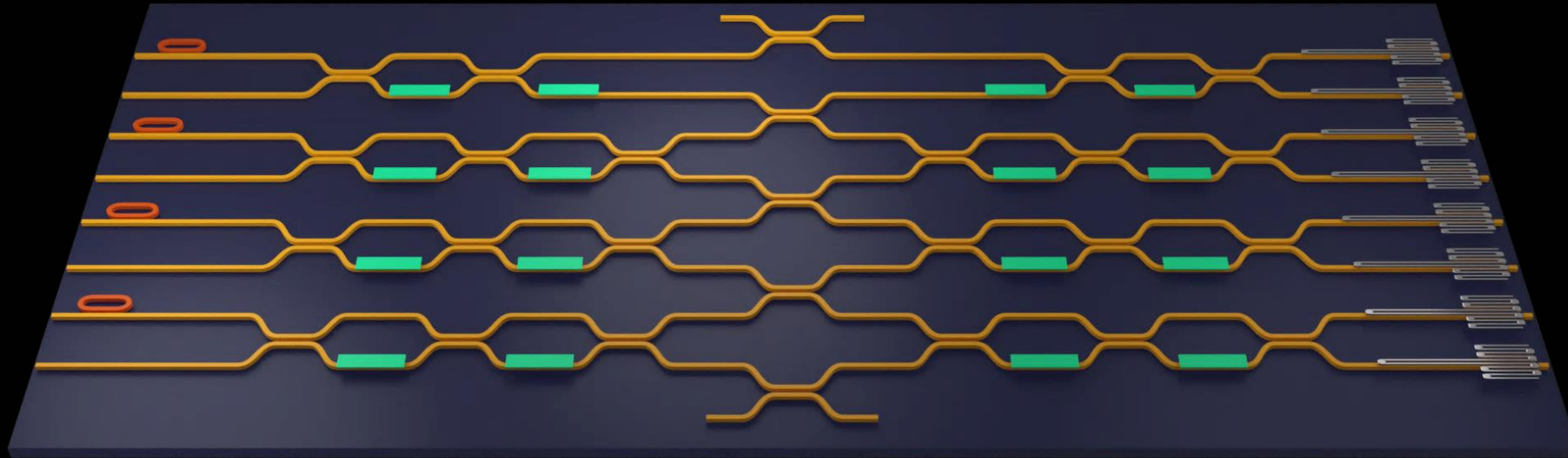


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# Photonic Quantum Computing Stack

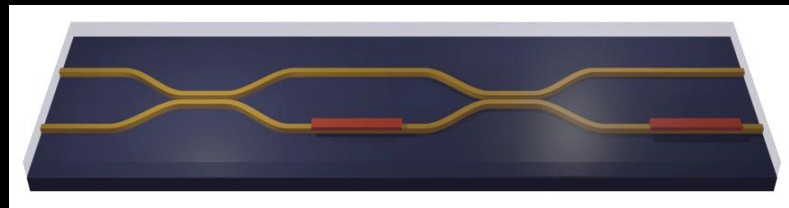
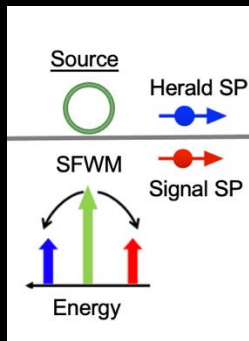




Single Photon Source

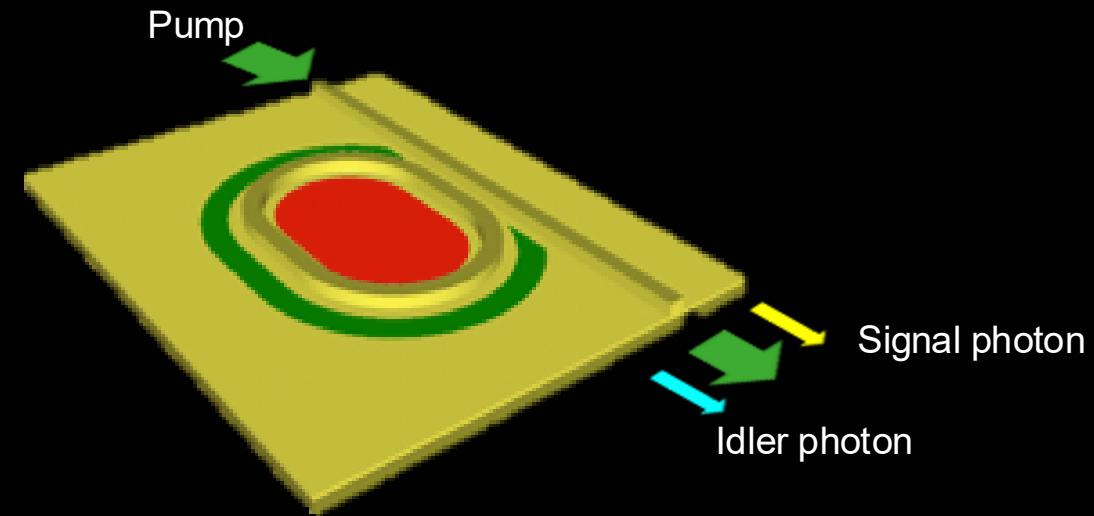
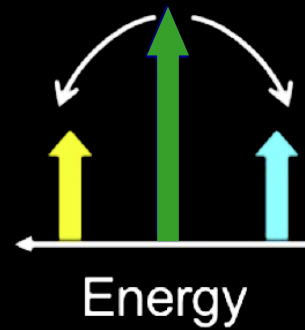
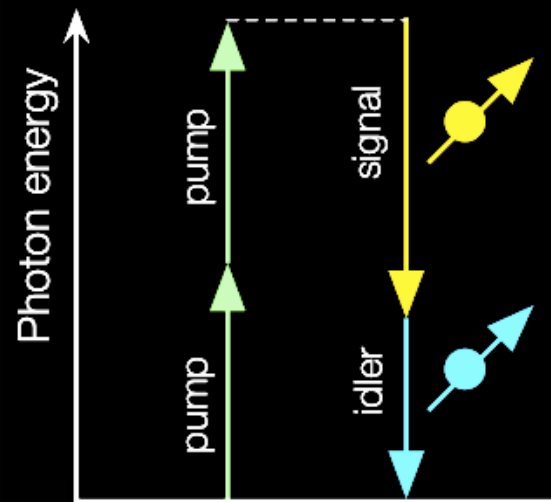
Photon Manipulation

Single Photon Detector



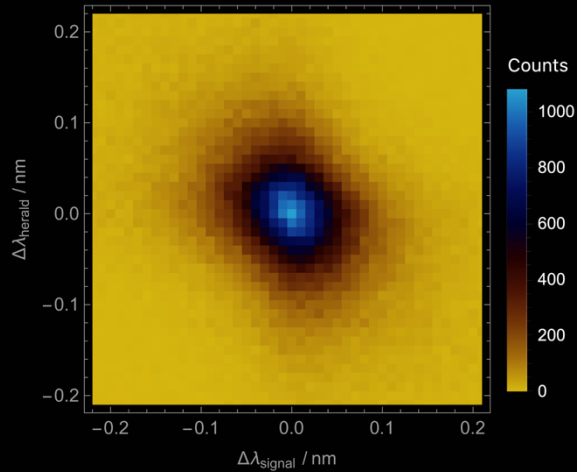
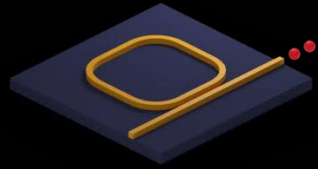
# Photon generation

## Spontaneous four-wave mixing



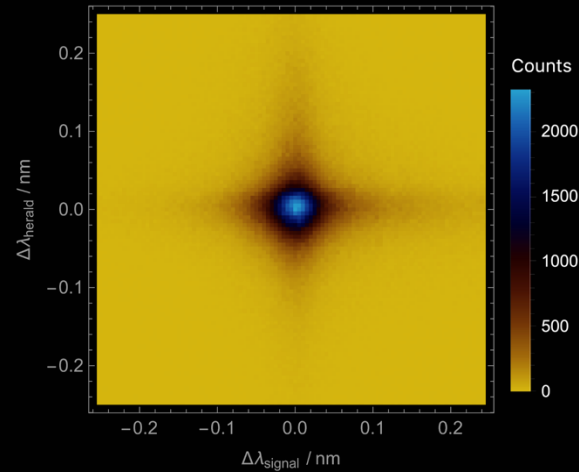
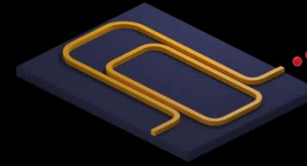
Bright pump beam scattered via parametric nonlinear interaction with  $\chi^3$  of Si or SiN to produce photon pairs

# Single photon generation



~90% purity

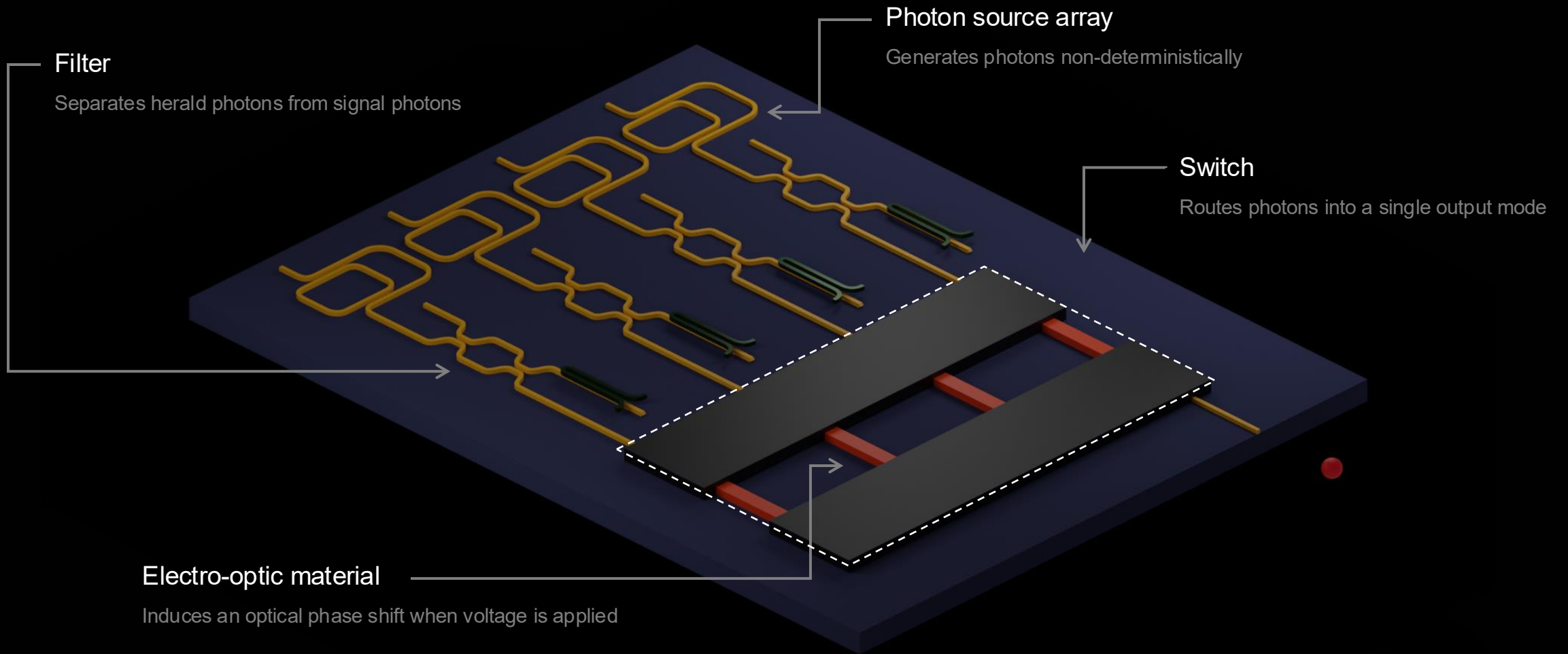
EXPERIMENT



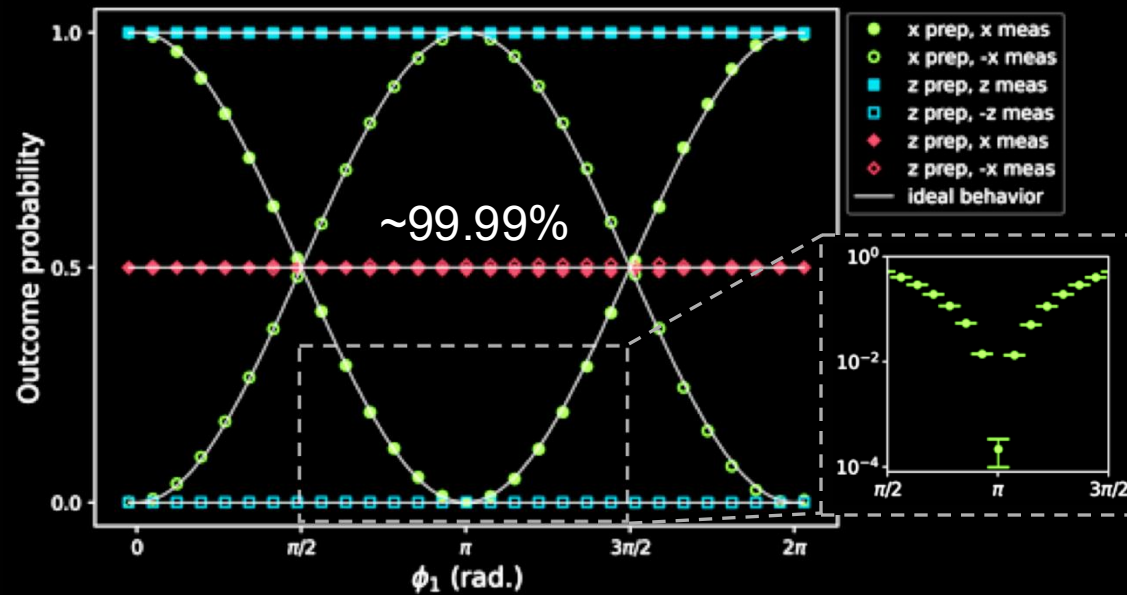
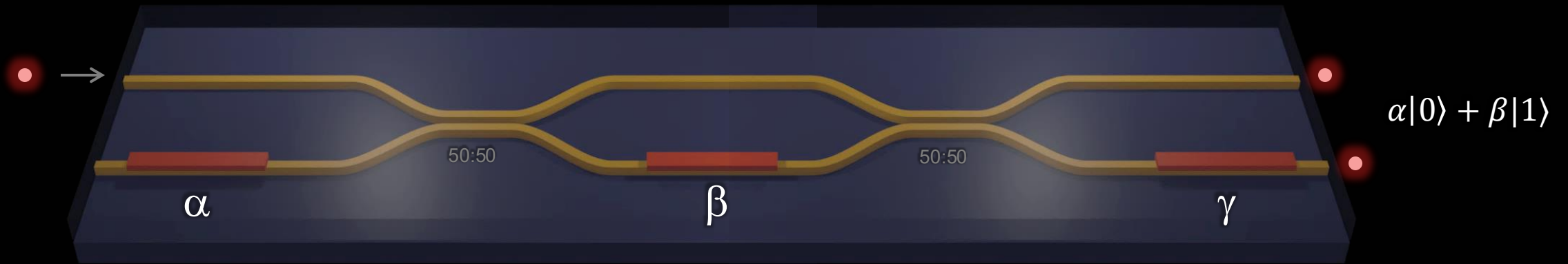
~99.5% purity

EXPERIMENT

# Optical switching



# Single qubit preparation and readout

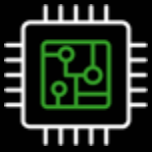




PsiQuantum made a **highly differentiated bet** – to pursue a **large-scale, error corrected system** from the beginning



**Photonic qubits** uniquely overcome the **scaling challenges** associated with error correction



PsiQuantum is **now developing quantum chips** in the production line of a **mature chip foundry**



Customers have come to the realization that they will need a large-scale, fault-tolerant system of the type that PsiQuantum is building

<https://www.youtube.com/@PsiQuantum/videos>