// CAP Congress 2024

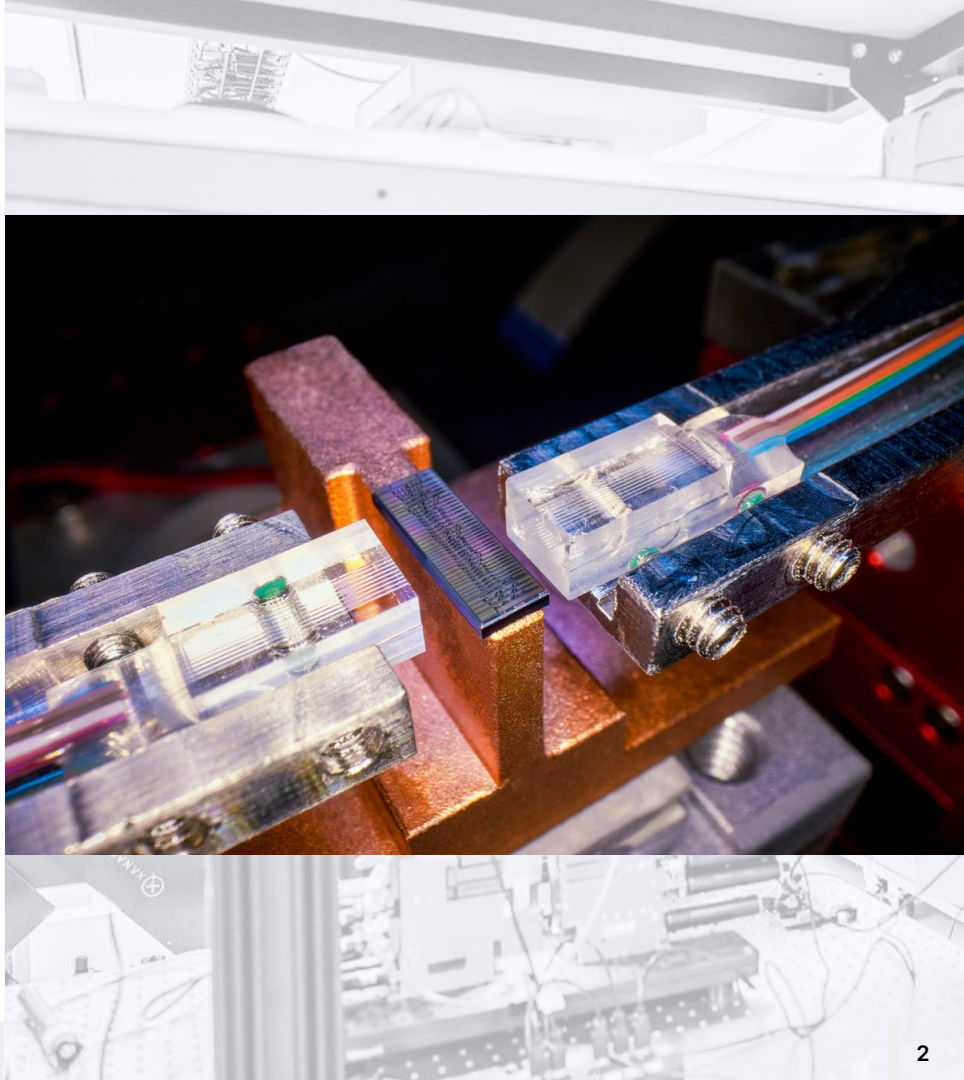
XANADU

Working in the quantum computing industry: Activities, needs and future directions

01

Xanadu

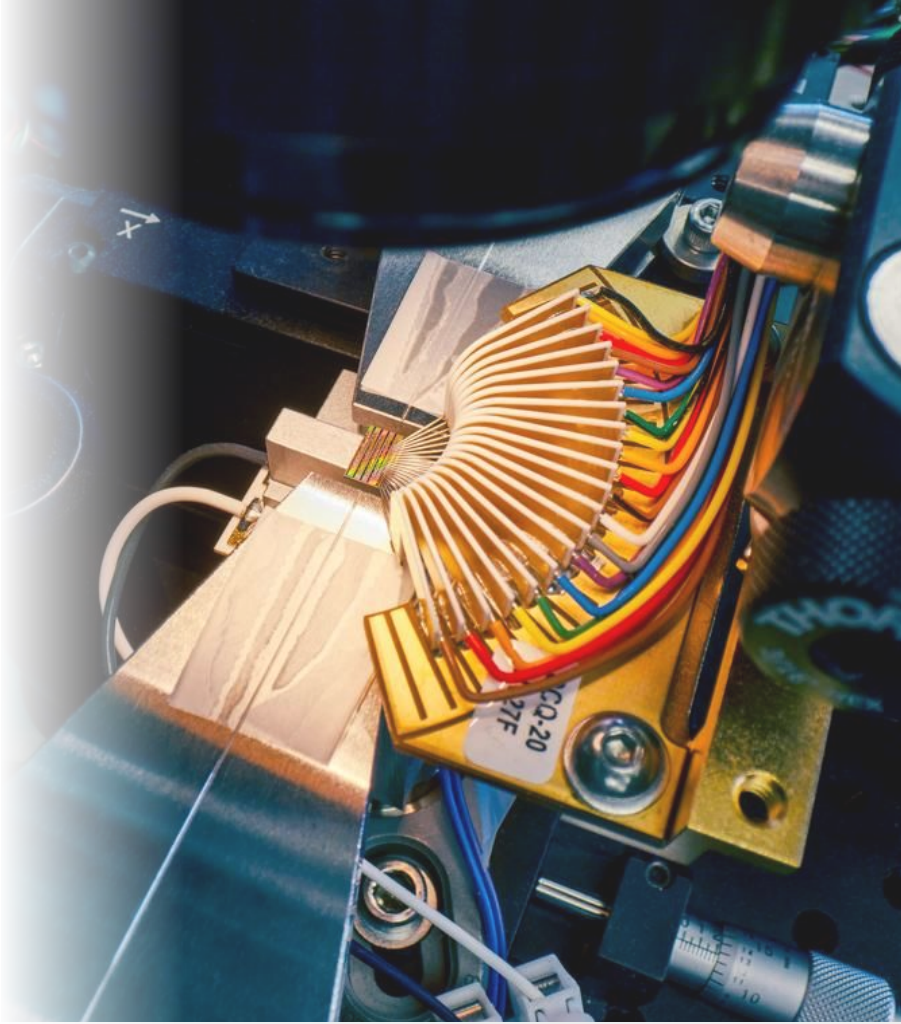
We build quantum computers using light



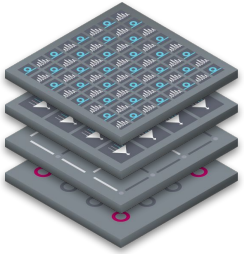
// Our Mission

To build quantum computers that are **useful** and **available** to people everywhere

Founded	Headquarters	People
2016	Toronto	200+



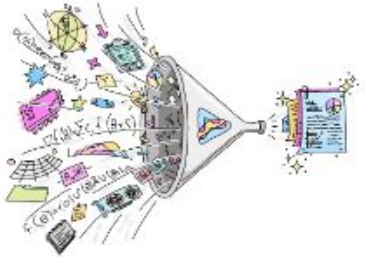
Full-stack quantum computing



Photonic Quantum Hardware

PENNYLANE

Pioneering Quantum Software



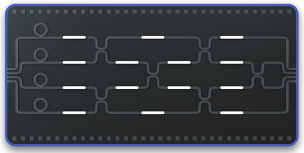
Quantum Algorithms R&D

02

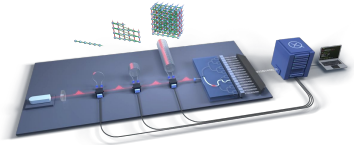
Xanadu’s fault-tolerant architecture

Roadmap to fault tolerant quantum computers

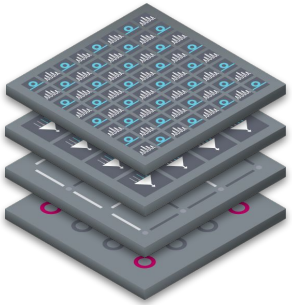
X Series chip 〉 Borealis 〉 FTQC Module 〉 FTQC Data Center



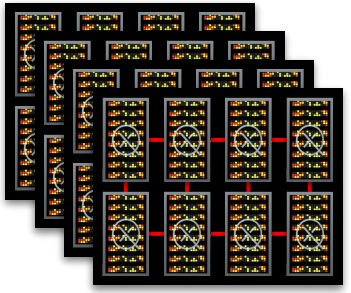
1st photonics device available on the cloud



1st commercially available QC with computational advantage

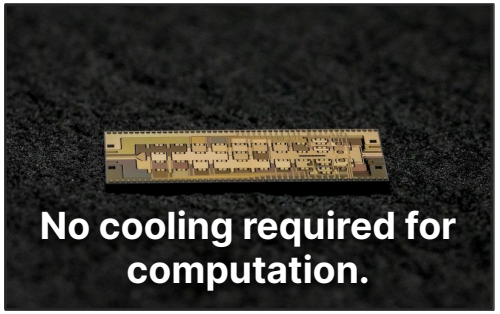


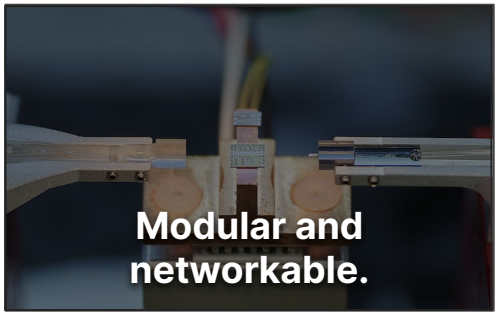
1st manufacturable module with few logical qubits

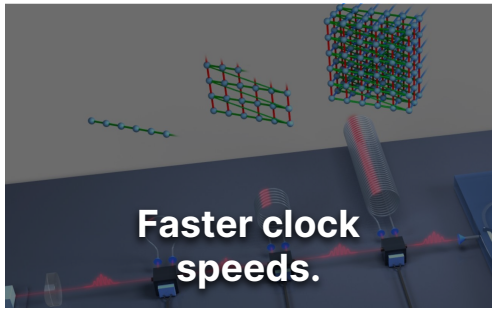


Making available 100+ logical qubits to partners

Benefits of photonic quantum computers

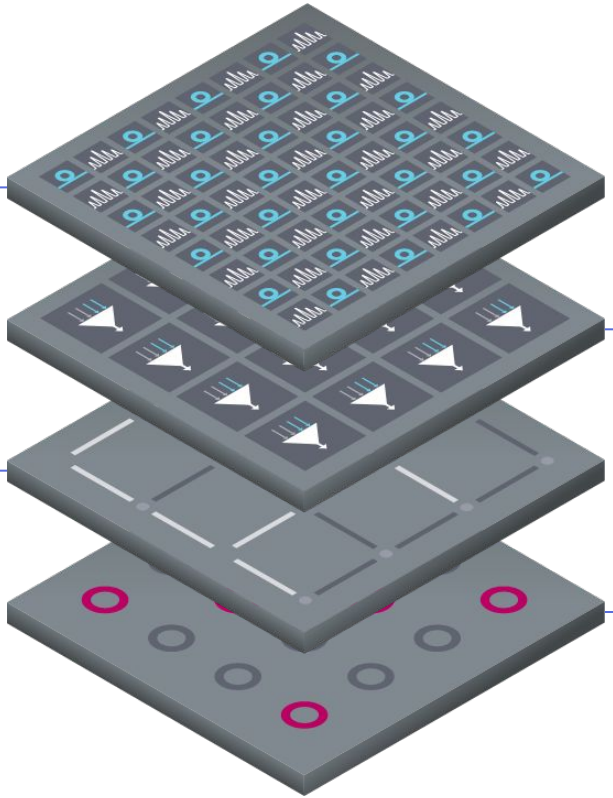






Xanadu's FTQC Architecture

Component 1:
State preparation



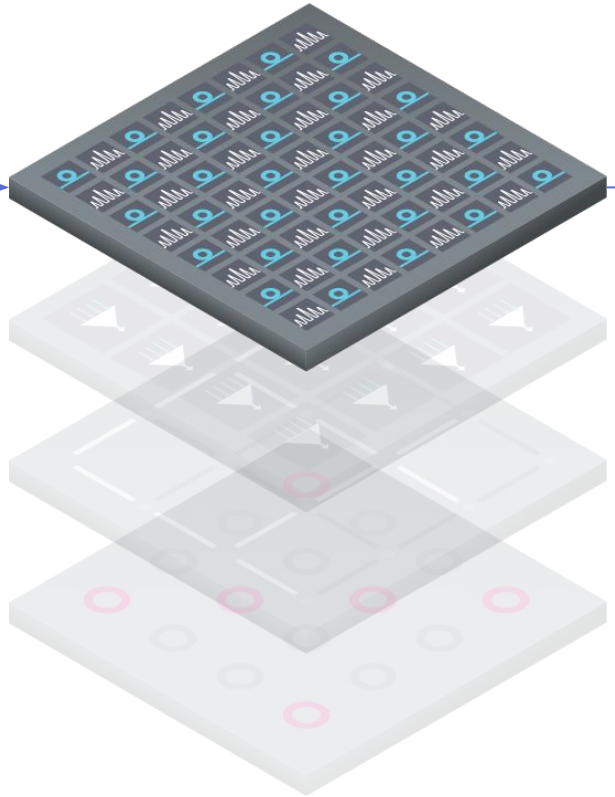
Component 2:
Multiplexer

Component 3:
Stitcher

Component 4:
Quantum processing unit (QPU)

State preparation: Generates qubits probabilistically

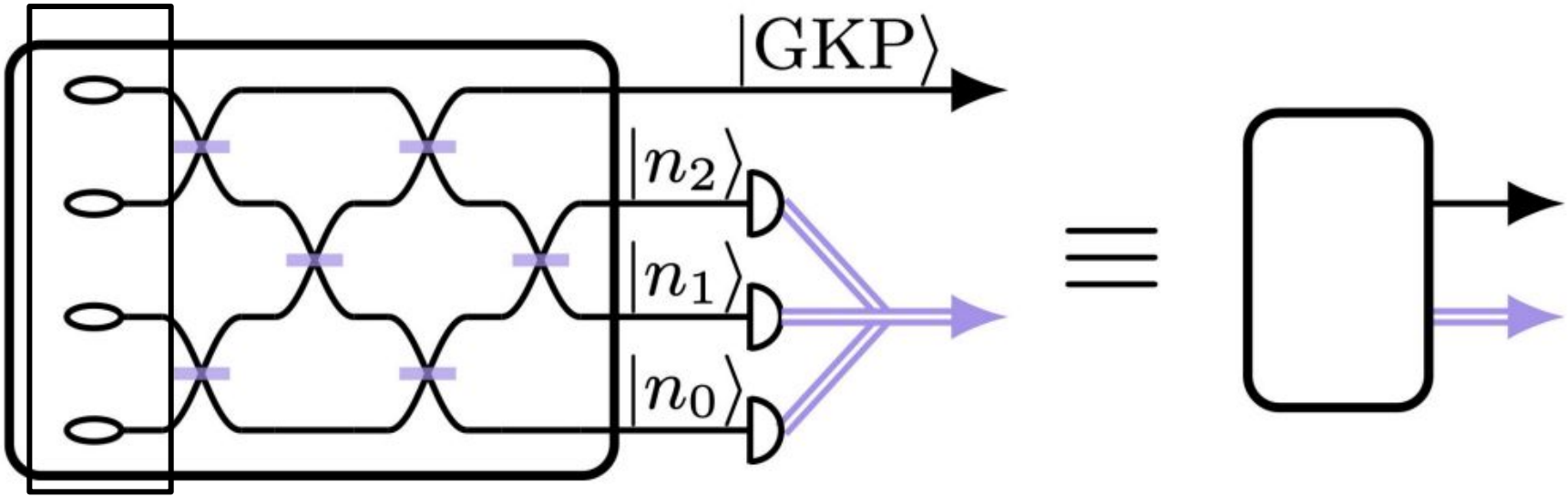
Input:
Standard laser light



Output:
GKP state + squeezed state

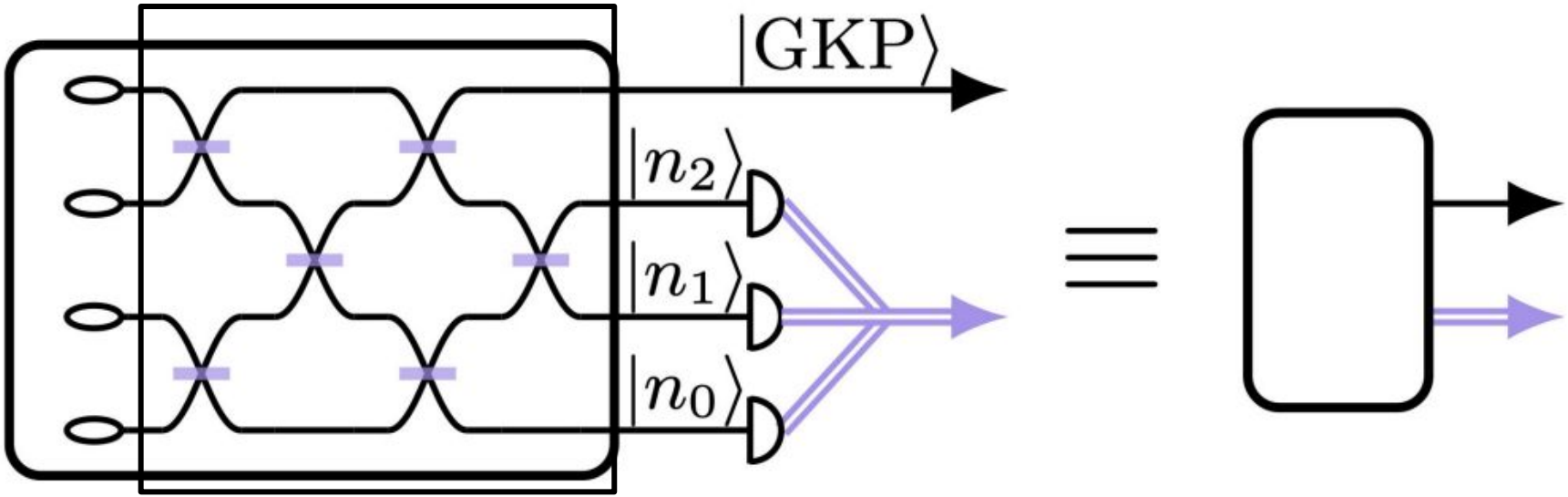
Mechanisms:
- Squeezers
- Gaussian Boson Sampling chip

State preparation: Generates qubits probabilistically



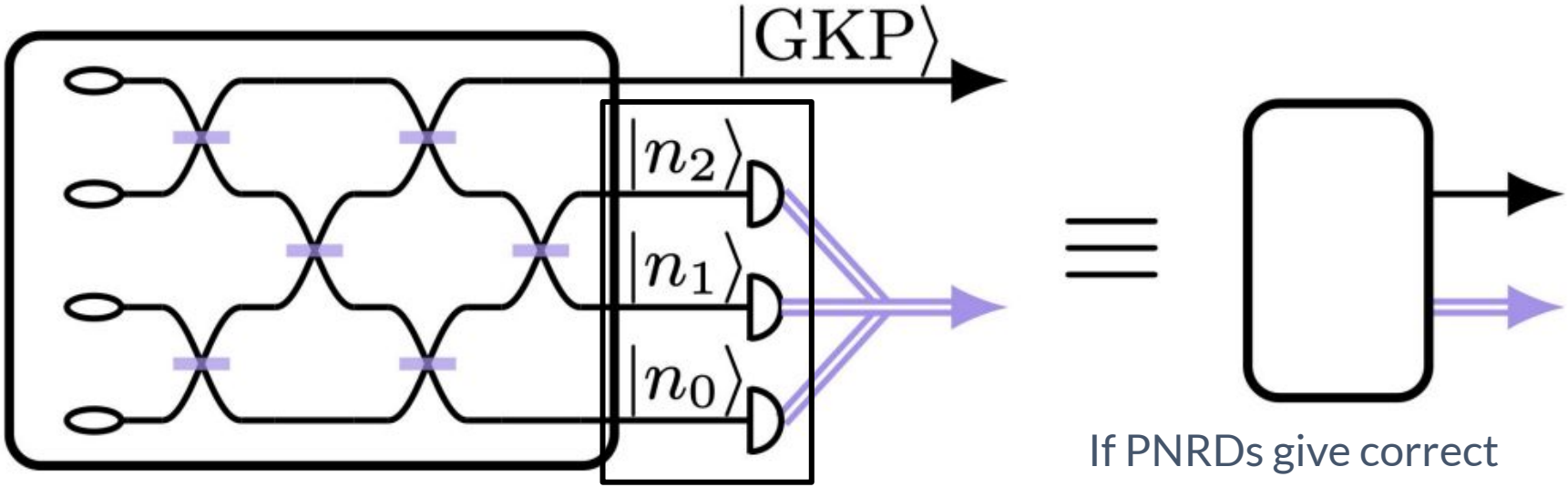
Squeezed states

State preparation: Generates qubits probabilistically



Linear optics

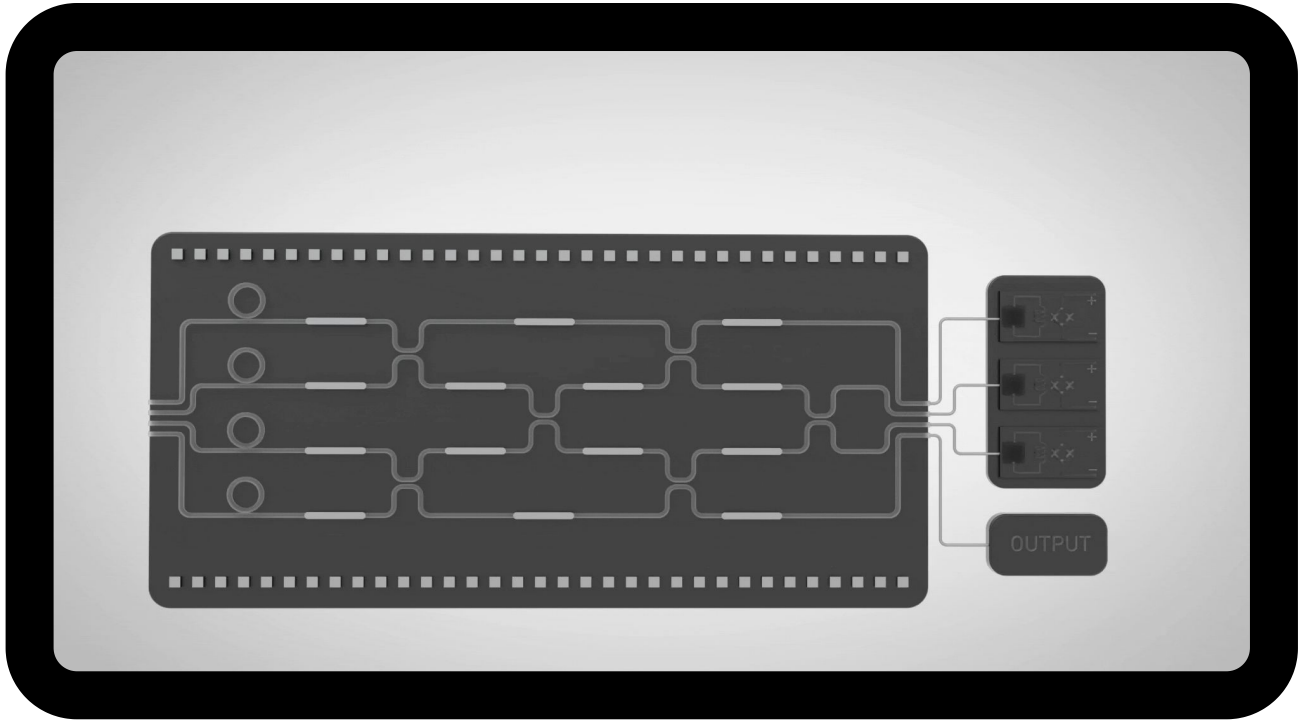
State preparation: Generates qubits probabilistically



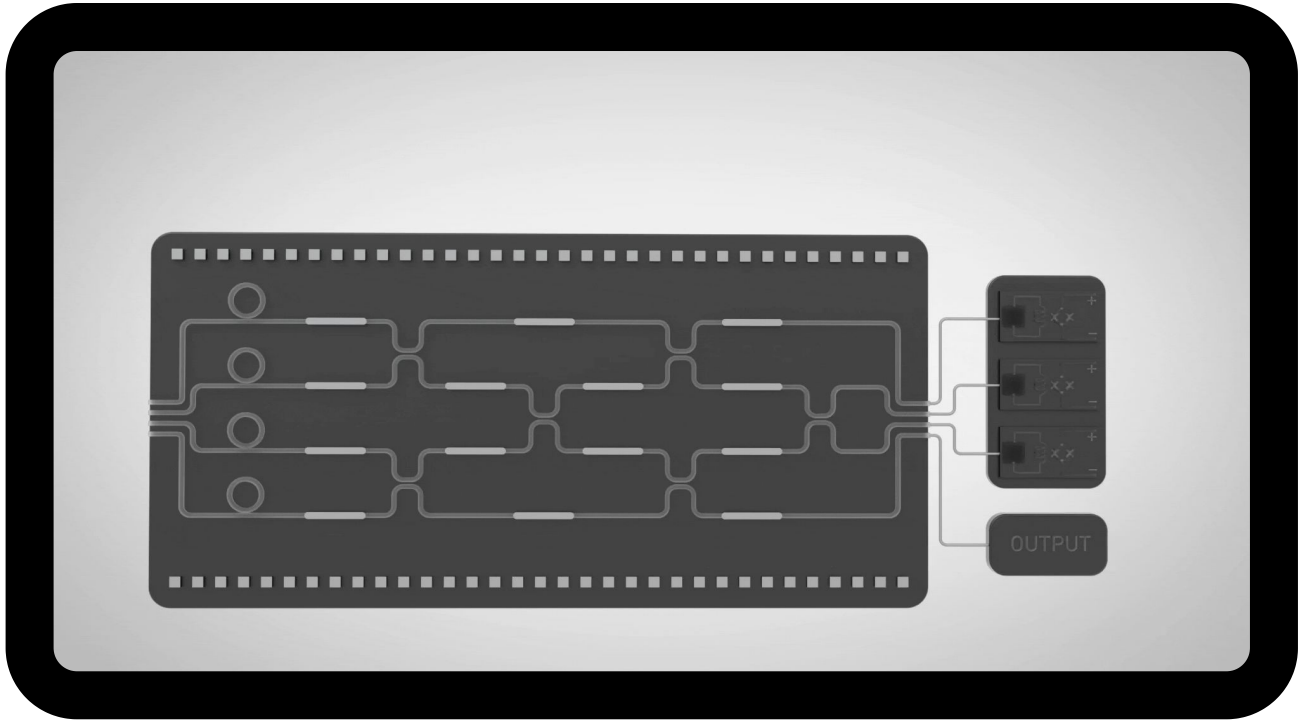
Photon-number resolving detectors

If PNRDs give correct measurement pattern, remaining modes are a GKP state (special states of many photons)

State preparation: Generates qubits probabilistically



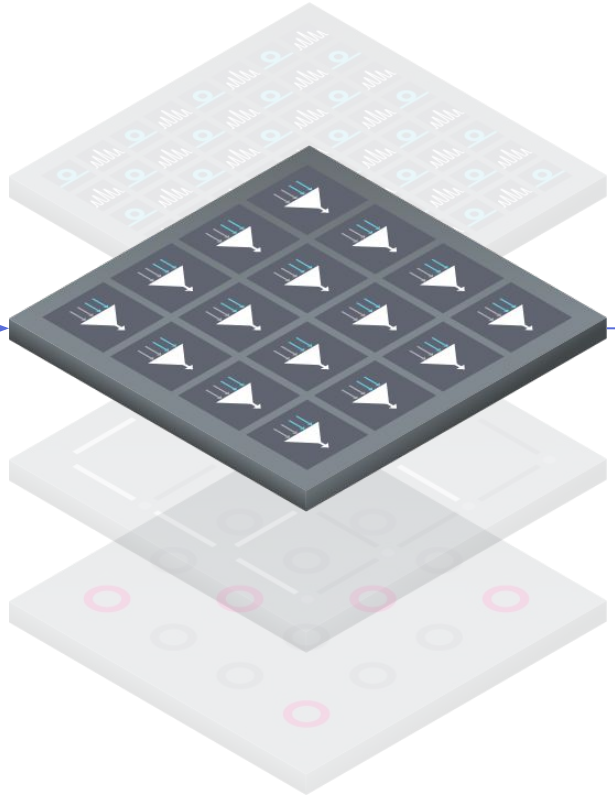
State preparation: Generates qubits probabilistically



BUT probability of successfully creating a GKP state is low

Multiplexer: Boosts probability of state preparation

Input:
Low probability GKP state

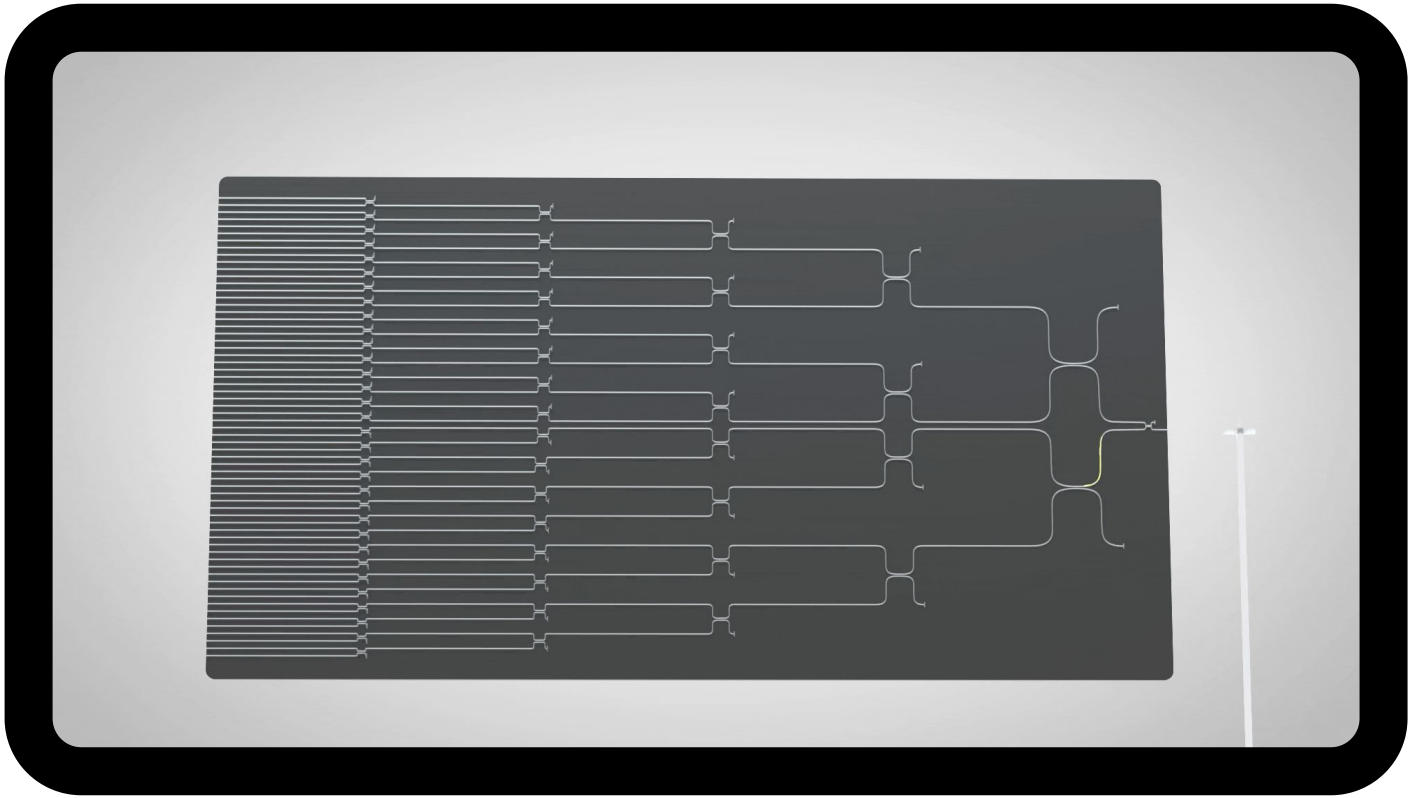


Output:
High probability GKP state or Squeeze state

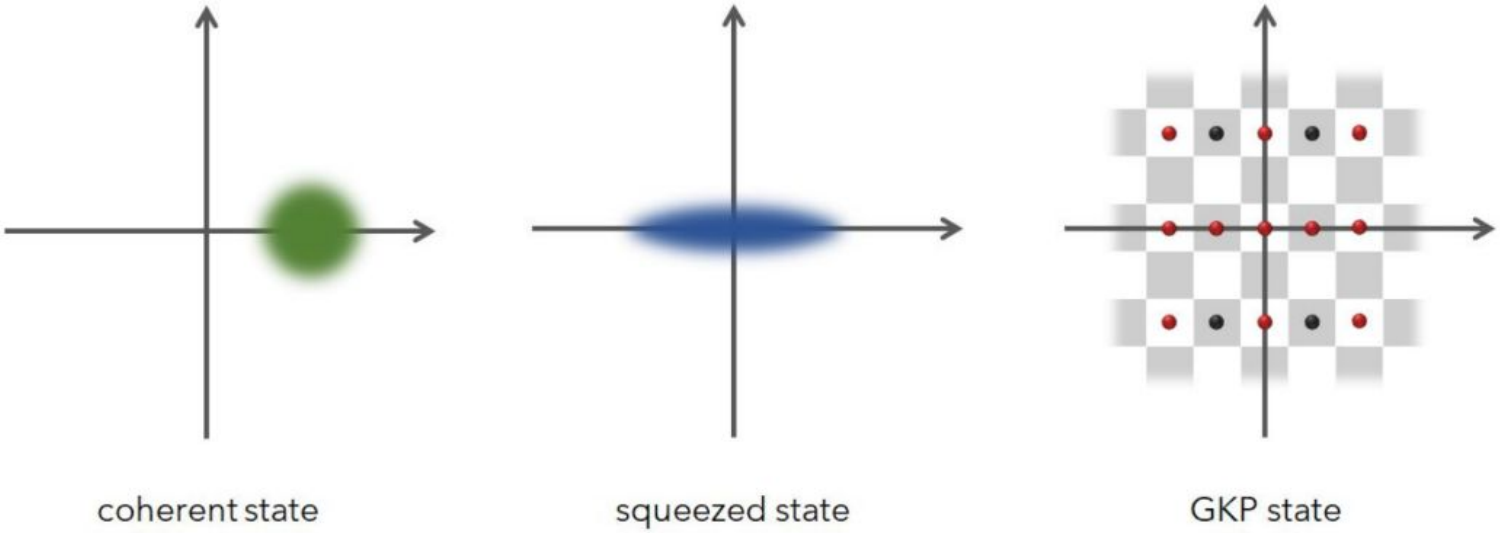
- Boosts generation rates of GKP states
- Failed GKP states replaced with squeezed states

Mechanisms:
- Fast optical switches
- MZIs of static beamsplitters and phase shifters

Multiplexer: Boosts probability of state preparation



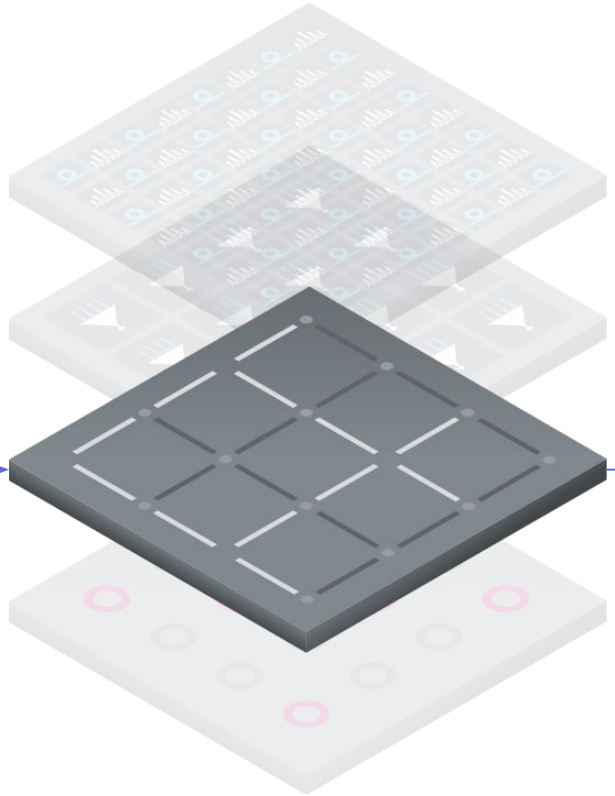
Fault-tolerant quantum computing with GKP states



GKP qubits allow the use of the large Hilbert space of light for error correction.

Stitcher: Entangles qubits in a 3D cluster

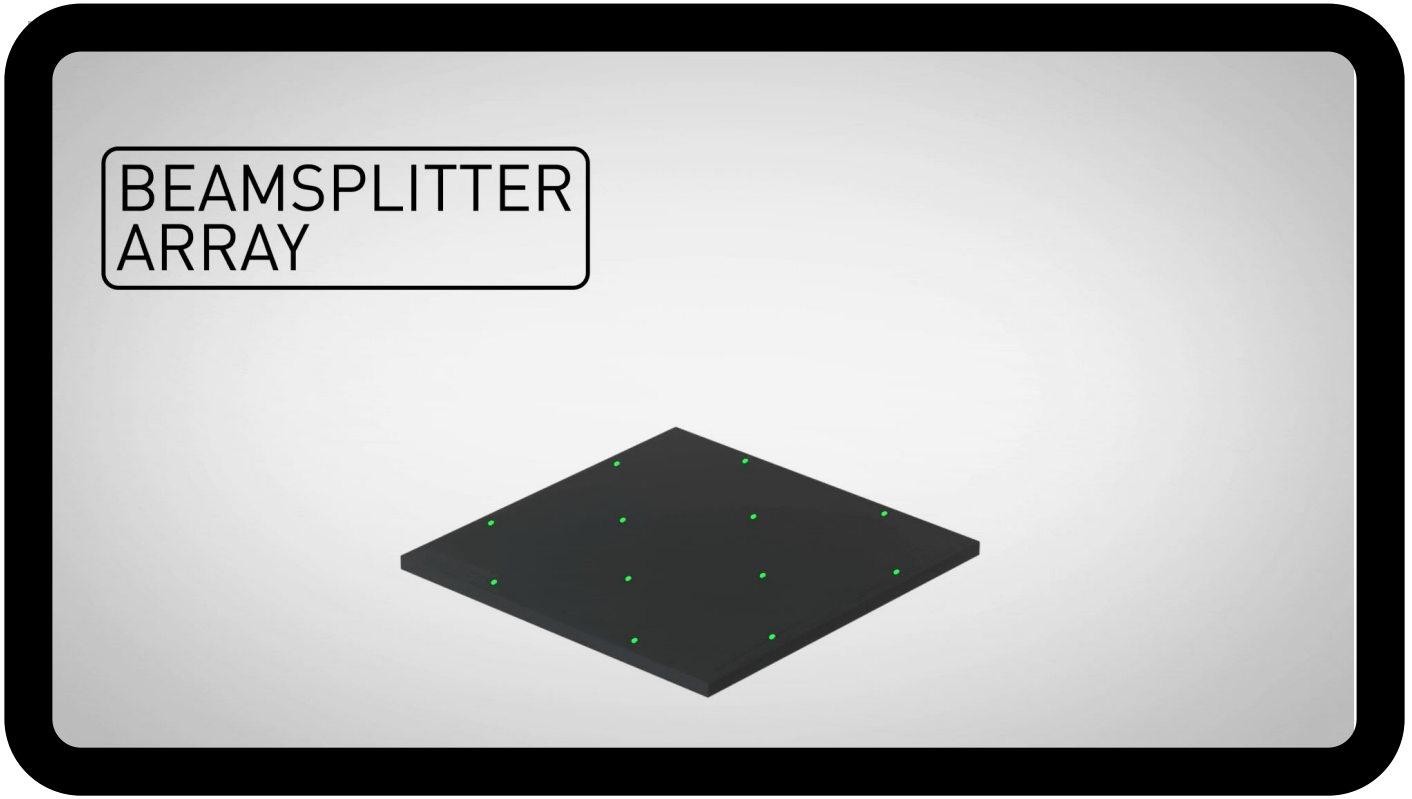
Input:
High probability GKP state or Squeeze state



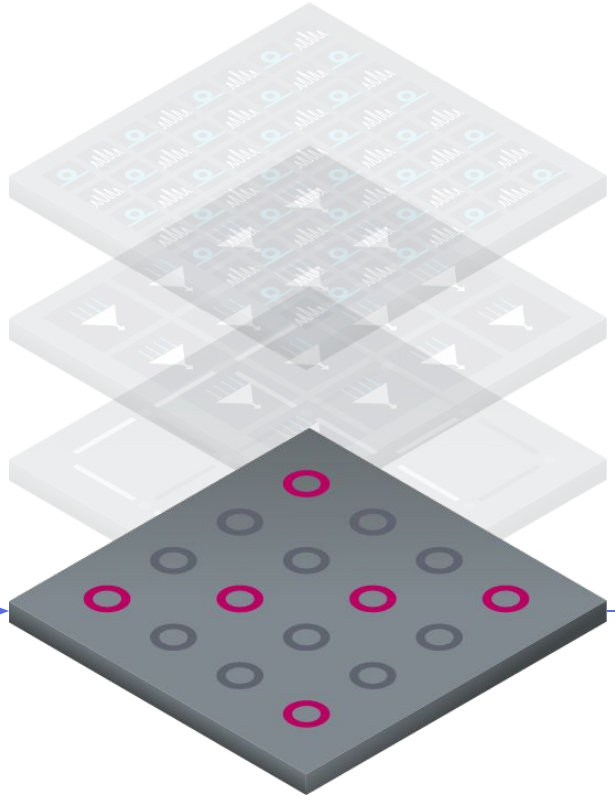
Mechanisms:
- Arrangement of static beamsplitters, phase shifters, and phase delays creating spacetime entanglement

Output:
3D cluster state (box of physical qubits)

Stitcher: Entangles qubits in a 3D cluster



QPU: Performs computation & error correction



Input:

Noisy qubits from the cluster state

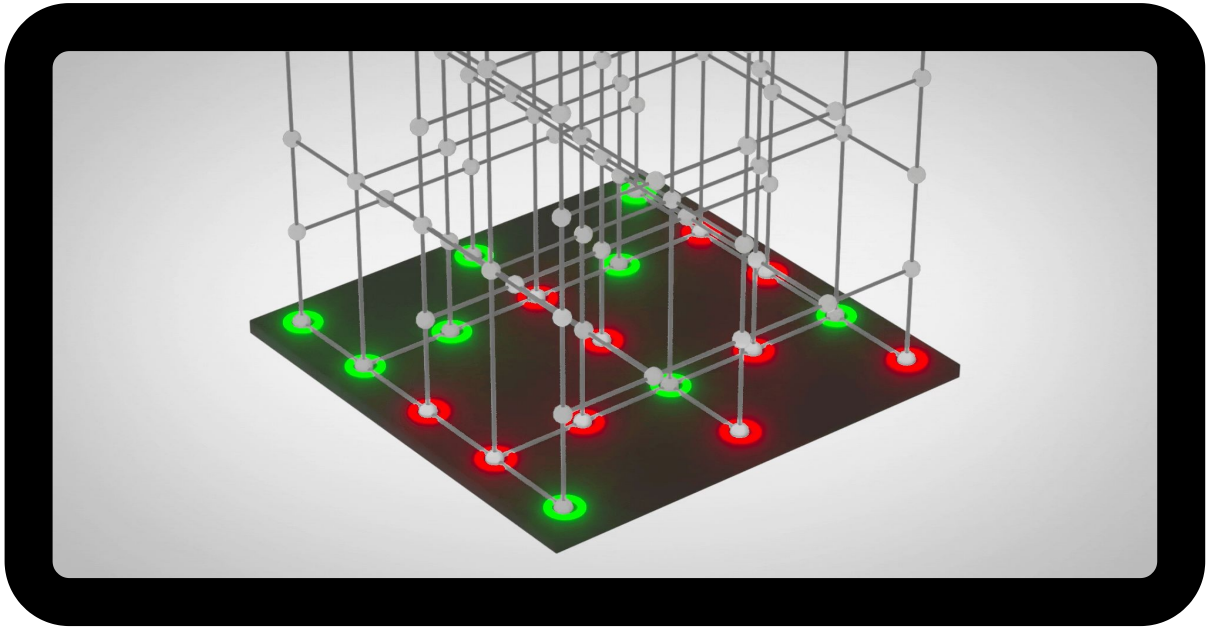
Mechanisms:

- Array of homodyne detectors (at room temperature!)
- Classical controller accepting measurement outcomes, decoding, and updating local oscillator phases

Output:

Corrected classical information

QPU: Performs computation & error correction

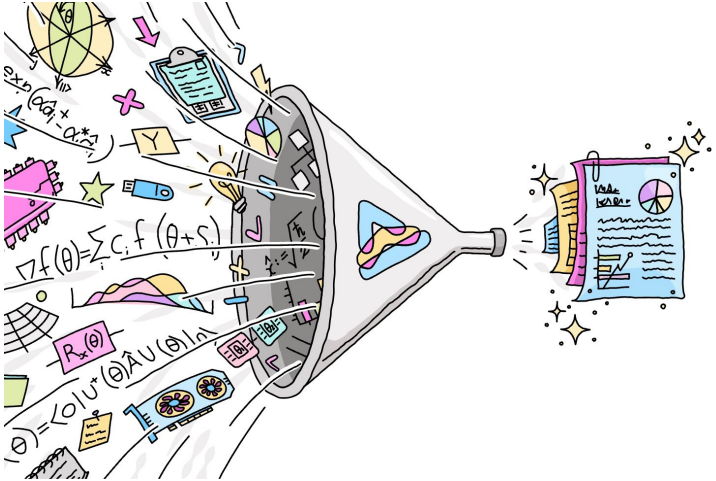


03

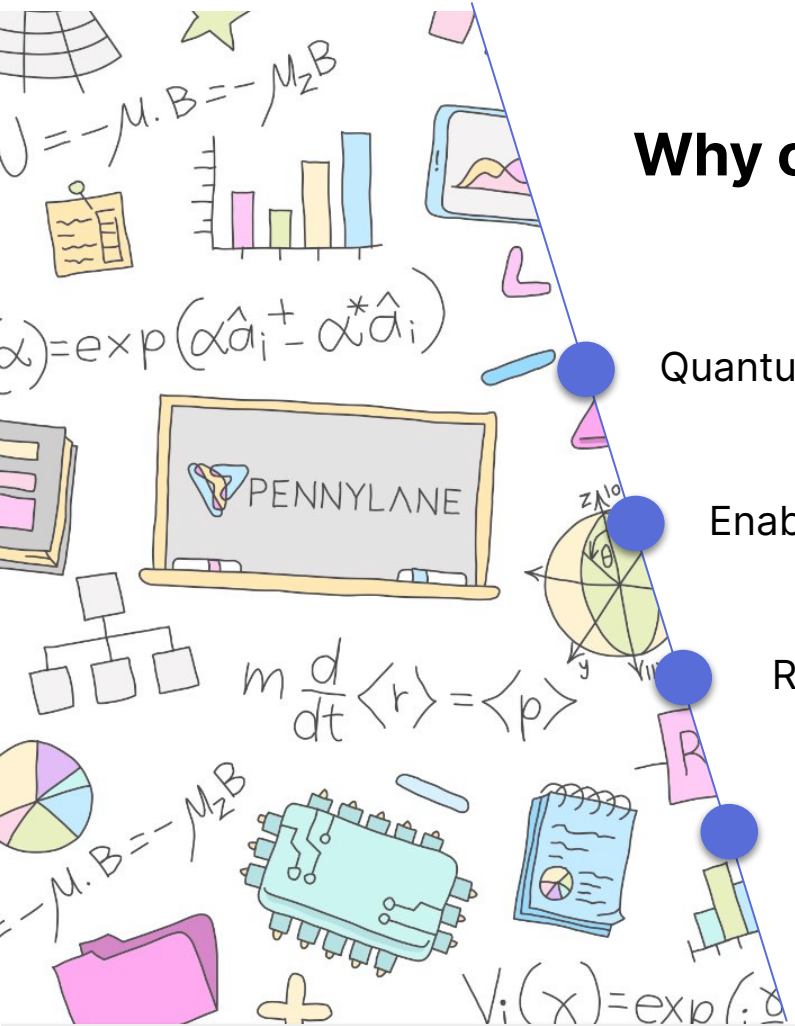
Pioneering Quantum Software

// Why?

Our software mission



“To make it easier for researchers to design, build, and execute the next-generation quantum applications”



// Why?

Why open-source quantum software?

- Quantum software is an invaluable research tool
- Enable researchers to use and access quantum hardware
- Research-driven-software
- Software-driven-research

// Software

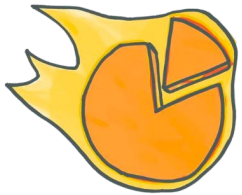
Libraries for every need

PennyLane

PENNYLANE

Differentiable quantum programming

Flaming Py



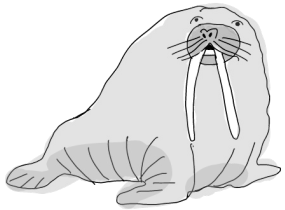
Quantum error correction

Mr Mustard

MR MUSTARD

A differentiable bridge between phase space and Fock space

The Walrus



Hafnians, Hermite polynomials, and Gaussian boson sampling

Strawberry Fields

STRAWBERRY FIELDS

Simulating and executing programs on photonic hardware

// Software

Libraries for every need

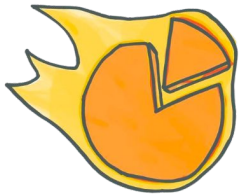
PennyLane is an open-source software framework for quantum computing and application development with the ability to run on all hardware.

PennyLane

PENNYLANE

Differentiable quantum programming

Flaming Py



Quantum error correction

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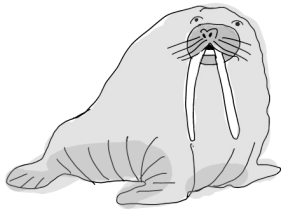


Hafnians, Hermite polynomials, and Gaussian boson sampling

Strawberry Fields

STRAWBERRY FIELDS

Simulating and executing programs on photonic hardware

Hardware & framework agnostic

PENNYLANE

Neutral atoms

QuEra COMPUTING INC.

Trapped Ions

IONQ

AQT

Superconducting Qubits

IBM

rigetti

OQC

Quantum Simulators

Google

Amazon Braket

Microsoft

Integrated Photonics

XANADU

Popular SDKs

TensorFlow

NumPy

PyTorch

// Use-case Development

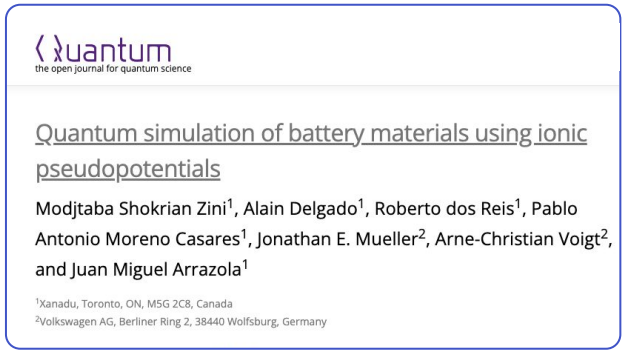
PennyLane for industry use-cases

	2019	2020	2021	2022	2023
Industry applications	Scotiabank, BMO Quantum computing for finance	Quantum computing for advanced manufacturing	VOLKSWAGEN AKTIENGESELLSCHAFT Quantum simulation of battery materials	Quantum computing for aerospace	Quantum simulation for sensing
Development with PennyLane	Advanced techniques for QML DARPA	PennyLane available on AWS Cloud - Braket aws	Hybrid computing Platform - cuQuantum NVIDIA	Optimized workflow NERSC	Compilation of hybrid workflow for CFD Rolls-Royce, river Lane

// Use-case Development - QChem

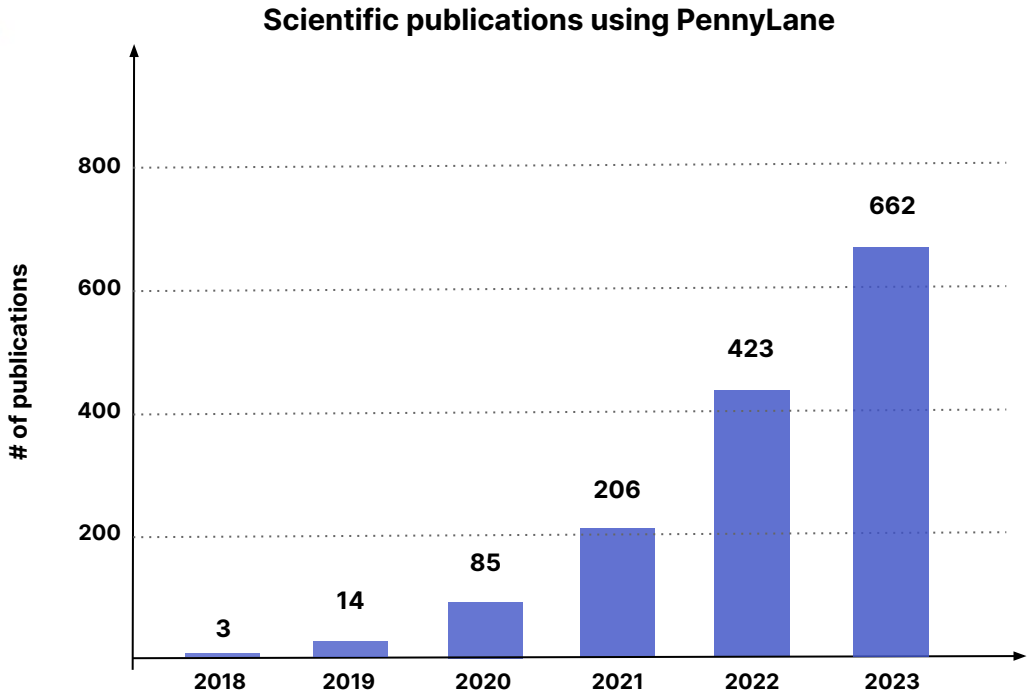
Battery research with Volkswagen

- **First company** to describe in detail how QC can be used to simulate key properties of Li-ion batteries
- Perform resource estimation to simulate battery properties
- Reduce qubit count by **2x**
- Reduce gate count by factor of **10,000x**
- **Two joint patents** and **three scientific publications** [1], [2], [3]



Relevant papers:
[1] Simulating key properties of lithium-ion batteries with a fault-tolerant quantum computer
[2] Quantum simulation of battery materials using ionic pseudopotentials
[3] Initial state preparation for quantum chemistry on quantum computers

Growing research activities with PennyLane



04

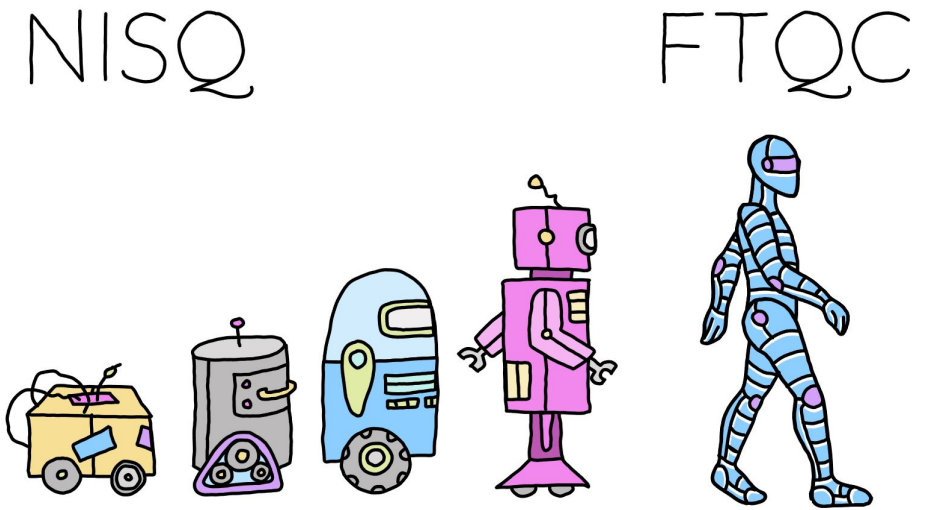
A perspective on the needs and future direction of the quantum industry

From NISQ to ISQ to FTQC

- NISQ (Noisy Intermediate-Scale Quantum) Technology (~2017-2024?)

- ISQ Technology (possibly within the next 5 years)
  - See “From NISQ to ISQ” by Juan-Miguel Arrazola, head of algorithms at Xanadu.

- Fault-tolerant quantum computing (FTQC)



From NISQ to ISQ to FTQC

NISQ

- ~100's qubits, <1000 quantum gates.
- Limited by noise in quantum systems (no error correction).
- Focus on hybrid algorithms.
- Exploratory phase of quantum hardware.

ISQ

- Tens of logical qubits (qubits protected from noise), ~1000's quantum gates.
- Novel algorithm development.
- Scale relevant for scientific/academic. applications
- First industrial applications.

FTQC

- Hundreds to thousands of logical qubits.
- Will likely require millions of physical qubits.
- Tens of millions of quantum gates.
- Scale most relevant for industrial applications.

04

How do we get to fault-tolerance?

// CANADA

Global leader in quantum technology

- **$1B+** has been invested in quantum technologies
- **100+** ecosystem players
  - companies, research labs, academic institutions, accelerator/incubators
- Research and commercial **highlights**:
  - BB84, QKD scheme by Bennett-Brassard, 1984
  - D-Wave, the world's first QC company, 1999
  - Xanadu demonstrates quantum advantage with Borealis, 2022

// National Quantum Strategy

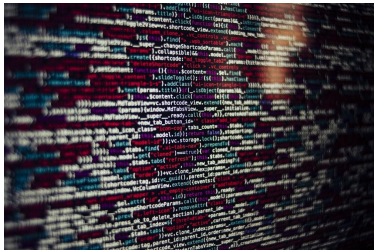
Canada's continued leadership in quantum

National Quantum Strategy **$360M** Research Commercialization Talent	**Year 2025**	**$533M** Economic impact	**1,100** Jobs
	Year 2045	**$139B** Economic impact	**209k** Jobs

Source: What We Heard Report, Government of Canada (2019)

Canada’s quantum workforce

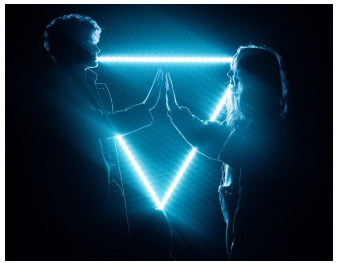
PEOPLE IN QUANTUM COMPUTING



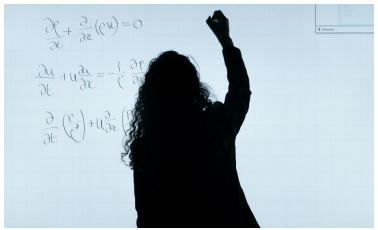
What my parents think I do

What my friends think I do

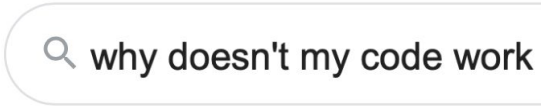
What society thinks I do



What the media thinks I do



What I think I do



What I actually do

Careers in the quantum industry

- Three ways to get into the field:
  - Studying + luck + the right people (Network!)
  - Projects/portfolio
  - Research papers

Careers in the quantum industry

- Three ways to get into the field:
  - Studying + luck + the right people (Network!)
  - Projects/portfolio
  - Research papers
- Note: Some roles require graduate (MSc and PhD) degrees but other do not.
- Generally, technical roles fall in two categories:
  - Software development and applications.
  - Hardware (experimental and theoretical).

Careers in the quantum industry: Software

How can you gain experience?

- Open a GitHub account and start contributing to open-source projects.
- Develop your own projects and show them off!
- Participate in Hackathons.
- Internships (whether in the quantum industry or not)

Careers in the quantum industry: Hardware

How can you gain experience?

- Join a lab in your university!
- Internships.
- Make your own projects.
- Current focus of industry: scaling to large systems/reducing noise.
  - Systems engineering
  - Numerical simulations of systems.

// The Xanadu Residency Program

A 17-week paid summer program

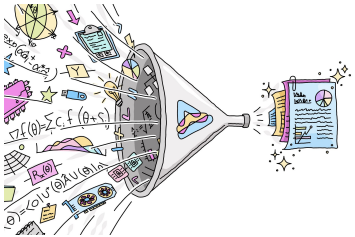
Be mentored and supervised by Xanadu's world-class scientists, developers, and educators. Join us in Toronto, May 2025!

Applications for 2025 cohort open in Fall 2024

// Potential Projects

Residency Groups

Research



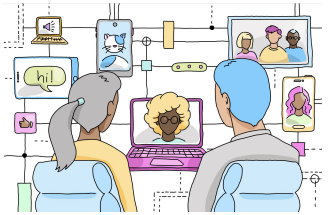
Quantum machine learning, quantum computing, and photonics.

Software

PENNYLANE

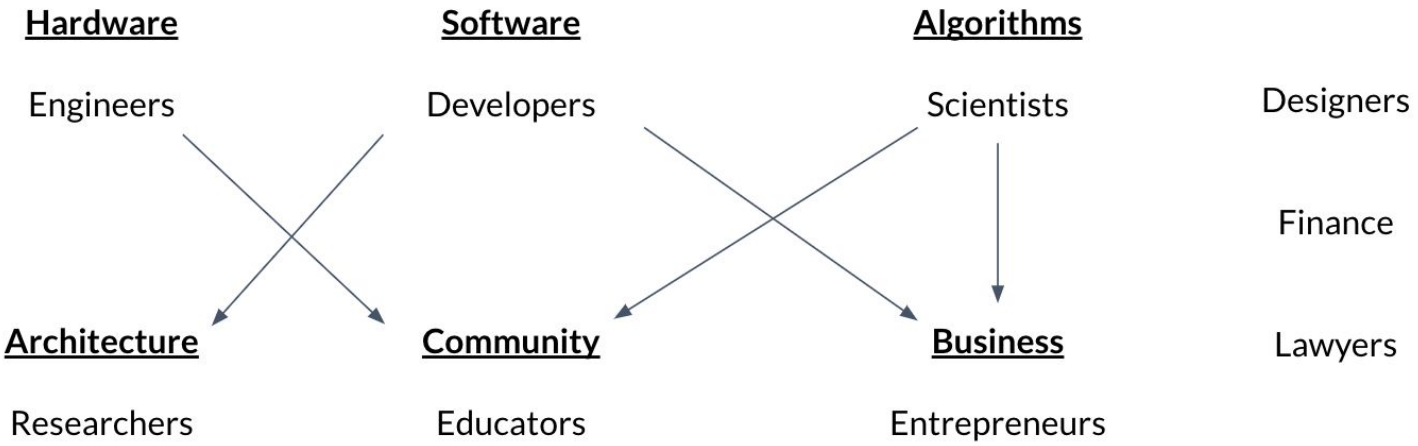
Quantum software

Education



Train the next generation

Some career opportunities



And much more … check them out at xanadu.ai/careers

Be part of the Xanadu community

Make an issue & give us a star

github.com/pennylaneai

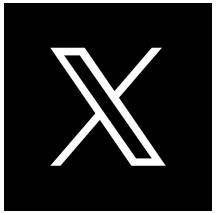
Ask on our forum

discuss.pennylane.ai

Post on Slack

bit.ly/Xanadu-Slack

Tweet us



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