Long-lived particle Anomaly detection with parameterized quantum circuits

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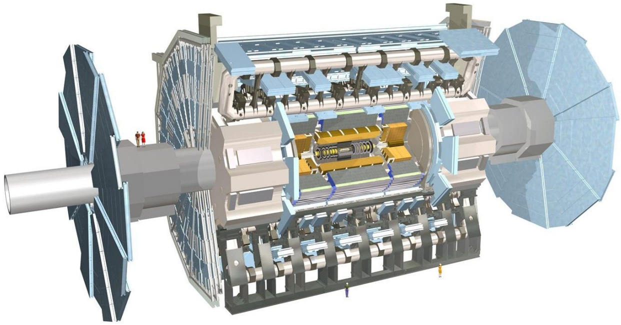
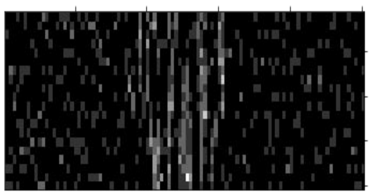
Motivation

ATLAS

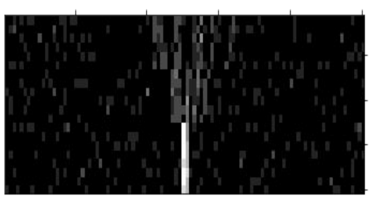


Collect data

Standard



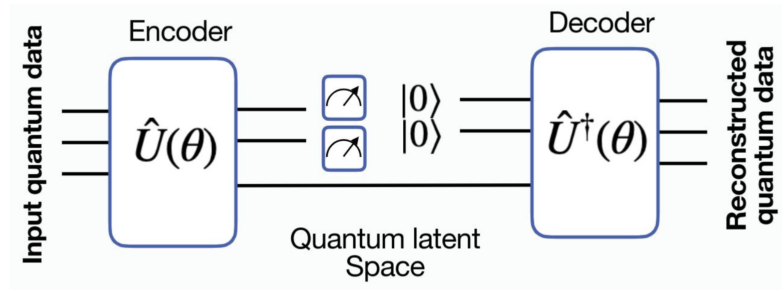
Anomalous



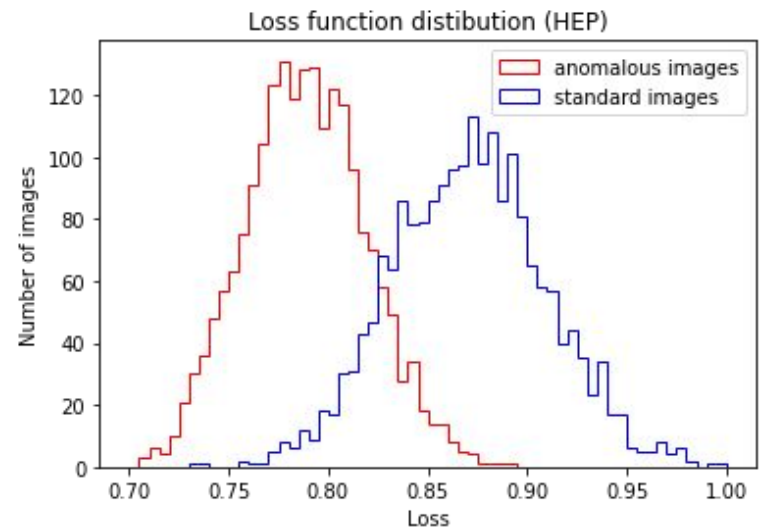
Analyze

With the development of **quantum sensing** in particle detectors we may expect future instruments to output quantum data

Quantum autoencoder



Classify



Result obtained with a simulation

Quantum hardware implementation

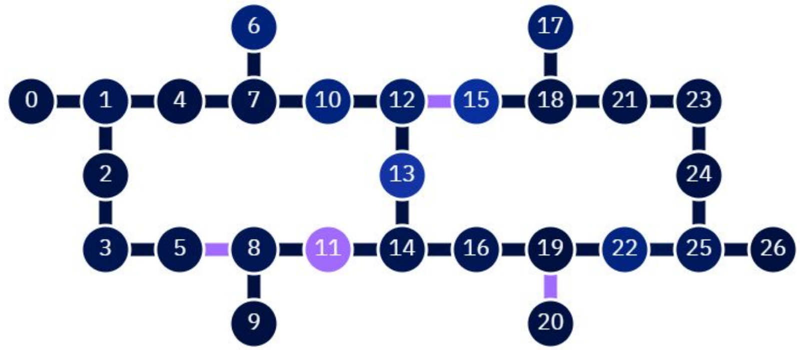
NISQ devices limitations:

- High level of noise, short decoherence times.
- Qubits connectivity.
- Amplitude encoding.

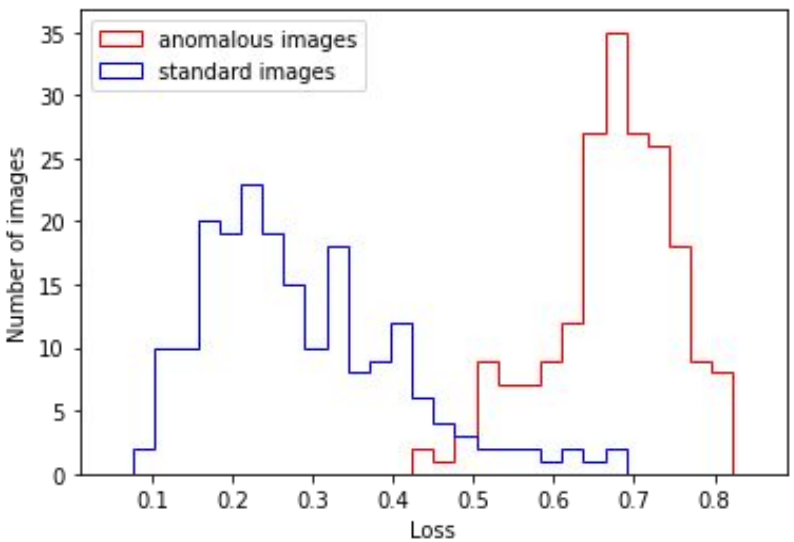
Adaptations:

- Reduce circuit and task complexity.
- Match hardware connectivity.
- Train circuit to approximate encoding

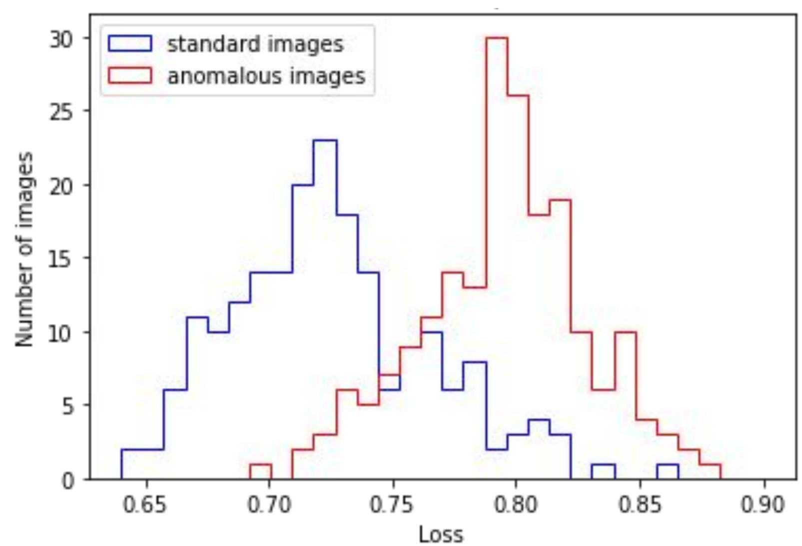
IBM hanoi



Simulation (no noise)



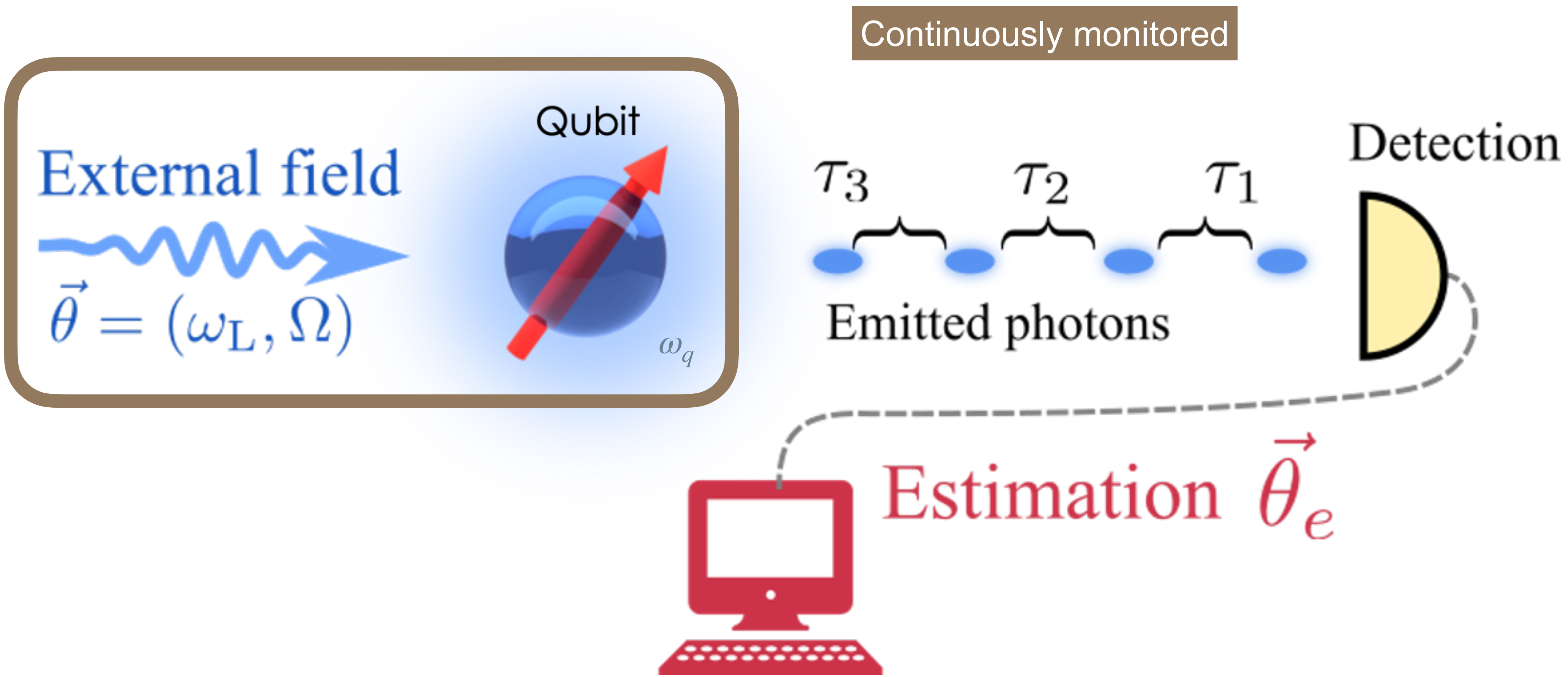
Hardware



Parameter estimation from quantum-jump data using neural networks

Enrico Rinaldi
Quantinuum
2024 April 30, EuCAIFCon

A simple model of an open quantum sensor



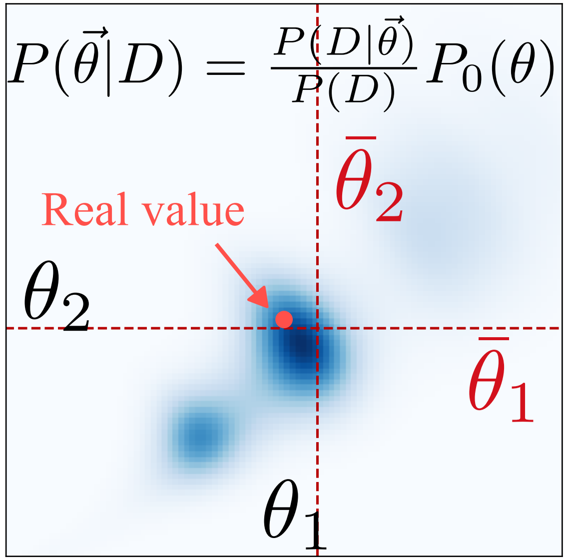
Can we precisely and robustly extract the value of the system's parameters?

$\vec{\theta}_e = \{\Delta = \omega_q - \omega_L$ and $\Omega\}$

Estimation $\vec{\theta}_e$

Bayesian Estimation

$$D = [\tau_1, \tau_2, \ldots, \tau_m]$$

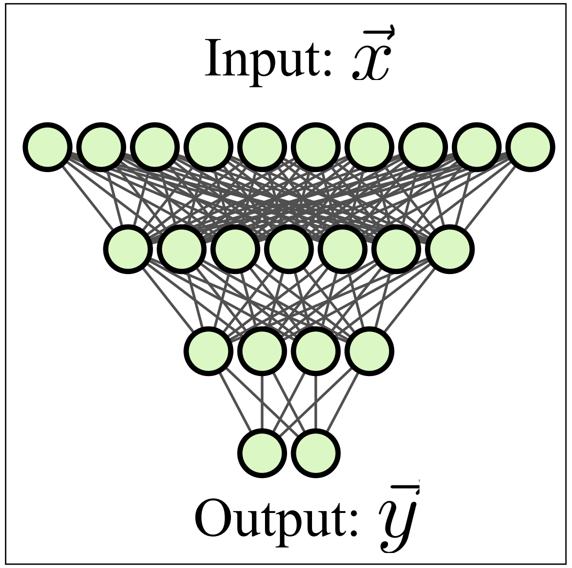


Estimation

$$\vec{\theta}_e = [\bar{\theta}_1, \bar{\theta}_2]$$

Machine Learning

$$\vec{x} = [\tau_1, \tau_2, \ldots, \tau_m]$$



Estimation

$$\vec{\theta}_e = [y_1, y_2]$$

Board 56

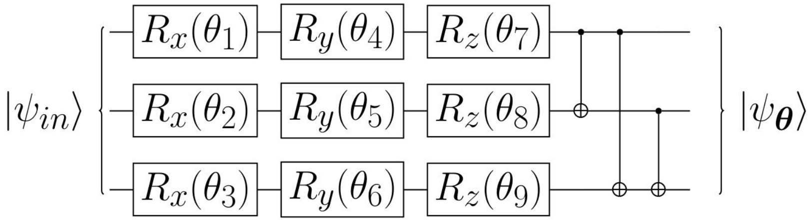
Benchmarked to be robust to noise and 10000x faster than Bayesian inference!

Quantum and classical methods for ground state optimisation in quantum many-body problems

Thomas Spriggs [1], Arash Ahmadi [1], Mohammed Boky [1], Eliska Greplova [1]

[1] Kavli Institute of Nanoscience, Delft University of Technology, Delft 2628CJ, Netherlands

(Variational) wavefunctions



- System of qubits, which are two level systems:
  - 00, 01, 10, 11
- Wavefunction is ‘just’ a vector of amplitudes

$$|\psi\rangle = \sum_{i=1}^{2^n} \alpha_i \, |\phi_i\rangle$$

- Variational wavefunction is some parameterised function to give some

$$|\psi(\theta)\rangle \approx |\psi\rangle$$

- We will compare two methods to create this variational wavefunction: a quantum circuit and a neural network

A. Peruzzo, J. McClean, P. Shadbolt, M.-H. Yung, X.-Q. Zhou, P. J. Love, A. Aspuru-Guzik, and J. L. O’Brien, “A variational eigenvalue solver on a photonic quantum processor,” Nature Communications, vol. 5, July 2014.

G. Carleo and M. Troyer, “Solving the quantum many-body problem with artificial neural networks,” Science, vol. 355, p. 602–606, Feb. 2017

Non-stabiliserness

- Non-stabiliserness, or *magic*, is a measure of how much ‘quantum resource’ is needed to perform operations on a wavefunction
- Given that the neural network is classical, does this limit its ability to find the ground state wavefunction of a quantum system?

- In short, no*. But see my poster for more details
  - In this work we explore each platform’s ability to find the ground state wavefunction with energy and magic equal to the analytic solution (available for small systems)

University and INFN of Ferrara

Hybrid quantum graph neural networks for particle tracking in high energy physics

EuCAIFCon 2024

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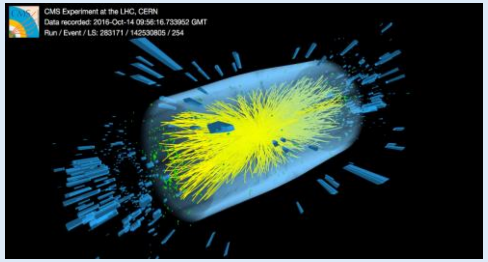
Context

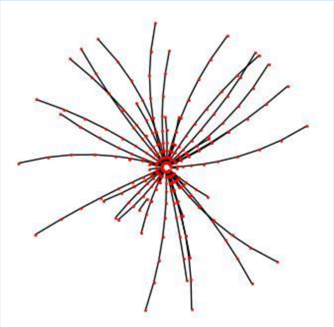
Tracking in high energy physics → particle trajectories

- hits in a detector layer → **nodes**
- track segments → **edges**

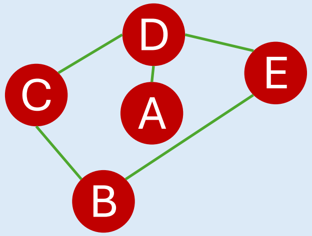
→ **graph**!



→



can be seen as →



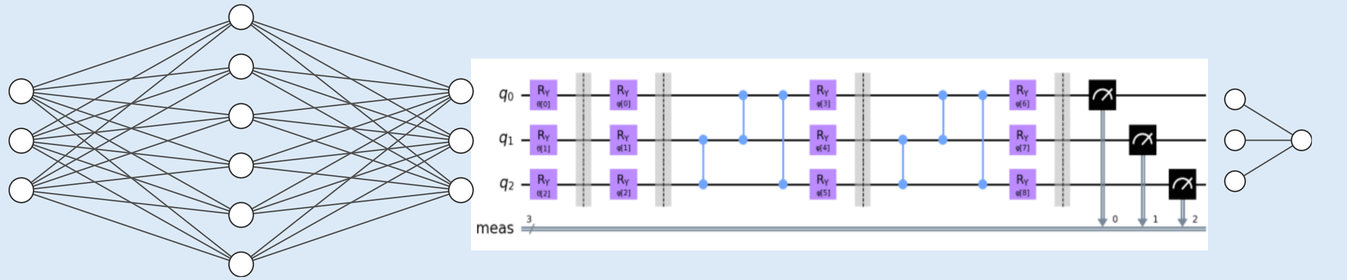
In the coming years at LHC we expect a great increase in particle density per event → research on new technologies:

Graph neural networks + **Quantum technologies**

Quantum GNN

The network

InputNet (feature expansion) → **Edge Network** (doublets) ⟲ **Node Network** (triplets) → **Edge Network** (edge probabilities)



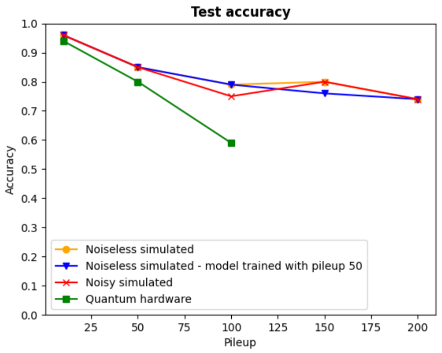
The hybrid architecture

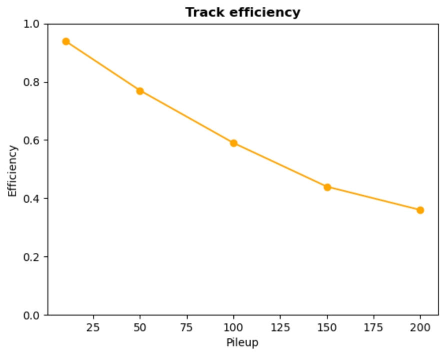
- Sequence of node and edge layers
- Classical weights
- Attention mechanism + information passing

- Operators acting on **quantum states**
- Quantum circuit parameters
- **Entanglement** + **quantum parallelism**

Results

- **Network accuracy vs pileup**
  - Quantum simulator
  - Quantum hardware





- **Track efficiency vs pileup**