Classical-Quantum Algorithms

for Anomaly Detection

SCHOOL OF SCIENCE
THE UNIVERSITY OF TOKYO

Masahito Yamazaki
University of Tokyo

KAVLI IPMU

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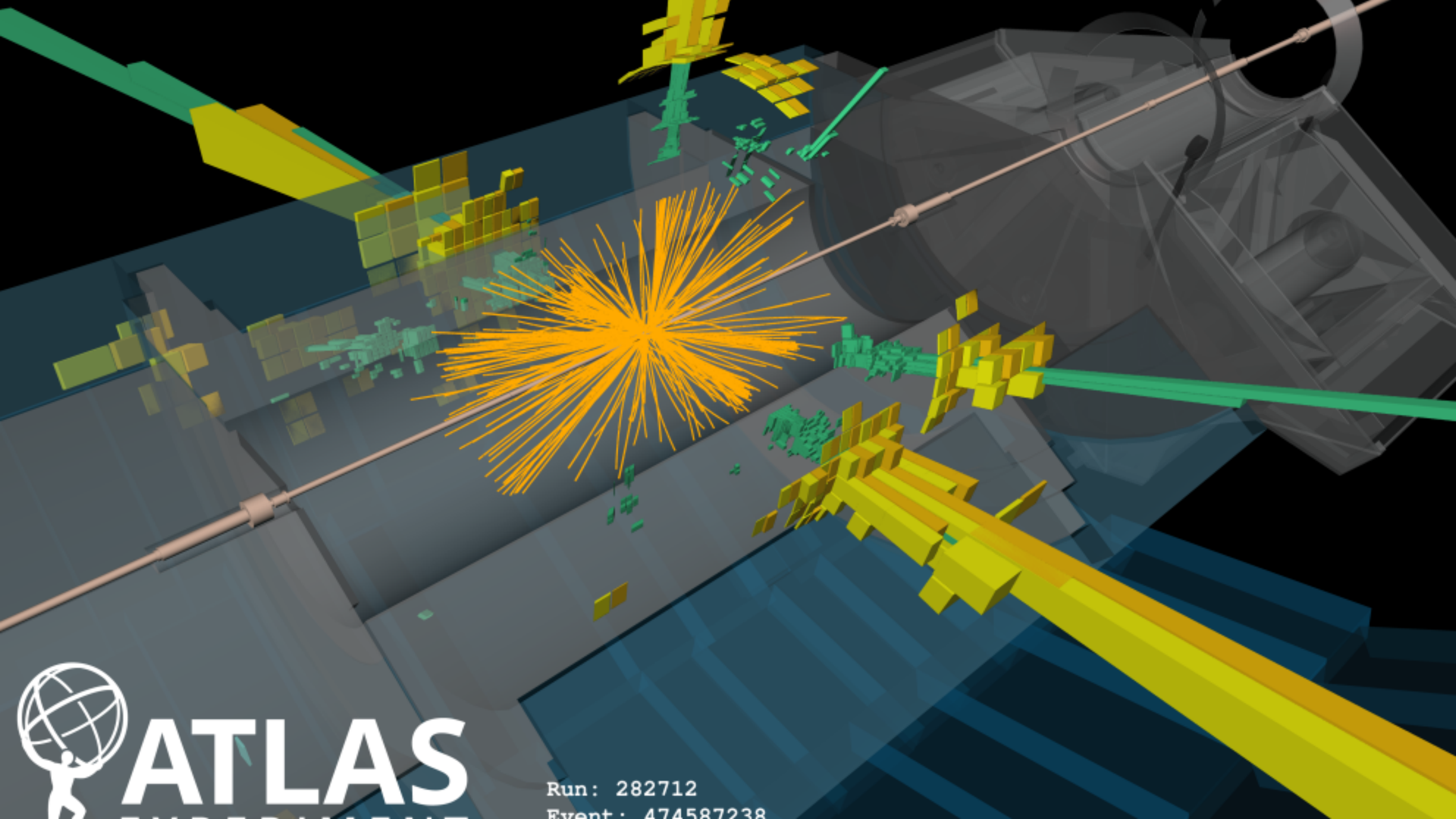
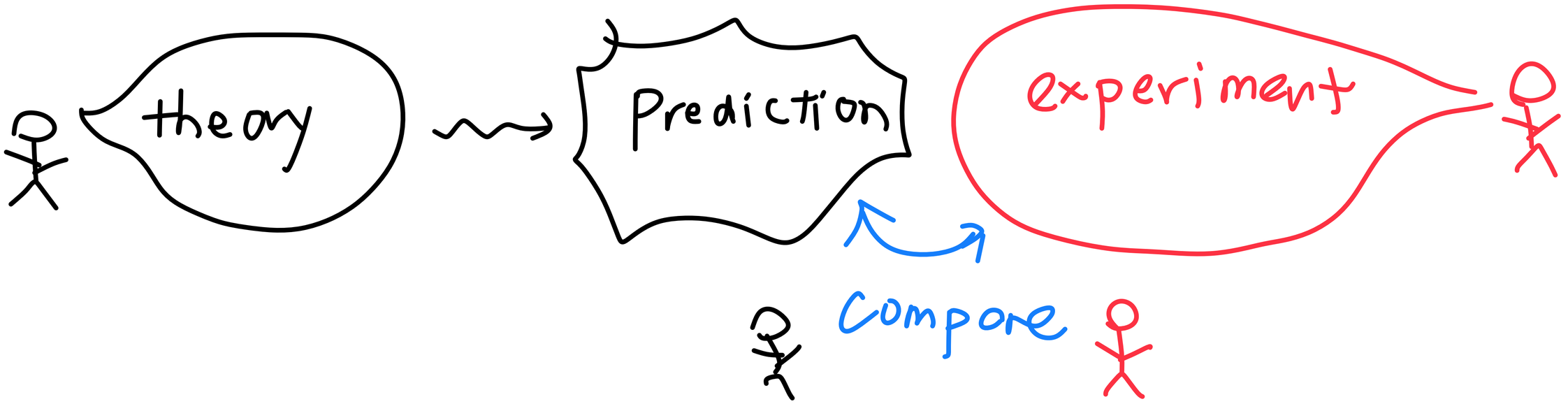
QUP

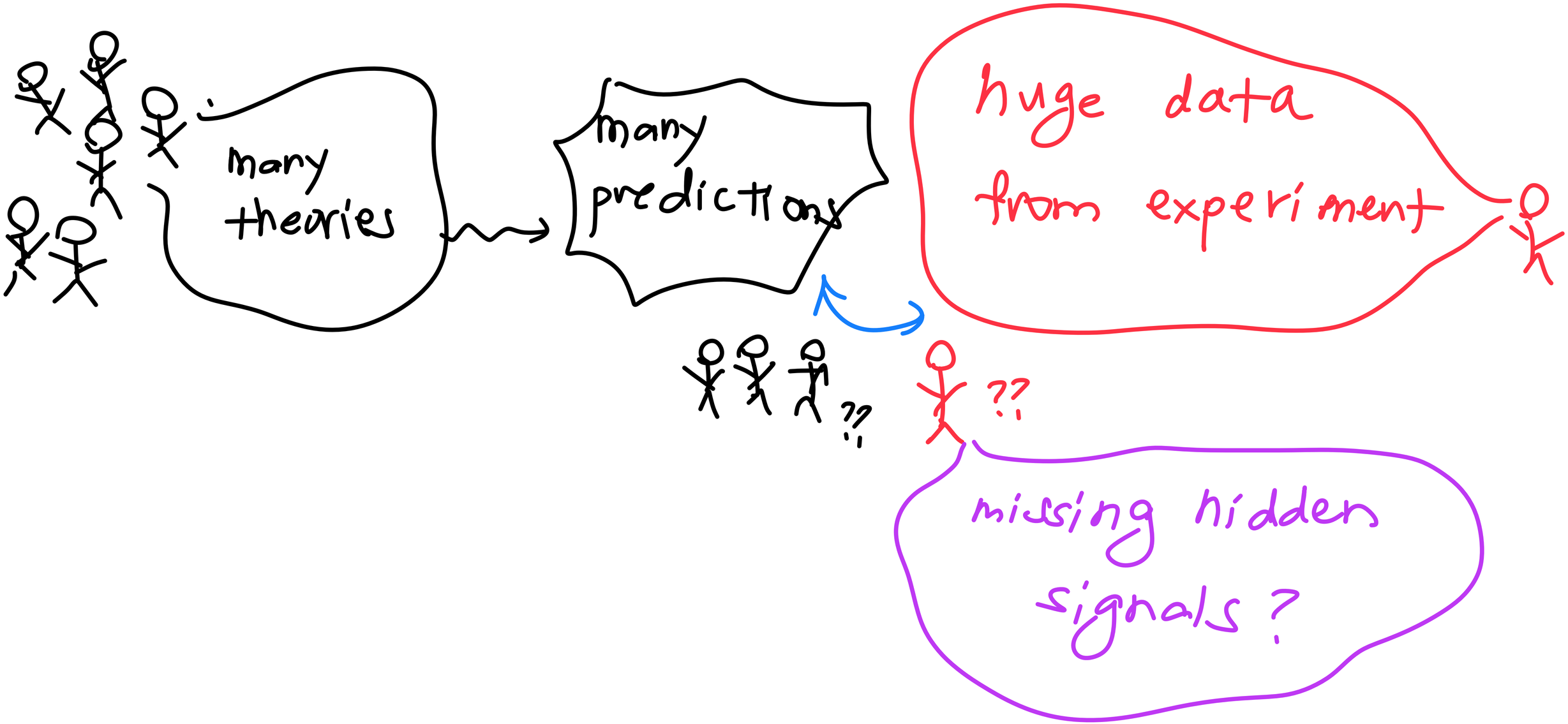
1. HEP


ATLAS
Run: 282712
Event: 474587238

Typical Strategy: Top-Down from Theory



Typical Strategy: Top-Down from Theory



- ATLAS/CMS has implemented model-agnostic searches
(need to be careful with look-elsewhere effects)

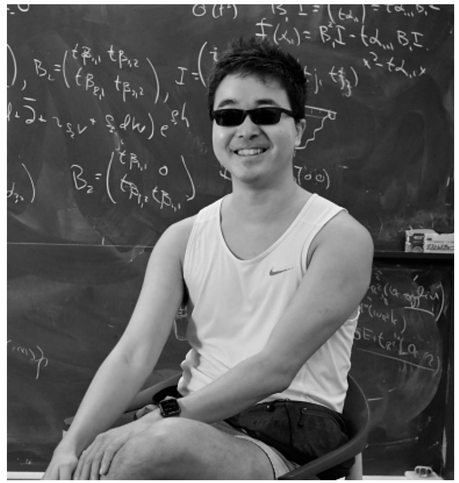
- Some proposal for density-based methods in phase space
(e.g. search for bumps)

Heimel, Kasieczka, Plehn, Thompson, 1808.08979
Farina, Nakai, Shih,1808.08992

- We discuss similarity learning (self-supervised ML)

Dillon, Favaro, Feiden, Modak, Plehn, 2301.04660

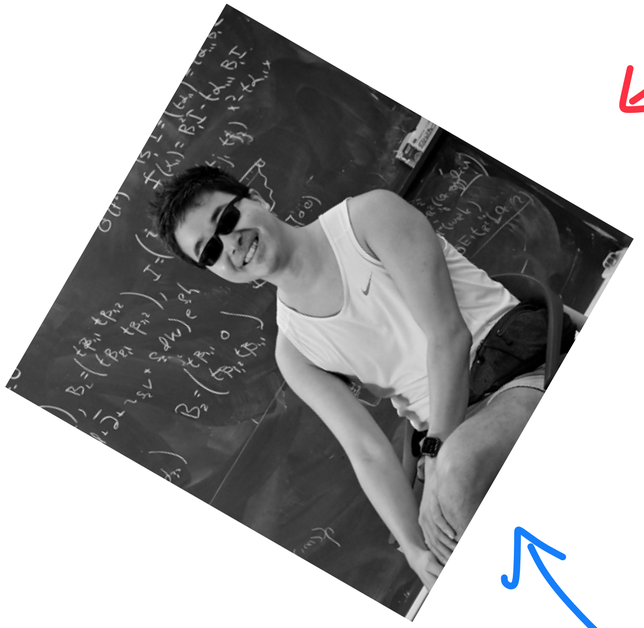
Similarity Learning

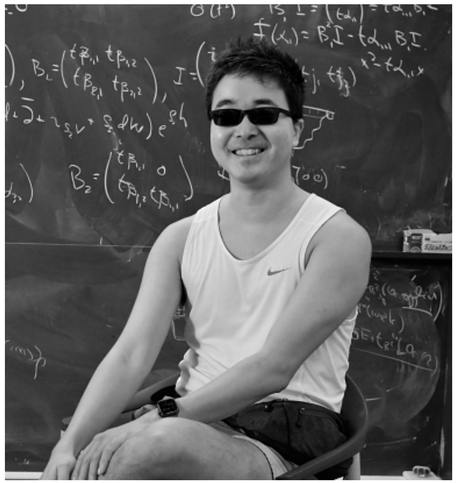


different

Similarity Learning

augmentation



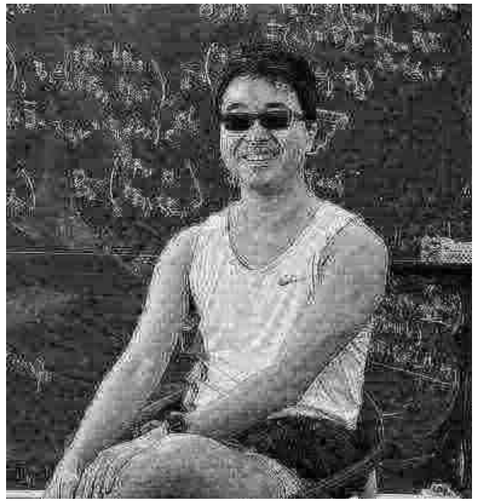


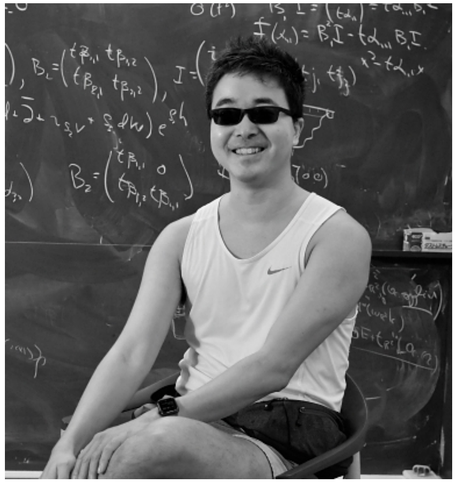
Similar

different

Similarity Learning

augmentation

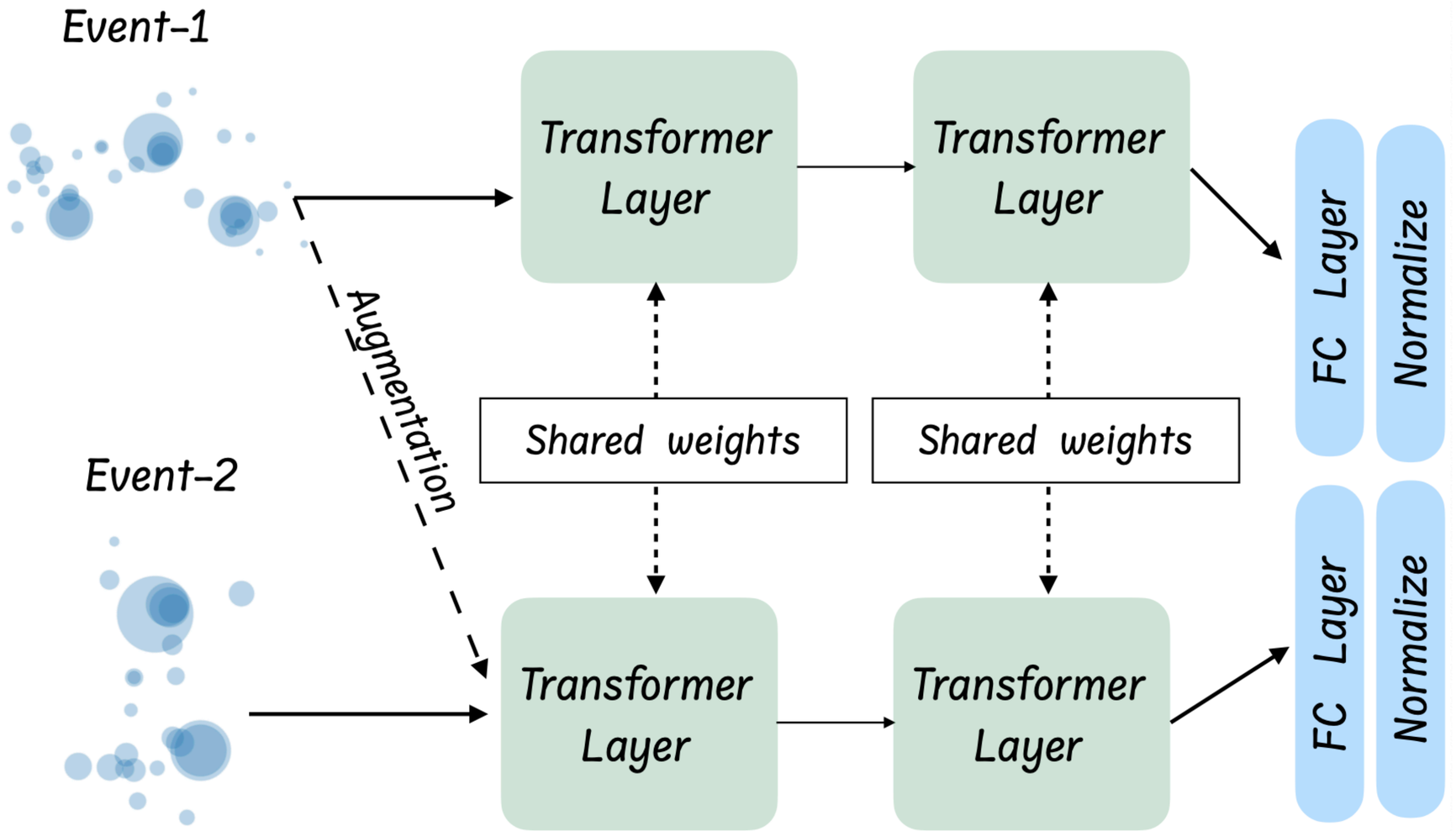




Similar

different

Similarity Learning with Transformers



2. Quantum x HEP

My interest: Quantum Algorithms

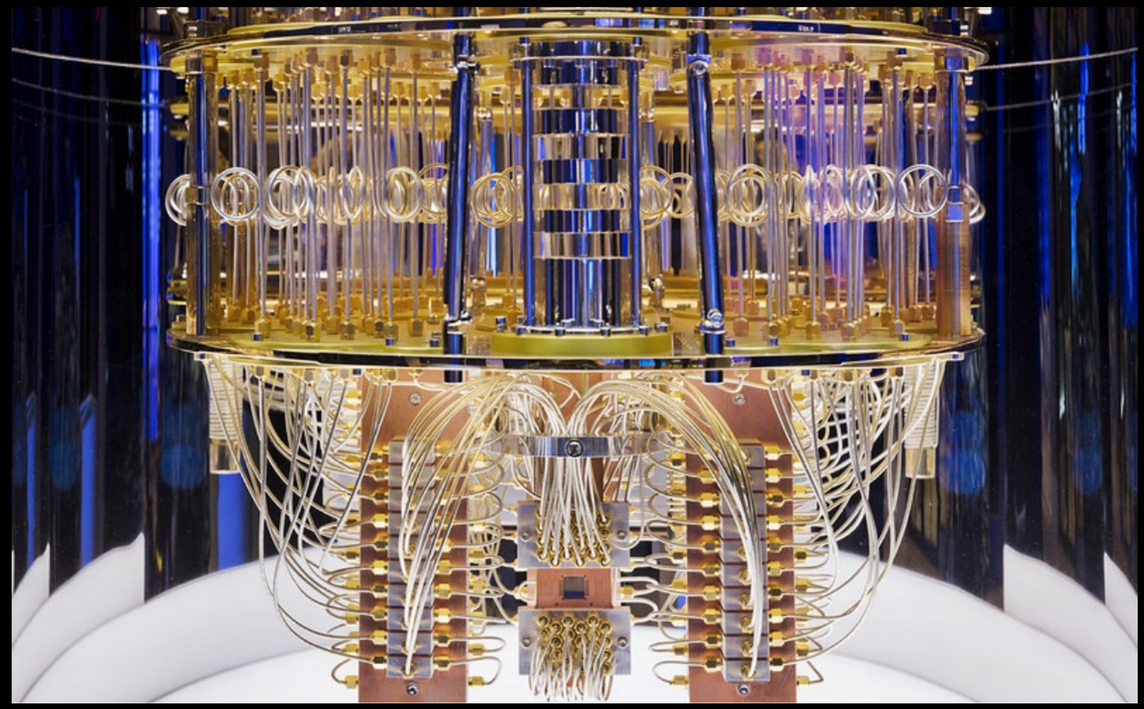
for HEP Experiment Data Analysis?

(e.g. anomaly detection)

+

= ??

Quantum Computers have Arrived



127 qubit machine @ Kawasaki, Japan

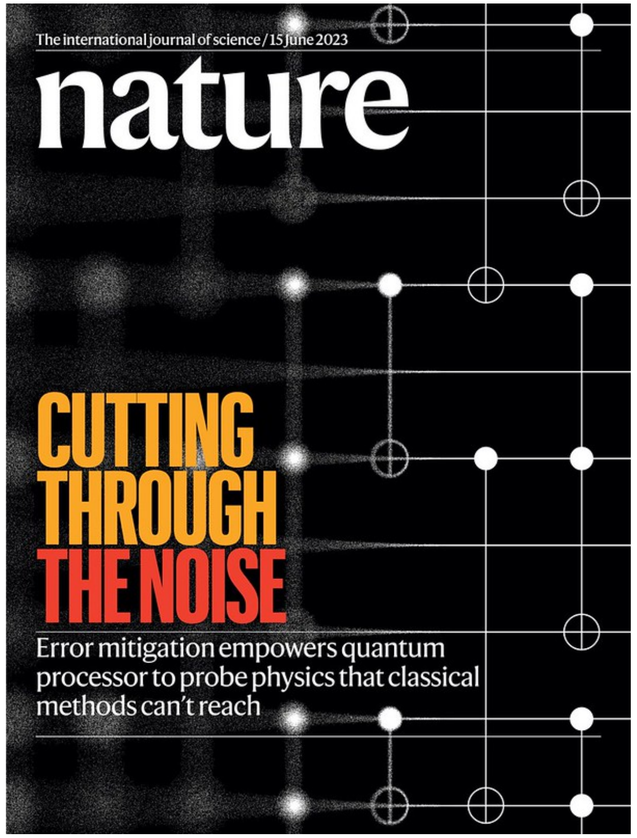
✡ Quantum computers today are noisy

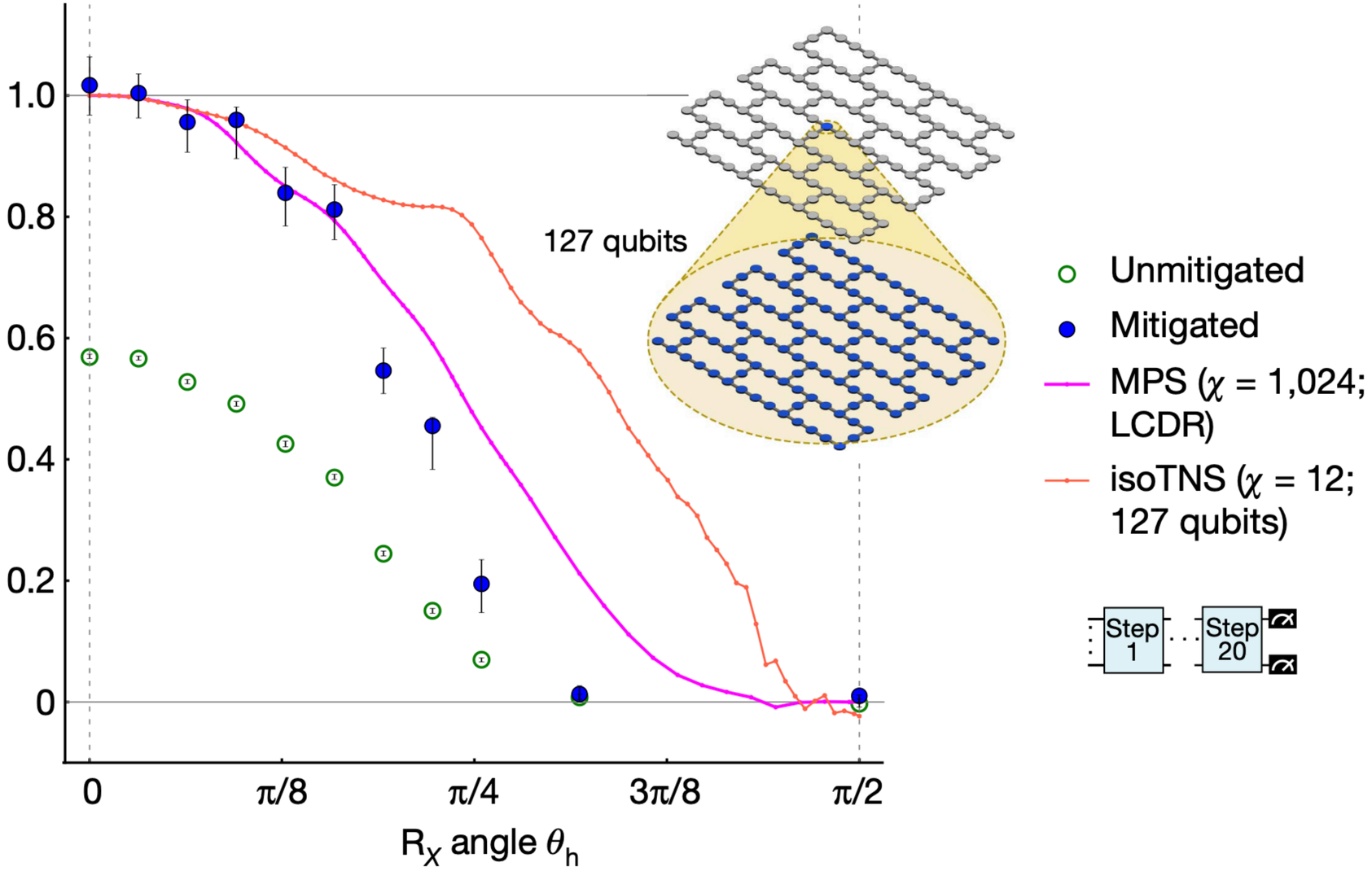
→ We need “error mitigation” by classical computers,
at least before the era of full error correction

✡ One should not expect “practical” results too easily

(classical AI/ML already good)

The Era of “Quantum Utility”





“Quantum” as a State-of-Art

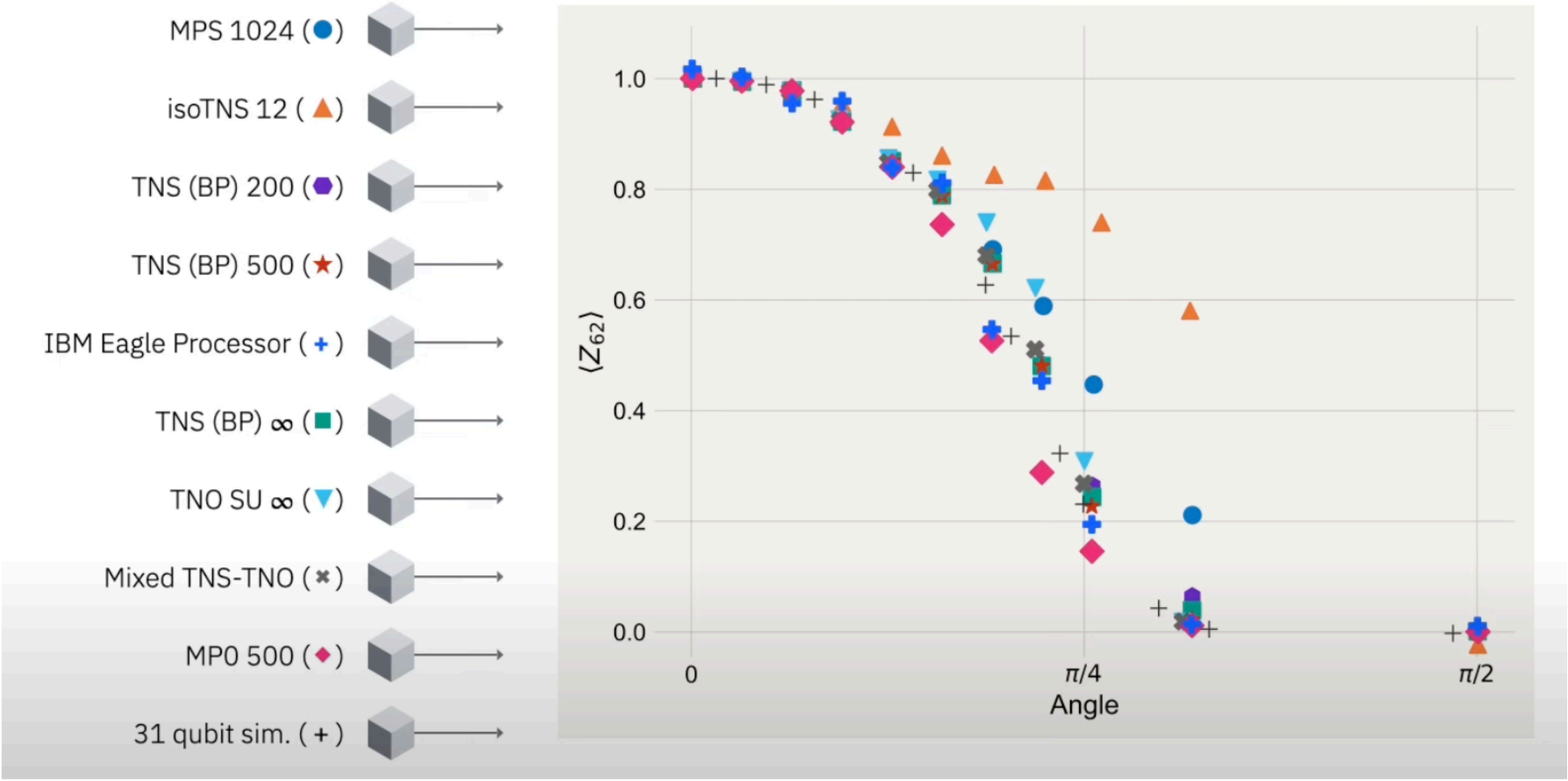
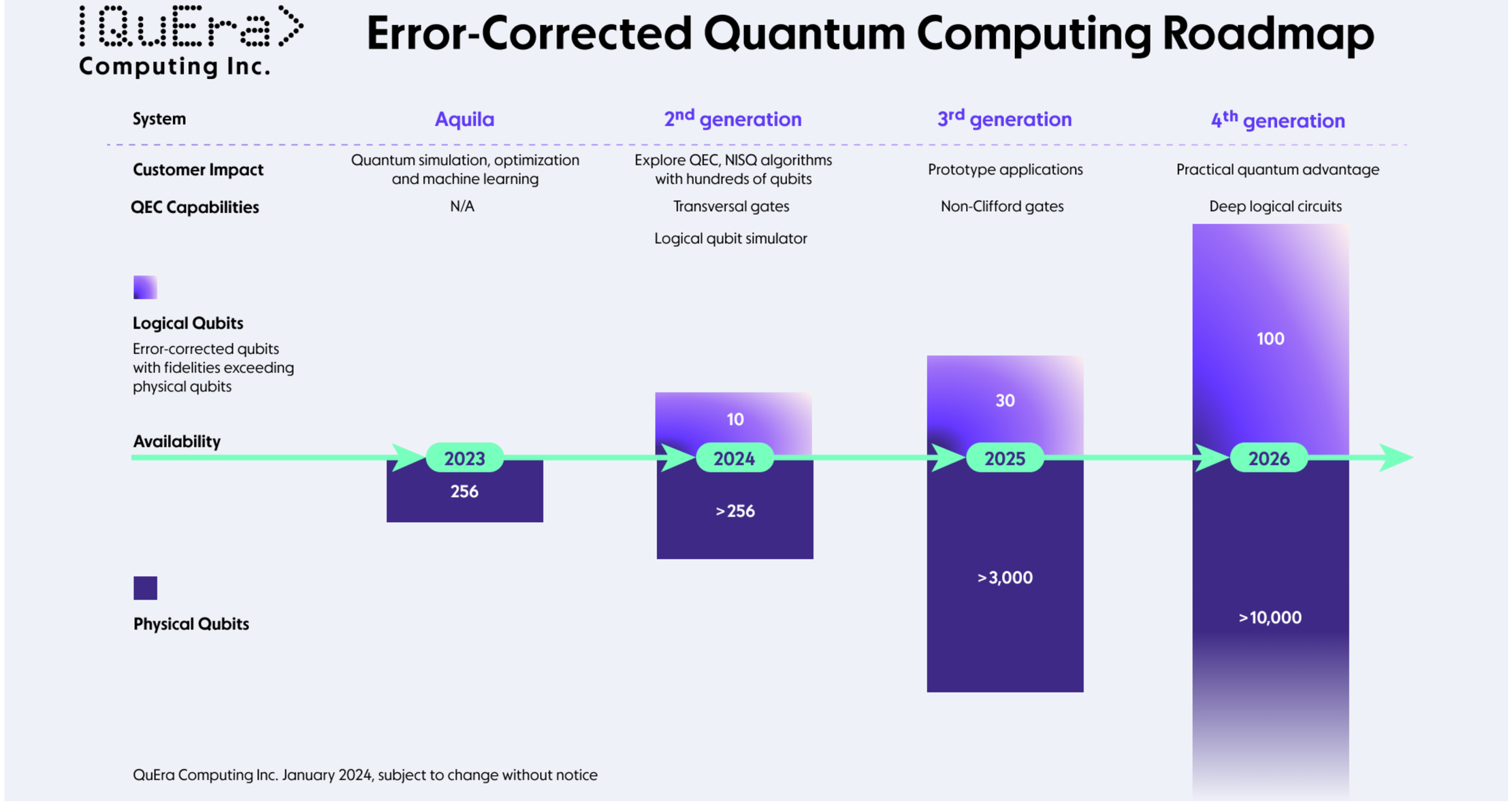


Figure from IBM QCD24 conference

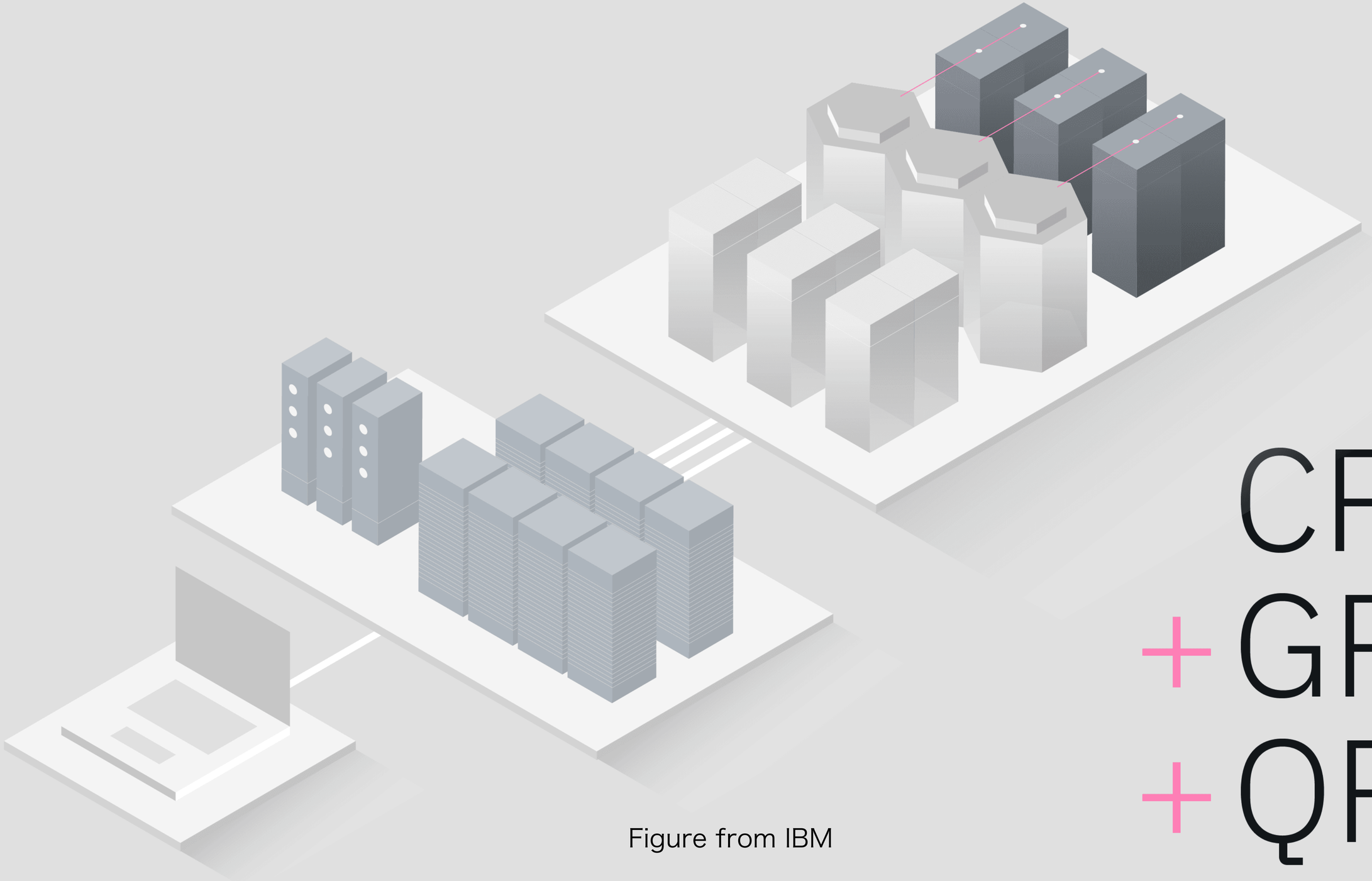
Rapid Progress Expected



- Quantum computers will NOT replace classical computers anytime soon

→ we should aim for quantum-classical hybrid

- We can try to enhance classical AI/ML by quantum algorithms (quantum-clasiscal hybrid)



CPU
+GPU
+QPU

Figure from IBM

3. Classical/Quantum Similarity Learning

“Quantum Similarity Learning for Anomaly Detection”

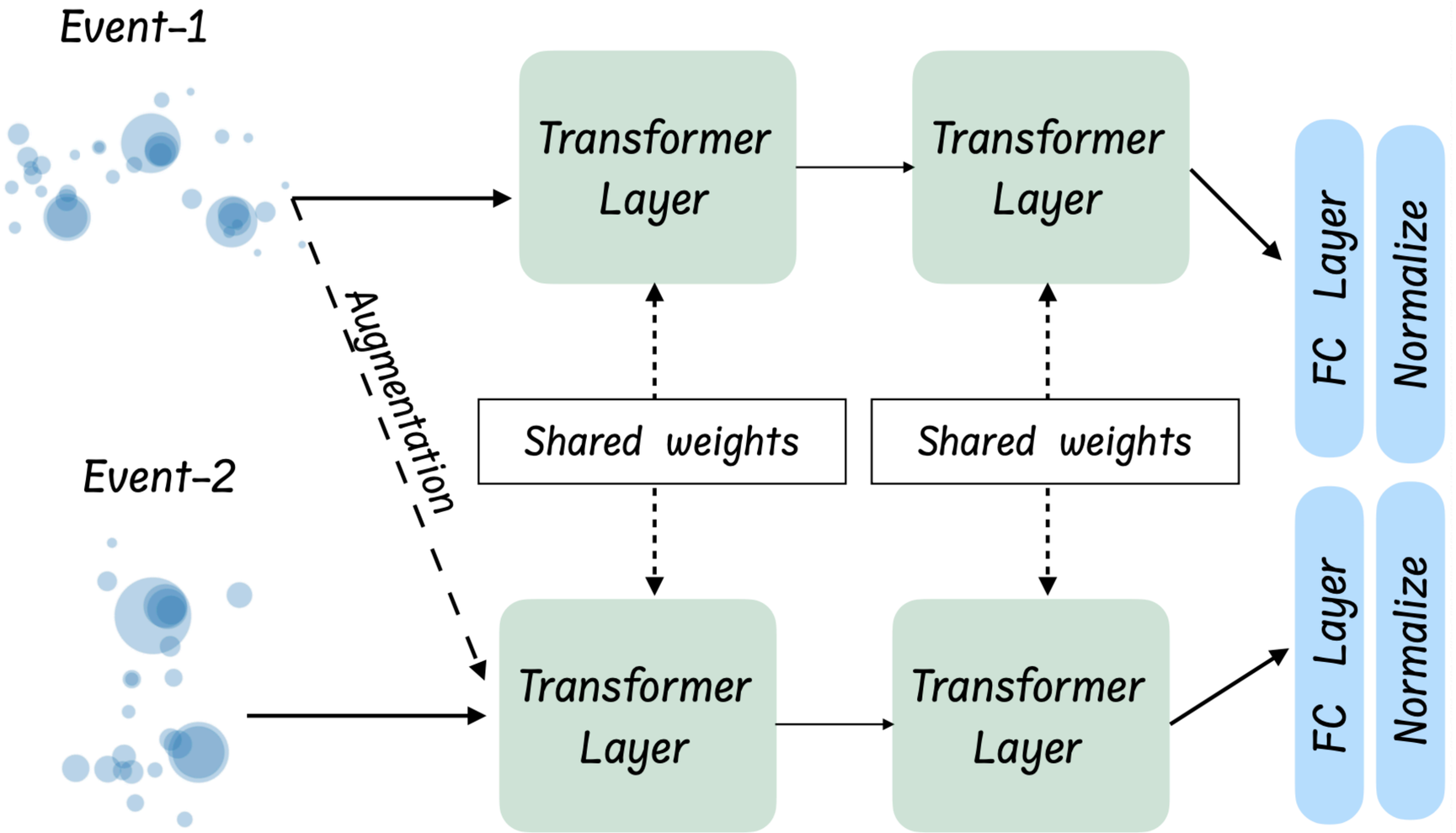
arXiv: 2411.09927 [hep-ph]

collaborators

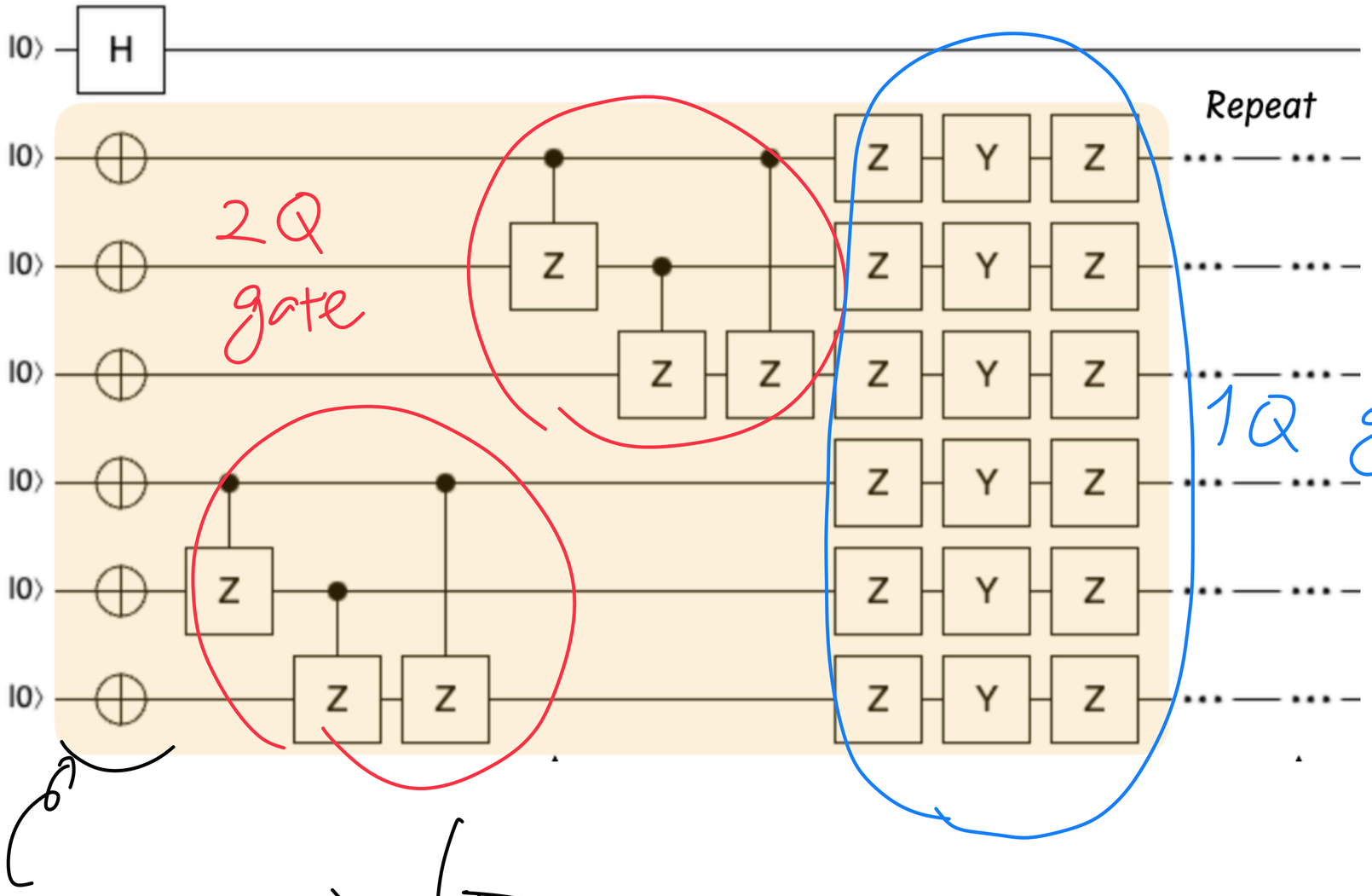
A. Hammad (KEK)

M. Nojiri (KEK)

Classical Part (Re)

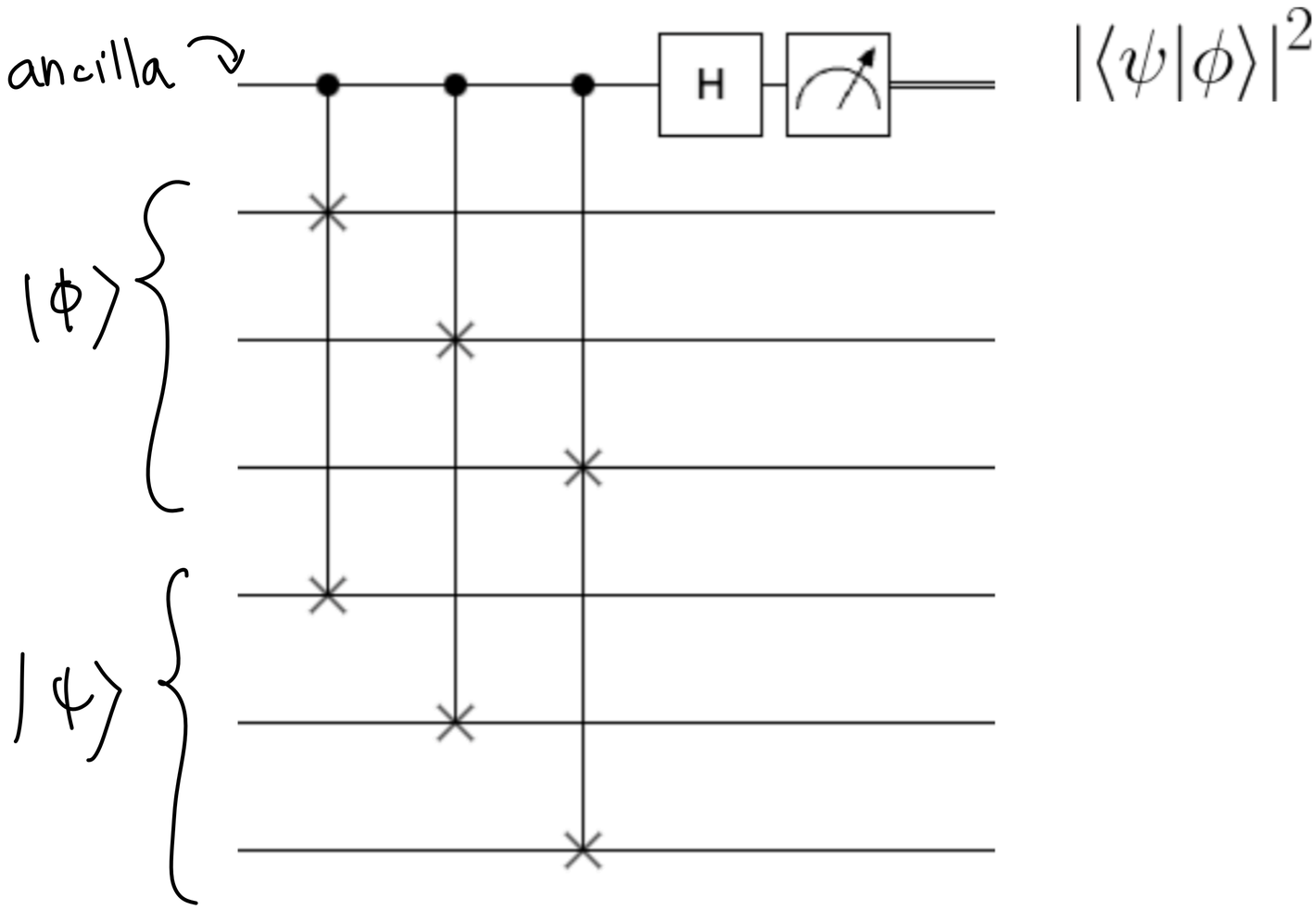


Variational Encoding Layers

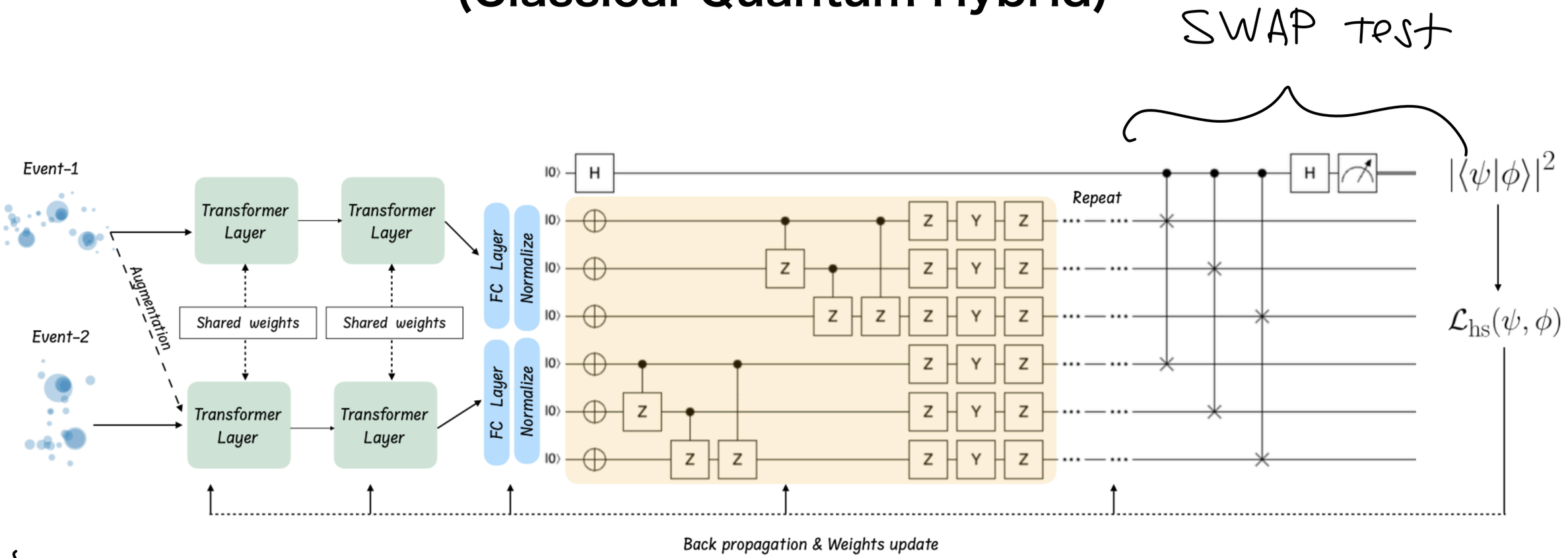


$$|\psi(\theta, x)\rangle = \left(\prod_i R_z(x_i + \theta_i)\, R_y(x_j + \theta_j)\, R_z(x_k + \theta_k) \right) |0\rangle^{\otimes n}$$

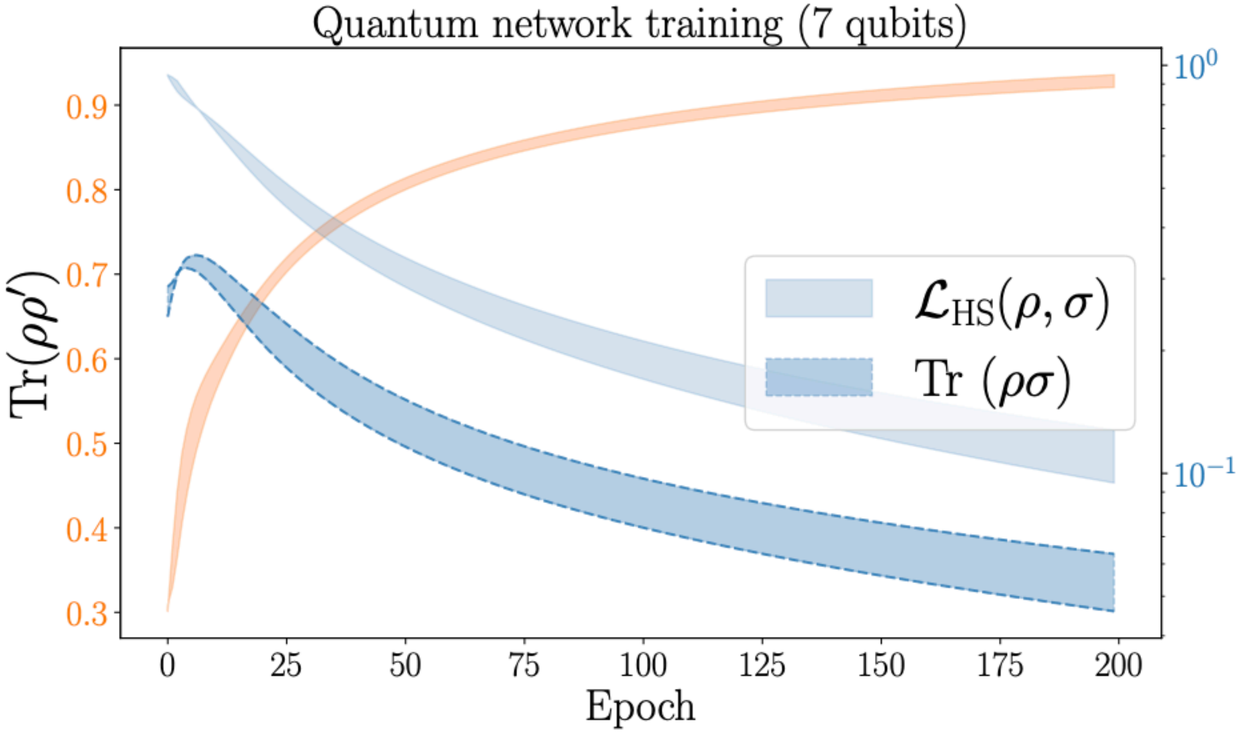
SWAP Test

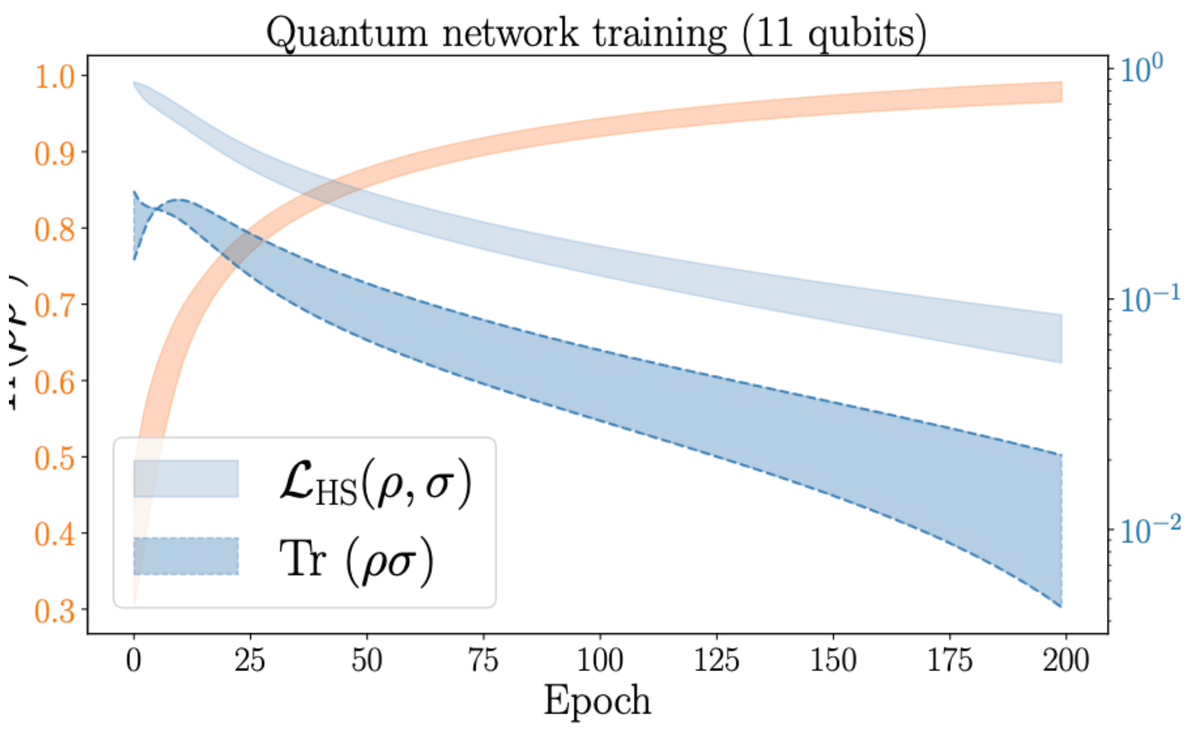


Total Setup
(Classical-Quantum Hybrid)



Training Metrics

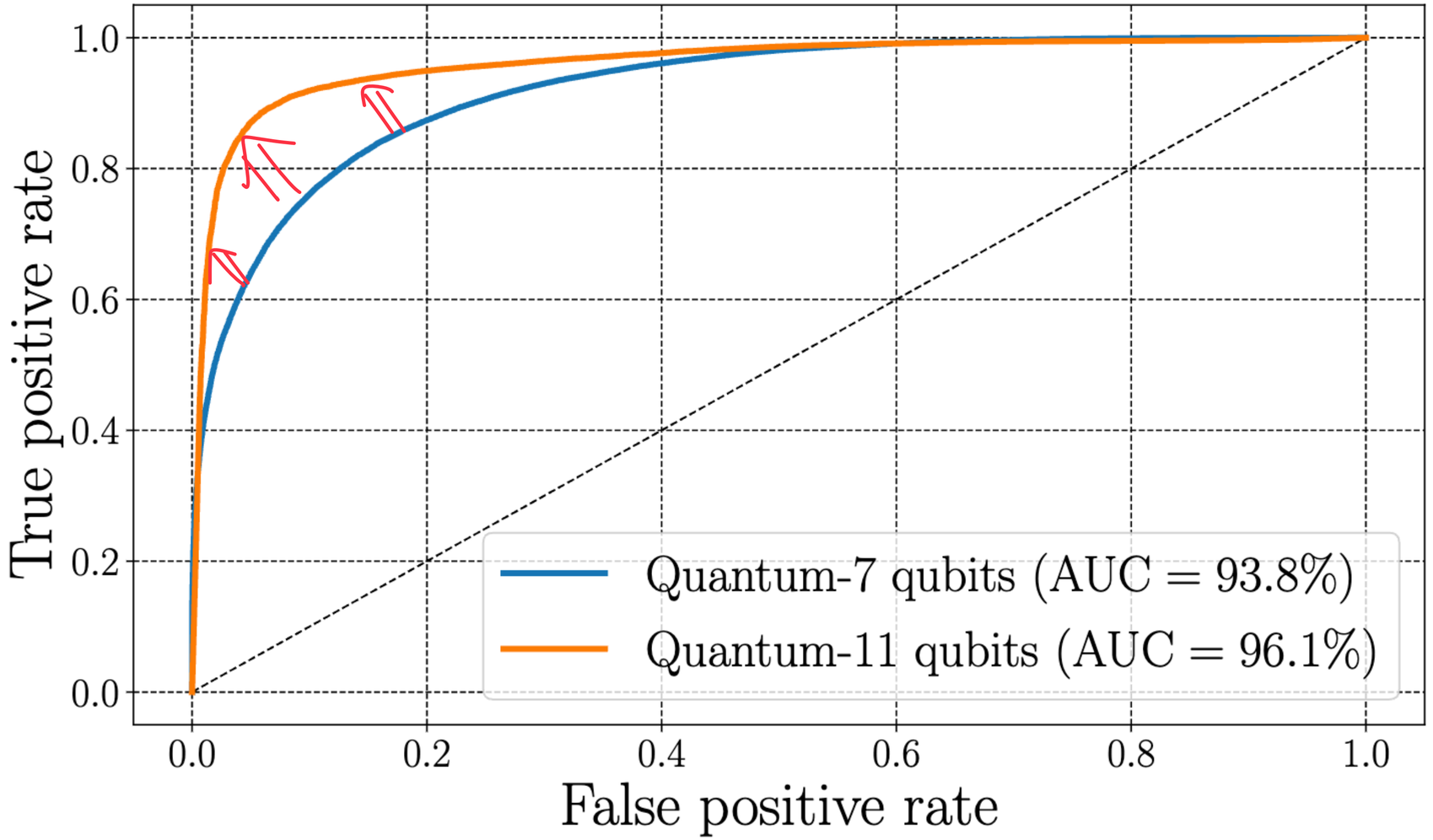




ρ' ← augment

$$\rho = \frac{1}{M} \sum_{i \in \text{batch}} |\psi^1\rangle\langle\psi^1| \quad \text{and} \quad \sigma = \frac{1}{M} \sum_{j \neq i \in \text{batch}} |\psi^2\rangle\langle\psi^2|$$

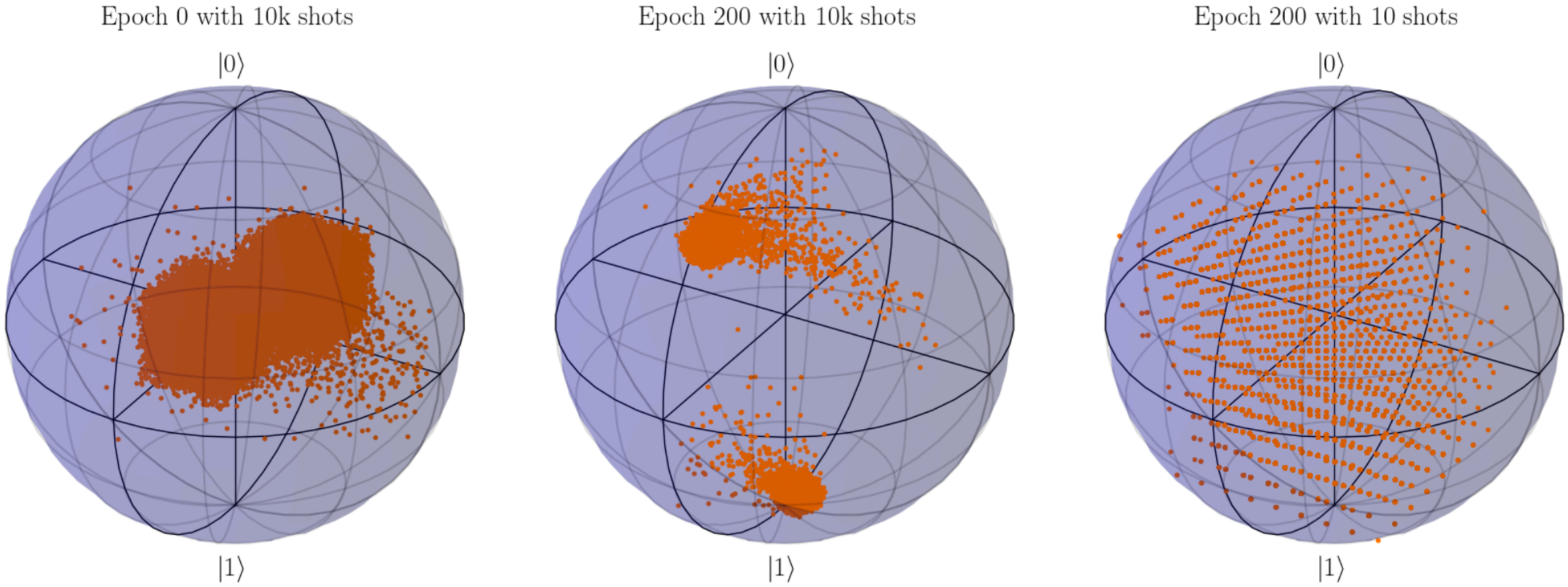
Receiver Operating Characteristics (ROC) Curve



Our results are on classical simulators,

but real quantum devices today are noisy …

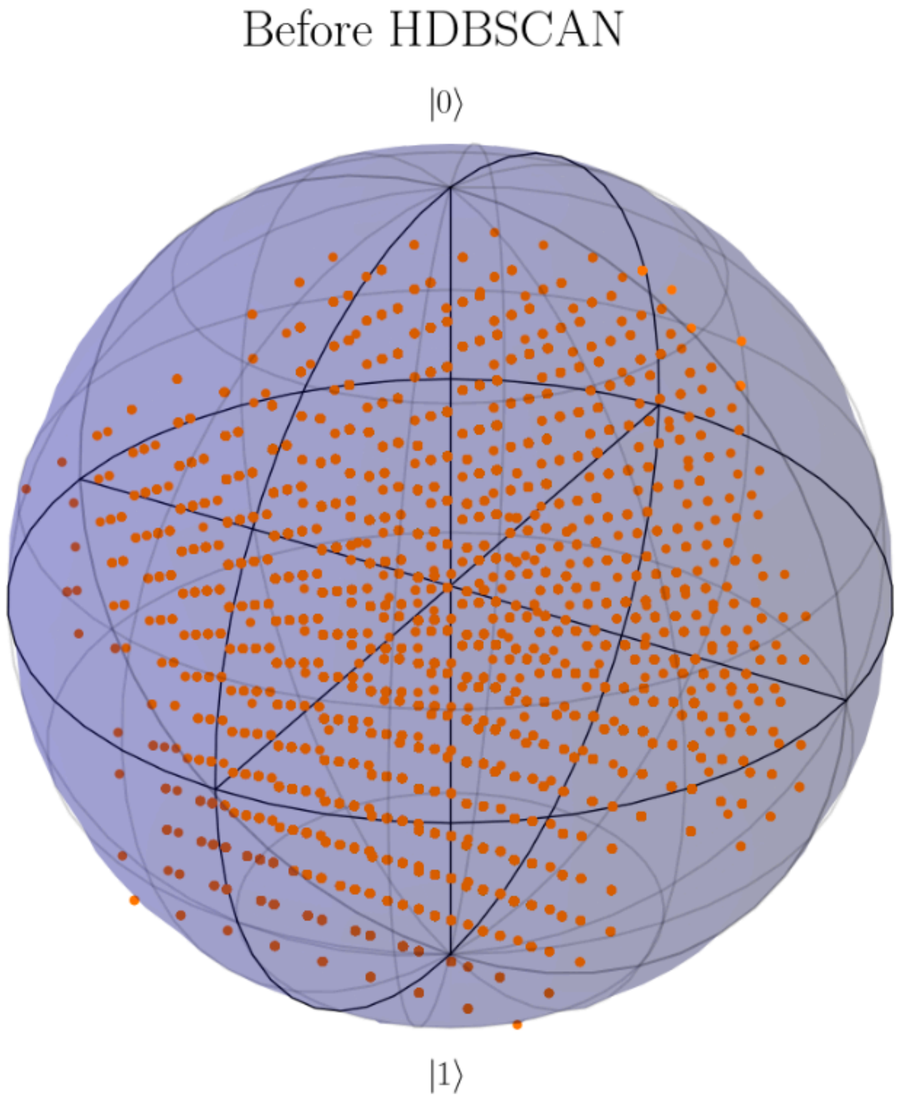
Example of Noise: Shot Noise

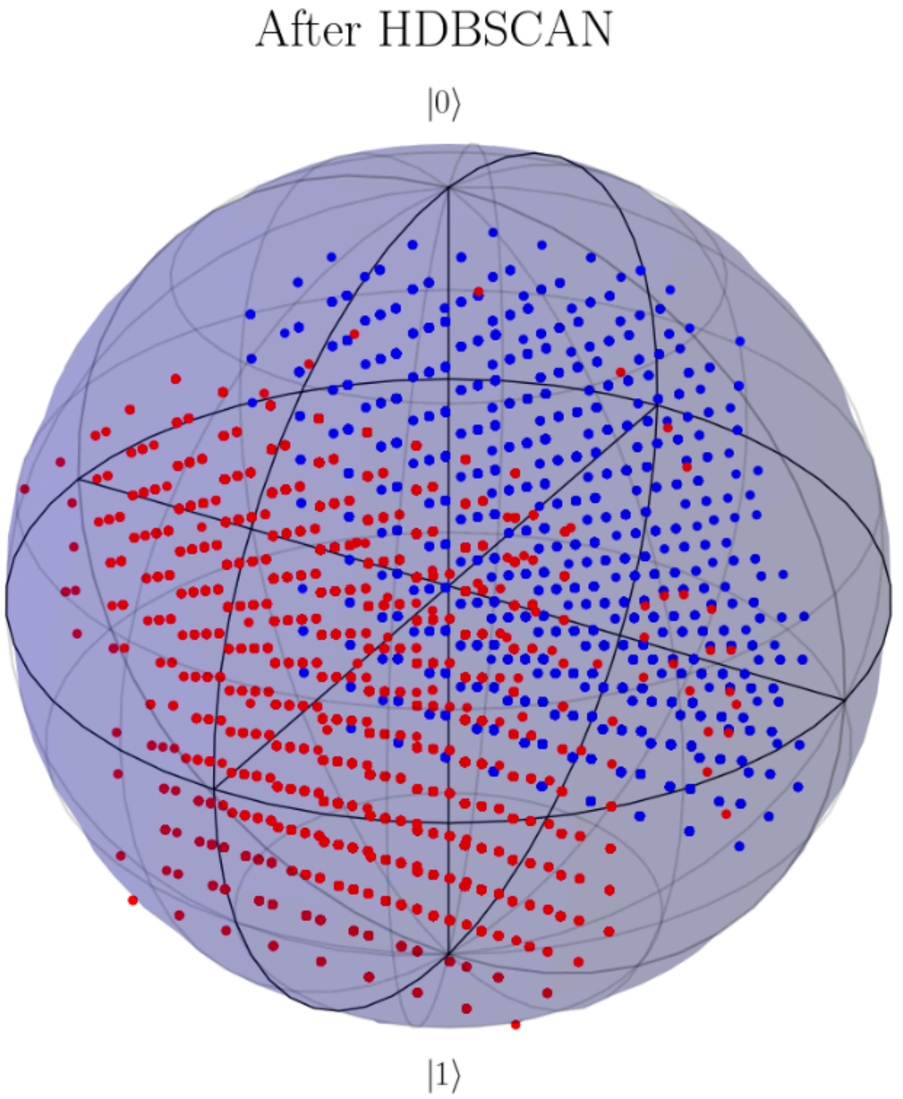


20,000 training events

Utility of Clustering

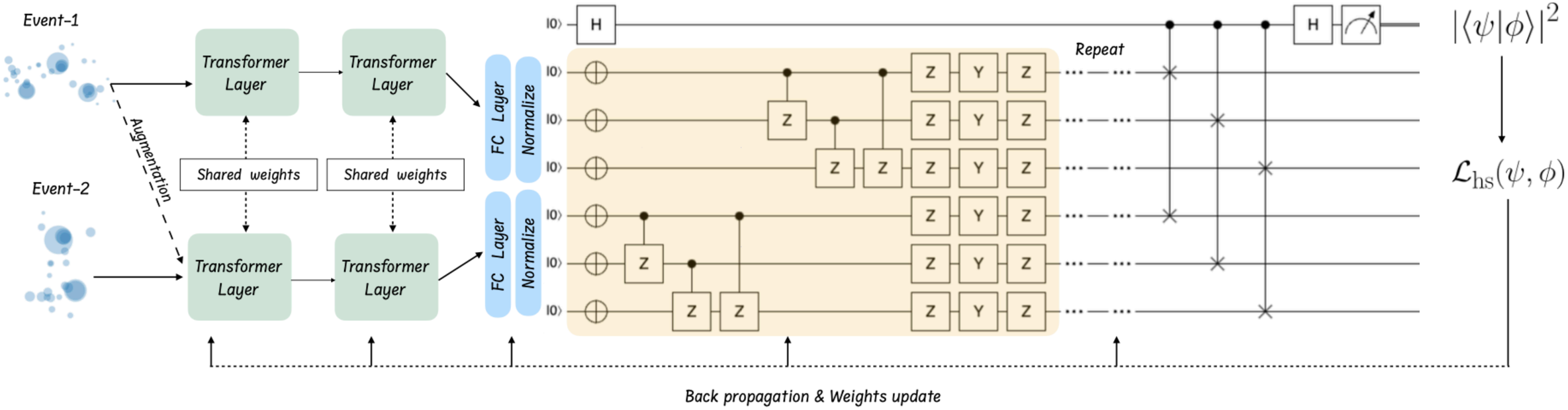
e.g. HDBSCAN = Hierarchical Density-Based Spatial Clustering of Applications with Noise



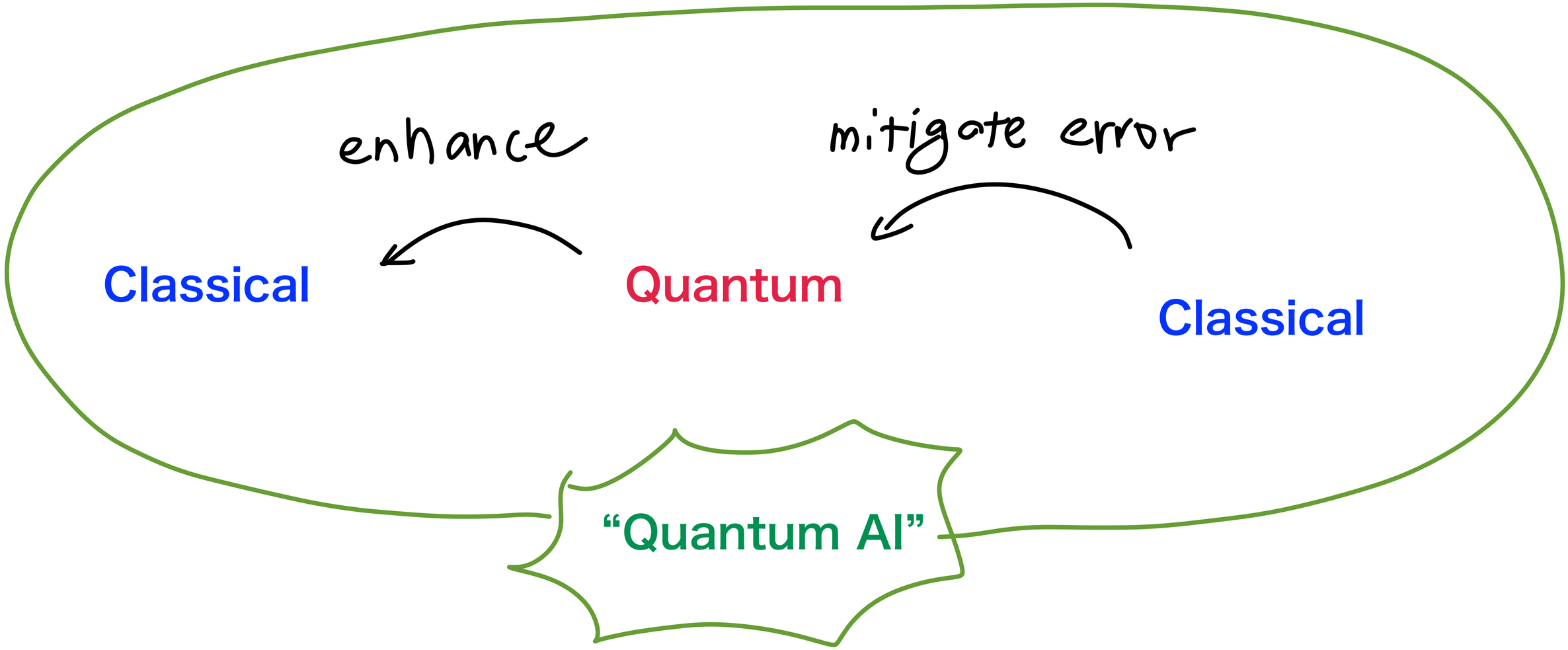


Summary

- QPU will be indespensable for future HPC
- We discussed applications of classical-quantum hybrid algorithm for anomaly detection in colliders



Summary


enhance
mitigate error
Classical
Quantum
Classical
“Quantum AI”