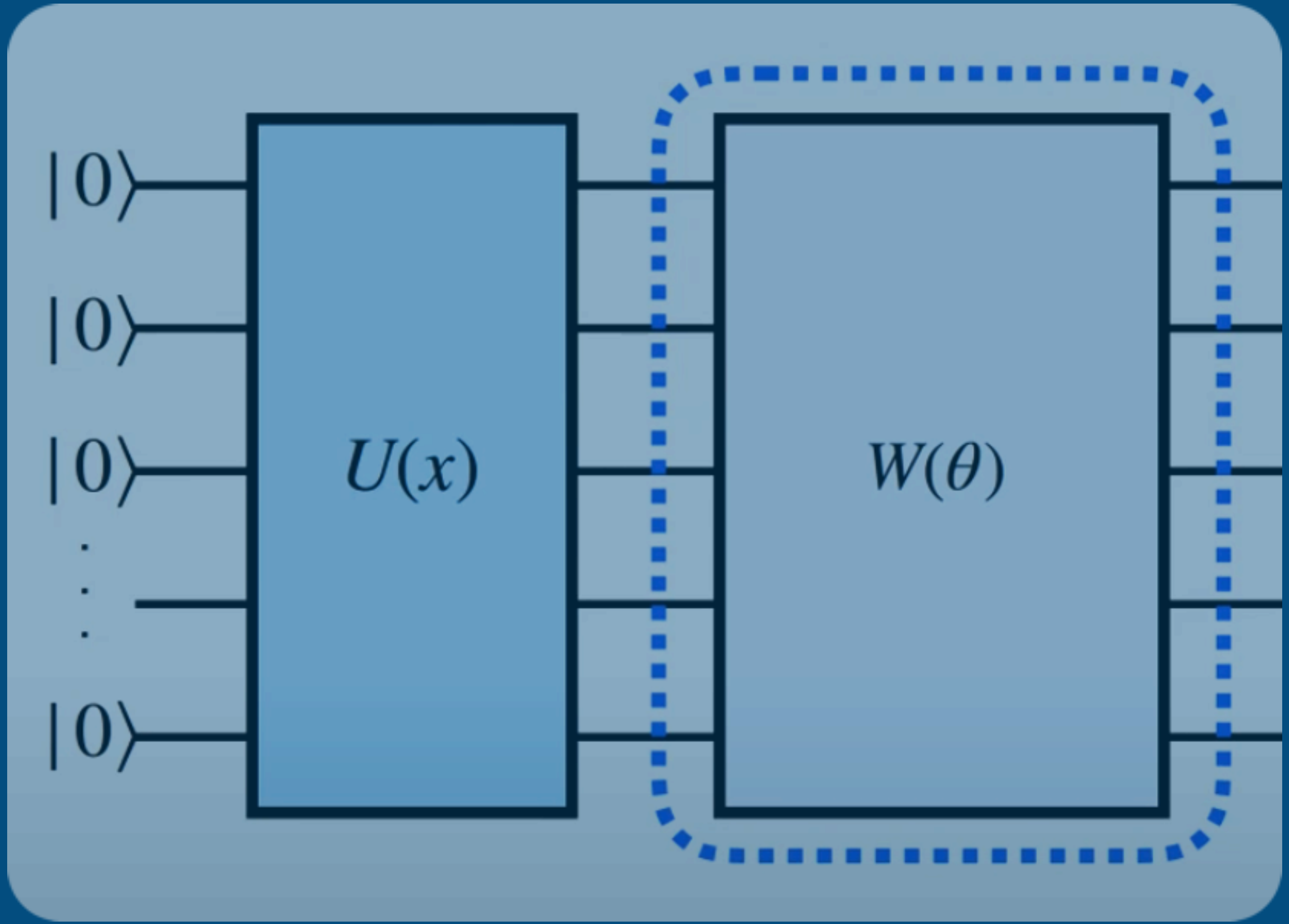
Long-lived Particles Anomaly detection with parametrized quantum circuits



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ML@INFN: machine learning activities at INFN Roma - 6 Marzo 2023

Istituto Nazionale di Fisica Nucleare

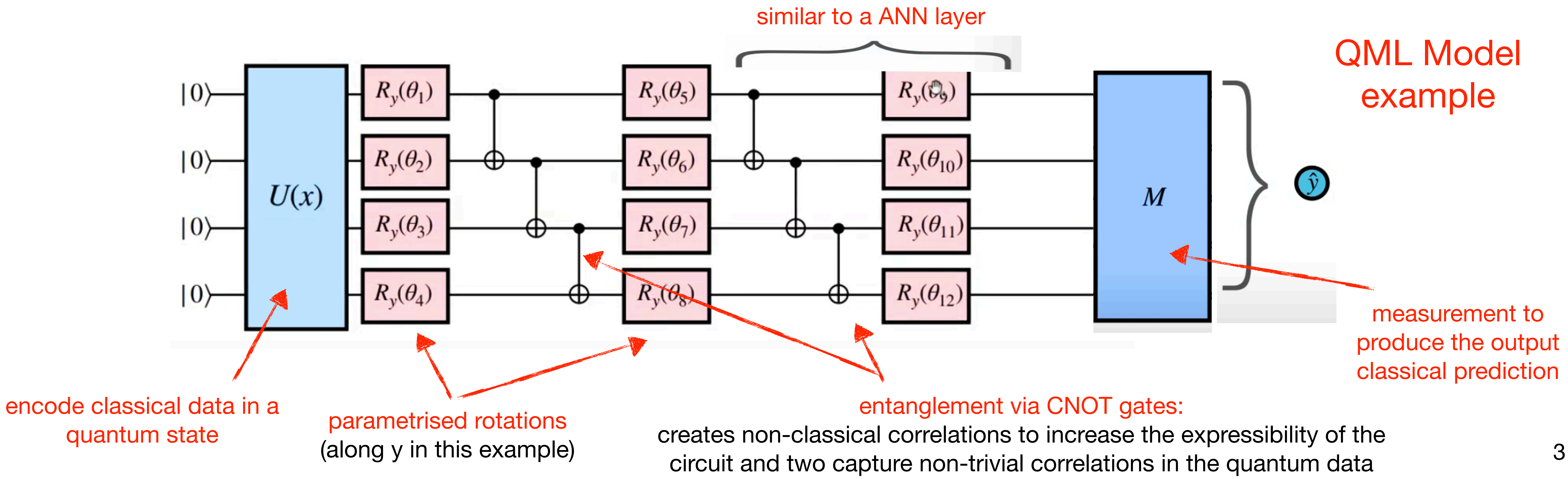
WHY PARAMETRIC QUANTUM CIRCUITS?

- quantum computing algorithms traditionally designed assuming the availability of fault-tolerant quantum processors supporting a very large number of qubits
- in practice current quantum computers support only $O(10^1\text{-}10^2)$ qubits, and in the near term this number will not exceed $O(10^3)$ and not all necessarily able to interact with each others: these are the so called noisy intermediate-scale quantum (NISQ) devices
  - no error correction: NISQ produce only approximate results of computations
  - limit algorithms to use only a few qubits and gates with deep impact on quantum algorithmic design
- this makes interesting to find useful computational problems that can be solved by small-scale quantum devices while exhibiting speedups in runtime to the best known classical algorithms

ML is one of such problems …

QUANTUM-ML ON NISQ DEVICES

- QML refers to an emerging design paradigm to program gate-based QC, that follows a two-step methodology akin to classical machine learning:
  - first is fixed a priori a, possibly generic, parametric architecture for the quantum gates that define the quantum algorithm
  - then the parameters are tuned via classical optimization techniques based on data and on measurements of the outputs of the circuit (as is done in classical ANNs for example)
- in this view QML has a narrow scope than general QC, is a sort of quantum-assisted ML (advantage: can be studied and exploited now)



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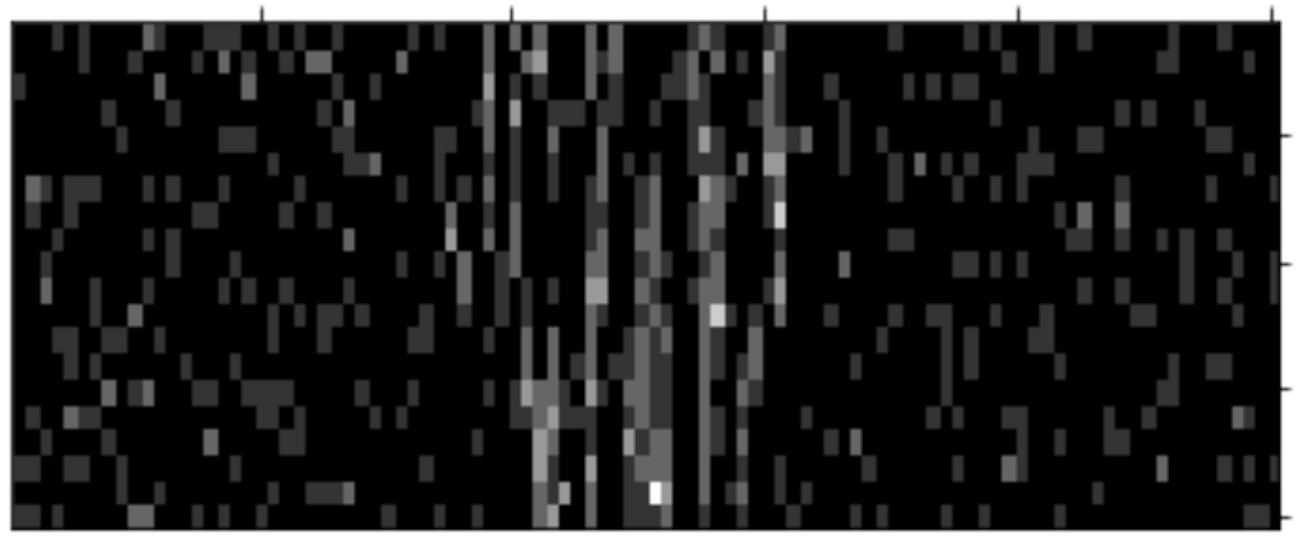
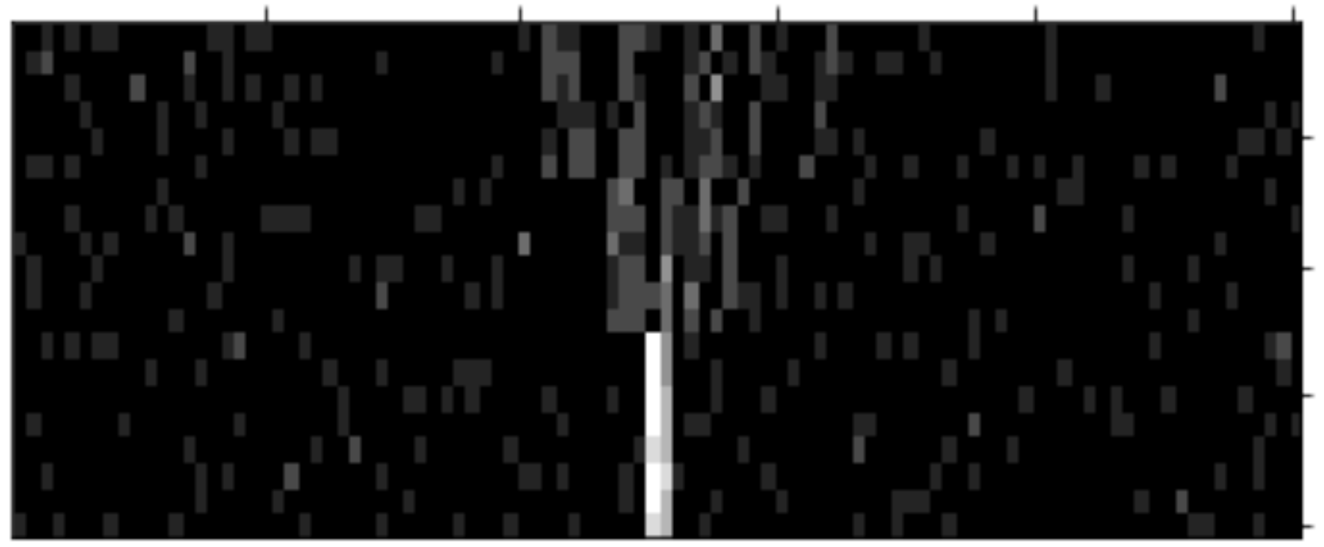
ANOMALY DETECTION ON NISQ

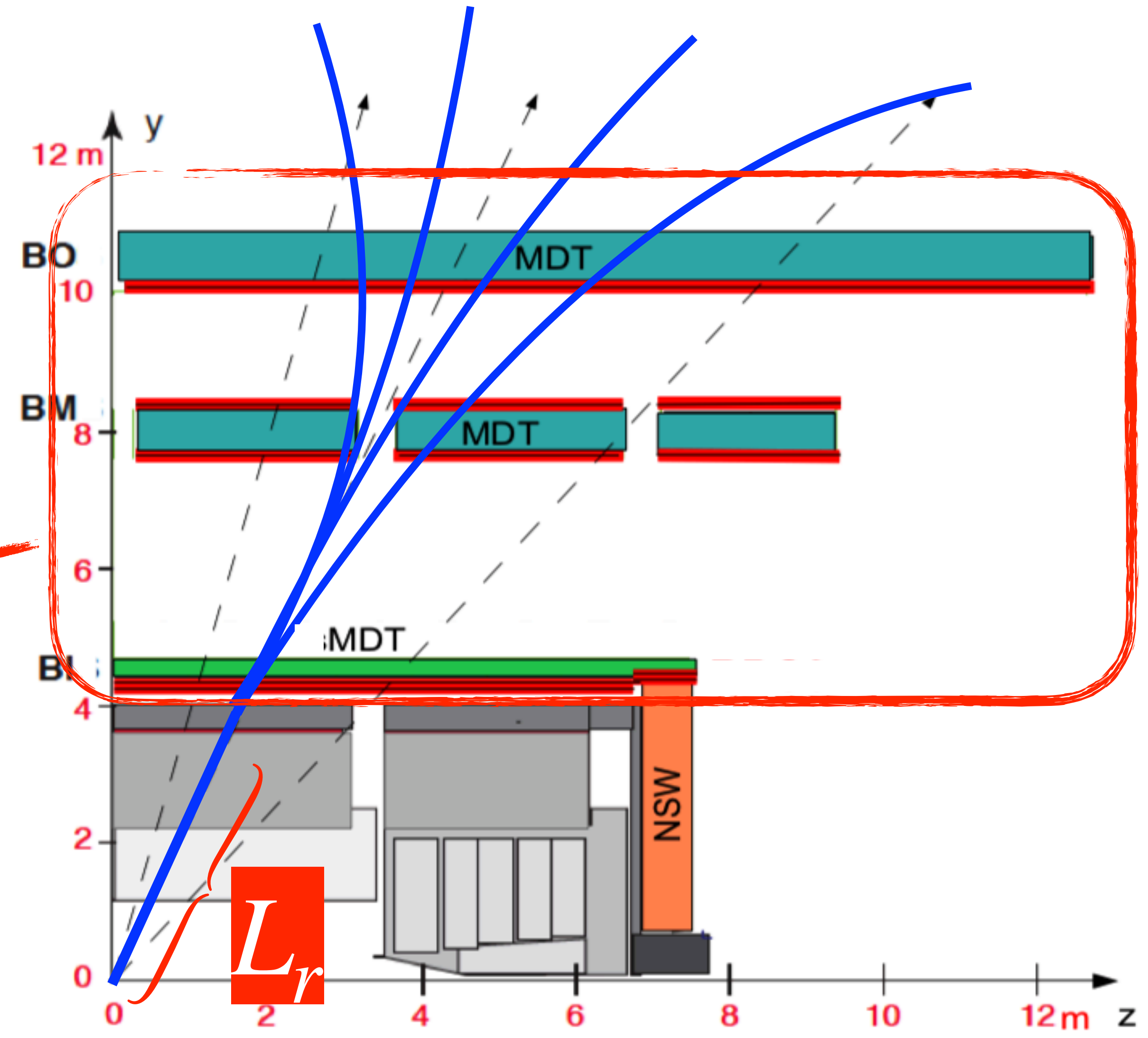
- Task: identification of anomalous patterns in a HLT muon trigger



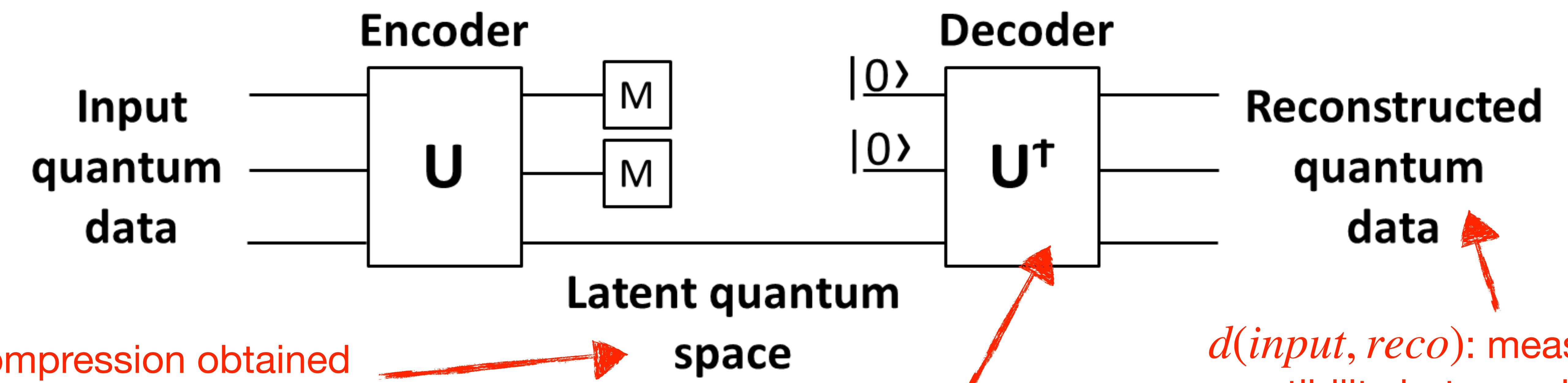
"Normal" image
decay with $L_r \in [0,1]\, m$



"Anomalous" image
decay with $L_r \in [2.5,4]\, m$



- A Quantum-AutoEncoder:



compression obtained by dropping q-bits

decoder = complex conjugate of the encoder

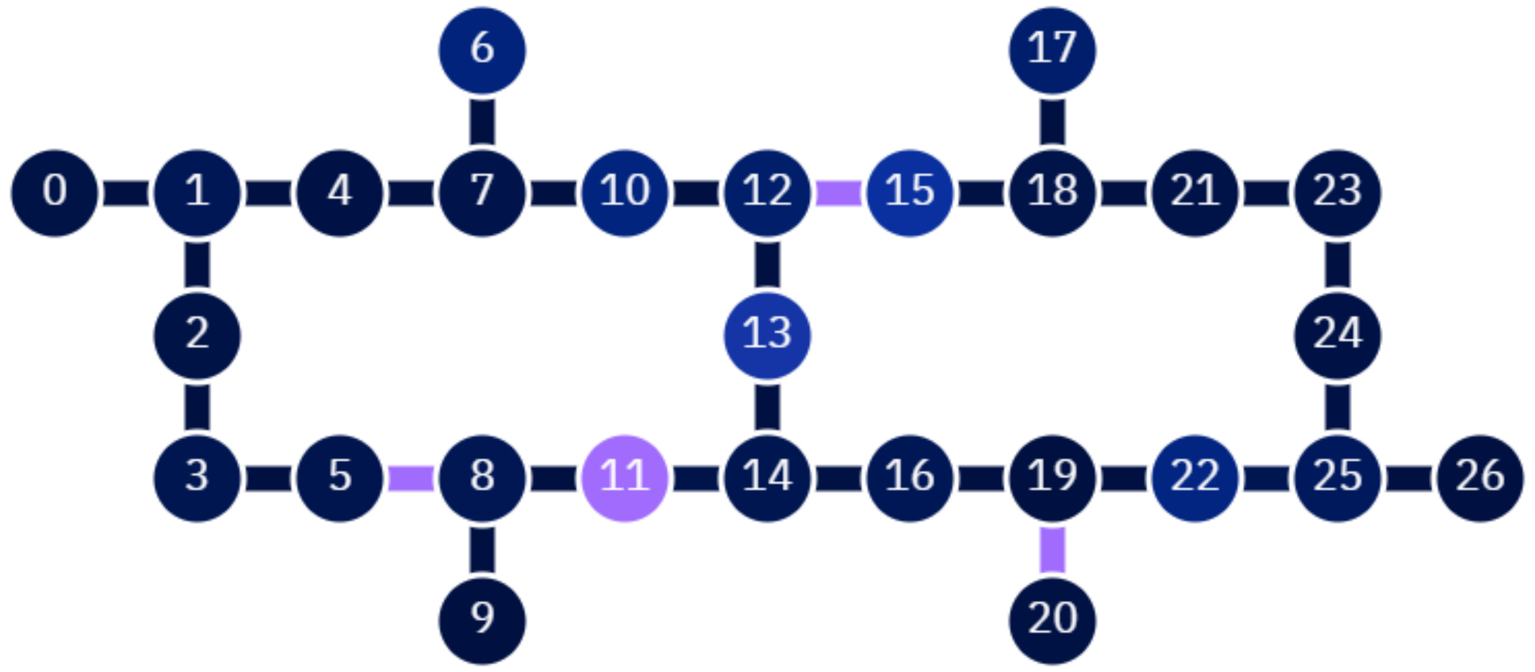
$d(input, reco)$: measure of compatibility between input and training set (eg "normal") latent representation

Main issues:

- avoid barren plateaux
- minimise use of "noisy" qubits due to quantum encoding of the classical data
- hardware adaptation of the parametric QC

RESULTS ON IBM Hanoi QC

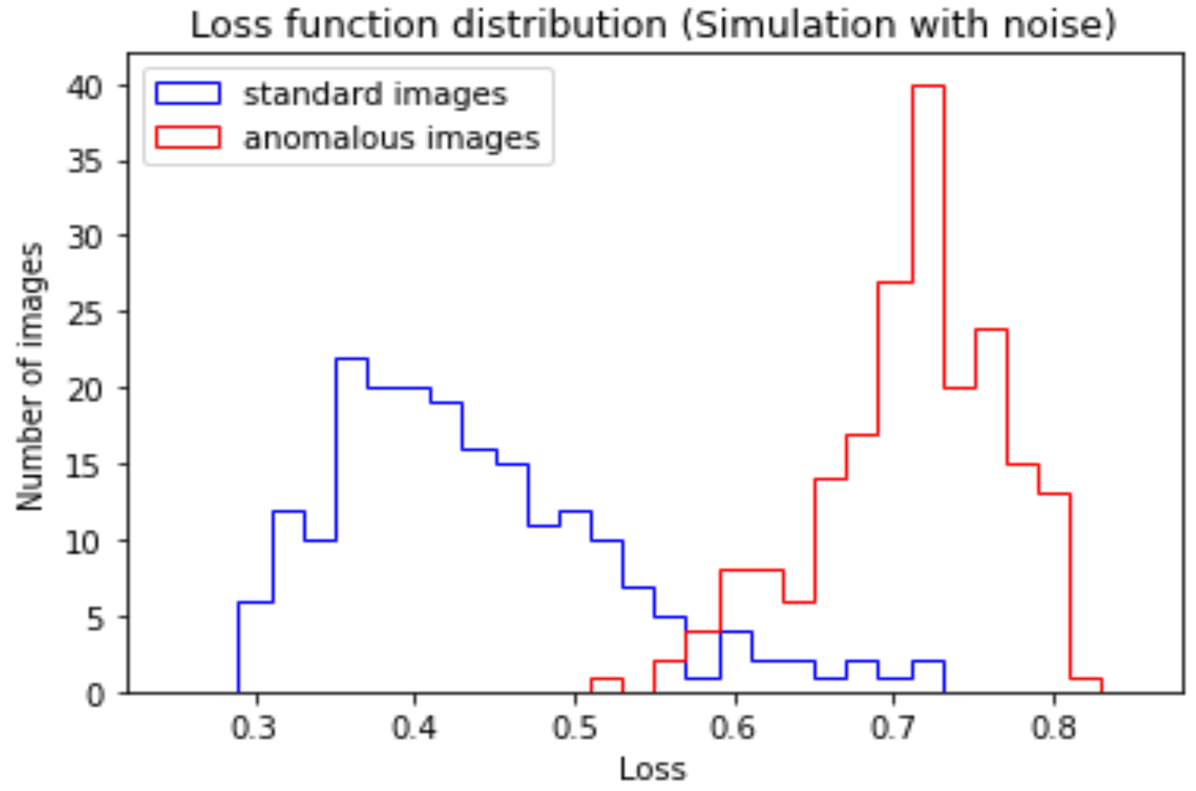
IBM Hanoi (26 qbit)

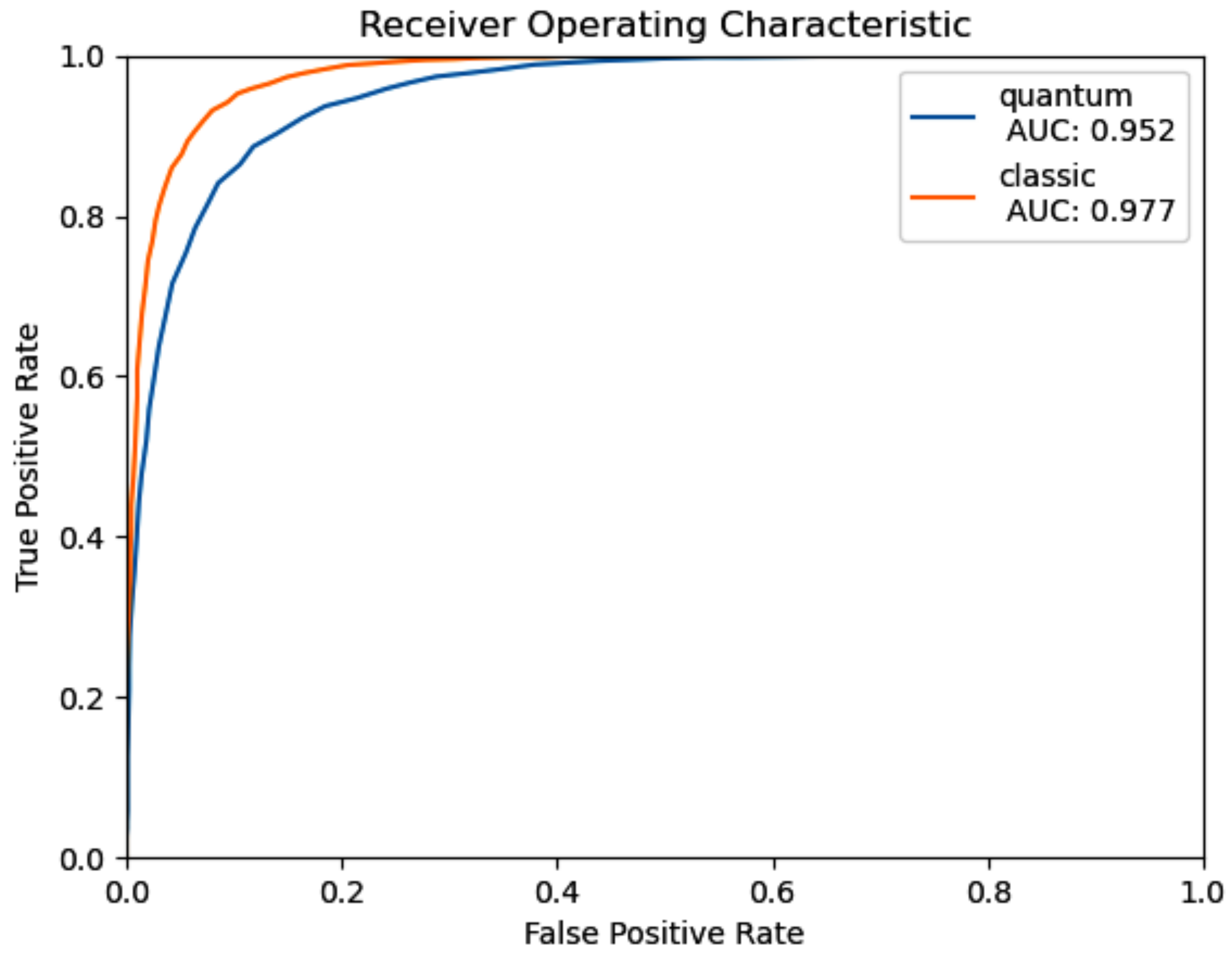


- encoder-decoder based on 8 rotation+hg layers:

```
q0:   —RX—RY—RZ—o————————X—RX—RY—RZ—o————————X—RX—RY—RZ—o————————X—RX—RY— ...
q1:   —RX—RY—RZ—X—o——————|—RX—RY—RZ—X—o——————|—RX—RY—RZ—X—o——————|—RX—RY— ...
q2:   —RX—RY—RZ———X—o————|—RX—RY—RZ———X—o————|—RX—RY—RZ———X—o————|—RX—RY— ...
q3:   —RX—RY—RZ—————X—o——|—RX—RY—RZ—————X—o——|—RX—RY—RZ—————X—o——|—RX—RY— ...
q4:   —RX—RY—RZ———————X—o—|—RX—RY—RZ———————X—o—|—RX—RY—RZ———————X—o—|—RX—RY— ...
q5:   —RX—RY—RZ—————————X—o—RX—RY—RZ—————————X—o—RX—RY—RZ—————————X—o—RX—RY— ...
```

- initial state preparation requires deep circuits with number of (noisy) C-NOT gates that grows exponentially in number of qubits
- new technique developed: approximate amplitude encoding (AAE)
  - train another parametric QC for an approximated amplitude encoding
  - substantially reduced the number of required C-NOT gates allowing the circuit be implemented in the IBM hardware





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