Feasibility Study of Quantum Particle Transformer

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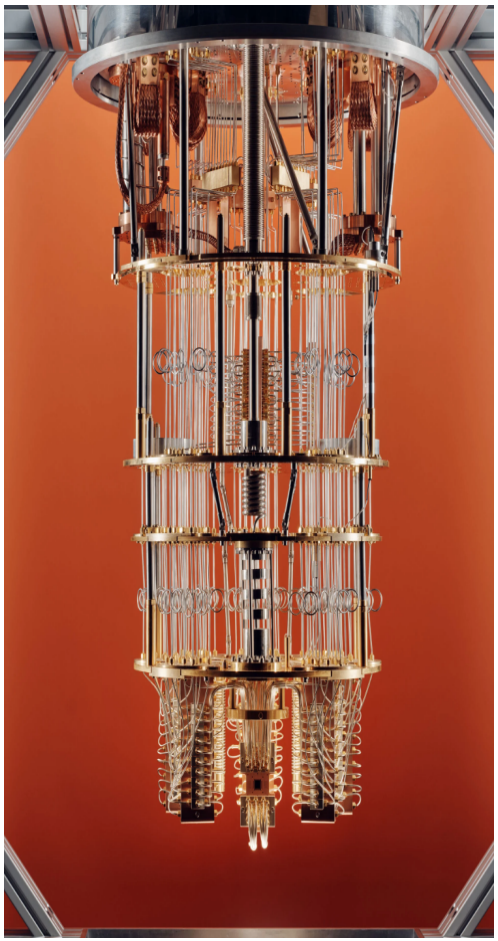
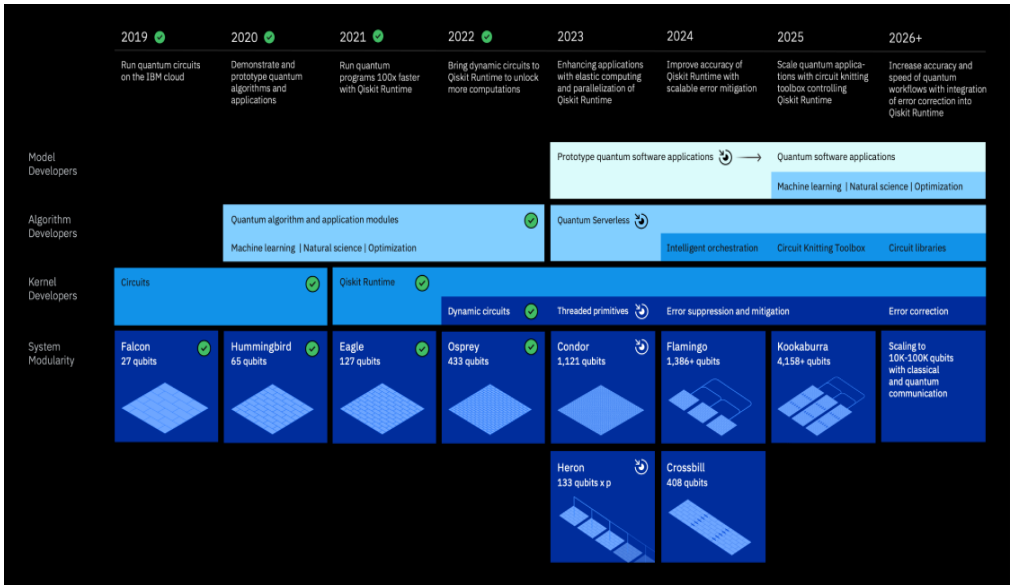
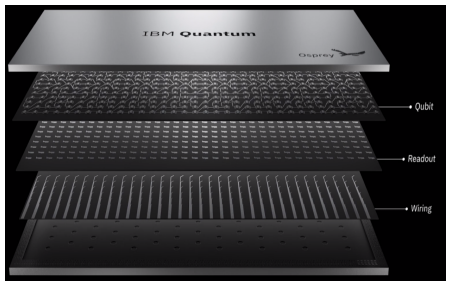
IBM Quantum Computer



Credited to Thomas Prior for TIME



- IBM has ambitious pursuits:
  - 433-qubit IBM Quantum Osprey
  - three times larger than the Eagle processor
  - going up to 10k-100k qubits
- Taking quantum computing out of the lab:
  - NY provides over 20 quantum computing
  - Scales the processors with high availability



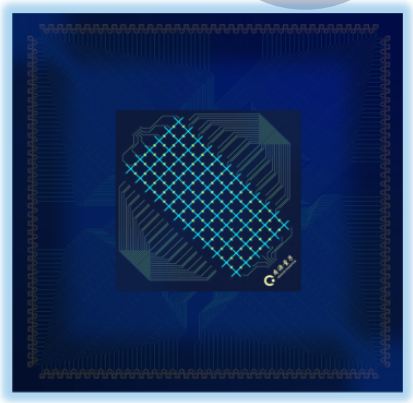
IBM Quantum Osprey

NY Quantum Computing Data Center

- IBM provides up to 7 qubits for free with an opportunity to apply for a researcher account with more qubits.

Origin Quantum Computer (Wuyuan)

- Origin Quantum 64-qubit superconductor QPU
  - single-qubit gate fidelity $> 99.9\%$
  - double-qubit gate fidelities $> 98\%$
  - readout fidelity $> 96\%$
- A quantum computing control system dedicated to superconducting quantum chips



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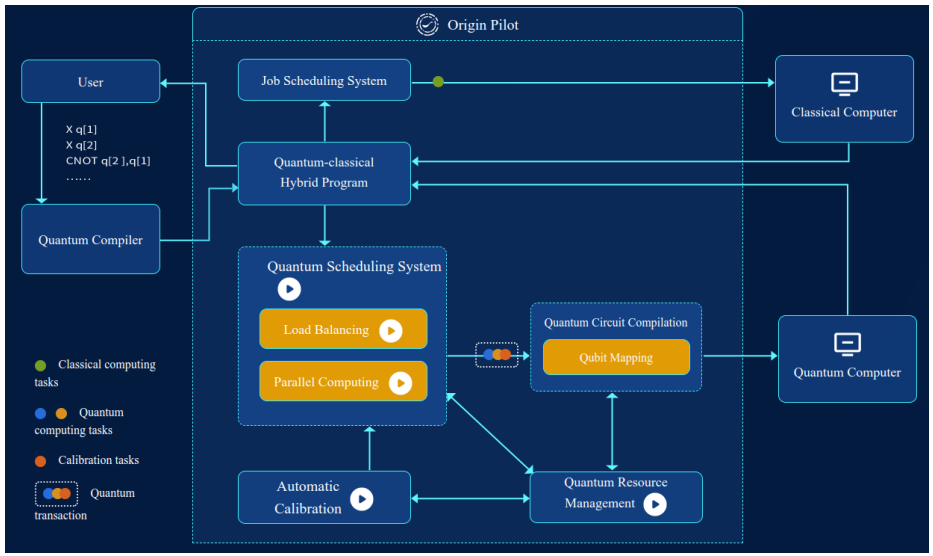
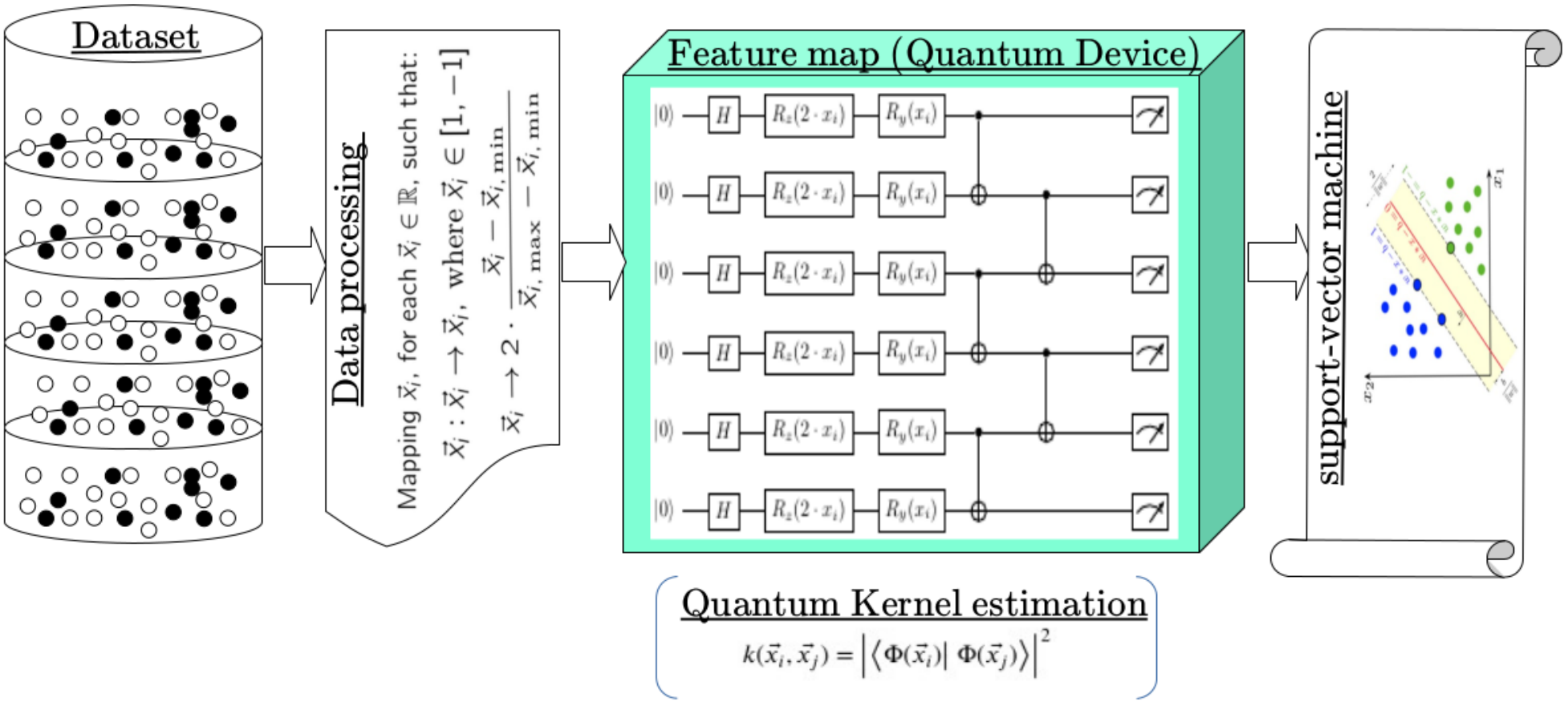


TJ-SQMC-300

- This is the first Quantum Computer Operating System in China. One could use up to 6 qubits for free.
- Also, the Quafu platform offers more qubits- announced during the International Symposium on Quantum Information Sciences at the Beijing Academy of Quantum Information Sciences.

Quantum Kernel Method

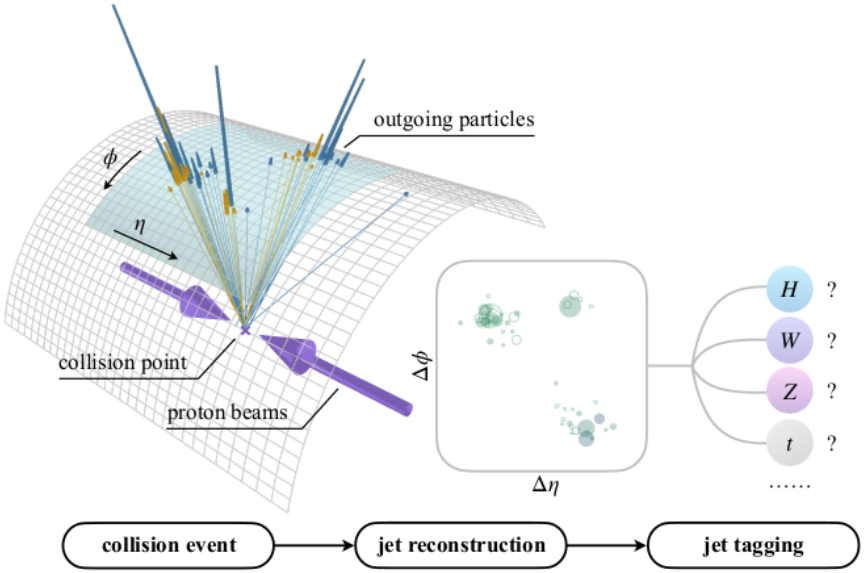


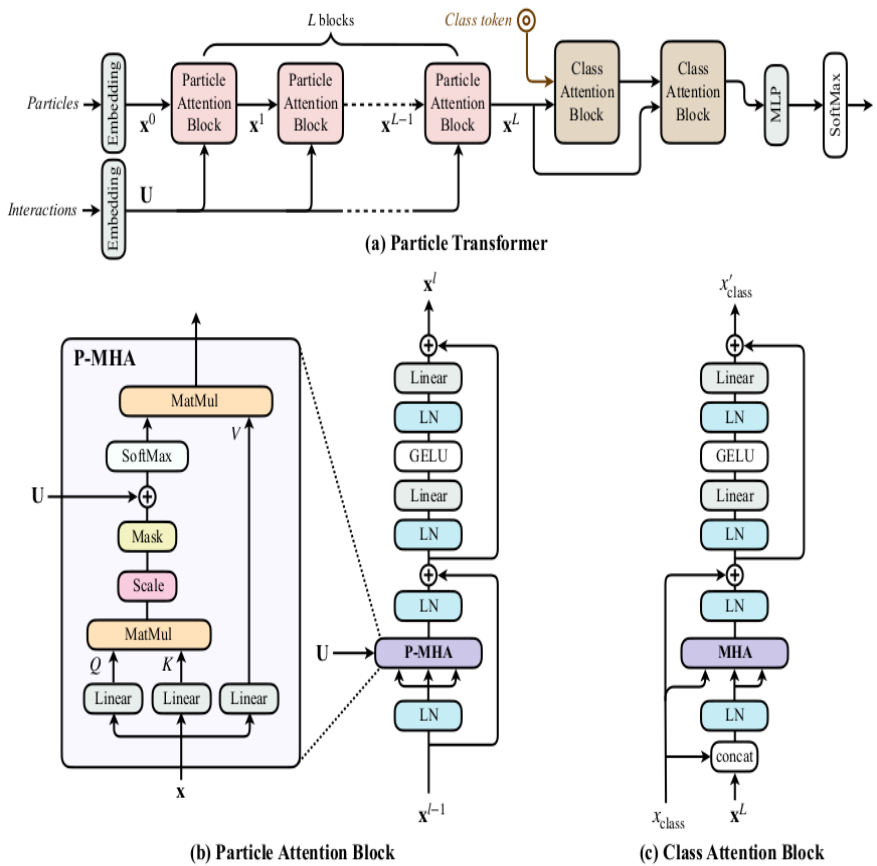
- Most of the quantum machine learning studies involve encoding classical dataset to high dimensional quantum dataset. We use similar terminology and achieved comparable results between IBM & Wuyuan.

Particle Transformer

Jet tagging classification in particle physics

- The algorithm was developed for jet tagging at the CMS experiment. It improves jet tagging significantly.
- Now there's a plan to use the same technique at the ATLAS experiment's jet tagging.

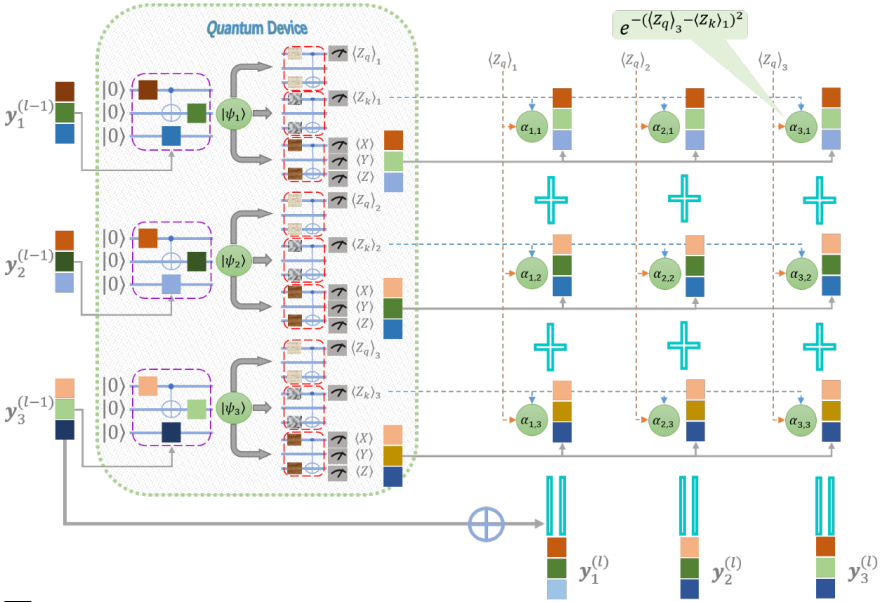


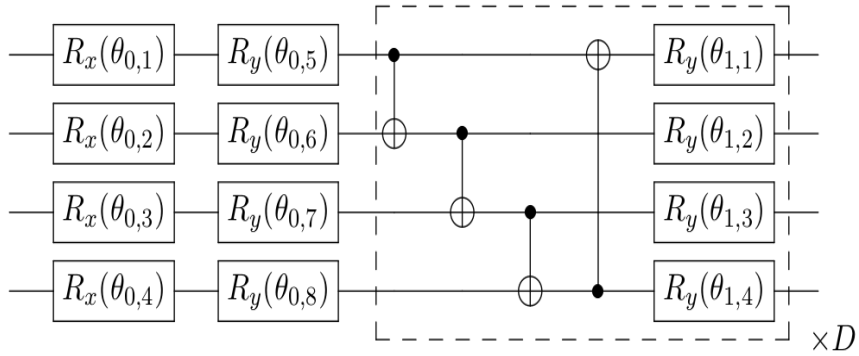


- Particle: a list of features for each particle
- Interactions: features involving a pair of particles
- Passing through a series of "attention" to MLP
- ArXiv: 2202.03772: Particle Transformer

Quantum Self-Attention Neural Networks

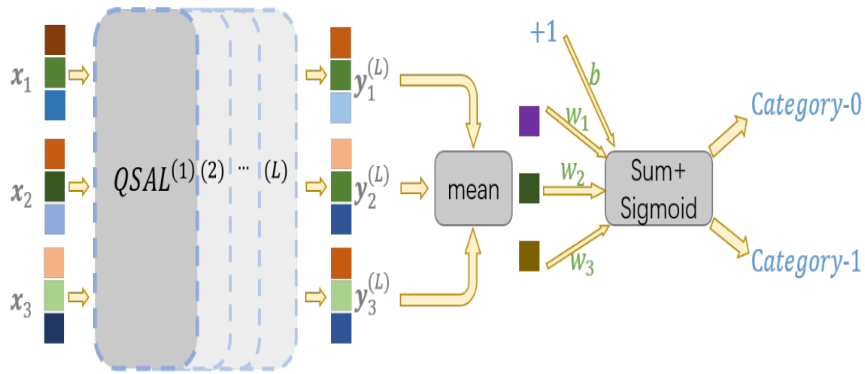
- The algorithm is used for text classification. It has the potential advantage of mining hidden correlations between words that are hard to explore classically.





- The quantum ansatz circuit on the self-attention

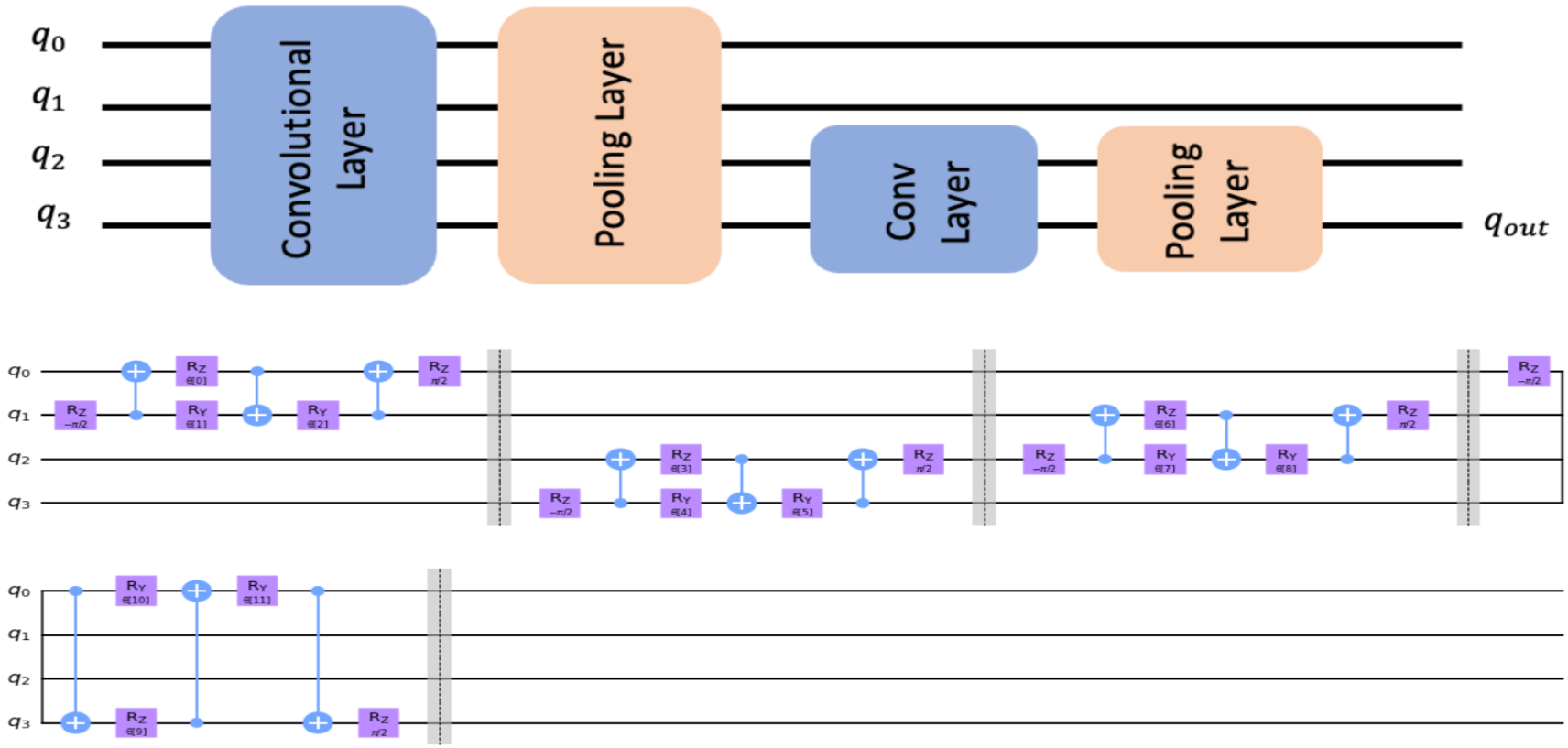
- The algorithm consists of:
  - A quantum self-attention layer
  - A loss function and an analytical gradients
- Classical input used as a rotation angles of Ansatz
- The computed states passed to another Ansatz
- The output query and keys computed using Gaussian function to obtain quantum self-attention coefficients.
- See the ArXiv: 2205.05625 paper.



- A series of classical vectors input to the algorithm.
- The classification is performed classically.

Quantum Convolution Neural Network

- Introducing self-attention into the quantum realm complicates the structure of the feature map.



- Reducing the dimensionality of our circuit and then define layers in terms of gates applied to a circuit

Summary

Quantum computing has become an very interesting topic to explore/develop and benefit a wide range of fields such as high energy particle physics.

- ☐ Particle transformer is a bit complicated with all the self-attention added to it.
- ☐ However, using a convolution neural network reduces the quantum circuit's complexity.
- ☐ It's possible to develop a Quantum Particle Transformer but we should be careful with the self-attention.