Precise Quantum Angle Generator Designed for Noisy Quantum Devices

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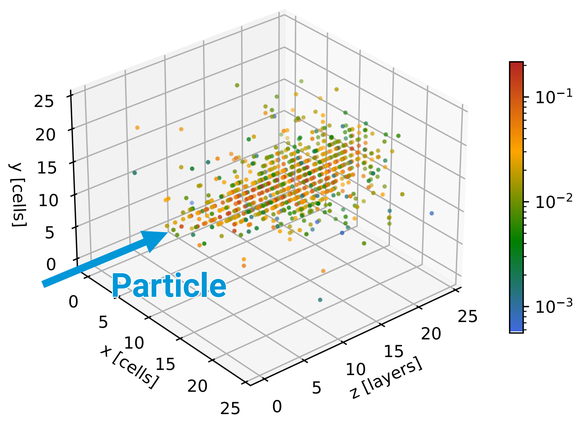
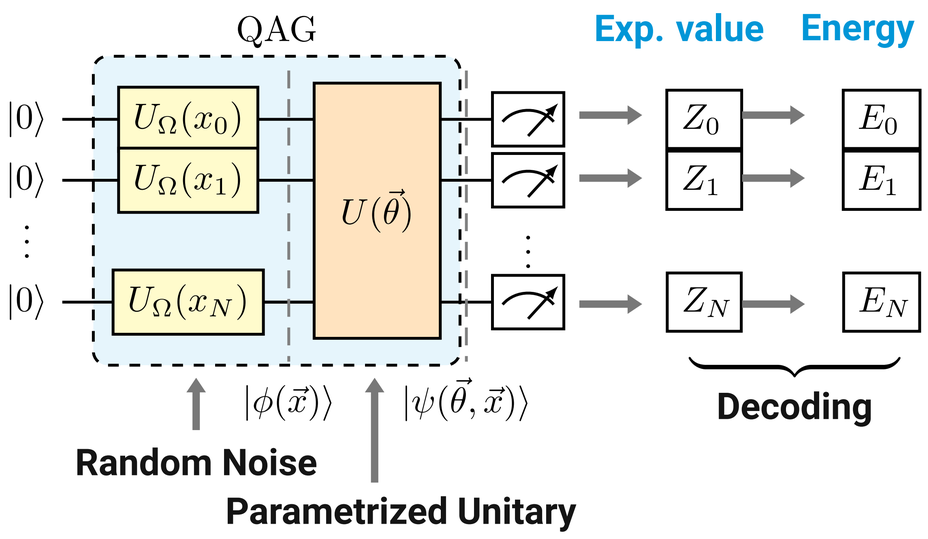
Quantum Angle Generator

- **Use case**: Simulation of shower images from electromagnetic calorimeters in Particle Physics with Quantum Machine Learning.
- **Dataset**: Training and test datasets both consisting of 1,000 samples of 1D images recorded by particles within the energy range of $[225, 275]$ GeV.

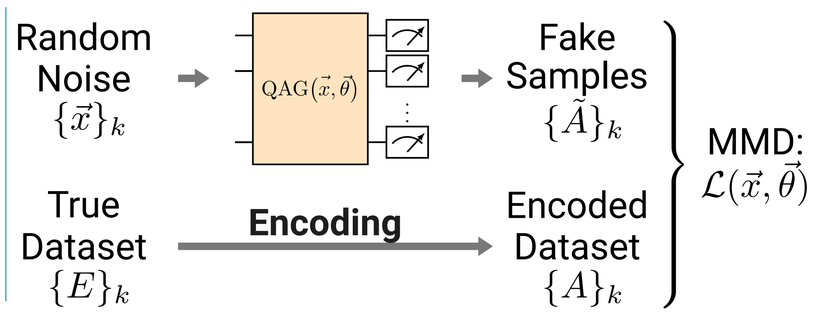


- **Model**: Quantum generative model that employs angle encoding.
  - **Encoding**: classical images into a quantum state, by turning pixel energy into a rotational angle of a qubit.
  - **Decoding**: translate quantum state into an energy by measuring qubit multiple times (n_{shots}).

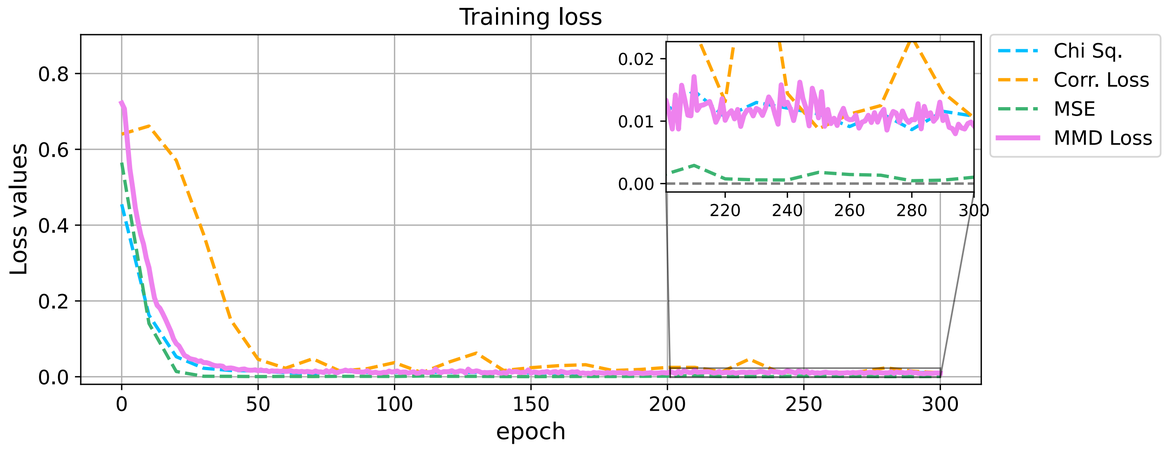


Training evaluation

Loss: Maximum Mean Discrepancy (MMD)
Optimizer: ADAM / SPSA



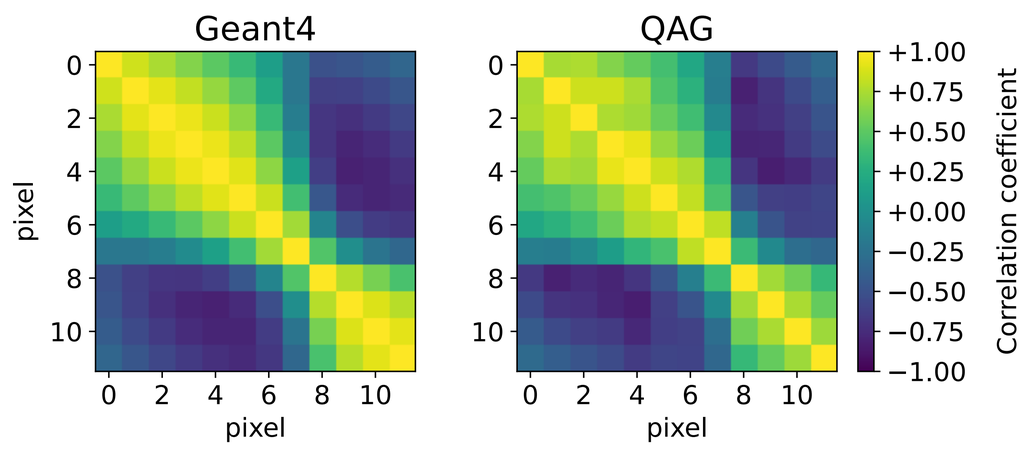
Loss function:



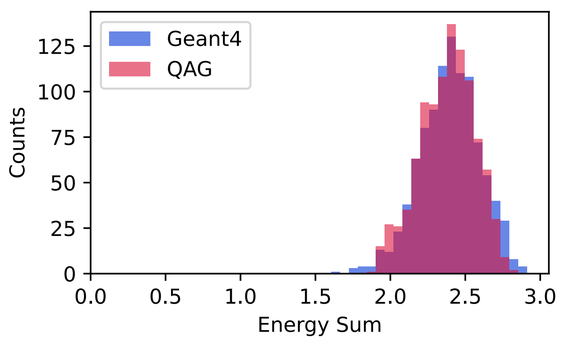
★ Training results **stable** and **converges fast**, MMD loss is able to effectively learn **correlations between pixels**

Inference evaluation

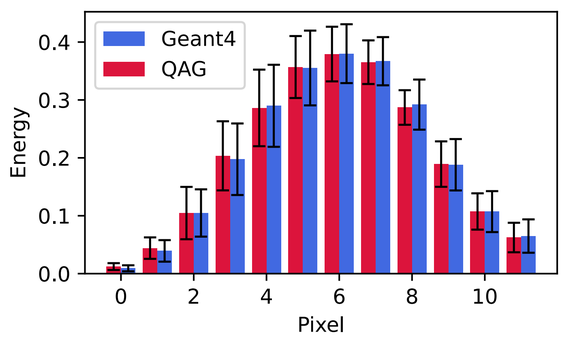
Correlations:



Total energy:



Energy average:

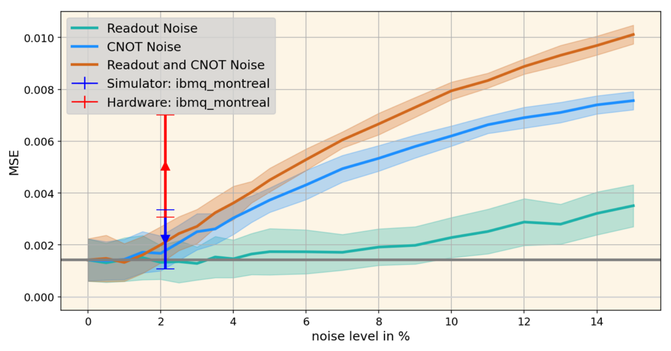


★ The model successfully captures pixel correlations and accurately reproduces the expected energy distributions

Noise study

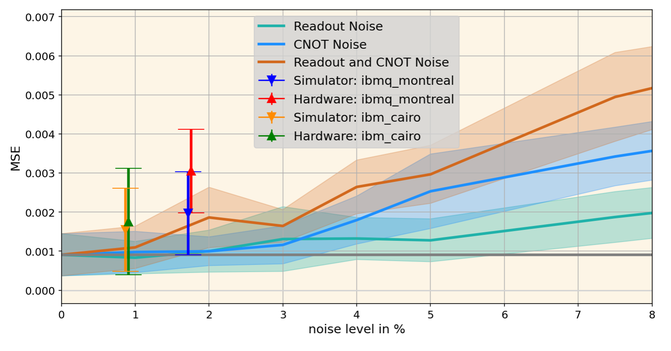
Inference:

- Device: *ibm_montreal*
- Noise applied **only when doing inference**
- Baseline: model without noise



Training:

- Devices: *ibm_montreal* and *ibm_cairo*
- Noise applied **during training phase**
- Baseline: model without noise



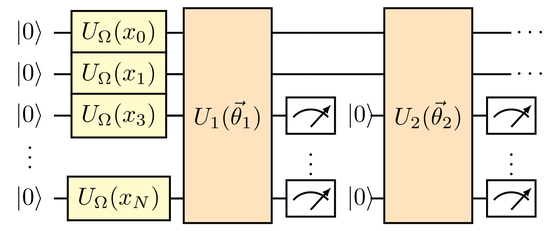
★ Significantly higher accuracies for the models trained on noisy instances. The model is capable to **adapt to the underlying noise**

Future plans

Current objectives:

- Accurate study on all **hyperparameters**
- Increase the number of qubits, (Recurrent QAG)

Recurrent QAG:



References

[1] Florian Rehm, Kerstin Borras, Pooth Oliver: *Deep learning and quantum generative models for high energy physics calorimeter simulations*, RWTH Aachen University, PhD Dissertation (2023)

[2] Florian Rehm, Sofia Vallecorsa, Kerstin Borras, Dirk Krücker, Michele Grossi, Valle Varo: *Precise Image Generation on Current Noisy Quantum Computing Devices*, Quantum Science and Technology (2023)

Paper

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