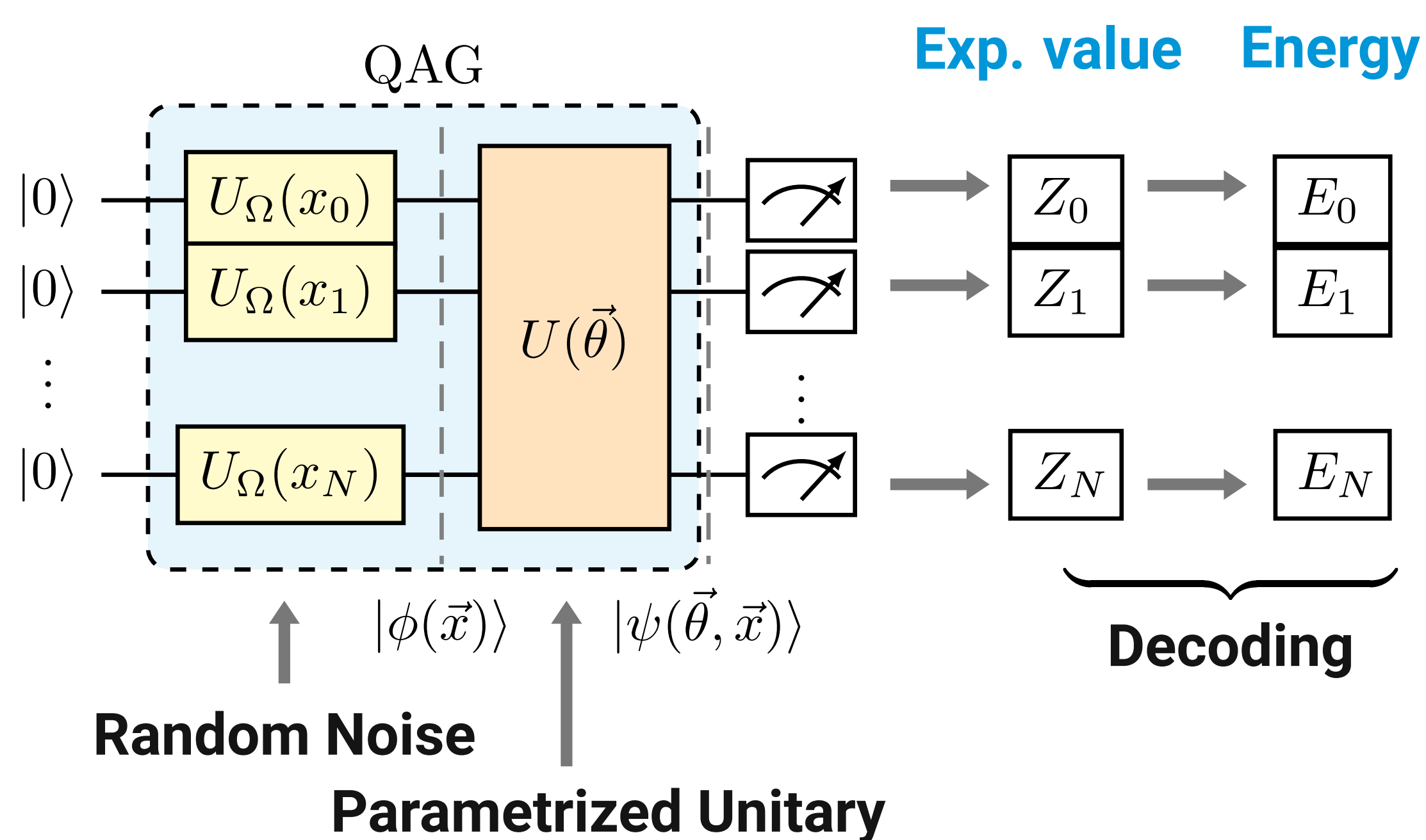
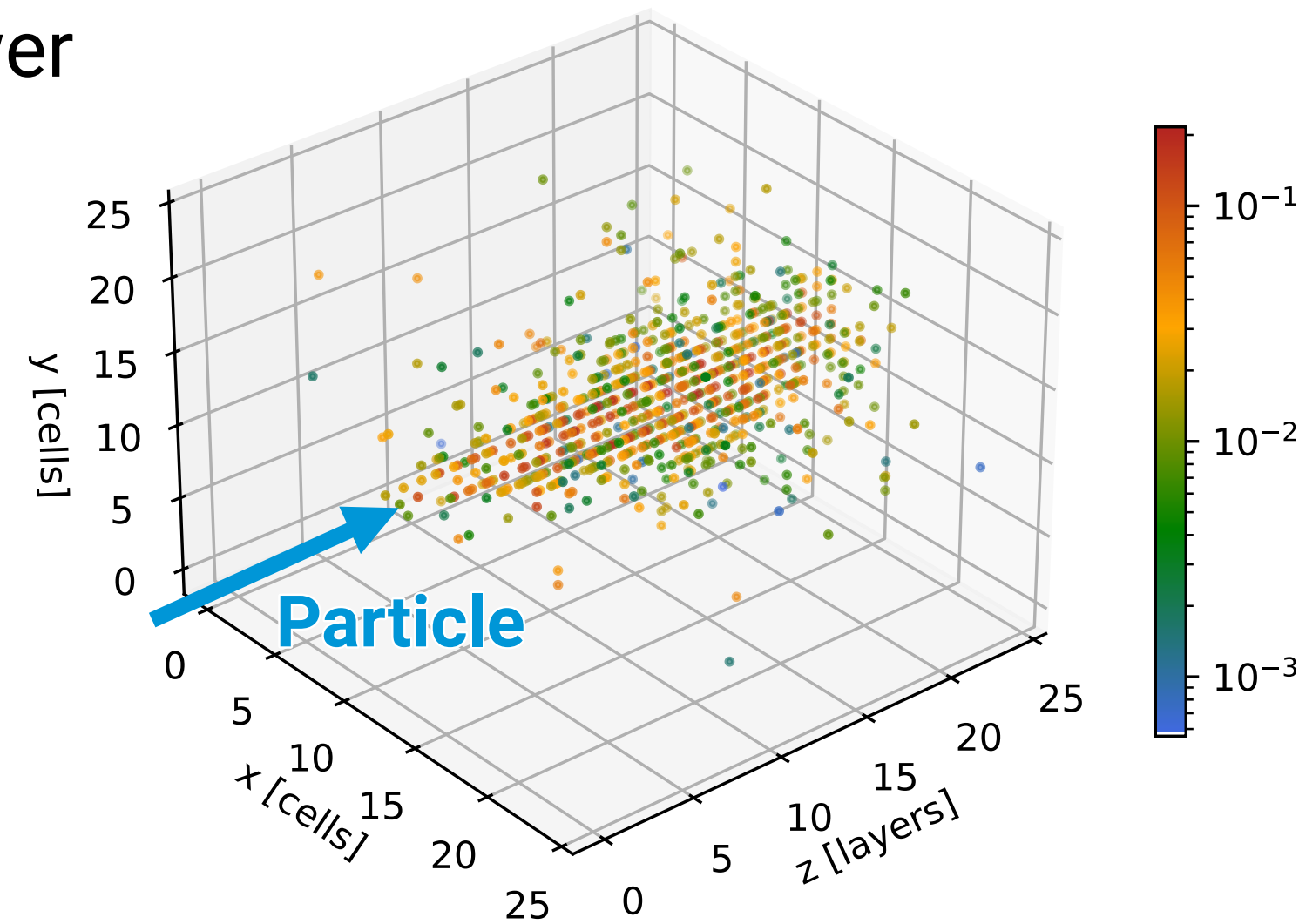


Precise Quantum Angle Generator Designed for Noisy Quantum Devices

S. Monaco^{1,2}, F. Rehm³, S. Vallecorsa³, M. Grossi³, K. Borras^{1,2}, D. Krücker¹, S. Schnake^{1,2}
¹DESY, ²RWTH Aachen University, ³CERN

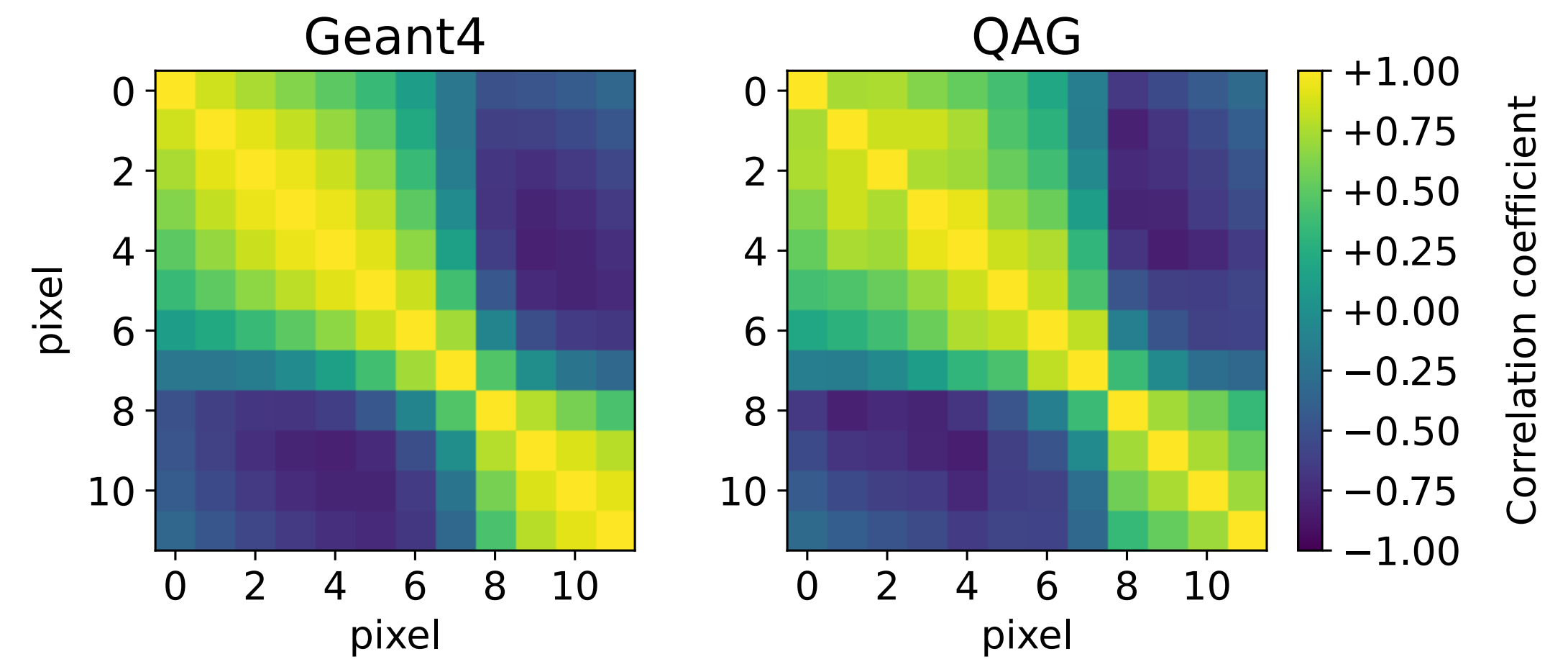
Quantum Angle Generator

- 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}).

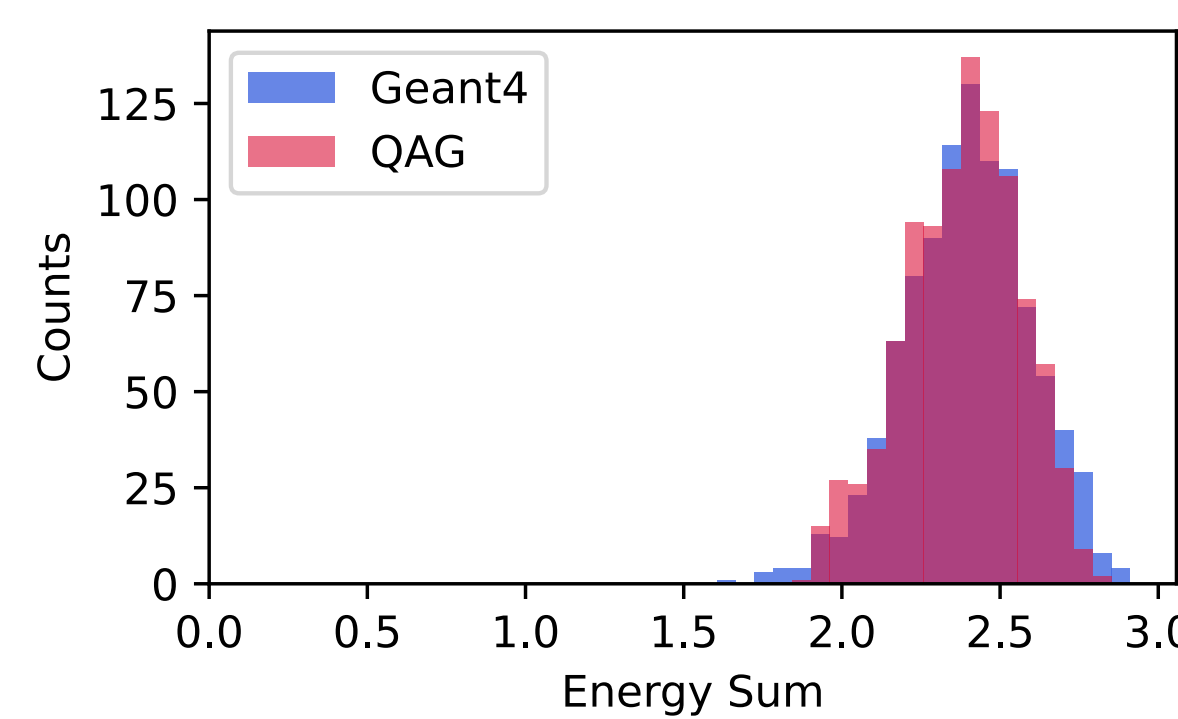


Inference evaluation

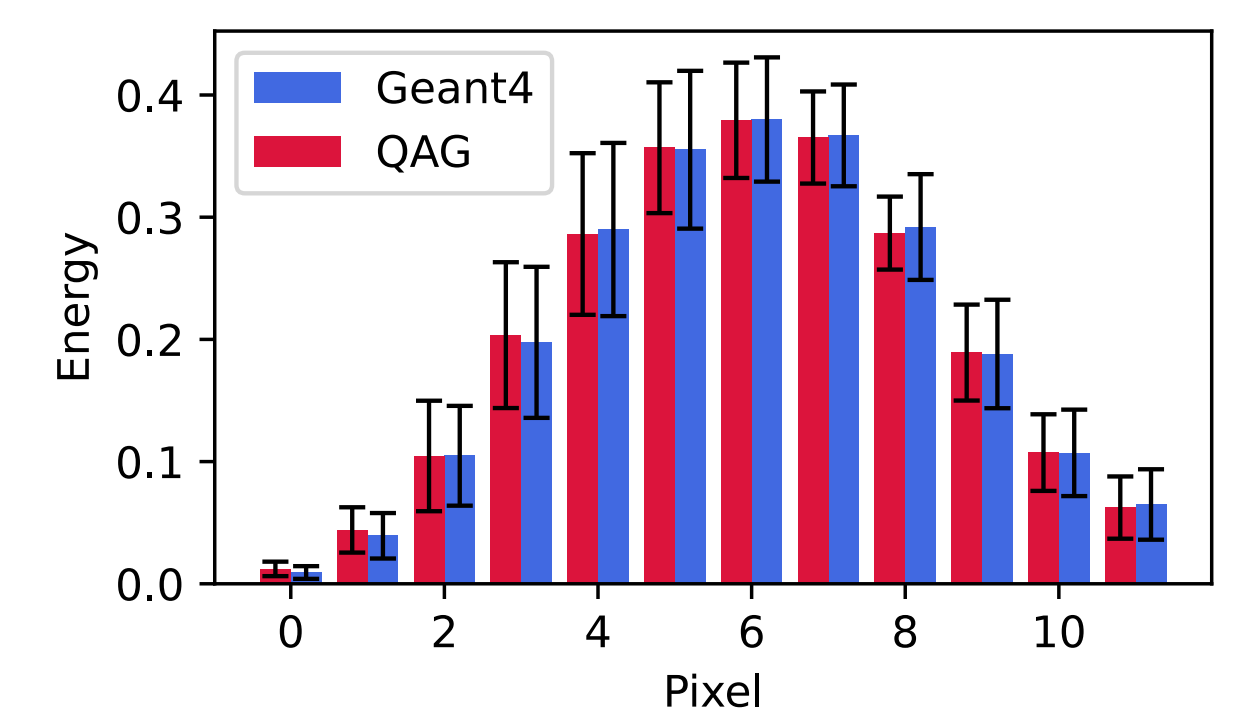
Correlations:



Total energy:

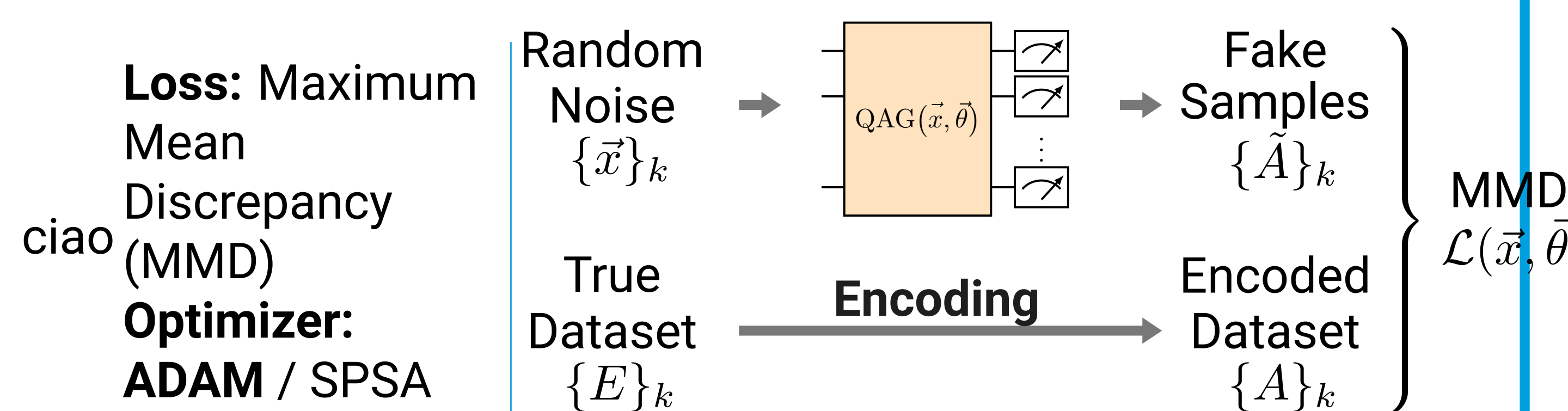


Energy average:

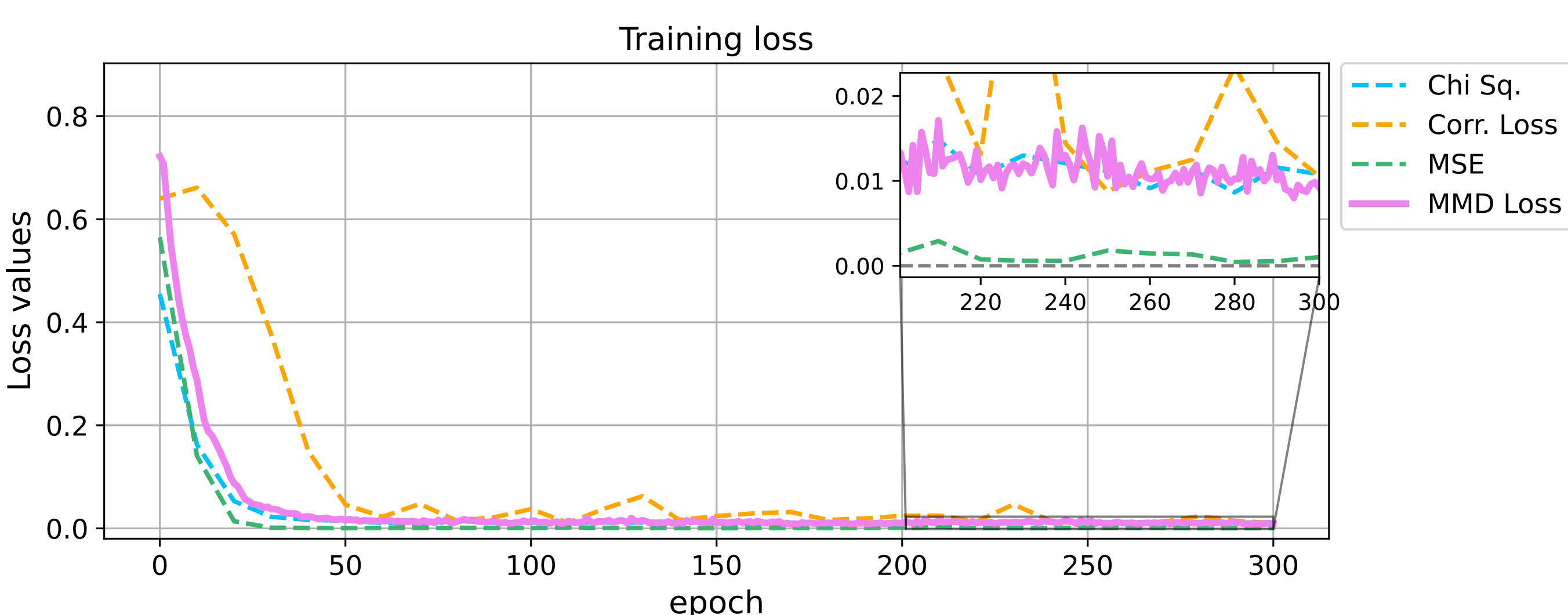


★ The model successfully captures pixel correlations and accurately reproduces the expected energy distributions

Training evaluation



Loss function:

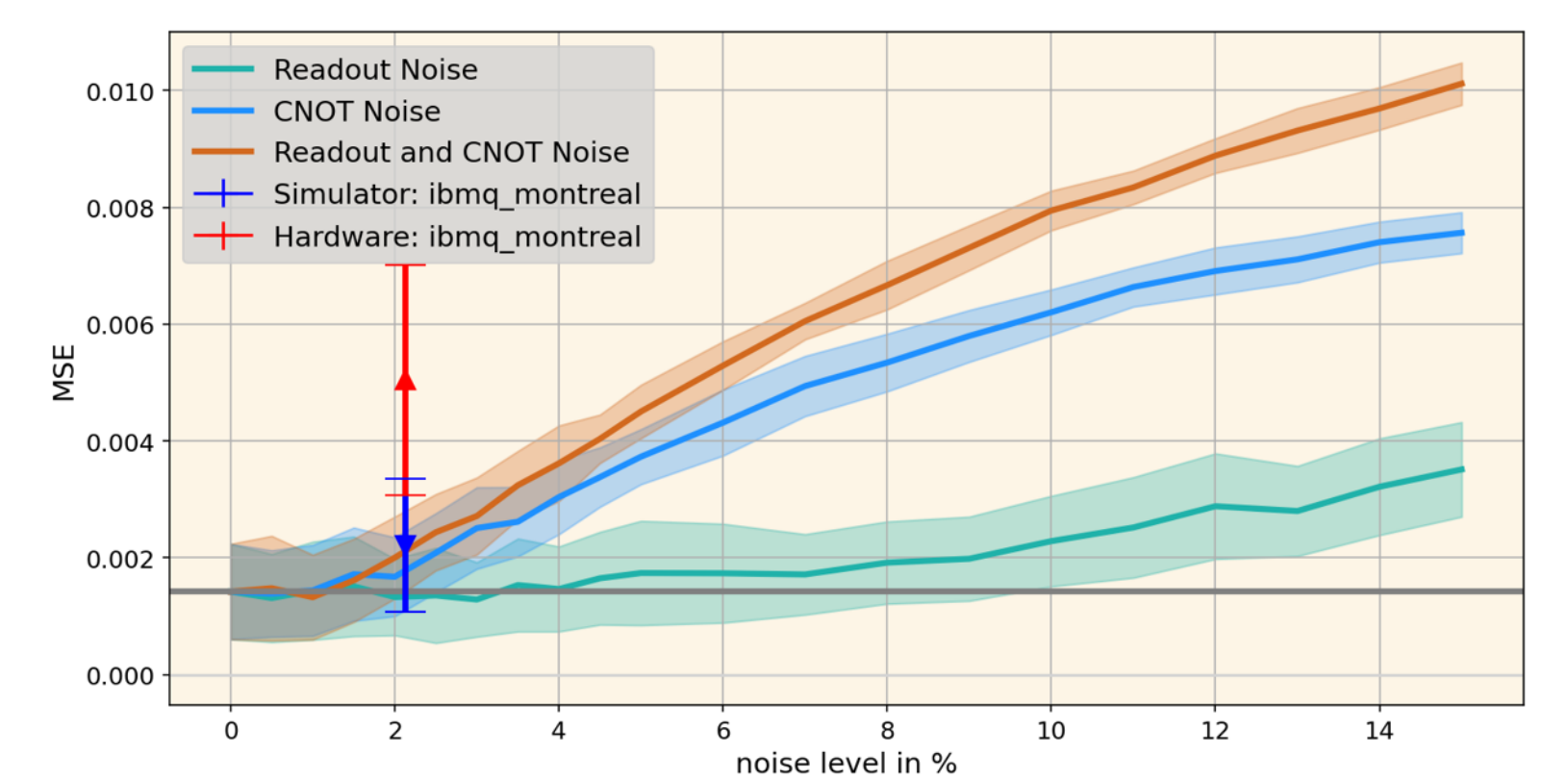


★ **Stable training and fast convergence**, MMD loss is able to effectively learn **correlations between pixels**

Noise study

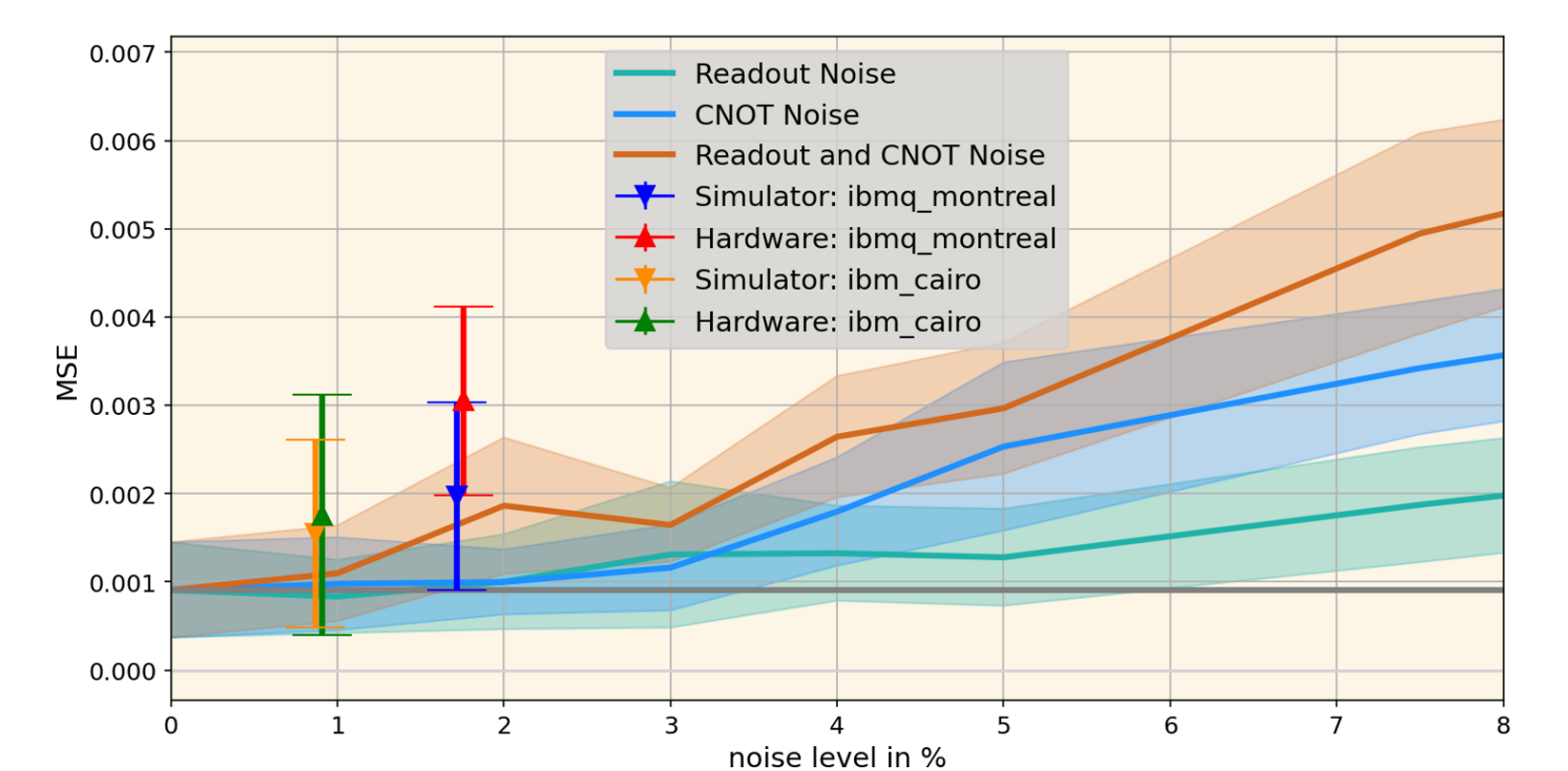
Inference:

- 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

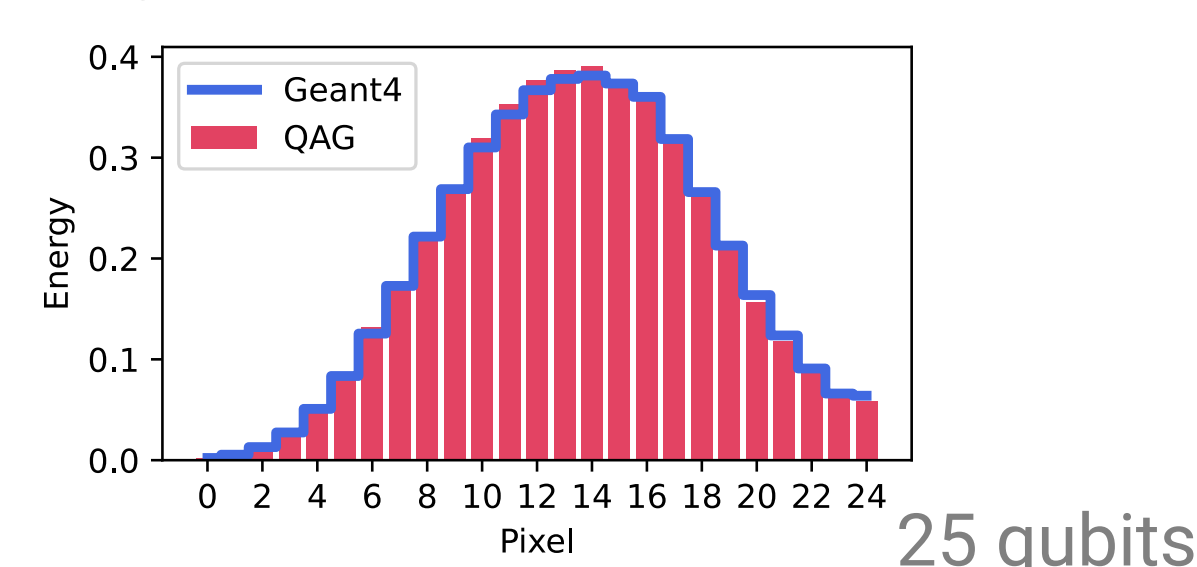


★ Significantly higher accuracies for the models trained on noisy instances. The model is capable to **adapt to the underlying noise**

Current projects

Upcoming improvements:

Increase in number of qubits through *approximate methods*



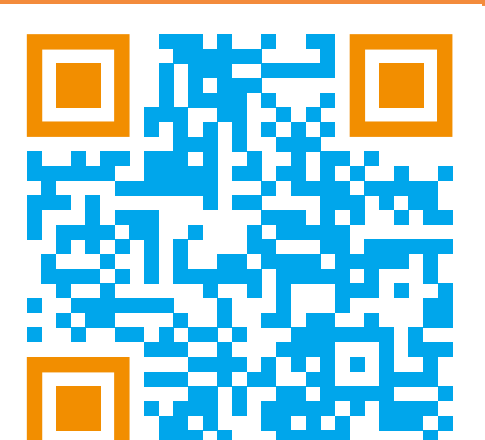
Implementation on hardware:

IQM **IBM**
 Supercond. QC Supercond. QC
electron
 Ion-trap QC

References

- [1] Florian Rehm: *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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