Precise Quantum Angle Generator Designed for Noisy Quantum Devices.

Florian Rehm[1,2], Sofia Villacorsa[1], Michele Grossi[1], Kerstin Borras[2,3], Dirk Krücker[3], Simon Schnake[2,3], Alexis-Harilaos Verney-Provatas[2,3], **Valle Varo[3]**

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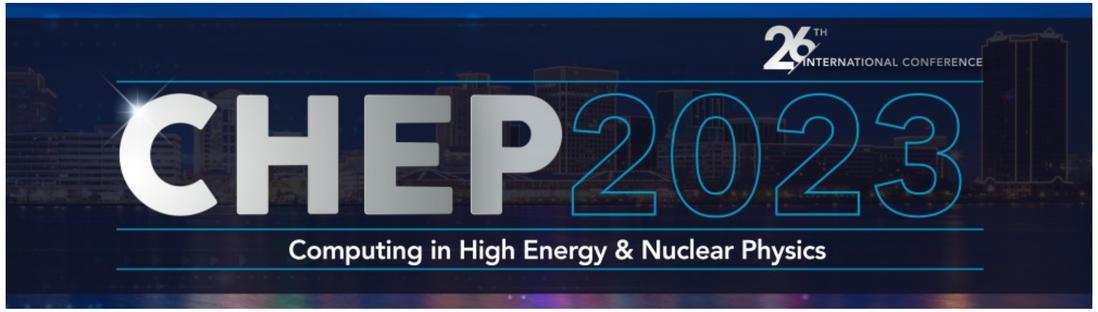

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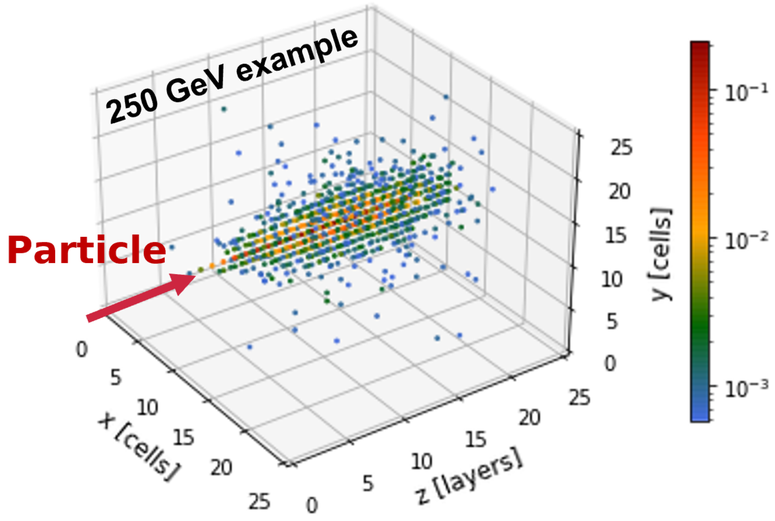
1. Use Case

- Simulate calorimeter showers in the forward detector region with 200 pile-up events at HL-LHC.
- Training and test datasets both consisting of 10000 samples each of eight-pixel images recorded by electrons within the energy range of [225, 275] GeV.



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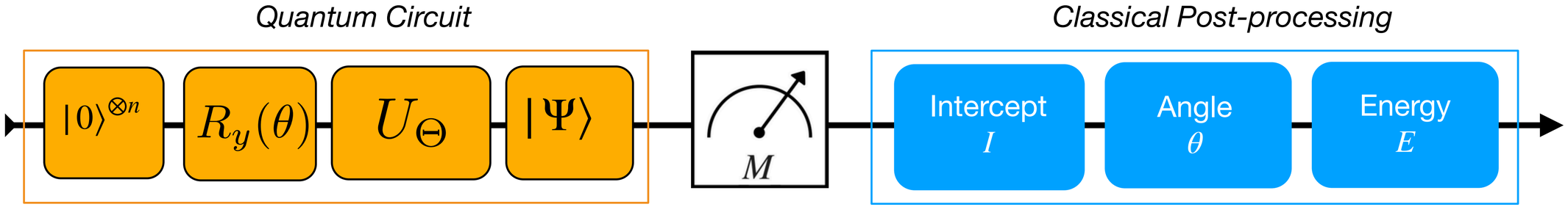
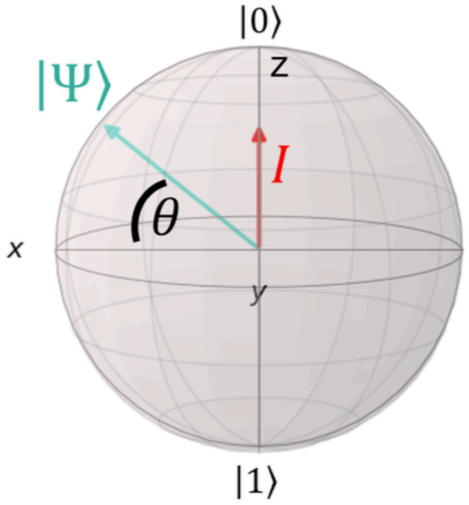
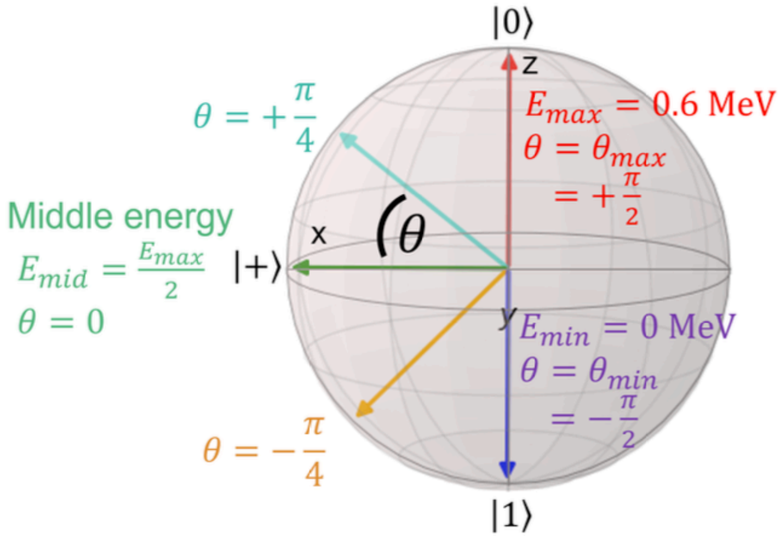
2. QAG Model

- Fully quantum generative model based on variational quantum circuits.
- Sample from noise and turn rotational angle of a qubit into pixel energy.







$$I = 2 \cdot \frac{\text{counts}\,|0\rangle}{\text{nb}_{shots}} - 1$$

$$\theta = \arcsin(I)$$

$$E = \frac{\text{E}_{max}}{2\theta_{max}}(\theta + \theta_{max})$$

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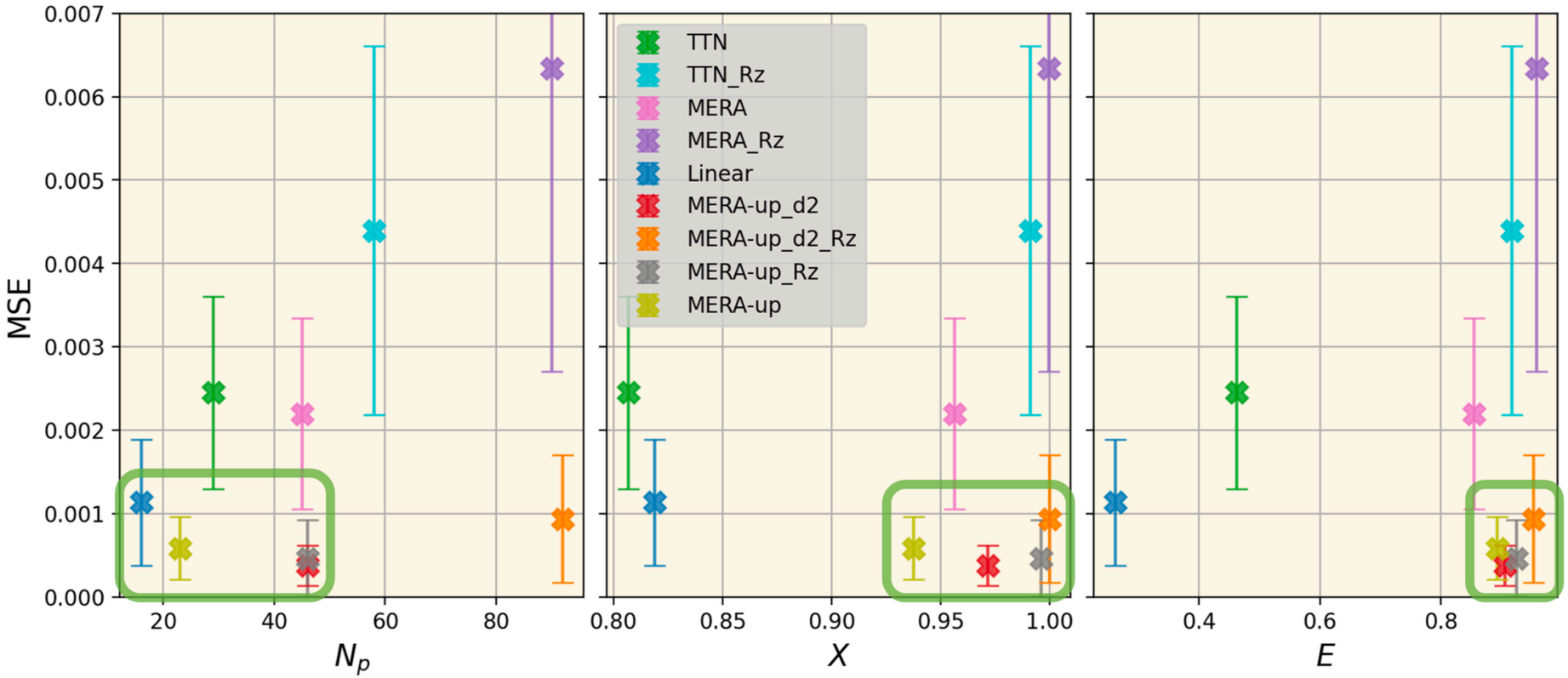
3. Architecture

- When only a limited number of qubits are available, our study favours the **MERA-up circuit**, a MERA (Multi-scale Entanglement Renormalization Ansatz) inspired topology. (shorten)



trainable parameters | expressibility | entanglement capability

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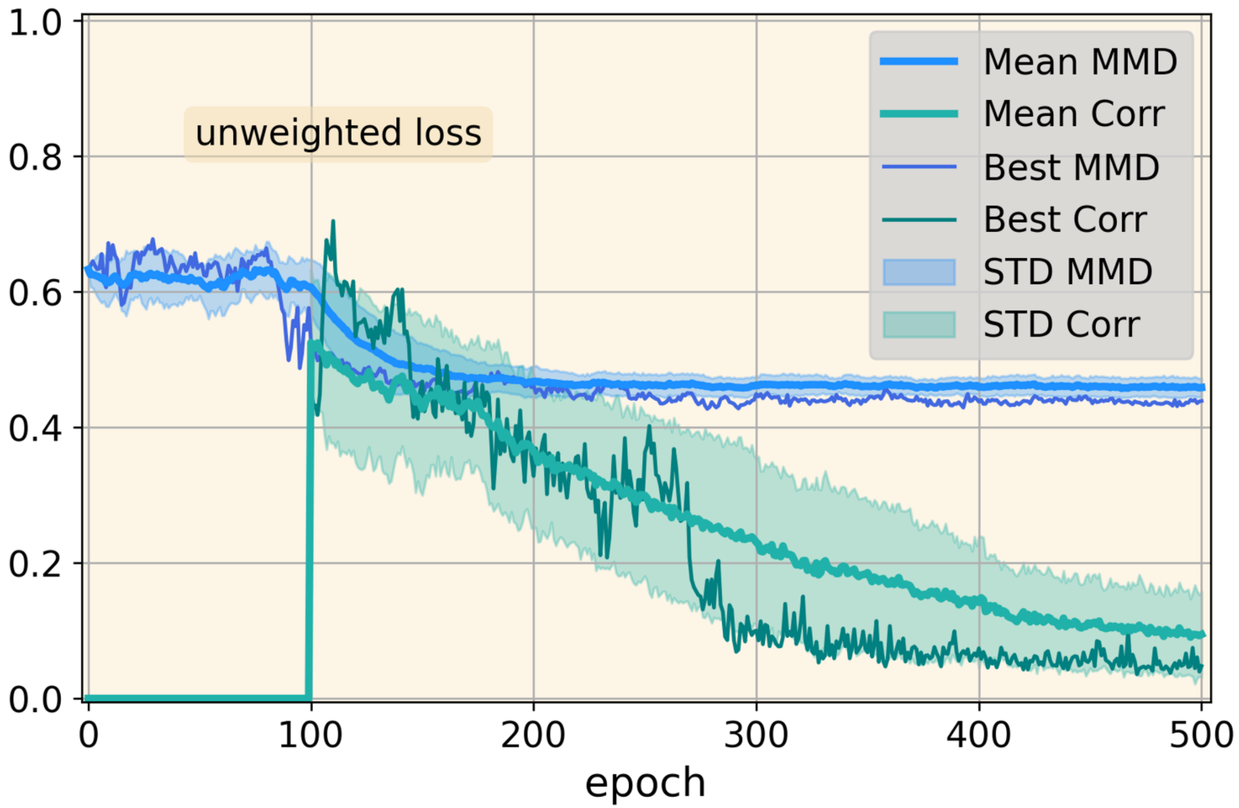
4. Training

- **Loss:** Mean Maximum Discrepancy (MMD)* + Correlation (Corr)**
- **Optimiser:** Simultaneous Perturbation Stochastic Approximation (SPSA).



*Greton et al. 2012

**Corr loss = MSE (between G4/QAG) of the pixel-pixel correlations)

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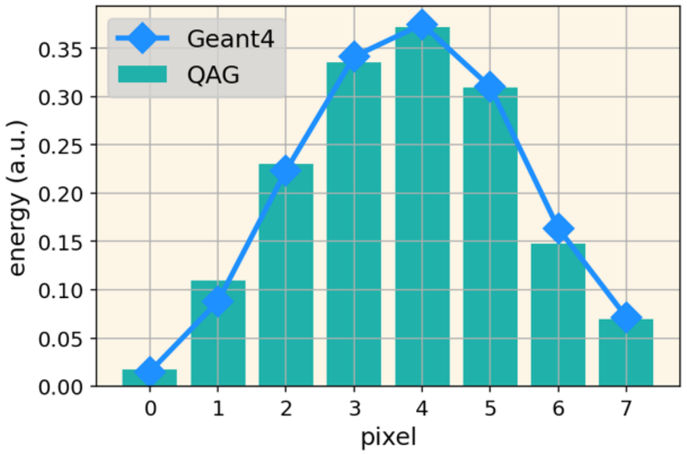
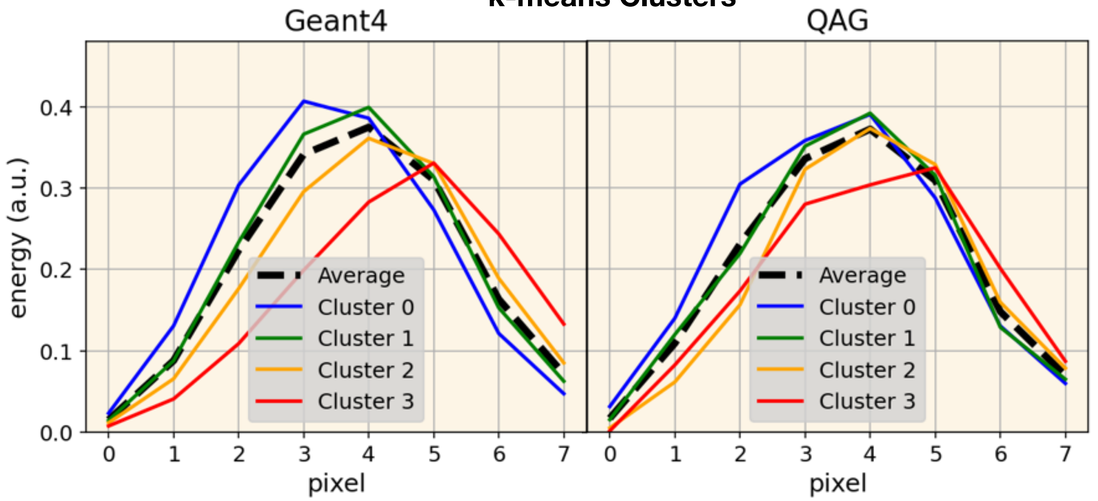
5. Inference

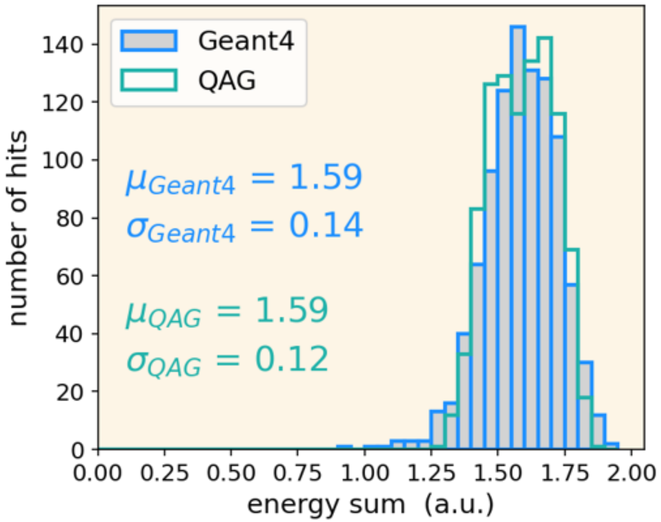
Average Calorimeter shower shape



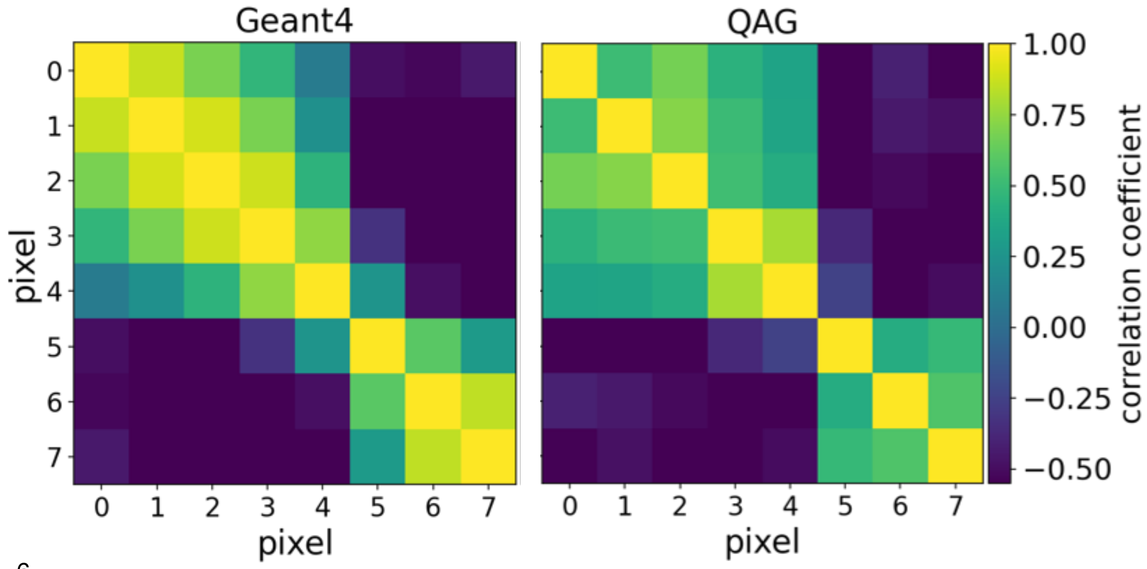
k-means Clusters



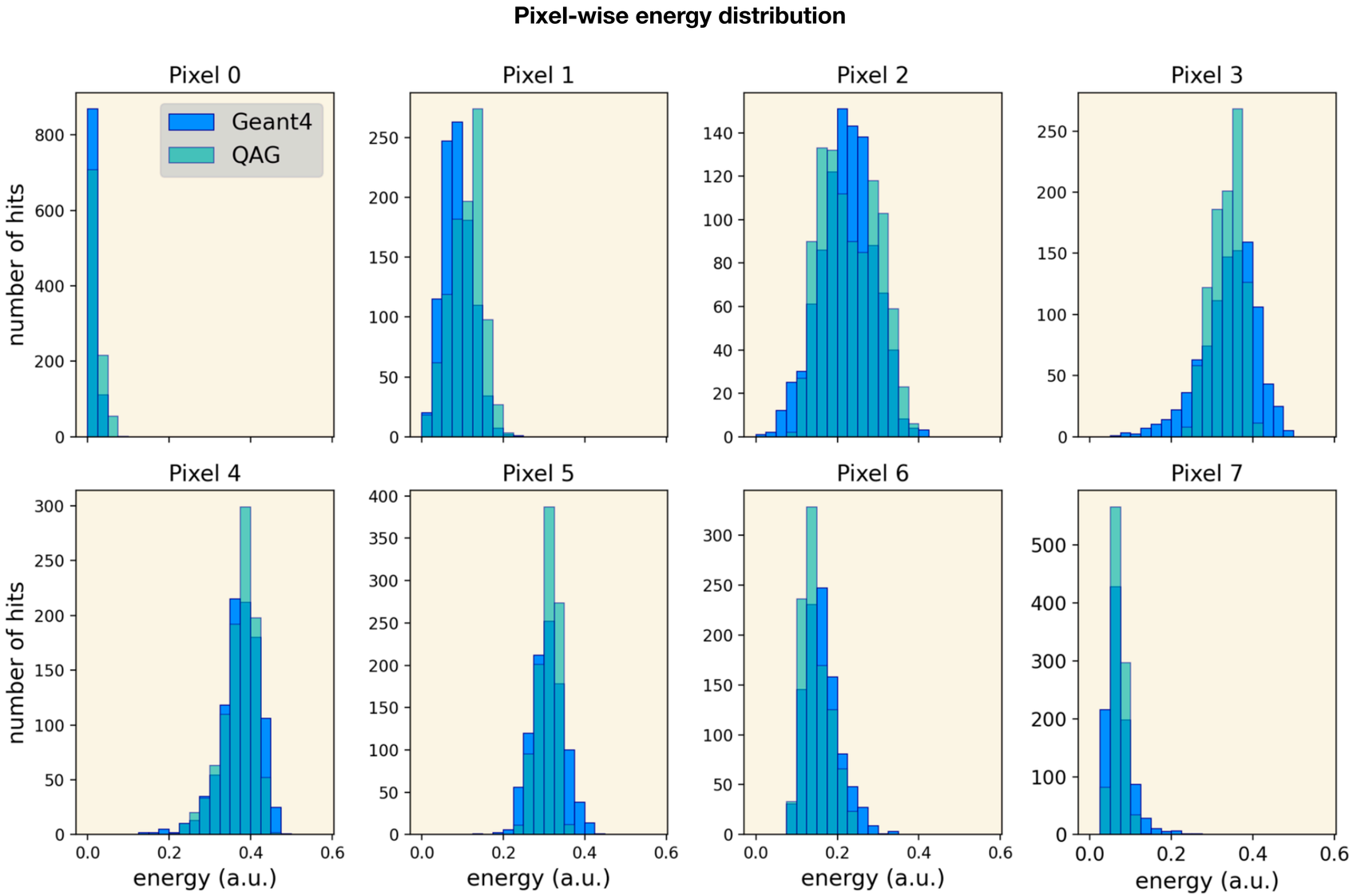
Energy Sum



Pixel-wise correlation



5. Inference



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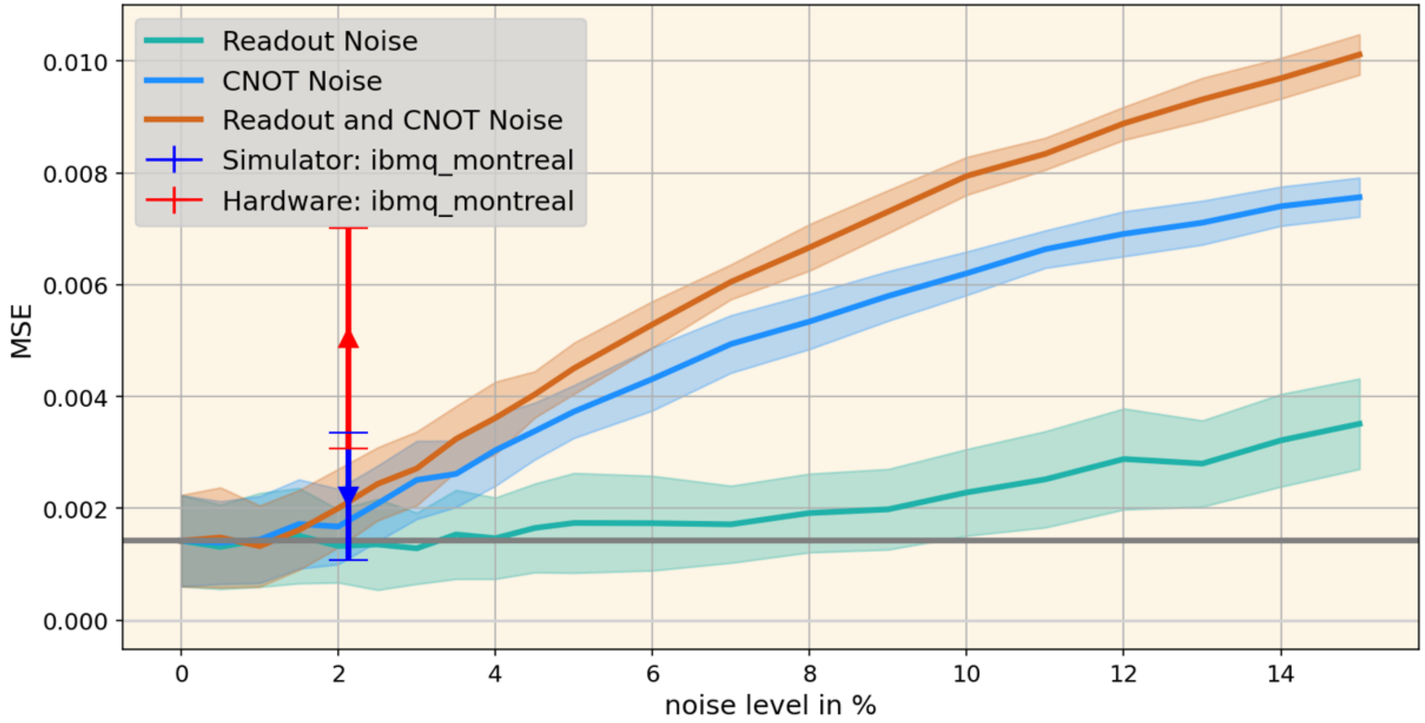
6. Quantum Noise Study

Inference

- Train baselines **W/O** noise -> Select best -> Inference w/ noise
- Types of noise: simulated fake / simulated hardware / real quantum hardware.



Training w/o noise ⟶ susceptible

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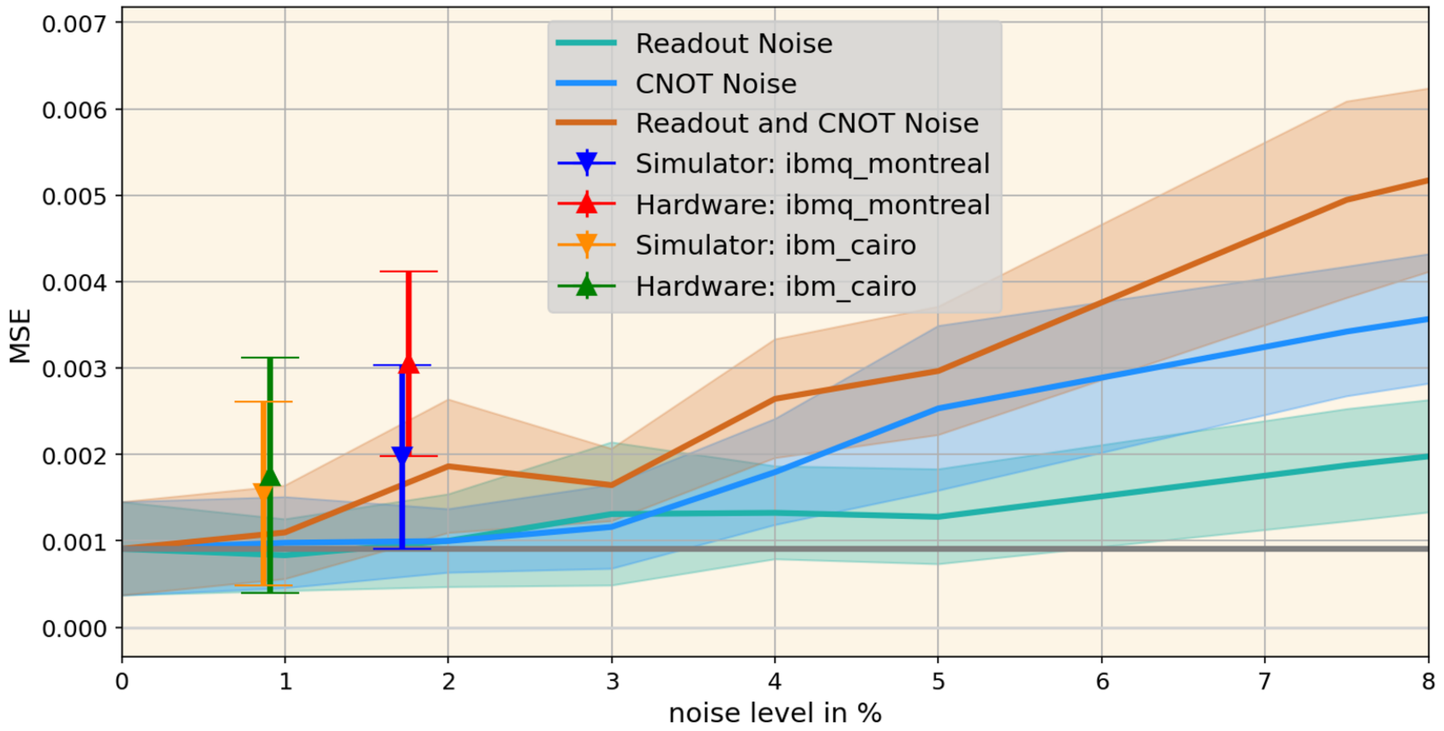
6. Quantum Noise Study

Training

- Train baselines **W/** noise -> Select best -> Inference w/ noise
- Two real hardware devices tested.



Training w/ noise ⟶ more robust.

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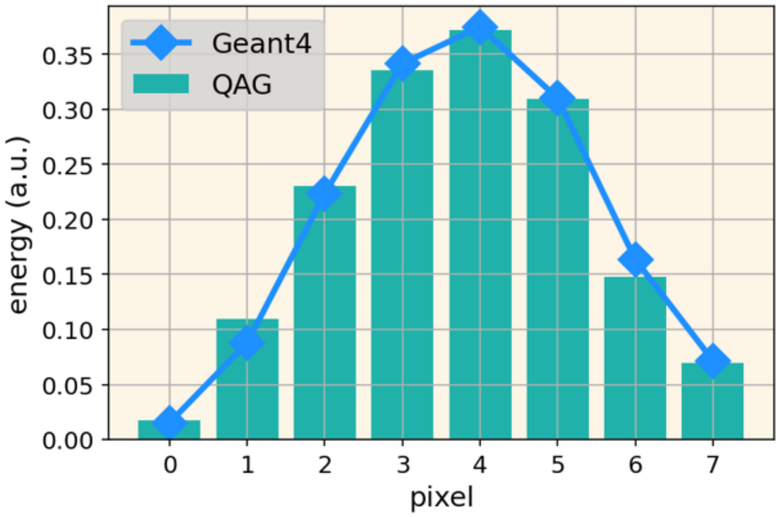
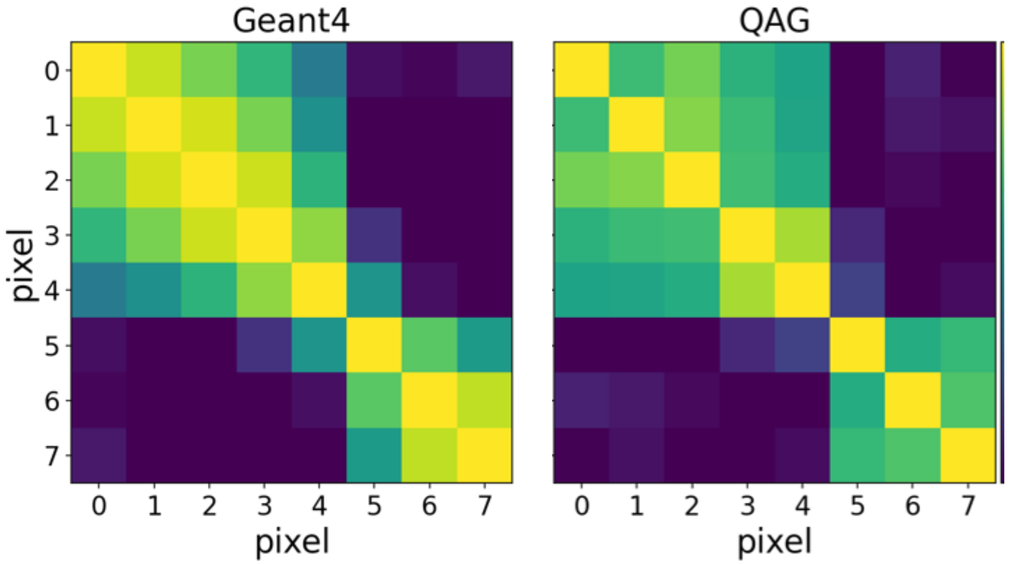
7. Conclusions

- The QAG model **generates high-quality images with good precision**, as validated by various metrics.
- Even when **fake quantum hardware noise** is added during inference, the model remains stable up to approximately **1.5% (inference) and 3% (training)**.
- When the noise-less trained model is used on real quantum hardware, there is a decrease in accuracy. However, **training the model on the actual hardware** allows it to learn and adapt to the noise characteristics, leading to **improved precision**.





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Thank you!

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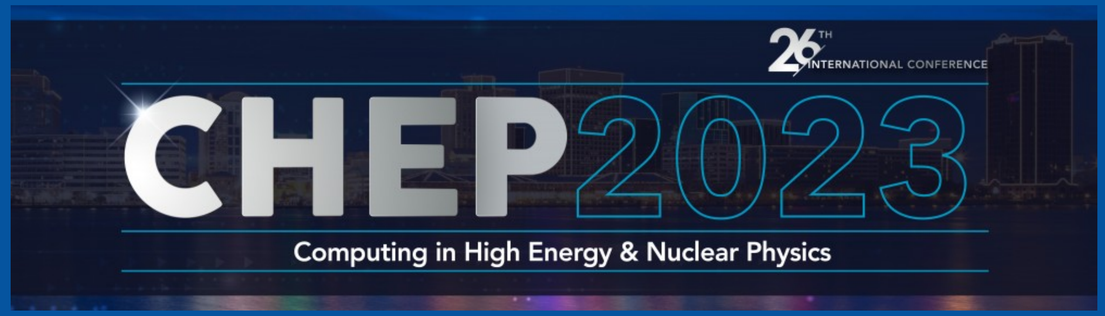

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