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Quantum Generative Modeling for Calorimeter Simulations in Noisy Quantum Device

Quantum-based generative models offer an alternative route for simulating intricate phenomena in high-energy physics. One notable example is the simulation of calorimeter showers, which involve highly stochastic and high-dimensional data crucial for determining particle types and reconstructing energy in experiments such as those conducted at the LHC. As the complexity and scale of these simulations grow, classical computing methods face increasing limitations, highlighting the potential of quantum strategies. In this work, we explore the capabilities of parameterized quantum circuits deployed on Noisy Intermediate-Scale Quantum (NISQ) platforms to replicate calorimeter shower patterns and evaluate their potential in practical applications.

A major component of the study is the impact of quantum noise—one of the key limitations in near-term quantum systems. Although variational circuits can partially mitigate such effects through training, the broader implications of noise in quantum generative modeling remain relatively underexplored. To address this, we introduce the Quantum Angle Generator (QAG), a variational quantum model trained with a Maximum Mean Discrepancy (MMD) loss function to generate images through the intrinsic probabilistic outputs of quantum circuits.

We carry out a thorough investigation of hyperparameters and benchmark QAG against a standard feed-forward neural network, comparing their respective performance under different noise conditions. Our results, based on both simulation and execution on real quantum hardware, indicate that QAG models trained directly on quantum devices can adapt to hardware-induced noise, resulting in stable and high-quality outputs even under significant noise levels and calibration variability.

Secondary track

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