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Quantum Invertible Neural Networks for Fast Calorimetry as Quantum Generative Model with high interpretability at Future Colliders

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Future collider experiments will require fast, scalable, and highly accurate calorimeter simulation to cope with unprecedented event rates and detector granularity. While machine-learning-based simulation has become a central strategy, the next step may come from quantum-native generative models capable of learning expressive, bijective mappings between physics parameters and detector observables. In this work we explore the feasibility of such an approach through a fully quantum-inspired generative framework based on Quantum Invertible Neural Networks (qINN), an architecture that remains largely unexplored in high-energy physics.
The qINN model provides a reversible transformation between input kinematic variables and calorimeter shower observables, enabling explicit likelihood evaluation and enhancing interpretability, an increasingly valuable feature for, and not only, detector design studies. The framework is developed and validated using ATLAS fast calorimeter simulation (fastCaloSim) software and runs on ATLAS open data, ensuring full reproducibility and allowing easy adaptation to different detector concepts in sight of future colliders application. Moreover, its structure accords to the current best-performing algorithm in fastCaloSim which takes advantage of a classical INN core.
We present methodology, software integration, and initial performance studies on both energy deposition and shower shape generation, focusing on fidelity, robustness, and scalability with respect to detector geometry and granularity. Early results demonstrate the promise of qINN-based generative models as a foundation for quantum-enhanced fast calorimeter simulation, opening a pathway toward simulation tools tailored for next-generation collider detectors.

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