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Quantum Diffusion Models for HEP

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Diffusion models have recently emerged as powerful generative tools, capable of learning and synthesizing high-dimensional data distributions. In high-energy physics (HEP), these models provide an innovative route to address complex inverse problems—most notably, reconstructing the true particle-level signals from detector-smeared measurements. Traditional unfolding methods, which attempt to invert detector effects, often struggle with high-dimensional correlations and tend to depend on strong prior assumptions. In contrast, diffusion models employ an iterative denoising process that transforms random noise into samples drawn from the target distribution, thereby naturally capturing the intricate structures and uncertainties of HEP data. This inherent flexibility positions diffusion models as promising candidates for both simulating realistic detector responses and enhancing analysis techniques for precise signal recovery.
In our approach, we propose to harness the potential of analog quantum computing to construct a quantum diffusion framework. This framework is designed to emulate the iterative denoising process of classical diffusion models within a quantum setting, leveraging the analog quantum system's natural ability to perform continuous transformations and process complex, high-dimensional data. Central to our method is Quantum Reservoir Computing (QRC), which utilizes the rich, nonlinear dynamics of a high-dimensional quantum reservoir to effectively denoise noisy inputs.
We study the impact of channeling the data through this reservoir, and we anticipate that the quantum system can filter out unwanted noise requiring fewer denoising steps and simpler network architectures compared to classical approaches.

Secondary track

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