

Quantum Computing for HEP Theory and Phenomenology

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Quantum computing offers an exponential speed-up in computation times and novel approaches to solve existing problems in high energy physics (HEP). Current attempts to leverage a quantum advantage include:

- **Simulating field theory:** Most quantum computations in field theory follow the algorithm outlined in [1–3]: a non-interacting initial state is prepared, adiabatically evolved in time to the interacting theory using an appropriate Hamiltonian, adiabatically evolved back to the free theory, and measured. Promising advances have been made in the encodings of lattice gauge theories [4–8]. Simplified calculations have been performed for particle decay rates [9], deep inelastic scattering structure functions [10, 11], parton distribution functions [12], and hadronic tensors [13]. Calculations of non-perturbative phenomena and effects are important inputs to Standard Model predictions. Quantum optimization has also been applied to tunnelling and vacuum decay problems in field theory [14, 15], which might lead to explanations of cosmological phenomena.
- **Showering, reconstruction, and inference:** Quantum circuits can in principle simulate parton showers including spin and color correlations at the amplitude level [16, 17]. Reconstruction and analysis of collider events can be formulated as quadratic unconstrained binary optimization (QUBO) problems, which can be solved using quantum techniques. These include jet clustering [18], particle tracking [19, 20], measurement unfolding [21], and anomaly detection [22].
- **Quantum machine learning:** Quantum machine learning has evolved in recent years as a subdiscipline of quantum computing that investigates how quantum computers can be used for machine learning tasks [23, 24]. As summarized in [25], only a few *bona fide* applications of quantum machine learning in a high energy physics setting have appeared: for event classification [26–28] and exploratory studies of track reconstruction [29, 30].

While the current impact of quantum computing on HEP theory and phenomenology is limited, there is hope that future advances on both quantum devices and quantum algorithms will help alleviate the anticipated computational crunch in high-energy particle physics. In the planned white paper we shall try to identify promising opportunities for further applications of quantum computing in HEP theory and phenomenology, with specific emphasis on event generators and simulations.

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