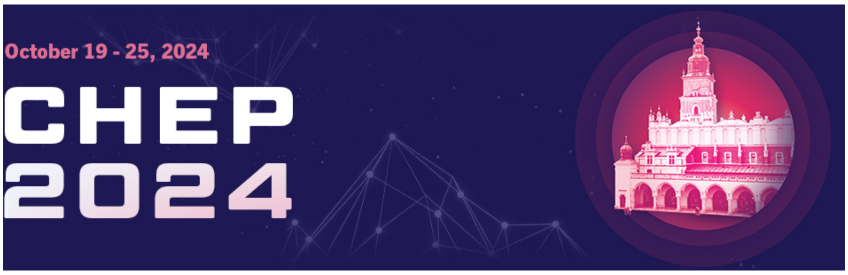

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From Hope to Heuristic: Realistic Runtime Estimates for Quantum Optimisation in NHEP

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Noisy intermediate-scale quantum (NISQ) computers, while limited by imperfections and small scale, hold promise for near-term quantum advantages in nuclear and high-energy physics (NHEP) when coupled with co-designed quantum algorithms and special-purpose quantum processing units.
Developing co-design approaches is essential for near-term usability, but inherent challenges exist due to the fundamental properties of NISQ algorithms.
In this contribution we therefore investigate the core algorithms, which can solve optimisation problems via the abstraction layer of a quadratic Ising model or general unconstrained binary optimisation problems (QUBO), namely quantum annealing (QA) and the quantum approximate optimisation algorithm (QAOA).
Applications in NHEP utilising QUBO formulations range from particle track reconstruction, over job scheduling on computing clusters to experimental control.
While QA and QAOA do not inherently imply quantum advantage, QA runtime for specific problems can be determined based on the physical properties of the underlying Hamiltonian, albeit it is a computationally hard problem itself.

Our primary focus is on two key areas:
Firstly, we estimate runtimes and scalability for common NHEP problems addressed via QUBO formulations by identifying minimum energy solutions of intermediate Hamiltonian operators encountered during the annealing process.
Secondly, we investigate how the classical parameter space in the QAOA, together with approximation techniques such as a Fourier-analysis based heuristic, proposed by Zhou et al. (2018), can help to achieve (future) quantum advantage, considering a trade-off between computational complexity and solution quality.
Our computational analysis of seminal optimisation problems suggests that only lower frequency components in the parameter space are of significance for deriving reasonable annealing schedules, indicating that heuristics can offer improvements in resource requirements, while still yielding near-optimal results.

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