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Improvements on QAOA for Particle Trajectories at LHCb

Wednesday 10 September 2025 11:00 (30 minutes)

Reconstructing the trajectories of charged particles as they traverse several detector layers is a key ingredient for event reconstruction at LHC and virtually any particle physics experiment. The limited bandwidth available, together with the high rate of tracks per second O(10ˆ10) - where each track consists of a variable number of measurements - makes this problem exceptionally challenging from the computational perspective. With this in mind, Quantum Computing is being explored as a new technology for future detectors, where larger datasets will further complicate this task [1].

Several quantum algorithms have been explored in this regard - e.g., Variational algorithms and HHL [2][3] - offering a heterogeneous set of advantages and disadvantages. In this talk, an extensive study using the Quantum Approximate Optimization Algorithm (QAOA) for track reconstruction at LHC will be presented. This algorithm is focused on finding the ground state for combinatorial problems, thus making it a natural choice. Furthermore, the robustness of QAOA to hardware noise when compared to other algorithms makes it a good candidate for the near-term utility era in Quantum Computing. In this talk, implementations with simplified simulations will be presented, both for QAOA and a modified version of the algorithm that could improve performance in comparison with Quantum annealers as per recent Q-CTRL results [4]. Finally, a complete study of hardware requirements, prospects on improving scalability, and energy consumption for different technologies will also be discussed.

[1] QC4HEP Working Group, A. Di Meglio, K. Jansen, I. Tavernelli, J. Zhang et al., Quantum Computing for High-Energy Physics: State of the Art and Challenges. Summary of the QC4HEP Working Group, PRX Quantum 5 (2024) 3, 037001, arXiv:2307.03236 (2023).
[2] A. Crippa, L. Funcke, T. Hartung, B. Heinemann, K. Jansen, A. Kropf, S. Kühn, F. Meloni, D. Spataro, C. Tüysüz, Y. C. Yap, Quantum Algorithms for Charged Particle Track Reconstruction in the LUXE Experiment, Comput Softw Big Sci 7, 14, arXiv:2304.01690 (2023).
[3] D. Nicotra, M. Lucio Martinez, J. A. De Vries, M. Merk, K. Driessens, R. L. Westra, D. Dibenedetto, D. H. Campora Perez, A quantum algorithm for track reconstruction in the LHCb vertex detector, JINST 18 P11028 (2023).
[4] N. Sachdeva, G. S. Hartnett, S. Maity et al., Quantum optimization using a 127-qubit gate-model IBM quantum computer can outperform quantum annealers for nontrivial binary optimization problems,arXiv:2406.01743v4 (2024)

Significance

This reports shows an extensive research on QAOA's scalability and sustainibility assessment when applied to track reconstruction in particle physics, building on previous results where these features were a bottleneck.

References

Experiment context, if any

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