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1 Particle - 1 Qubit: Particle Physics Data Encoding for Quantum Machine Learning

Wednesday 9 July 2025 09:55 (17 minutes)

We present 1P1Q, a novel quantum data encoding approach tailored specifically for particle physics, where each particle in collision events is mapped onto an individual qubit. This method bypasses classical data compression, enabling direct and lossless representation of event-level kinematic details on quantum devices. We showcase the effectiveness of 1P1Q in two key quantum machine learning (QML) applications: unsupervised anomaly detection using a Quantum Autoencoder (QAE) and supervised classification employing a Variational Quantum Circuit (VQC).

Our results highlight that the QAE significantly outperforms classical autoencoders in distinguishing signal jets from background Quantum Chromodynamics (QCD) jets, achieving superior performance with dramatically fewer trainable parameters. Meanwhile, the VQC achieves competitive performance comparable to state-of-the-art classical methods such as Particle Transformer, yet requires minimal computational complexity and significantly fewer parameters. Additionally, we demonstrate, for the first time, successful validation of the QAE using real experimental data from the CMS detector at the LHC, confirming the practical applicability and robustness of our quantum models.

These results underscore the potential of the 1P1Q encoding strategy as a powerful and scalable quantum framework for analyzing high-energy collider data, allowing for a clear pathway towards the integration of quantum computing techniques within particle physics analyses.

Secondary track

T16 - AI for HEP (special topic 2025)

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