Unsupervised Beyond-Standard-Model Event Discovery at the LHC with a Novel Quantum Autoencoder

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One of the main goals of High-energy physics (HEP) research at the LHC is to discover new physics phenomena in collision events. Traditional unsupervised machine learning methods trained on Standard Model processes have been employed for this purpose. With the LHC transitioning to its high-luminosity phase, the need for efficient data processing algorithms becomes critical. Quantum computing, particularly quantum machine learning (QML), is a promising field for addressing these challenges due to its potential computational advantages.

This study explores the potential of unsupervised anomaly detection for identifying physics beyond the Standard Model that may appear at proton collisions at the Large Hadron Collider. Our model for detecting anomalies within the kinematic data is the quantum autoencoder (QAE), which compresses quantum information into a smaller Hilbert space [1]. We introduce a novel quantum autoencoder (QAE) circuit ansatz designed specifically for this task and demonstrate its superior performance compared to previous approaches [2]. To assess its robustness, we evaluate the QAE on larger problem sizes and various types of new physics 'signal' events that have not yet been addressed in particle physics using QAEs. Additionally, we develop classical autoencoders (CAEs) that outperform previous QAEs but remain outpaced by the new quantum ansatz despite its significantly reduced number of trainable parameters. Finally, we investigate the properties of QAE circuits, focusing on entanglement and magic. We introduce a novel metric in the context of parameterised quantum circuits; stabiliser 2-Rényi entropy, to quantify magic [3], and the previously studied Meyer-Wallach measure for entanglement [4]. Intriguingly, both metrics decreased throughout the training process, along with the decrease in the loss function. This suggests that models preferentially learn parameters that reduce these metrics. This study highlights the potential utility of QAEs in searching for physics beyond the Standard Model at the Large Hadron Collider and opens exciting avenues for further research into the role of entanglement and magic in quantum machine learning, more generally.

The novel QAE circuit presented in this study offers a powerful tool for detecting BSM events at the LHC. Its superior performance, even with a reduced number of trainable parameters, highlights the potential advantages of quantum computing in HEP. The findings also contribute to understanding the roles of entanglement and magic in quantum machine learning, paving the way for further research in this exciting field.

References

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