Contribution ID: **177** Contribution code: **INSTR/SW** Type: **Poster**

Detection of Transient Gamma-Ray Bursts Signal through Quantum Convolutional Neural Network, A performance study and Benchmarking

Astrophysics, and specifically gamma-ray astronomy, are transitioning into an era characterized by vast and complex datasets. The ability to make new discoveries depends on the efficient and accurate analysis of this data, necessitating the adoption of innovative methodologies. Deep Learning has become increasingly vital in addressing astrophysical challenges, with its application expanding rapidly. However, the potential of Quantum Deep Learning in this field remains largely unexplored and offers a promising frontier for advancing data analysis capabilities.

On the other hand, efficient detection and analysis of Gamma-Ray Bursts (GRBs) are critical for advancing our understanding of these high-energy events. The Cherenkov Telescope Array (CTA) represents a new era in gamma-ray astronomy, equipped with over a hundred sensitive and fast-reacting Cherenkov telescopes. The CTA's real-time analysis software is designed to promptly generate science alerts and analyze observational data, making rapid and accurate GRB detection a priority.

In this study, we focus on enhancing the detection of GRB signals using Quantum Convolutional Neural Networks (QCNNs) on CTA simulation datasets. Building on previous research that demonstrated QCNNs' ability to accurately identify GRB signals in AGILE mission data, we apply and test various QCNN architectures to optimize their performance for the CTA.

We implemented hybrid quantum-classical machine learning models using Parametrized Quantum Circuits, and evaluated their performance through the Pennylane and Qiskit libraries. Our analysis explored different QCNN architectures and encoding methods, including Data Reuploading, Angle, and Amplitude encoding, to identify the most effective configurations.

We compared QCNNs with classical Convolutional Neural Networks (CNNs) to evaluate improvements in model complexity and accuracy. The study also examined how hyperparameters, such as the number of qubits and encoding strategies, affect model performance and stability. Our findings show that QCNNs can achieve comparable accuracy to classical approaches, exceeding 90% accuracy with fewer parameters. However, QCNNs currently lag in training time efficiency due to the developing state of quantum deep learning technologies.

This work highlights the potential of QCNNs for GRB detection in the CTA, paving the way for their integration into next-generation astrophysical research tools. By demonstrating the capabilities and limitations of QCNNs, we set the stage for future advancements in real-time gamma-ray signal detection and analysis.

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Session Classification: Poster hang