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Real-Time Classification of Higgs Boson Production Mechanisms for the ATLAS Trigger System Using FPGA-Optimized Machine Learning Models

The High-Luminosity Large Hadron Collider (HL-LHC) will demand highly efficient and fast data processing systems to handle unprecedented event rates. In this study, we present a novel approach to real-time classification of Higgs boson production mechanisms—focusing on gluon-gluon fusion (ggF) and vector boson fusion (VBF)—using machine learning (ML) models optimized for deployment on field-programmable gate arrays (FPGAs). Our goal is to enhance the ATLAS Level-0 trigger's ability to identify key physics signatures with minimal latency, improving the prioritization of events for detailed analysis.

We trained and validated lightweight ML models on simulated ATLAS datasets, leveraging high-level features such as jet kinematics, forward jet tagging, and missing transverse energy to distinguish ggF and VBF events. The models were quantized and converted to FPGA-compatible firmware using the hls4ml library. Resource utilization, latency, and accuracy were evaluated, achieving inference times well within the nanosecond-scale budget while maintaining classification performance comparable to traditional algorithms.

This study demonstrates the feasibility of implementing sophisticated ML algorithms in FPGA-based trigger systems, offering significant advancements in real-time event classification. By extending this framework, we aim to support a broader range of Higgs production mechanisms and refine searches for rare processes, contributing to the HL-LHC's discovery potential.

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