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Unsupervised Machine Learning for Anomaly Detection in LHC Collider Searches

Searches for new physics at the LHC traditionally use advanced simulations to model Standard Model (SM) processes in high-energy collisions. These are then compared with predictions from new-physics theories like dark matter and supersymmetry. However, despite extensive research, no definitive signs of physics beyond the Standard Model (BSM) have been found since the Higgs boson's discovery.

This lack of direct discoveries has motivated the development of model-independent approaches to complement existing hypothesis-driven analyses. Unsupervised machine learning offers a novel paradigm for collider searches, enabling the identification of anomalous events without assuming a specific new-physics model or prior theoretical expectations.

Anomaly detection has become an area of increasing interest in the high-energy physics (HEP) community [1]. Machine learning techniques provide a powerful framework for identifying events in data that deviate significantly from the expected background-only hypothesis. Unlike traditional supervised classification methods, which require labeled datasets where each event is assigned a known category (signal or background), anomaly detection methods operate in an unsupervised or weakly supervised manner. This allows them to learn from unlabeled data and detect deviations indicative of potential new physics.

A significant breakthrough in fully unsupervised machine learning has been reported by the ATLAS collaboration [2], where a Variational Recurrent Neural Network (VRNN) was trained directly on recorded jet data. This method establishes an anomaly detection signal region (SR) by selecting the hypothesized X particle based purely on its structural incompatibility with background jets.

Starting from the seminal work reported by the ATLAS collaboration [1] we will review the latest efforts in anomaly detection in fully hadronic final state within the ATLAS collaboration. Two main AD techniques will be discussed: Deep Transformer and Graph Anomaly Detection (EGAT, GIN). First results obtained with the LHC Olympics dataset are reported, along with their initial applications to search for high mass diboson resonances in fully hadronic final states using $\sqrt{s}$ = 13 TeV pp collisions with the ATLAS detector.

[1] The LHC Olympics 2020 a community challenge for anomaly detection in high energy physics, Rep. Prog. Phys. 84 (2021) 124201

[2] Phys. Rev. D 108 (2023) 052009

AI keywords

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Track Classification: Patterns & Anomalies