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Deep Learning reconstruction of neutral mesons from multiple calorimetric clusters in LHCf

In this work, we introduce a deep learning-driven strategy to enhance the reconstruction of neutral meson events in the Large Hadron Collider forward (LHCf) experiment. Located in the very forward region of the LHC, LHCf measures neutral particles produced at very small angles in proton-proton and proton-ion collisions, providing crucial input for modelling hadronic interactions in ultra-high energy cosmic ray air showers. A central difficulty for LHCf is the accurate and efficient reconstruction of neutral mesons from their decay photons. The mesons of interest, π^0 , η and K^0_s , predominantly decay into multiple photons, two for π^0 and η , and four for K^0_s via a secondary decay into two π^0 mesons, leading to high photon multiplicities, intricate event topologies, and overlapping calorimetric signatures. These effects severely challenge traditional reconstruction algorithms, which struggle to resolve nearby photon calorimetric clusters and consequently suffer degraded resolution and efficiency, especially for K^0_s reconstruction.

To address these issues, we design a deep learning pipeline composed of several specialized models arranged in sequential stages dedicated to event classification, particle identification, and regression of photon energies and impact positions. Each model exploits multimodal inputs that fully leverage the LHCf Arm2 detector design, combining calorimetric energy deposits with signals from the silicon tracking detectors. This multimodal approach significantly improves the determination of meson decay features, with particular gains in the treatment of complex K^0_s decays. The models are trained and tested on detailed Monte Carlo simulations that reproduce the Arm2 detector geometry and response, including realistic detector effects. Initial validation on simulated datasets demonstrates substantial performance improvements and underlines the strong potential of deep learning techniques for advancing event reconstruction in LHCf. These results enable more precise cosmic-ray physics studies and provide a solid foundation for future experimental applications.

This work has been carried out within the Spoke 2 as part of the activities in the Working Package 2 (“Tools and algorithms for Experimental Collider Physics”) under the flagship use-case “Flash Simulation and bleeding-edge Machine Learning applications”.

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