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Deep learning techniques for high-precision neutral meson reconstruction in the LHCf experiment

In this contribution, we present the machine learning-based strategy to improve the reconstruction of neutral meson events within the Large Hadron Collider forward (LHCf) experiment. The LHCf experiment is uniquely positioned in the very forward region of the LHC to investigate the hadronic interactions relevant to high-energy cosmic ray air shower simulations by measuring forward-produced neutral particles in proton-proton and proton-ion collisions at the LHC.

A primary challenge for the experiment is accurately and efficiently reconstructing neutral mesons from their decay photons. The particles of interest, specifically π^0, η and K^0_s, predominantly decay into multiple photons, two for π^0 and η mesons and four for K^0_s, produced via the secondary decay of two π^0 mesons. This increased photon multiplicity complicates event reconstruction, resulting in complex event topologies and overlapping calorimetric signals. Traditional reconstruction methods struggle to distinguish closely spaced photon clusters, reducing resolution and efficiency. These complexities are particularly pronounced in reconstructing K^0_s mesons due to the higher photon multiplicity from their secondary decay chain.

To overcome these limitations, we developed a deep learning pipeline comprising several models optimized for specific reconstruction tasks. The pipeline involves sequential stages for event tagging, particle identification, and precise estimation of photon energies and positions. Each model within this pipeline leverages multimodal input, fully exploiting the sensor design of the LHCf Arm2 detector. This multimodal strategy integrates calorimetric energy deposits and silicon tracking detector signals, enhancing the accuracy of meson decay vertex reconstruction, particularly for complex K^0_s events.

Models were trained and evaluated using detailed Monte Carlo simulations that replicate the geometry and response of the LHCf Arm2 detector, incorporating realistic detector effects. Preliminary validation results using simulated data demonstrate the effectiveness and promise of the deep learning approach developed. These findings highlight the significant potential of deep learning methods for enhancing event reconstruction capabilities in the LHCf experiment, opening new opportunities for precise studies in cosmic ray physics and laying the groundwork for further developments and applications in upcoming experimental analyses.

Secondary track

T05 - QCD and Hadronic Physics

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