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Overview of Machine Learning Applications at the Pierre Auger Observatory

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Running since 2004, the Pierre Auger Observatory remains the largest detector for extensive air showers induced by ultra-high-energy cosmic rays. The complex spatio-temporal information from shower footprints, comprised of particle arrival times and traces measured by water-Cherenkov detectors, is challenging to analyse with traditional methods but well-suited for machine learning based analyses. In this contribution, we provide an overview of the ML applications developed to leverage the high event statistics acquired by the Observatory. The deep learning methods that complement traditional analyses and introduce novel techniques to determine high-level shower observables are presented here.

One notable application is the prediction of the depth of shower maximum, X_{max}, allowing for high-statistics analysis of mass composition by studying the observable distribution as a function of energy. In the context of the energy spectrum, a neural network approach for energy reconstruction has demonstrated potential in reducing composition biases in the energy estimator. Aligned with AugerPrime, the ongoing upgrade of the Observatory, the impact of enhanced electronics and scintillation detectors was explored via simulations. Both transformers and convolutional networks are promising for the reconstruction of mass-composition sensitive observables like X_{max} and the muon number, demonstrating the benefits of the Observatory's upgrade.

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