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Deep Learning for Cosmic-Ray Observatories

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The Pierre Auger Observatory, located in the Argentinian Pampa, is the world's largest cosmic-ray experiment. It offers the most precise measurements of cosmic particles at ultra-high energies by measuring their induced air showers. The centerpiece of the Observatory is the surface detector (SD) consisting of over 1,660 water-Cherenkov detectors that cover an area of 3,000 km^2 and measure the arrival time distribution of shower particles at the ground. Due to its hybrid design, the SD array is overlooked by 27 fluorescence telescopes, enabling independent cosmic-ray measurements and the absolute calibration of the SD.
Traditionally, the analysis of the SD data is based on a few observables, such as the integrated signals of the signal traces or the arrival times measured at the different stations.

With the advent of deep learning unique potential for improved reconstructions emerged since the time-resolved signals can be exploited with unprecedented detail.
In this contribution, we will summarize the successful efforts of the Pierre Auger Collaboration in developing novel deep-learning-based strategies to improve event reconstruction and data analysis to shed new light on the composition and origin of cosmic rays. Furthermore, we will discuss employed strategies to improve the robustness of machine-learning models and methods to reduce the often-existing domain gap between training data and measured data taken under real operating conditions and estimate remaining systematic uncertainties.

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