Event-by-event reconstruction of the shower maximum X_{max} with the Surface Detector of the Pierre Auger Observatory using deep learning

Executive Summary

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What is this contribution about?

For the first time, a deep neural network (DNN) has been applied to reconstruct the atmospheric depth of shower maximum (X_{max}) using the data of the surface detector (SD) of the Pierre Auger Observatory.

Why is it relevant/interesting?

Measurements of X_{max}, the key observable for estimating the mass of the primary particle, are performed with fluorescence detectors (FD) having a duty cycle of 15%. Strict event selections required for the analysis of these measurements reduce the data set even more. Applying DNNs, X_{max} can be inferred with a high accuracy from SD data with nearly 100% duty cycle and very mild selection criteria, leading to a 10 – 15 times larger data set than the FD one.

What has been done?

We designed a DNN for the characteristics of the SD of the Pierre Auger Observatory and trained it on air showers simulated with the hadronic interaction model EPOS-LHC. The performance of the DNN was evaluated on various hadronic interaction models (EPOS-LHC, QGSJetII-04, Sibyll2.3). We used Auger hybrid events (reconstructed with both the SD and FD), to calibrate X_{max} from the DNN with X_{max} from the FD and determine the resolution of the new technique.

What is the result?

For energies above 30 EeV, the X_{max} reconstruction of the DNN is nearly unbiased with a resolution of 30 g/cm^2 (15 g/cm^2) for proton (iron). A bias was observed when applying the DNN — trained with EPOS-LHC — to simulations with other interaction models or Auger data. The biases can be removed by a calibration using hybrid measurements.

The DNN opens the possibility to gain new insights into the cosmic-ray composition up to the highest energies around 100 EeV, through the analysis of the data collected with the Pierre Auger Observatory over the last more than 15 years.

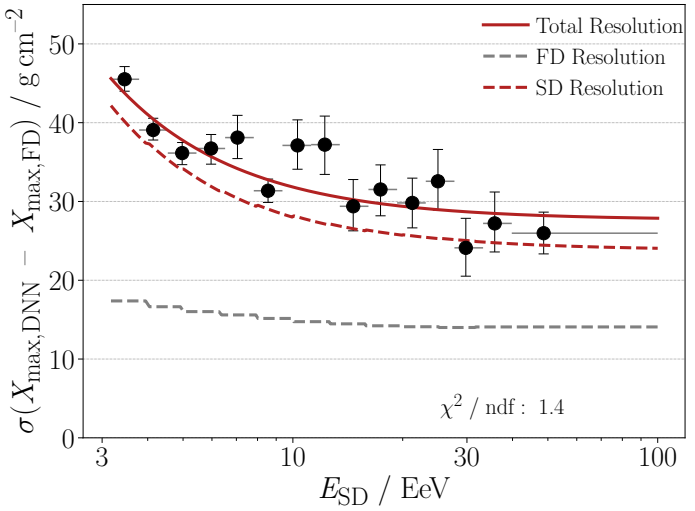

Figure 1: $\sigma(X_{\mathrm{max,DNN}} - X_{\mathrm{max,FD}})$ as a function of energy. Its fitted energy dependency is depicted as a continuous red line. The extracted resolution of the DNN is shown as a dashed red line after accounting for the resolution of the fluorescence detector (FD) (dashed grey line).