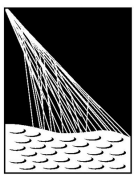
Extraction of the Muon Signals Recorded with the Surface Detector of the Pierre Auger Observatory using Recurrent Neural Networks

Juan Miguel Carceller [a] on behalf of the Pierre Auger Collaboration [b]

[a] University of Granada, Granada, Spain
[b] Observatorio Pierre Auger, Av. San Martín Norte 304, 5613 Malargüe, Argentina



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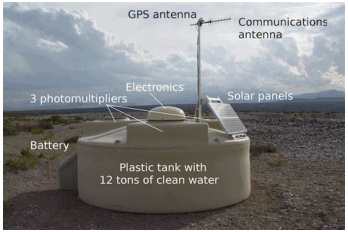
The Pierre Auger Observatory and the Surface Detector (SD)

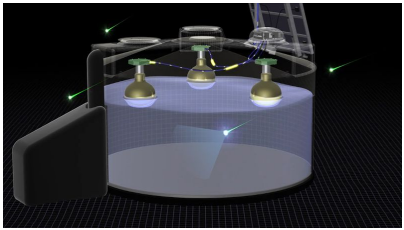
The Pierre Auger Observatory

- Hybrid detector: Surface Detector (SD) and Fluorescence Detector (FD)
- SD: 1660 surface detector stations located in a triangular array covering 3000 km^2
- FD: The array is overlooked by 27 fluorescence telescopes

The Surface Detector

- Measures the arrival time of secondary particles of the shower at the ground
- These particles emit Cherenkov radiation in water that can be detected with photomultiplier tubes
- Duty cycle $\sim 100\%$





The Muon Component

The total signal has contributions from the muon and electromagnetic component (e^-, e^+ and γ)

Muon component

- Earlier times
- Spiky

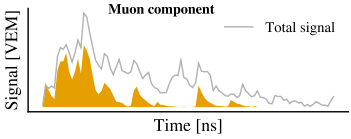
Electromagnetic component

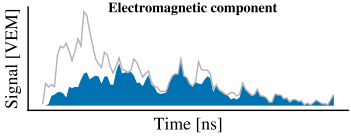
- Later times
- Spread and not very spiky

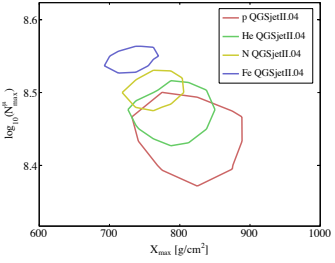
What can we do with the muon component?

- Infer information about mass composition
- Study hadronic interactions
- Searches of other primaries, such as photons

- The baseline design does not allow to separate the muon component for all events

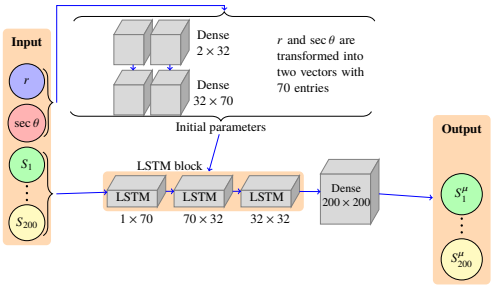


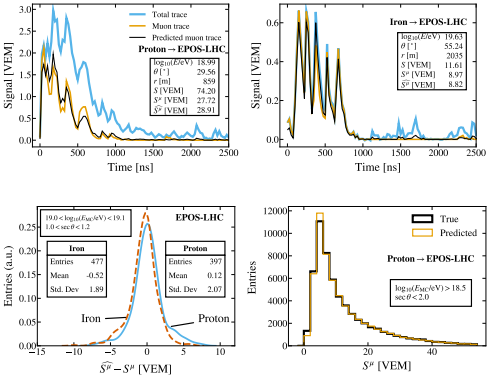




What do we do?

We train a neural network to predict the muon signal

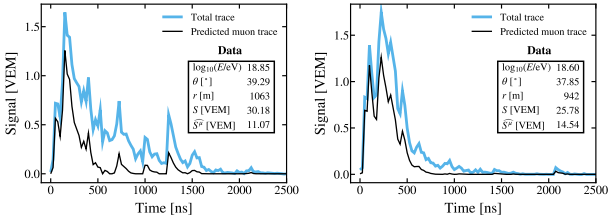




- The NN takes as input the total signal and predicts the muon signal
- The bias is close to 0 and RMS is between 1 and 2 VEMs (Vertical Equivalent Muons). The performance has been studied as a function of $\sec\theta$ and primary energy
- Similar performance when tested on simulations done with QGSJetII-04 and Sibyll 2.3

Application to Data

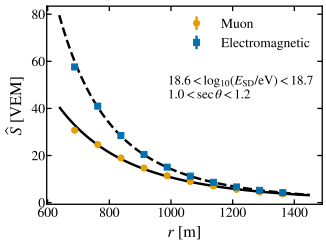
- We have tested our results on Data

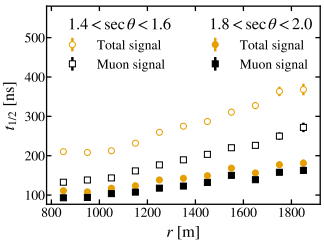


The predictions agree with expected features of the muon signal

- Earlier times
- Spiky signals

- The predictions agree with LDF parameterizations done by the AGASA collaboration
- The muon risetime has the expected behaviour





Points: NN results from Auger data
Lines: Fits using AGASA paremeterizations