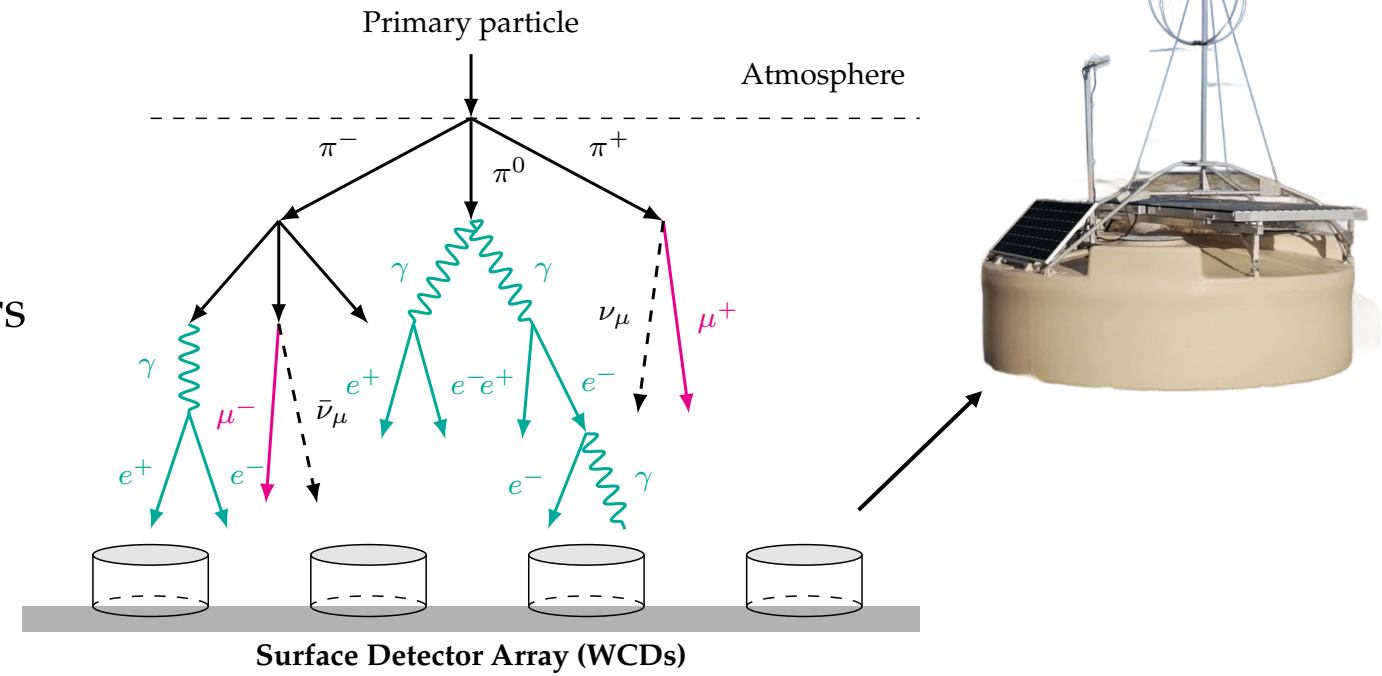
Ultra-high-energy cosmic rays

- Ultra-high-energy cosmic rays (UHECRs) are extraterrestrical particles exceeding energies of 1 EeV that continuously strike Earth
  - Their exact origins remain unresolved
  - Knowledge of the mass composition of the particles is key information

The Pierre Auger Observatory

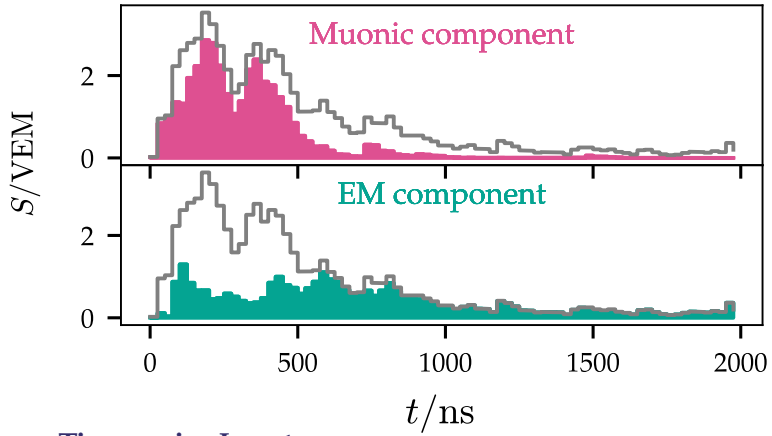
- Detects extensive air showers initiated by UHECRs, utilizing:
  - Fluorescence telescopes observing the longitudinal development of air showers
  - A Surface Detector (SD) array of 1660 water-Cherenkov detectors (WCD) covering 3000 km^2, observing the particle distribution on the ground [1]



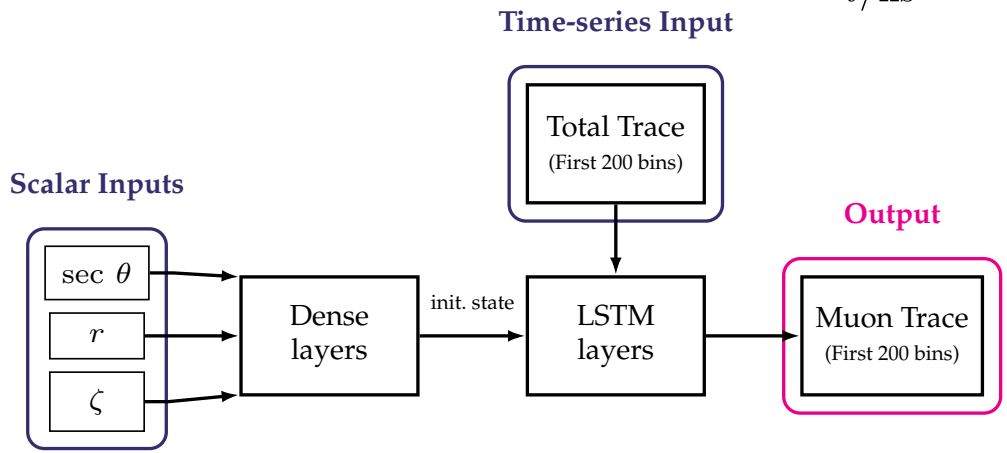
[1] The Pierre Auger Collaboration. NIMA, 798:172–213, 2015.

Prediction of temporal muon signal

- Number of muons on the ground is a strong mass-composition indicator
- However, WCD time signals are a combination of electromagnetic (EM) and muonic components
- In the WCD, muons and EM particles create distinct patterns
  - Muons arrive early, producing sharp spikes
  - EM particles are more dispersed, yielding smoother signals



- Goal: Estimation of the muon component in the WCD signal with Neural Networks, based on [2]
  - Dense + LSTM layers



[2] The Pierre Auger Collaboration. JINST, 16:P07016, 2021.

Prediction of temporal muon signal

- The target is the muon contribution in each of the first 200 bins of the total trace
- Sum of the muon trace = muon signal, S^{μ}
- The muon bias is below ±4% across the entire energy range