The Pierre Auger Observatory

Auger L'Aquila Group

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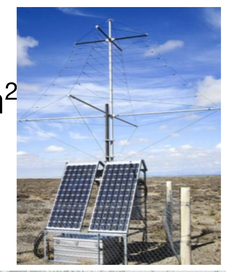
Pierre Auger Observatory

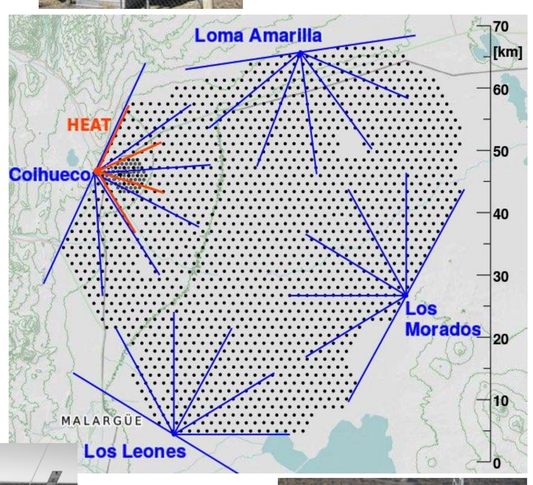
SURFACE DETECTOR (SD):

- **1600 stations** spaced 1.5 km over 3000 km^2 $E > 10^{18.5}$ eV (SD1500)
- **61 stations** spaced 750 m over 23.5 km^2 $E > 10^{17}$ eV (SD750)
- **19 stations** in 433 m grid, $E > 6 \cdot 10^{16}$ eV (SD433)



FLUORESCENCE DETECTOR (FD):

- **4 sites** (24 fluorescence telescopes 0-30°) $E > 10^{18}$ eV
- **HEAT** (3 telescopes 30-60°) $E > 10^{17}$ eV

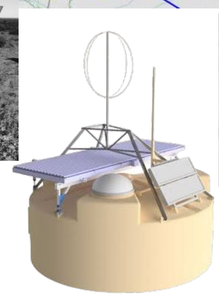


AUGER ENGINEERING RADIO ARRAY (AERA):

- **153 antennas** in 17 km^2 array

UNDERGROUND MUON DETECTOR:

- **19(61) stations** in the 433 m (750 m) array



ONGOING UPGRADE AugerPrime

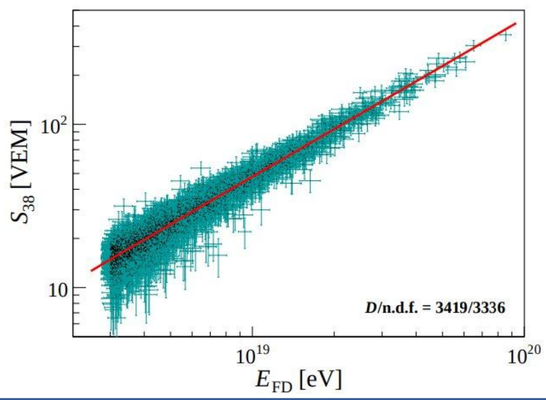
Atmosphere

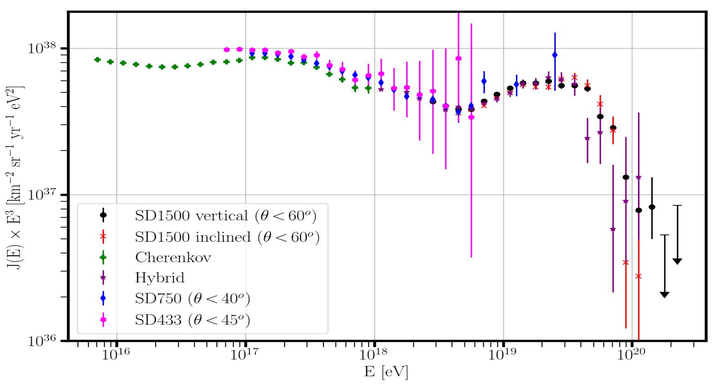
- SD and FD observations affected by different **atmospheric conditions**
- Extensive program to monitor the atmosphere above the Observatory
- Aerosols and clouds represent the most variable components
- **Aerosol extinction estimation** fundamental for showers reconstruction

Lidars and Laser facilities for calibration

Spectrum

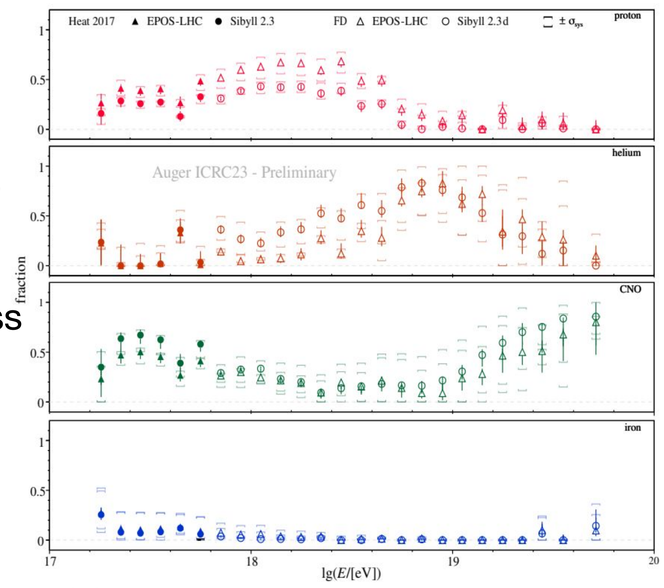
- **High statistics** of events reconstructed by SD1500
- SD energy estimator calibrated against FD energy (**Hybrid Events**)
- **Correction of the attenuation** in atmosphere
- **Ankle** confirmed and **Suppression** confirmed at $4.6 \cdot 10^{19}$ eV
- New feature: **instep**

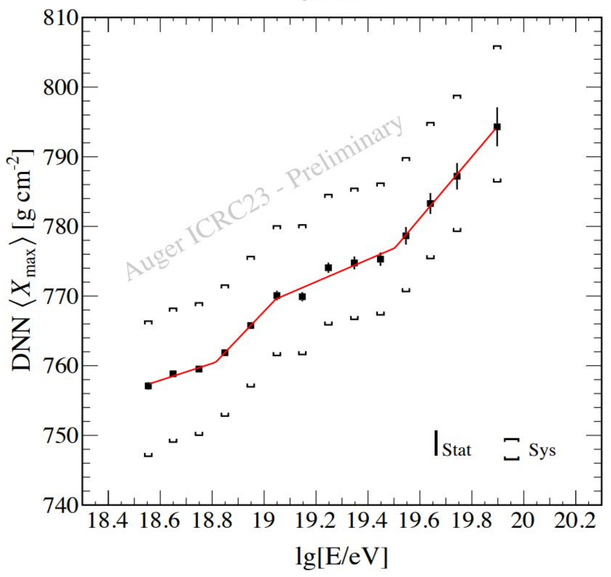




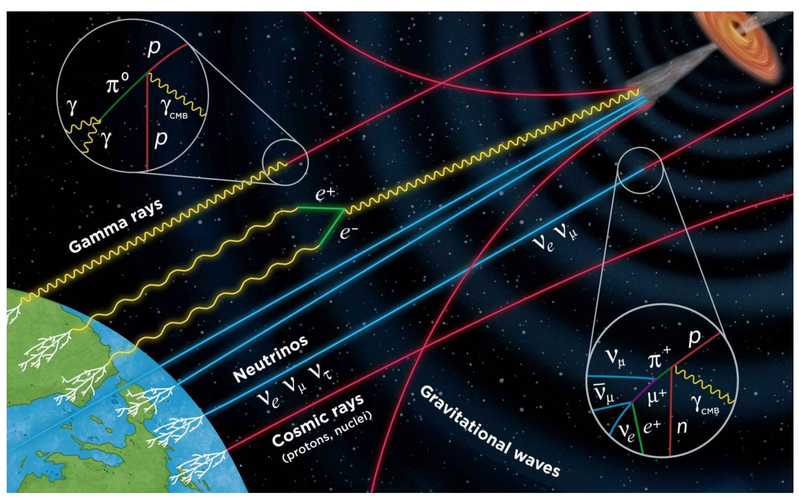
Mass Composition

- The Observatory provides **mass-sensitive observables** for studying the primary composition of **ultra-high-energy** cosmic rays (UHECRs)
- **FD** offers the **most accurate** mass composition **reconstruction**, but limited to dark nights and good weather
- **Alternative methods** have been developed (NNs, radio array)
- **SD** array has a duty cycle close to 100%, allowing for **higher statistics**
- The use of **deep neural networks** has been introduced to improve the SD mass composition reconstruction, exploiting the time structure of signals measured at each SD station





Interactions of UHECRs



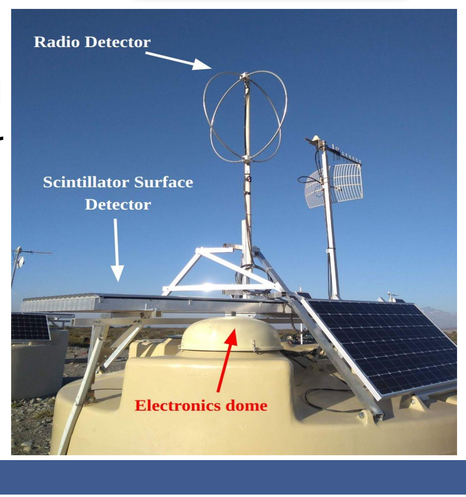
SimProp:
a simulation code for UHECRs propagation

- **Adiabatic energy losses** due to the expansion of the Universe
- Interactions with background photons (**CMB, EBL**):
  - **Pair production**
    $$N + \gamma \rightarrow N + e^- + e^+$$
  - **Pion production**
    $$p + \gamma \rightarrow \pi^+ + n$$
    $$\hookrightarrow \mu^+ + \nu_\mu$$
    $$\hookrightarrow e^+ + \nu_e + \bar{\nu}_\mu$$
  - **Disintegration of nuclei**
    $$^AZ + \gamma \rightarrow ^{A-1}Z + n$$
    $$p + \gamma \rightarrow \pi^0 + p$$
    $$\hookrightarrow 2\gamma$$
- **Lorentz Invariance Violations** (**LIV**) for both the extragalactic propagation and the shower development in the atmosphere

Future

- **AugerPrime Upgrade**:
  - **Primary Objective**: To enhance the study of ultra-high energy cosmic rays focusing on their composition and the effects of hadronic interactions at extreme energies
  - **New detectors installed**

- **Distinct Detector Responses**: The combined use of WCDs and the new detectors allows for more accurate differentiation between the **muonic** and **electromagnetic** components of cosmic ray showers
- **Upgraded Electronics**: new electronics for integrating and managing the new detectors



- **Best sensitivity** to UHE neutrinos slightly below 10^{18} eV
- **Integral limit** for neutrino energies between 10^{17} eV and $2.5 \cdot 10^{19}$ eV