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CONICET

PIERRE AUGER OBSERVATORY

The Underground Muon Detector of the Pierre Auger Observatory

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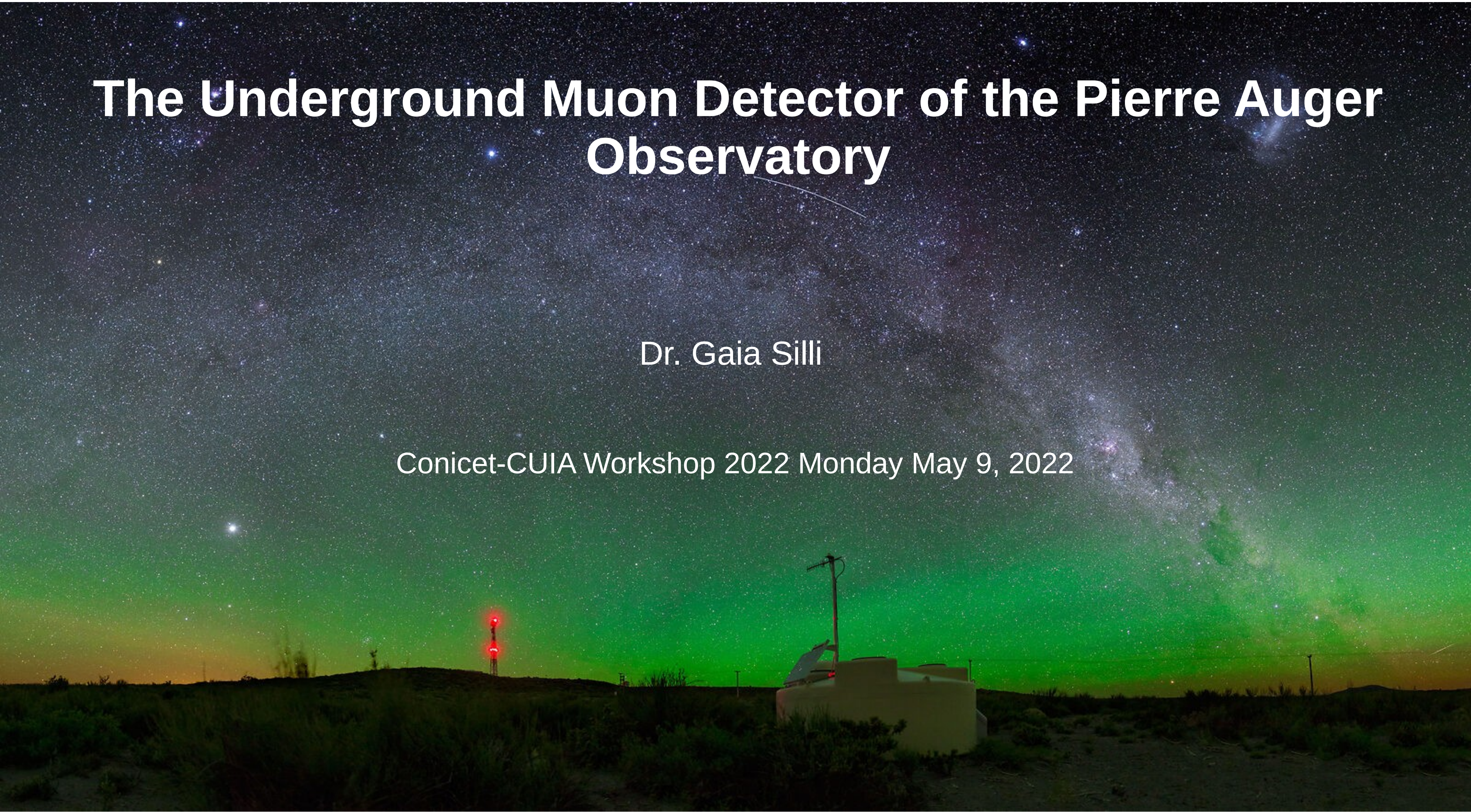
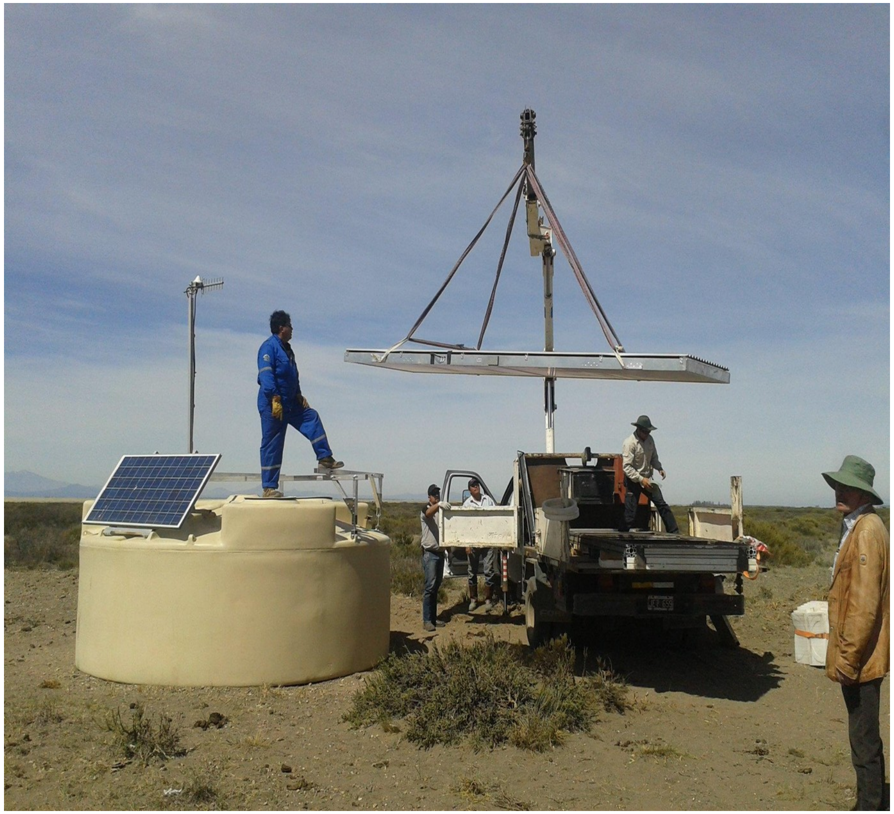
Conicet-CUIA Workshop 2022 Monday May 9, 2022



AugerPrime Upgrade

Main Goals :

- Measure the composition-discriminated flux
- Extension of the energy detection range to 10^{17} eV
- Understand the muon deficit in shower simulations



Improvements:

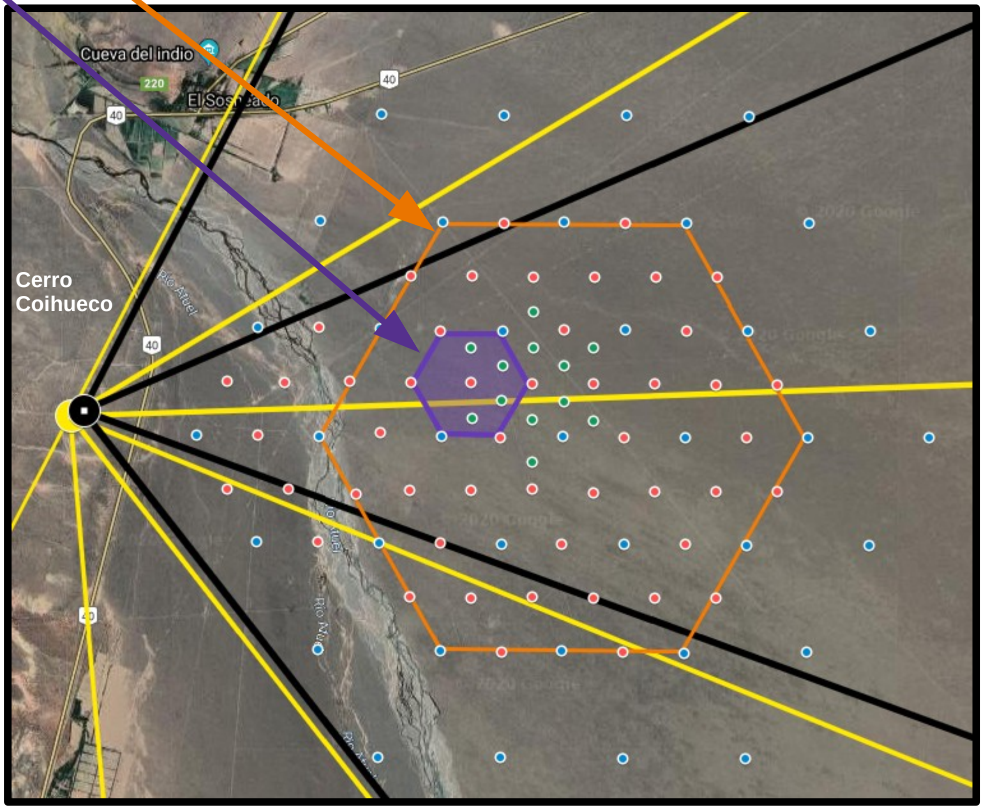
- SD: deployment of a Scintillation Surface Detector (SSD) in top of each station, upgraded electronics, deployment of radio antennas
- FD: Change in the operation mode to extend the duty cycle from 15% up to 20%.
- Design and Deployment of the Underground Muon Detector (UMD) for direct measurement of the muonic component of air-showers.

Based on:

- HEAT (High Elevation Auger Telescopes)
- AERA (Auger Engineering Radio Array)
- AMIGA (Auger Muons and Infill Ground Array)

AMIGA: Auger Muons and Infill for the Ground Array

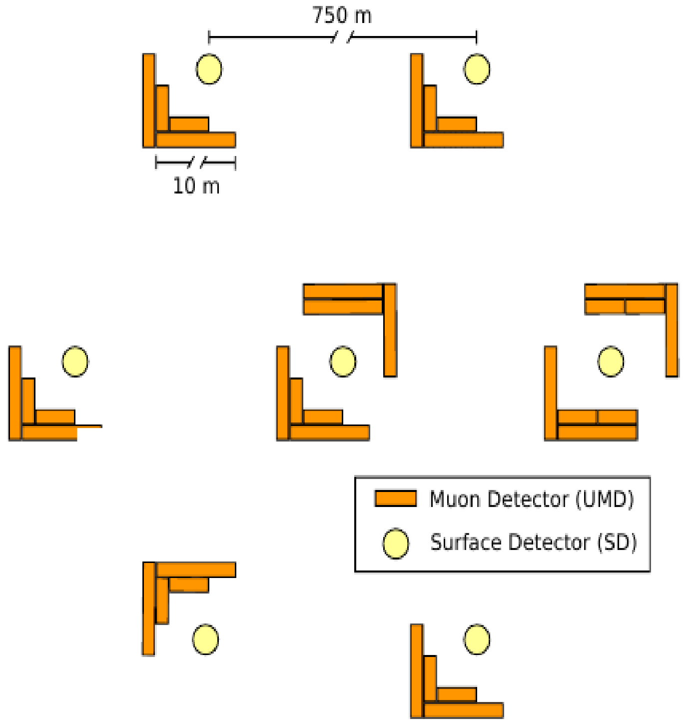
- measures the muonic component of the shower
- studies the transition zone (10^{17} and 10^{19} eV), from the galactic sources of cosmic rays to extragalactic sources
- Is compound by an infill of 80 pars of SDs (surface detectors) and BDs (buried detectors)
  - 61 of these with a separation of 750m
  - 19 remaining with a separation of 433m
- Main contribution from
  - Argentina
  - Italy
  - Germany
  - Spain
  - Mexico
  - Poland



ITeDA Participation in the Project

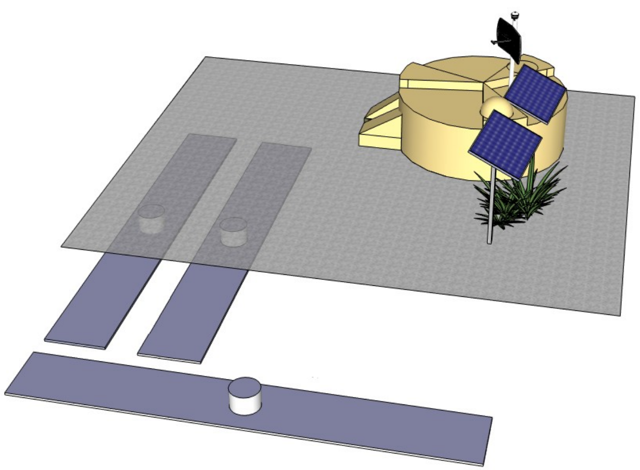
1. Simulations – Data Acquisition - Reconstructions
2. Scintillators Modules
3. Photomultiplier – Pulses – Database
4. Telecommunications
5. Design, Installation and Interconnection of the Electronic components.

AMIGA Engineering Array and final design



Layout of the **AMIGA Engineering Array - EA** (up to 2017). In the prototype phase, each 30 m^2 muon detector was segmented in 5 m^2 and 10 m^2 modules. Also, two positions were equipped with extra twin modules to asses the detector uncertainties.

joint and close collaboration with the Torino group

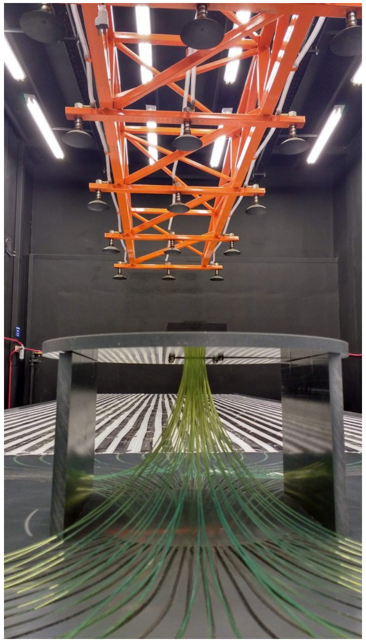


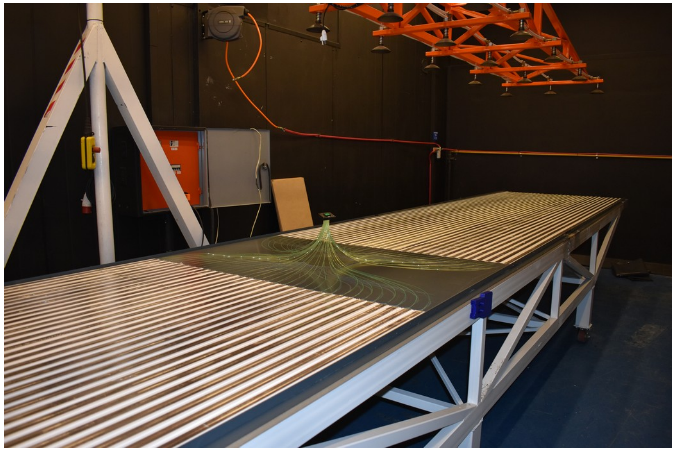
Final design

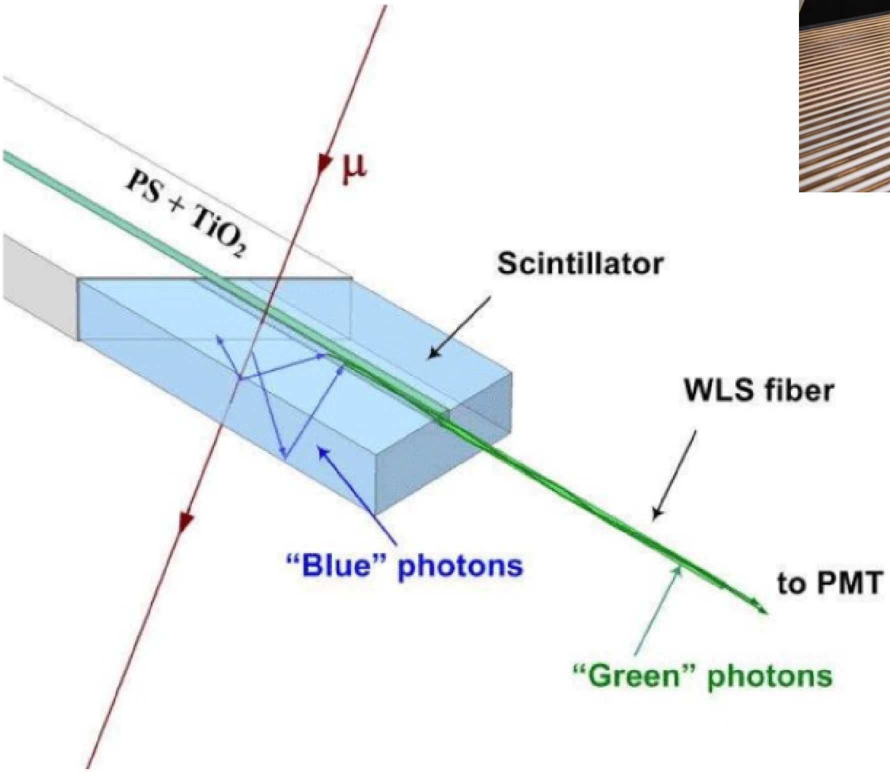
Underground Muon Detector station (UMD)
3 muons counters + SD station
PMTs → SiPMs

Amiga Module

- Each UMD module is composed by 64 plastic scintillation bars (400x4x1)cm and 64 optic fibers WLS (WaveLength-Shifting)
- A multi-pixel photosensor and electronic of acquisition who will work along with the surface detector







Particle detection principle

Scintillator: absorb the light produced in the primary scintillation process and then re-emit it at a longer wavelength

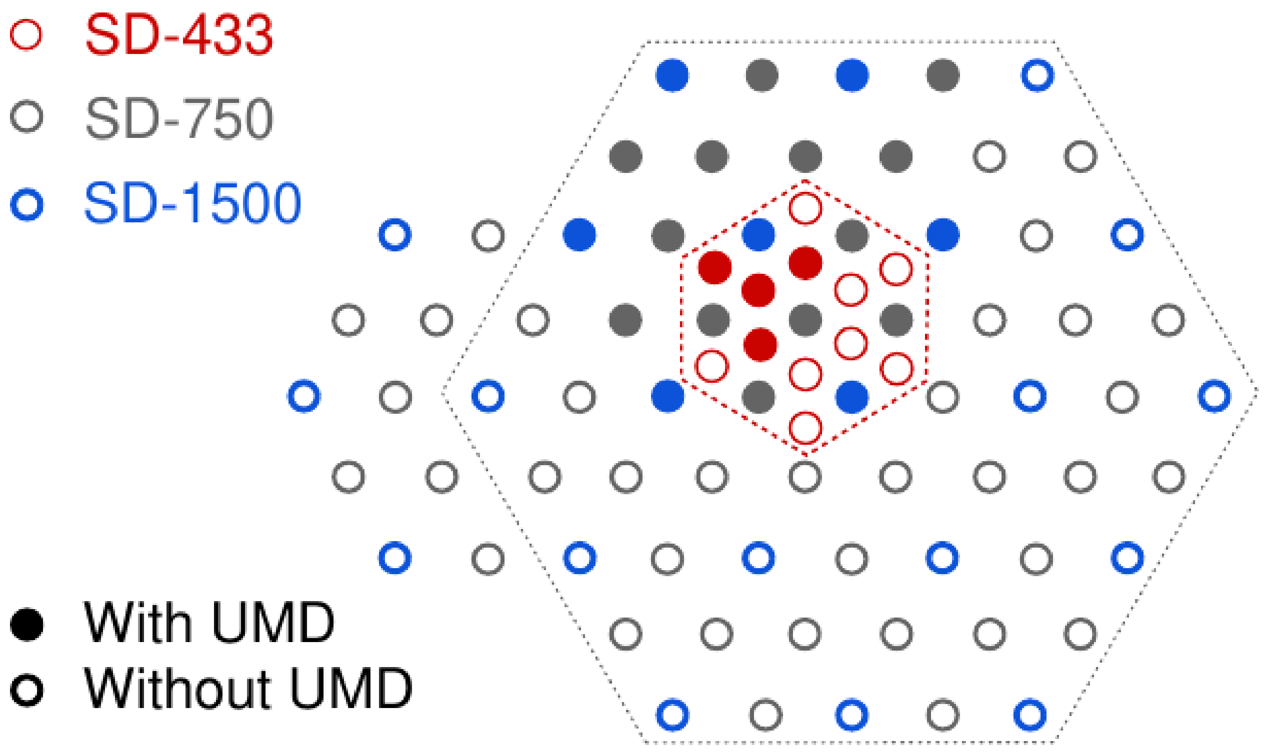
blue photons ⟶ green photons

green light is driven to the PMT located at the fiberend

UMD Deployment and Mechanics

Are buried approximately 2,5m underground to achieve the detection exclusively of the muonic component of the particle rain

Deployment at 2021 (Production Phase)



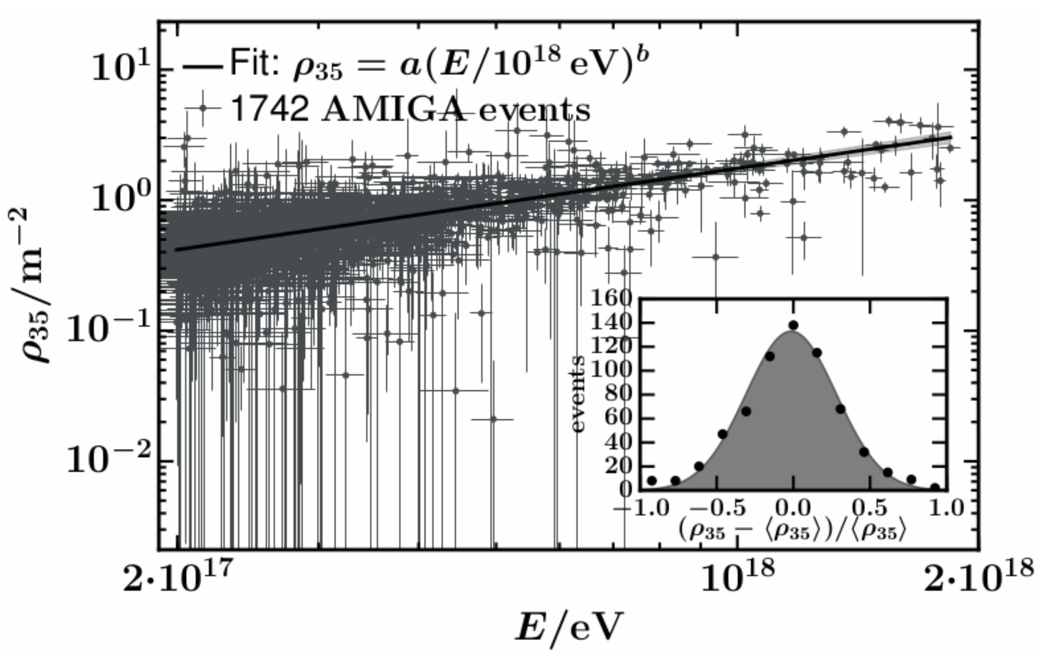
The deployment and commissioning of the UMD are currently on-going at a pace of 2 stations per month

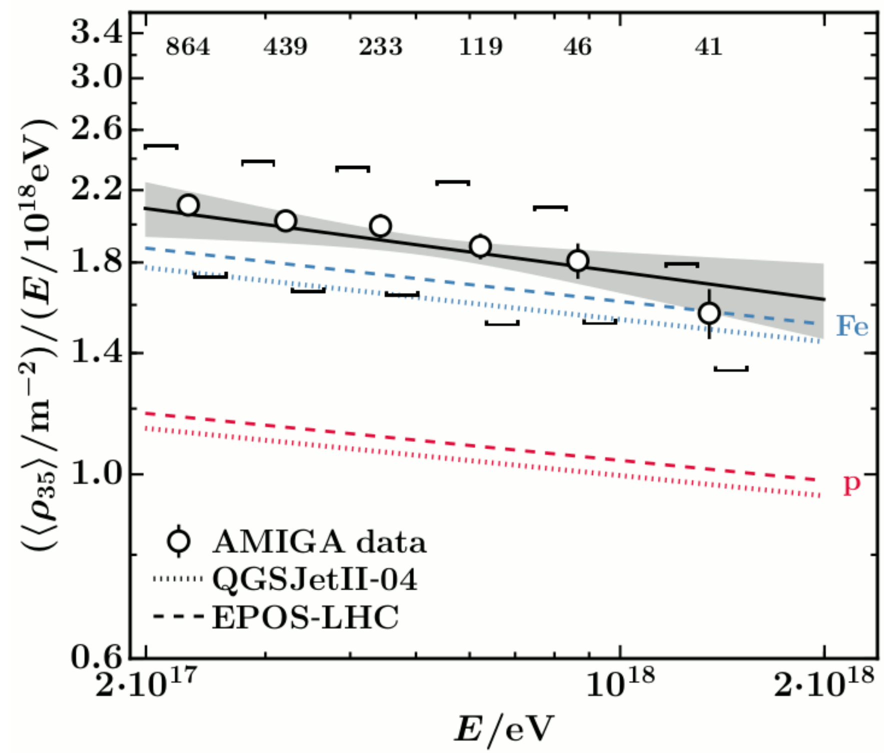
UMD results

Muon densities Vs energy $\Rightarrow \rho_{35}(E)$

First direct measurement of the muon densities at energies $10^{17.3}$ eV < E < $10^{18.3}$ eV

- ✔ Geometry & Energy from SD alone
- ✔ Event core contained in UMD hexagon
- ✔ Zenith < 45°





$$\rho_{35}(E) = a\cdot\left(E/10^{18}\,eV\right)^b$$

Pr : $b = 0.92$

Fe : $b = 0.91$ ► **8% (EPOS) – 14% (QGSJet) below measurements**

Data: $b = 0.89 \pm 0.04\,(stat) \pm 0.04\,(sys)$

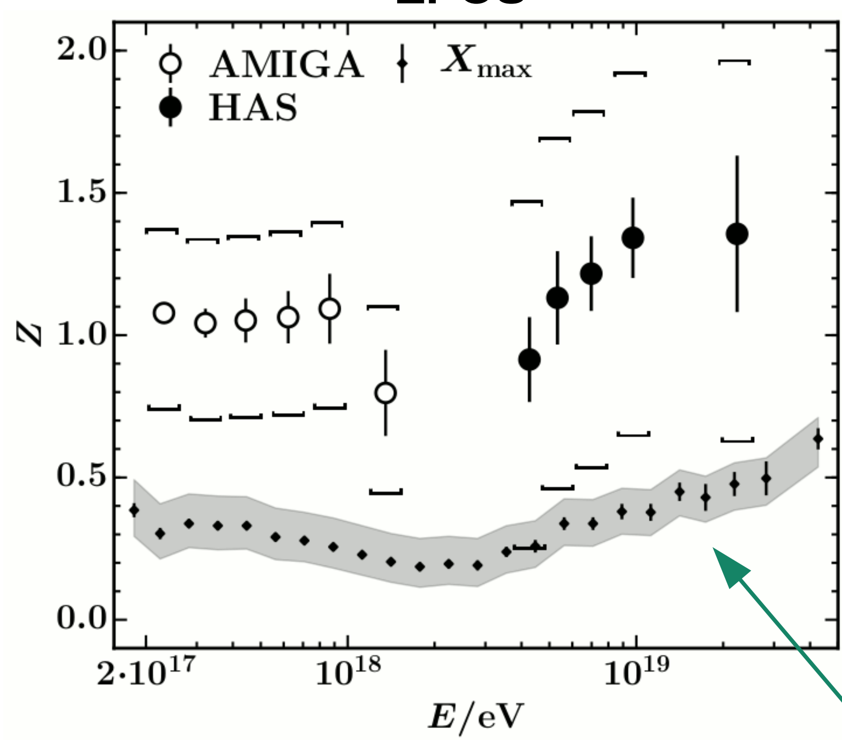
Comparison with other Auger measurements I

$$z_{\alpha} = \frac{\langle \ln(\alpha) \rangle - \langle \ln(\alpha) \rangle_p}{\langle \ln(\alpha) \rangle_{Fe} - \langle \ln(\alpha) \rangle_p}$$

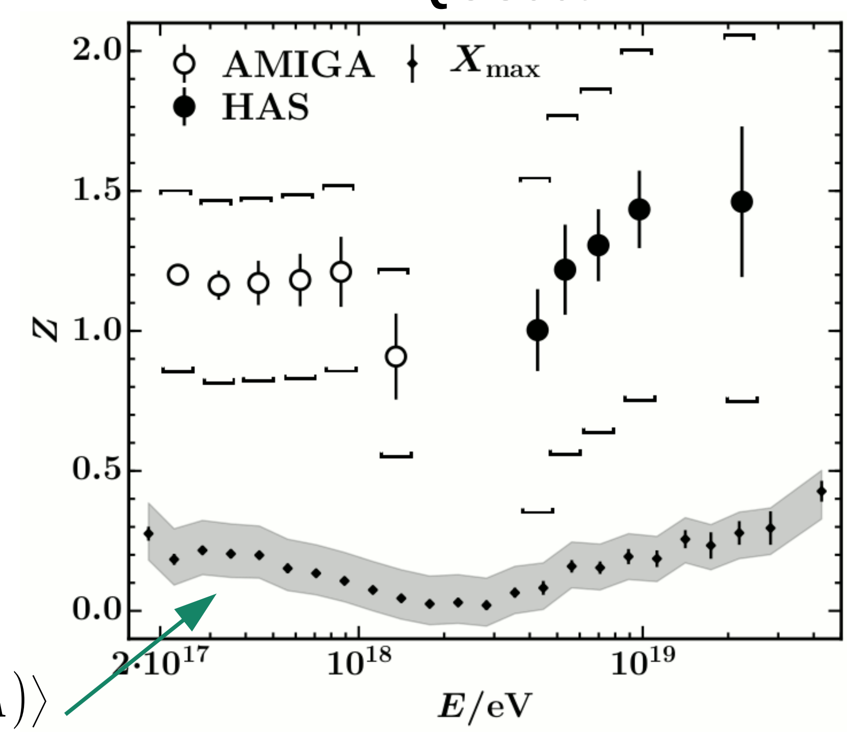
same composition sensitive observable for

- SD → R_{μ}
- FD → X_{max}
- UMD → ρ_{35}

EPOS



QGSJet

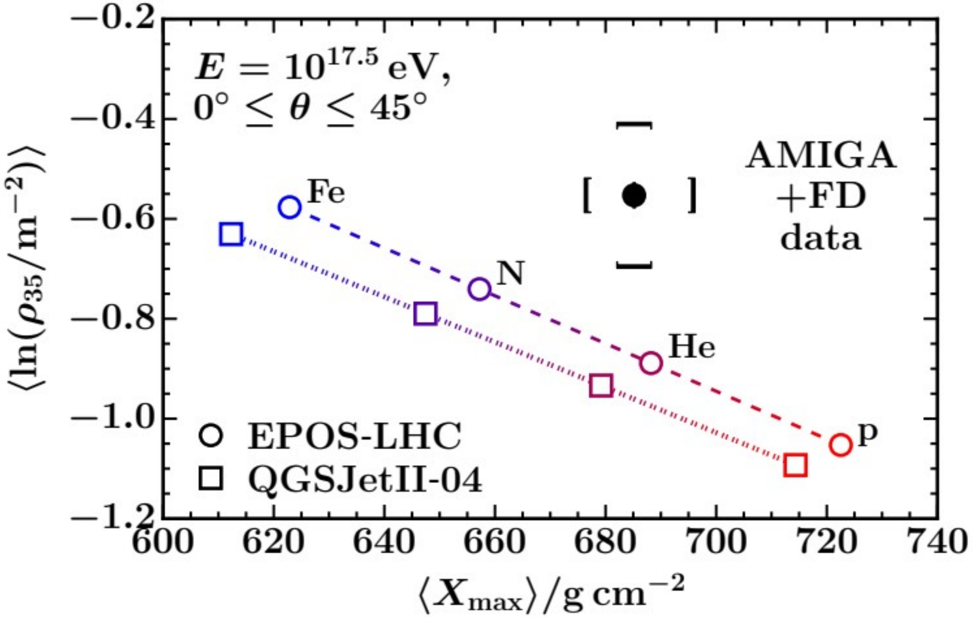


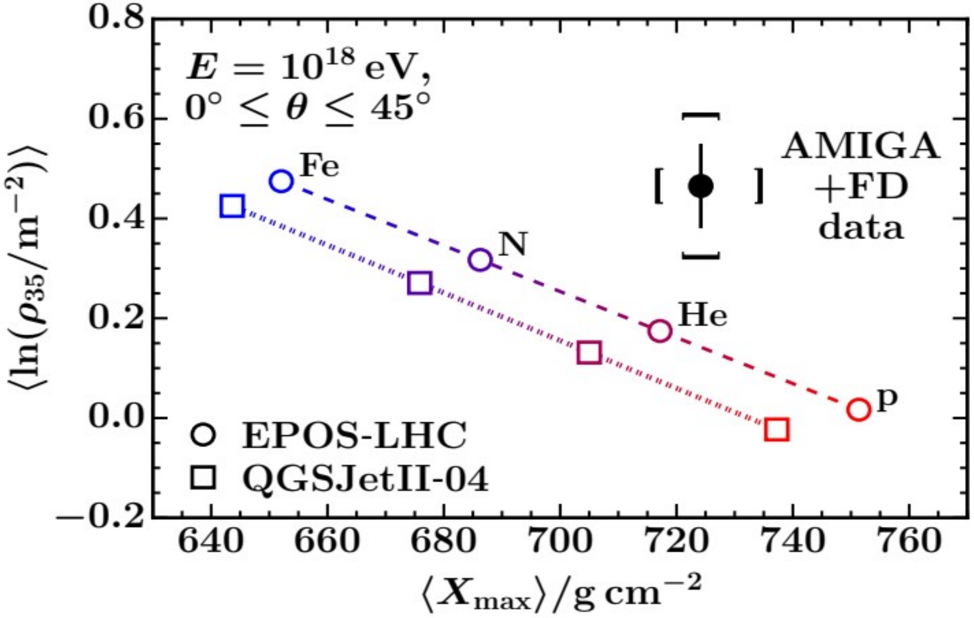
$$z_{X_{max}} = \frac{\langle \ln(A) \rangle}{\ln(56)}$$

- $\boldsymbol{X_{max}}$: directly correlated with primary mass
- **HAS**: estimate of the muonic component using highly inclined showers
- **AMIGA**: direct muon measurements using underground scintillator detectors

Comparison with other Auger measurements II

Bi-parametric analysis: X_{max}, ρ_{35}





muon deficits in LHC-tuned hadronic models

@$10^{17.5}$ eV

EPOS 38%

QGSJet 50%

@$10^{18.0}$ eV

EPOS 38%

QGSJet 53%

SD-433 results

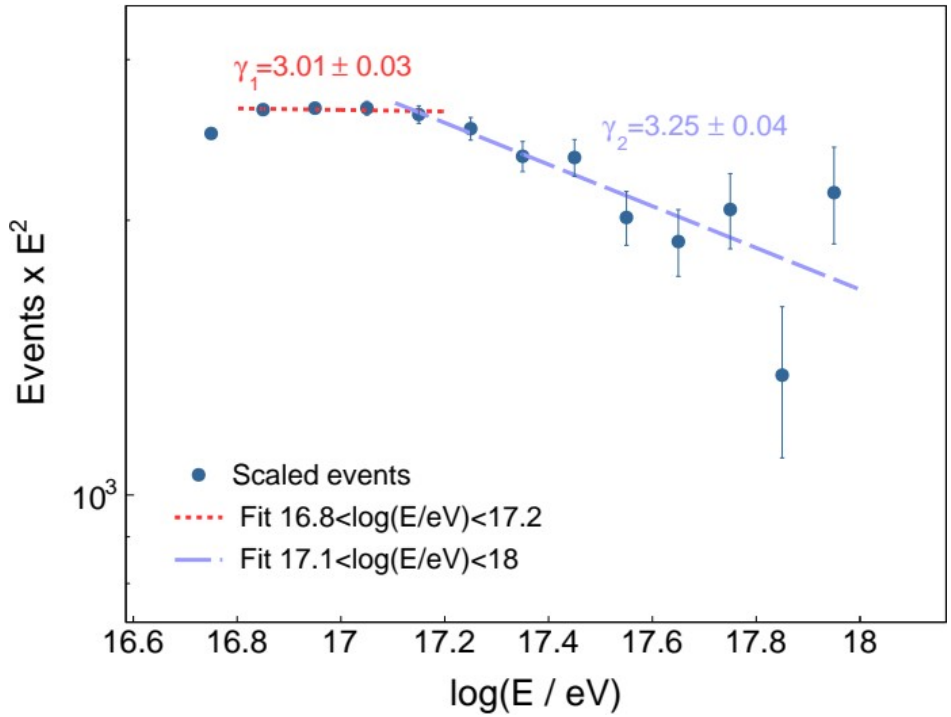
First energy spectrum measured with the SD-433

For a reliable energy measurement:

- E > $10^{16.7}$ **eV**
- Zenith < **45°**

} 97% efficiency

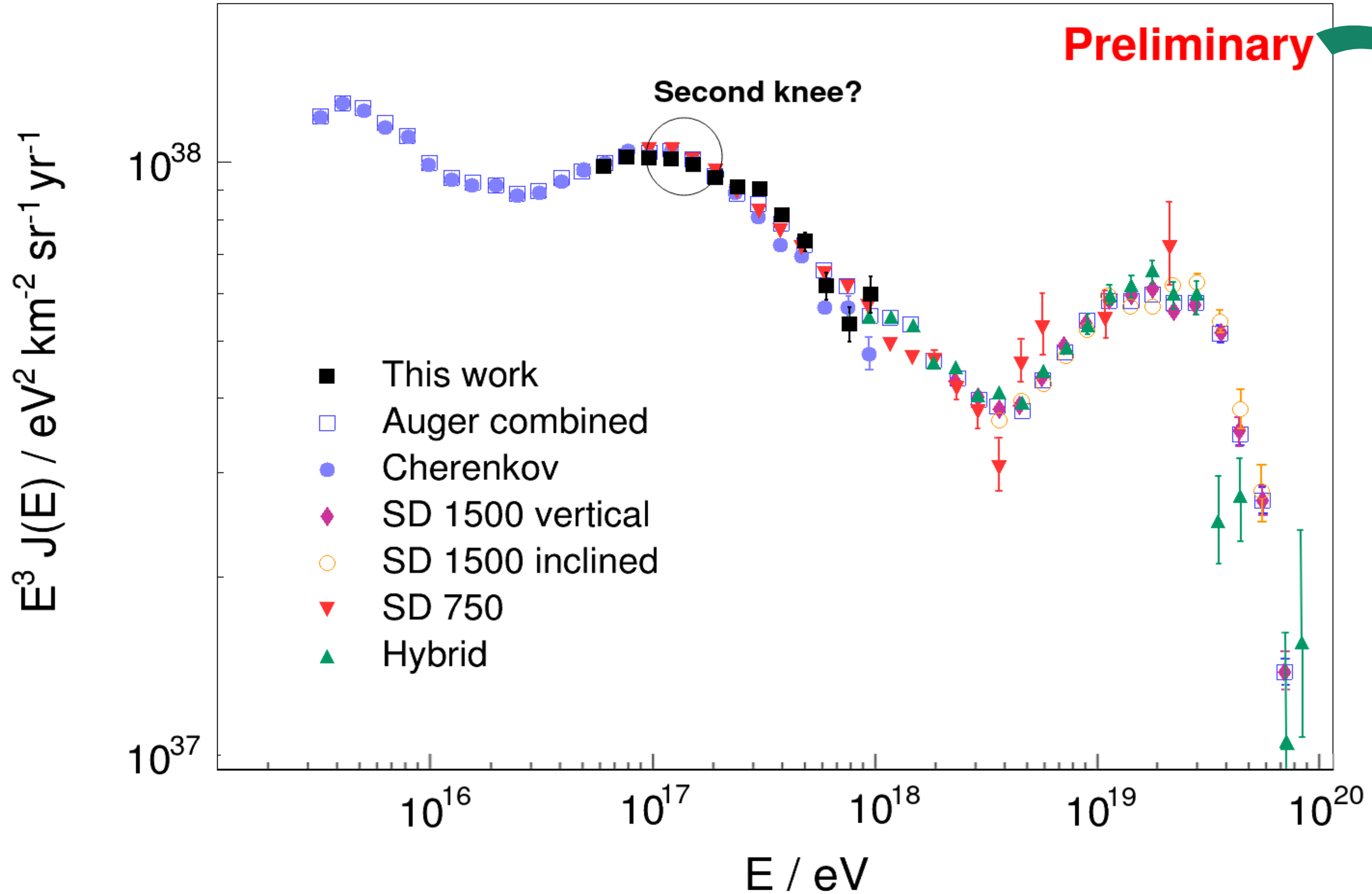
- fully reconstructed with fitted LDF slope
- showers fully contained in the array
- 21877 high quality events (~2% of totals) in the time range 01.01.2013 - 31.08.2018



a softening is visible around 10^{17} eV

$\gamma 1 \longrightarrow \gamma 2$

Comparison with other Auger measurements



an update of the energy calibration is needed

Lots of work to do...

promising results in the measurement of the 2nd knee

Summary

- The Pierre Auger Observatory is going through an upgrade phase named AugerPrime
- One of the improvements of this upgrade is the design and deployment of the Underground Muon Detector (UMD) and SD-433
- The first direct observations of a device dedicated exclusively to measuring the muonic component of EAS were presented
- The first preliminary energy spectrum measured with the SD-433 covering the energy range where the the second knee has been observed

promising results in the measurement of the muonic component of air-showers and of the second knee spectral feature

Outlook

Performance of cross-calibration studies between the UMD and the SD need to be done for an accurate estimation of the muonic component

AMIGA will contribute to a better understanding on the nature of the **mass composition** of cosmic rays and of the origin of the **second knee**

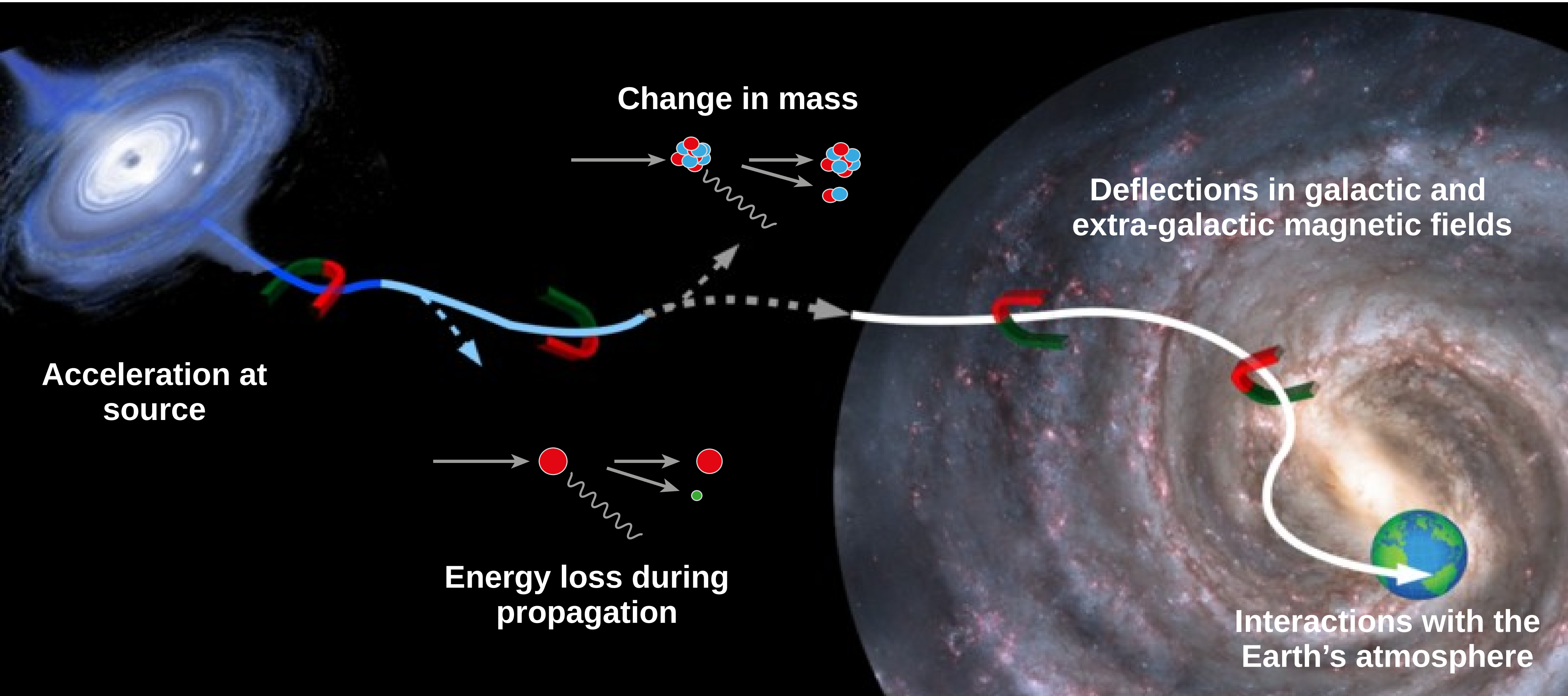
Backup

Ultra-high-enegy cosmic rays

Ionized nuclei with energies greater than 10^{18} eV

What are the sources?

How are they accelerated?



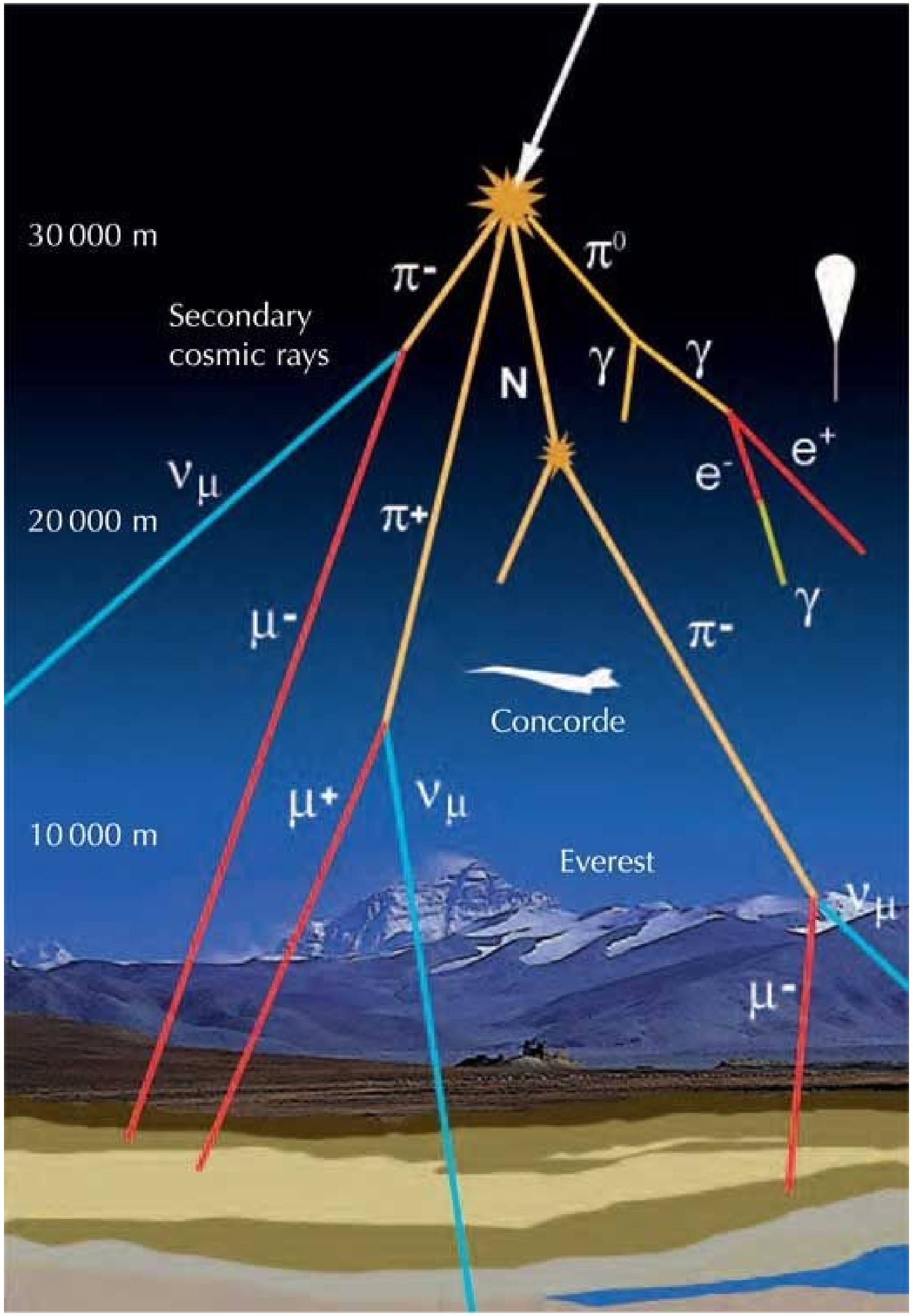
Extensive air showers

- Indirect measurements of high energy particles
- detection of the extensive showers of secondary particles

3 components + radiation
→ muonic
→ hadronic
→ electromagnetic

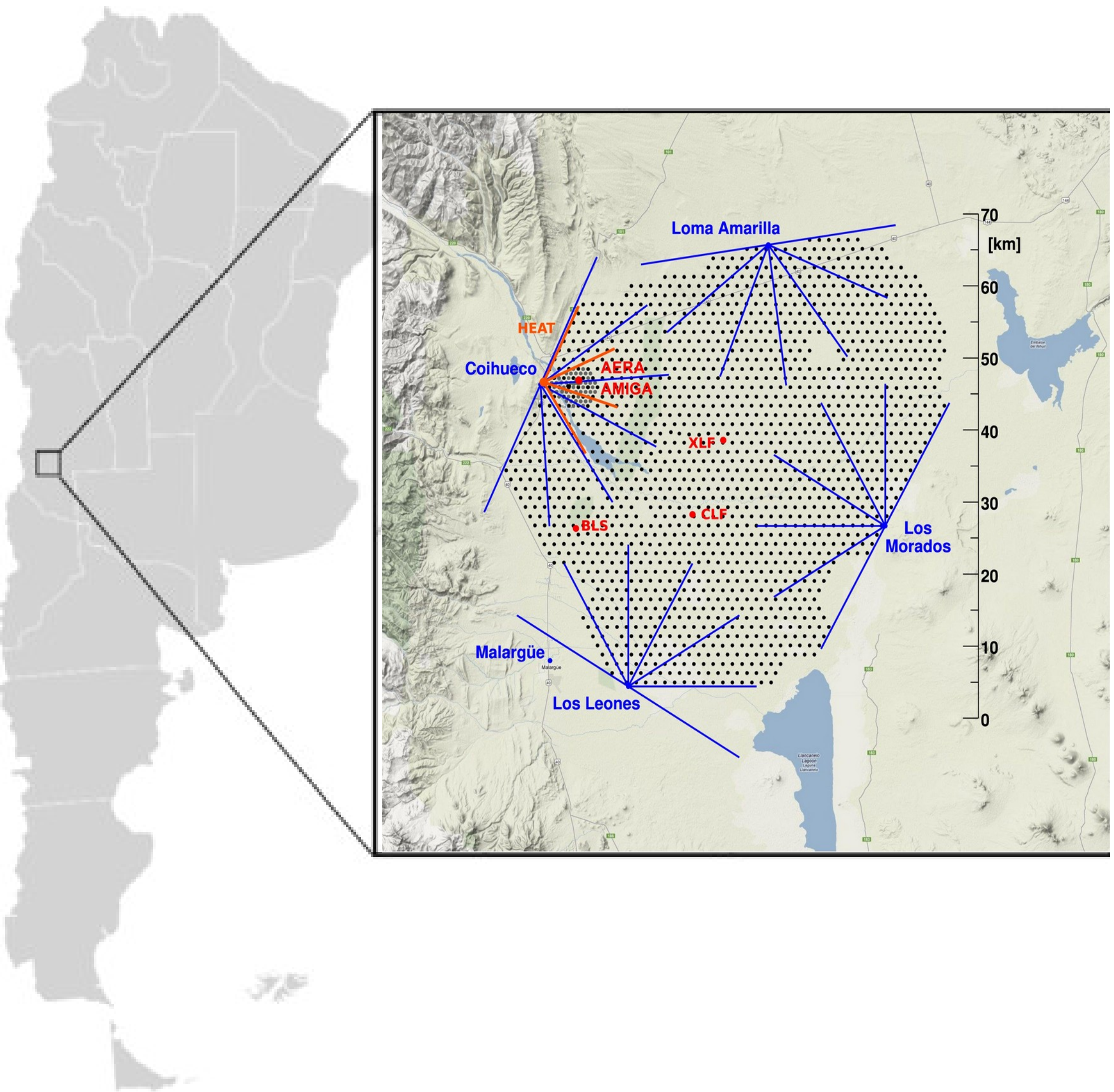
Measurements:

- source position
- energy spectrum
- mass composition



The Pierre Auger Observatory

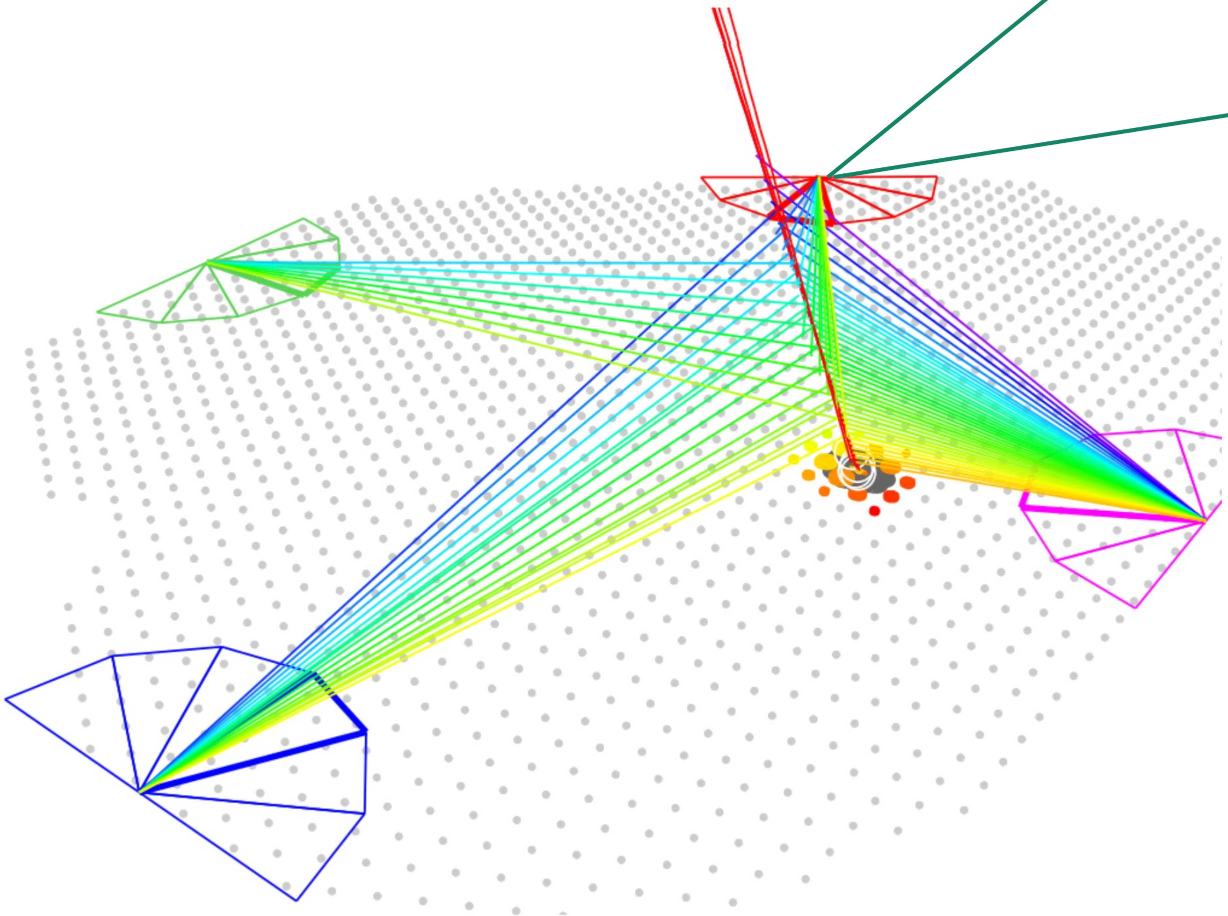
- Located in western Argentina's Mendoza Province
- It studies the highest-energy particles in the Universe (10^{18} eV (Ultra-High-Energy Cosmic Ray, UHECR)
- Area of 3000 km² (the size of Rhode Island, or Luxembourg)
- International collaboration of 18 countries (100 institutions approx)
- Hybrid detection tecnique

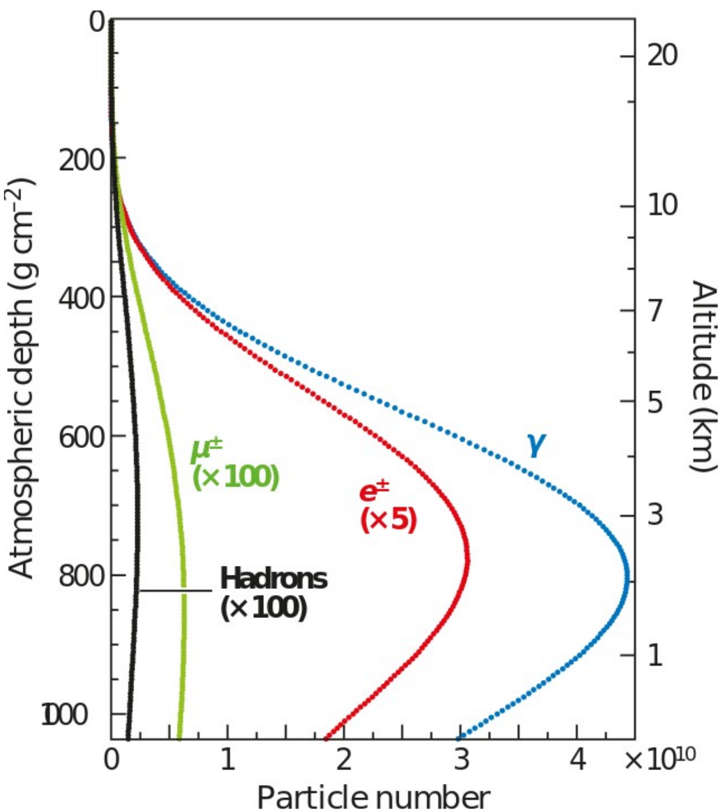


Hybrid tecnique

Fluorescence Detector

- 27 telescopes in 4 locations
- Measure the fluorescence light from excitation by shower particles
- ~15% duty cycle

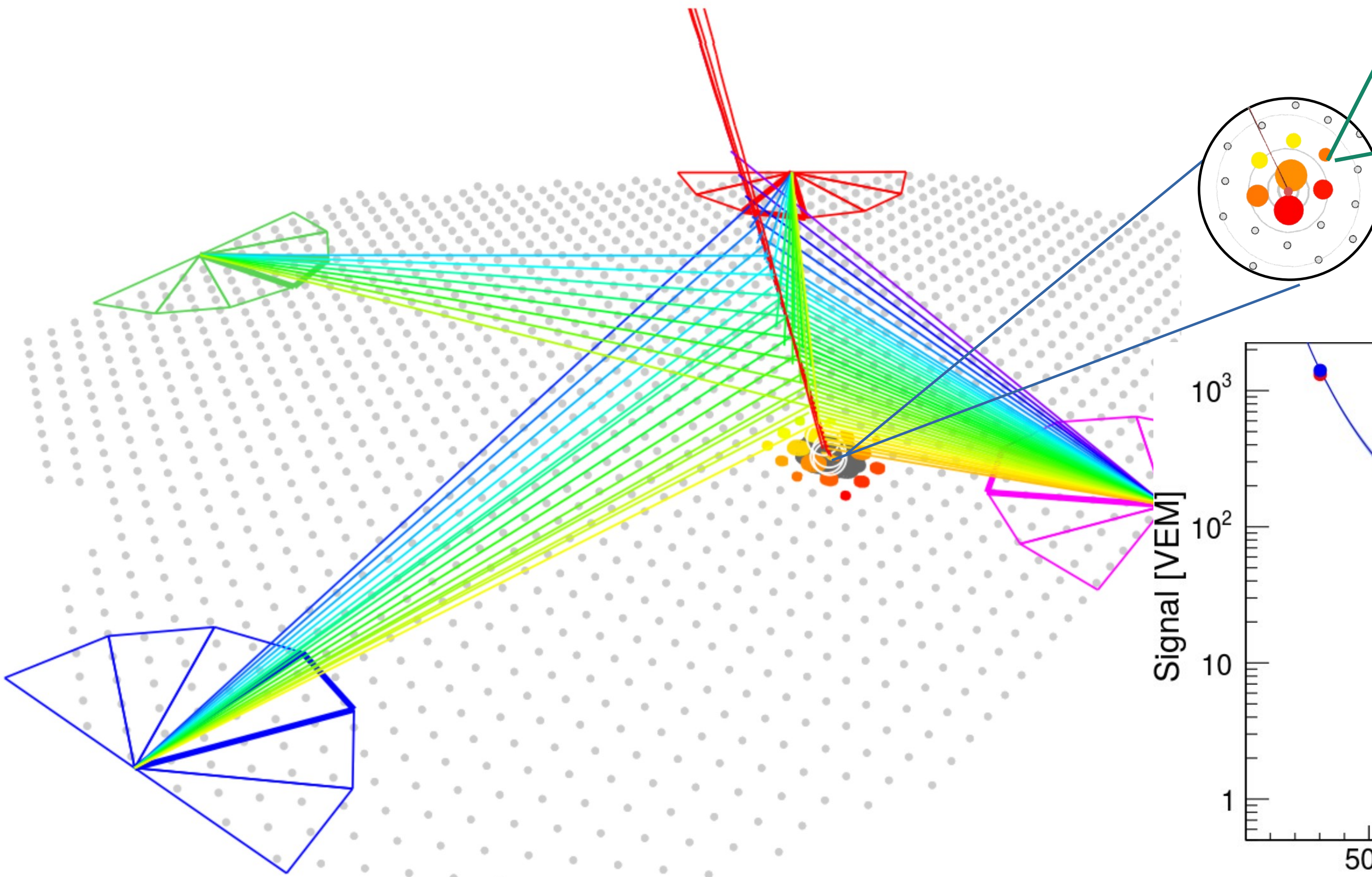


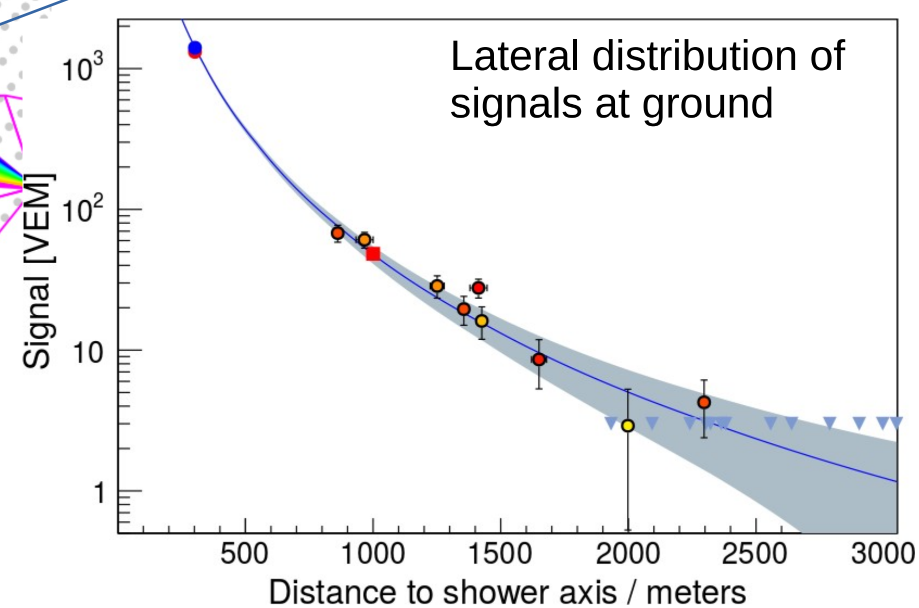


Hybrid tecnique

Surface Detector

- 1660 Water-Cherenkov Detectors (WCD)
- Measure the footprint of showers at ground
- ~100% duty cycle





AugerPrime: The Upgrade of the Pierre Auger Observatory

Improvements:

- A complementary measurement of the shower particles will be provided by plastic Surface Scintillator Detectors (SSD) placed above the existing 1660 water-Cherenkov Detectors (WCD).
- The surface detector stations will be upgraded with new electronics that will process both WCD and SSD signals. The new electronics will also provide faster sampling of ADC traces, better timing accuracy, increased dynamic range, and enhanced triggers.
- To increase the dynamic range, each WCD will be equipped with an additional “small PMT”, i.e., a smaller low gain photomultiplier tube, to register large pulses from very close showers that saturate the signal of the large PMTs.
- An Underground Muon Detector (UMD) will provide important direct measurements of the shower muon content and its time structure, while serving as verification and fine-tuning of the methods used to extract muon information with the SSD and WCD measurements.
- The operation mode of the Fluorescence Detector (FD) will be changed to extend measurements into periods with higher night sky background and twilight. This will allow an increase in the current ∼15% duty cycle of the FD to over ∼20%.
- Each Surface Detector station will be complemented with an antenna for radio detection of cosmic ray showers.