THE PIERRE AUGER OBSERVATORY AND ITS DETECTORS

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ABSTRACT

The Pierre Auger Observatory provides data related to cosmic rays. It studies secondary cosmic rays generated when primary cosmic rays, atomic nuclei produced in the Universe, collide with molecules in the earth's atmosphere.
The Observatory uses surface detectors (SD) and fluorescence detectors (FD).

INTRODUCTION

The construction of the Pierre Auger Observatory began in 2000. The Observatory is the largest in the world, it covers an area of 3,000 km^2 (30 times the size of Paris).
It is located on the vast plain known as the Pampa Amarilla in Western Argentina. It studies high-energy cosmic rays, particles produced in different sources in the Universe. This primary particles, when interact with the Earth atmosphere, produce a cascade of particles, called extensive air showers (EAS).
Pierre Auger Observatory uses a hybrid detection system to study EAS: it combines the information gathered from surface and fluorescence detectors.

METHODS

Studying cosmic rays we can understand matter that came from beyond our solar system, estimate the amount of matter in the universe and the amounts of different elements. Techniques for detecting cosmic rays depend on their energy. The higher the energy, the less abundant the particles, the larger the detectors must be. This means that it is possible to measure lower energies cosmic rays directly in space. At higher energies, the larger detectors must take place on the ground and can measure only secondary cosmic rays.
Earth's magnetic field influences the path of primary particles outside the Earth's atmosphere. The **EAS** produced in the atmosphere are made by three different components: Hadronic component, electromagnetic component and muonic component. The electromagnetic and muonic components are able to reach the earth. The muon component is more penetrating than the electromagnetic one.
Scientists of the Observatory have been able to detect events that reach over 10^{20}eV, the highest energy observed for a primary cosmic ray event so far.

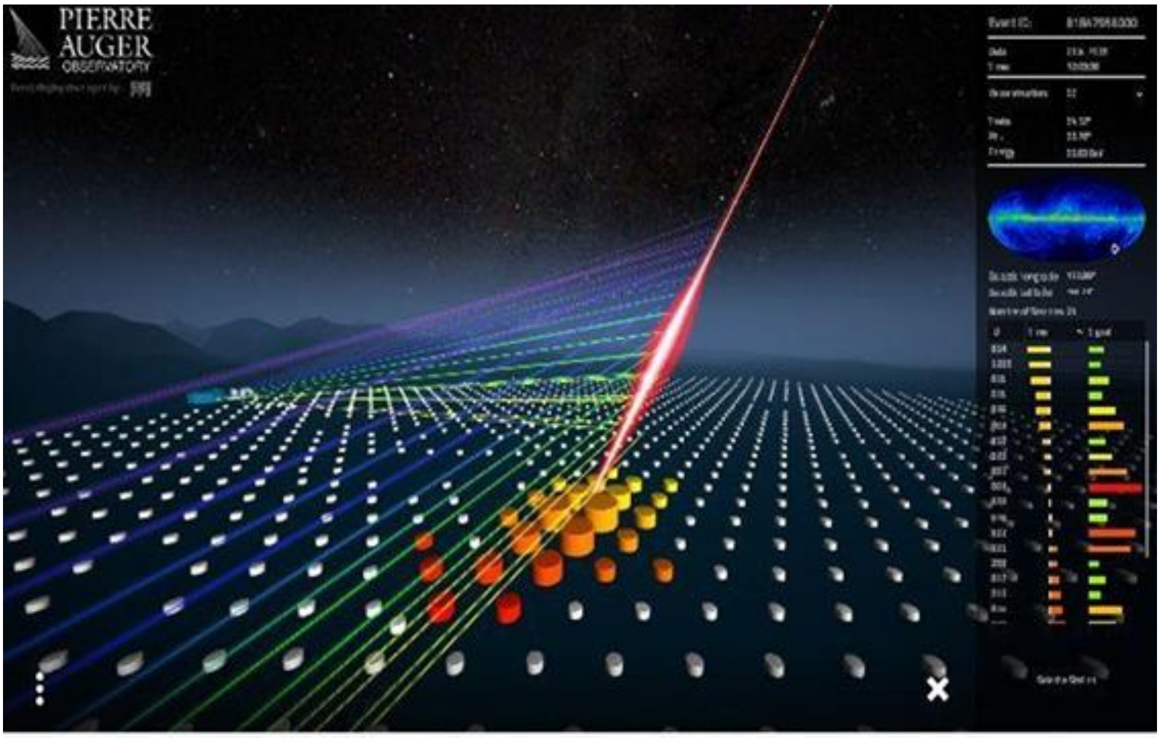


Fig.1 Representation of an EAS and the signals it releases in the detectors of the Pierre Auger Observatory.

The Pierre Auger Observatory combines the information of two types of detectors:

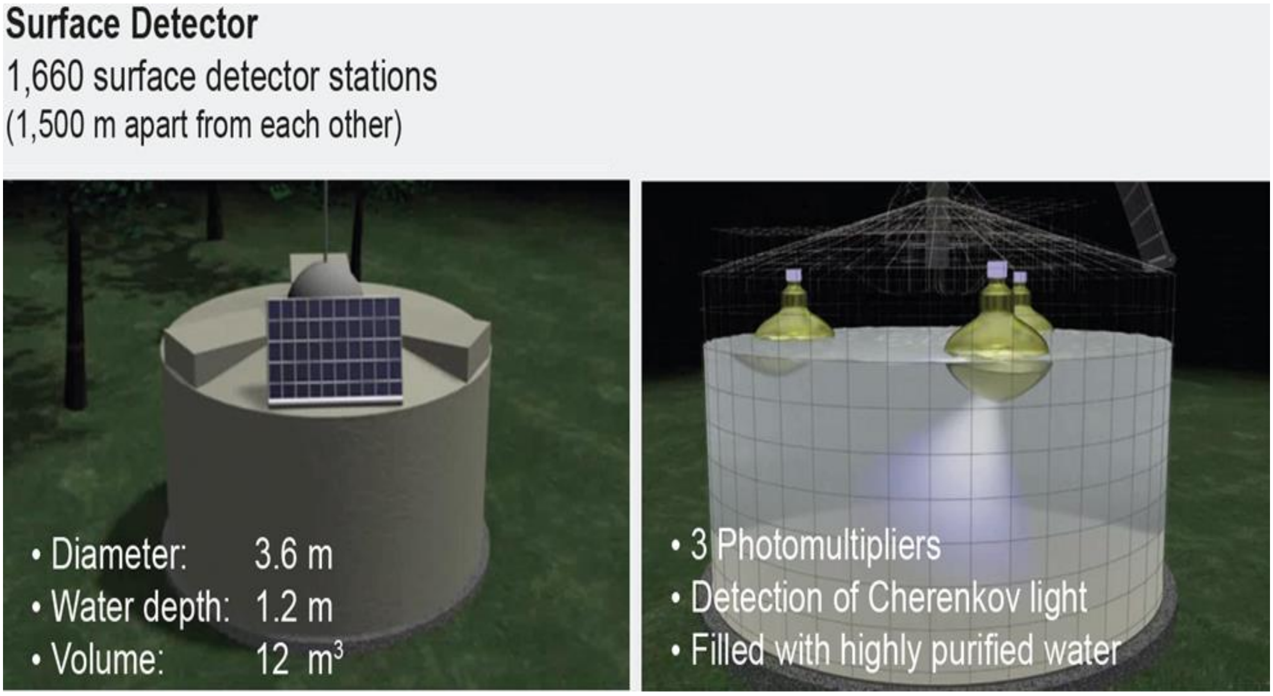
Fluorescence and surface detectors.

The *fluorescence detectors* give us information on the *longitudinal profile of the shower, i.e.* the number of shower particles as a function of the atmospheric depth crossed along the shower axis, the direction that the primary cosmic ray would have taken if it had not interacted.

The *surface detectors* give us information on the *transverse profile of the shower*, i.e. the *groun*d distribution of secondary particles as a function of the shower core, which is the point of intersection between the shower axis and the ground; the number of particles is greatest near the core and decreases as the particles move away from it.

The Surface Detectors (Cherenkov Detectors)

There are 1660 surface detectors (SD) stations in the Pampa Amarilla. They are Water-Cherenkov detectors (WCD).
WCDs are 12,000 lt tanks filled with ultra-pure /de-ionized water each other separated by 1.5 km. The internal parts of WCDs are completely dark except when particles from a cosmic ray air shower pass through it. If these energetic particles are traveling faster than the speed of light in water inside the detectors, they produce Cherenkov light measured by photomultiplier tubes mounted on the top of the WCDs. Extensive air showers contain billions of secondary particles and can cause nearly simultaneous bursts of light in more than five tanks. Scientists can determine the energy of the primary cosmic ray particle based on the amount of light produced by the secondary particles constituting the cosmic ray shower. When particles strike a station, a central computer communicates with the tanks hit by the shower particles via radio to decide whether the particles are part of a large shower. If it occurs, the information about the shower particles is stored and analyzed combining the measurements of the number of particles and their time of arrival at each station to determine the direction and energy of the original cosmic ray that set off the shower. The detector will measure about 30 cosmic ray events a year with energies above 10^{20} eV, along with large numbers of lower- energy ones.
A solar panel powers each station.



The Pierre Auger Observatory is upgrading its SD stations with Auger Prime. Data indicates that most energetic primary particles are not only protons, but also mostly heavy, highly charged nuclei deflected by cosmic magnetic fields, which makes difficult to track back to their origin. With these updates, it is possible in 10 years, scientists will be able to double the data set and identify the cosmic accelerators and their cosmic-

ray sources. This will also include the exploration of fundamental particle physics at energies beyond those accessible at terrestrial accelerators, and the observation of new physics phenomena.
The key element of the upgrade will be the installation of a plastic scintillator (**SSD**) on top of each existing surface detector station, furthermore enhanced SD electronics with an Upgraded Unified Board, addition of a small photomultiplier to the SD, installation of the underground scintillator muons detector AMIGA and measures to increase the duty cycle of the fluorescence detector.

Fluorescence detectors

Pierre Auger's fluorescence detectors are in four sites arranged around the perimeter of the surface detectors. Each site has six fluorescence telescopes whose field of view, i.e. the portion of the sky where they are able to detect the light generated by the shower, are blue lines on the map. The particles of the shower pass through the atmosphere, exciting the nitrogen and oxygen molecules of which the atmosphere is composed of, these trying to return to their fundamental state (their lowest energy state) emit fluorescence light. The fluorescence light reaches the telescope's entrance window, passing through a filter that selects the wavelengths between 300 and 400nm typical of fluorescence light, and is directed onto a matrix of 440 photomultipliers (PMTs). PMTs are instruments that collect the light and send it out in an electrical signal proportional to the amount of light collected.

The operation of the telescope is similar to that of a digital camera with extreme sensitivity: each pixel of the telescope camera consists of a photomultiplier capable of seeing only one photon at a time. Each coloured pixel represents a photomultiplier reached by the fluorescence light produced by the shower. The sequence of lit pixels represents the track of the shower.
Based on the arrival time and intensity of each PMT signal, it is possible reconstruct the longitudinal profile of the shower.

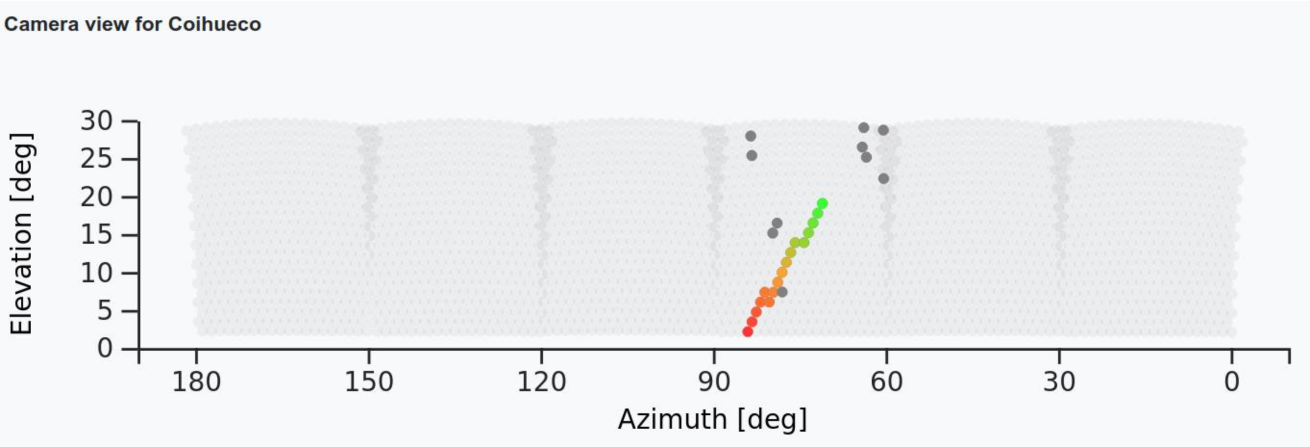


Fig.2 Each coloured pixel represents a photomultiplier reached by the fluorescence light produced by the shower. The sequence of lit pixels represents the track of the shower.

The number of particles in a shower increases when the secondary particles have enough energy to trigger new processes, which produce particles. When falling below this energy value, called critical energy, the atmosphere gradually absorbs particles whose number decreases.
$\mathbf{X_{max}}$ is the atmospheric depth at which the shower reaches maximum development, i.e. the maximum number of particles. This quantity depends on the type of primary cosmic ray that gave rise to the shower; therefore, if we measure it, we may find out whether a proton or iron nucleus triggered the shower.
In shower development, protons and neutrons behave in the same way.
From the reconstruction of the longitudinal profile, we can also derive the energy of the primary particle, which corresponds to the area under the curve, hence the integral, of the function describing the profile. The number of particles is related not only to the type of primary particle but also to its energy; the greater the energy, the deeper the swarm will develop.

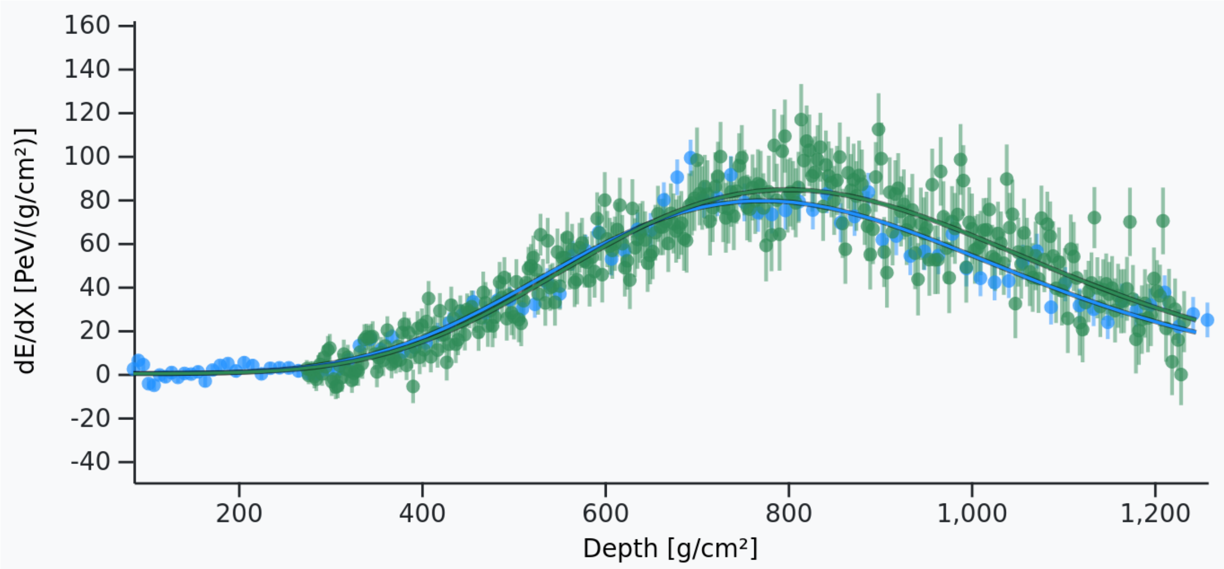


Fig.3 Longitudinal profile with Xmax Are visible double curves because of double observers

Conclusion

The Pierre Auger Observatory provides us with ultra-high-energy cosmic-ray data. The observatory studies mainly the secondary cosmic rays originating from the primary cosmic rays after colliding with molecules in the earth's atmosphere. The Pierre Auger Observatory uses surface and fluorescence detectors.

Surface detectors allow us to analyze the cross-sectional profile of secondary particles, i.e., their arrival on the ground. Fluorescence detectors analyze the longitudinal profile along the shower axis, i.e., the direction of the original cosmic ray.

Scientist have ascertained that, through current studies, we still know very little about the highest energy particles since these tend to collide with the atmosphere and thus generate new particles.

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