Auger Prime the new stage of the Pierre Auger Observatory, using Universality

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Abstract. The Pierre Auger Observatory is currently in an update stage denominated AugerPrime. The Observatory will have scintillator detectors on top of each of the surface stations (WCD). The main goal of AugerPrime is to improve the studies on mass composition for ultra high energy cosmic rays, for this purpose AugerPrime will use Universality. The model will parameterize the signal in four principal components, the objective is an adequate discrimination of the muonic and electromagnetic components. We are interested in the discrimination of these two components using simulations. To do that, we are working with OfflineTrunk (the official software of the Collaboration). Our work is focused on the development of some modules for analysis and study of the signal from AugerPrime.

1. Introduction

The cosmic rays were measured for the first time by Victor Hess in 1912, he made several experiments in a balloon with an electroscope. He supposed that as the altitude increases the radiation measure will decrease, however the results showed the opposite [1]. From that moment on, searches to understand and explain this new radiation started.

In 1938 Pierre Auger discovered the extensive air showers (EAS), showers of secondary particles caused by the collision of primary high energy particles with nitrogen molecules from air. He had positioned particle detectors high in the Alps and noticed that two detectors located several meters apart had signals of the arrival of particles at the same time. The conclusion was that he was measuring a shower of 10^{15} eV approximately, never seen before.

In 1962, John Linsley detected the first 10^{20} eV cosmic ray, in New Mexico, US. He used a ground based array of detectors to measure this cosmic ray. His observations suggested that not all cosmic rays are confined to the galaxy. This was the first evidence of ultra-high energy cosmic rays. In 2003 the Pierre Auger Observatory is proposed, to be the largest cosmic ray air shower array in the world.

2. The Pierre Auger Observatory

The main objective of the Observatory is the study of the ultra high energy cosmic rays (UHECR), with energies between $10^{18} - 10^{20}$ eV. The Observatory is located at Malarge, Argentina, at 1400 m over the sea level. The Pierre Auger Observatory combines two different techniques, one is the detection of the fluorescence due to a cosmic ray crossing the atmosphere and the other one is using water Cerenkov stations (WCD). The fluorescence array (FD) consists of 4 buildings located surrounding the surface array. Each building has six telescopes, the telescopes only can work during moonless nights and good weather [2]. The combination of these two techniques allows the observatory for more precise measurement of the ultra-high energy cosmic rays.

Both arrays FD and SD have extensions to measure low energy cosmic rays, around 10^{17} eV. To the FD array the low energy extension is the High Elevation Auger Telescopes (HEAT) which is situated in front of Coihueco, one of the four sites of the FD array. In the case of the SD array, the extension is called Infill. This region consists in 63 surface stations, separated by 750 m, half the usual separation [3]. Both arrays are located in the same region, with the purpose of having simultaneous measurements.

Currently the Observatory is beginning a new stage, called AugerPrime. This update consists on placing a scintillator detector on top of each WCD station, this makes possible the separation of the electronic and muonic components of the showers. It is planned that AugerPrime works for the next ten years, during this time the Observatory will have twice the original data and will be able to collect additional information for important questions as:

- Higher certainty of the origin of the flux suppression at the highest energies, if it is due to propagation effects, and the maximum energy reached by astroparticle sources.
- A proton flux contribution at highest energies.
- A better understanding of the air shower cosmic rays and the interaction of the particles in the atmosphere. This can lead the Observatory to study the hadronic models and a deeper study of the particle physics involved, to very high energies.

3. AugerPrime

One of the principal motivations for this additional array of detectors is to add information about the particles in the air showers independent from the measurements did by the water-Cerenkov stations. To do that, the additional measurements should be done in the same position as the WCD with a detector with different response to the components of the EAS. The chosen detector is a plane of plastic scintillator positioned on top of the surface detector [4].

The Surface Scintillator Detectors (SSD) consist in one module of $\approx 4m^2$ extruded plastic scintillators which are read out by wavelength-shifting fibers coupled to a single photo detector. The active part of the scintillator is a plane made by 12 1.5 m long bars of extruded polystyrene scintillator. Each bar is 1 cm thick and 10 cm wide. The fibers are positioned following the grooves of the routers at both ends, in a “U” configuration that maximizes light yield and allows the use of a single photomultiplier [5].

The external detector enclosure is made from aluminum to guarantee light tightness, robustness for 10 years of operation in the field, and enough rigidity for transportation. A double aluminum roof is installed, separated by 2 cm, to allow air flow and reduce the temperature changes. The temperature control is very important not just for correcting the behavior of the electronics but also for the aging of the detector.

3.1. Status

In march of this year the site to establish the Engineering Array (EA) of AugerPrime was decided, the requirements for the site were:

- An accessible area, relatively near to the Central Station.
- Solid ground, accessible during all year.
- Landowners should agree with the installation of new detectors.
- Due to communication problems, the infill area was avoided.

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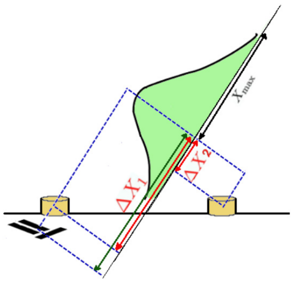

Figure 1. Integral along the shower axis of the density between the height at the projected detector position at the height of the shower maximum.

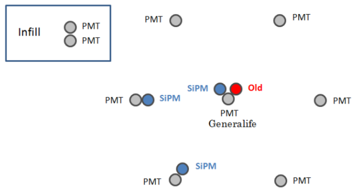

Figure 2. Layout of the Engineering Array. The different configurations of the detectors are shown.

The chosen place is around the tank called "Generalife". The EA will consist of 12 stations, ten of them will be allocated in a hexagon of the standard array. Two more will be placed in the infill area, with the objective of having more statistics. As show in Fig.2, the hexagonal array cell of 7 positions will include 4 single stations, 2 double and one triple station. The EA allows the comparison between the different proposed electronics for the SSD, and also between the old and new stations. According to planned, the EA start will be deployed in September of this year.

3.2. Universality

Additional to the SSD detectors, a new method to describe the air showers was proposed. This new method uses the shower universality, which states that the air shower can be entirely described by its energy, number of muons and maximum slant deep. According to this, an analytical parameterization of the signals was proposed. The signal will be separated in four components:

- The muonic component.
- The pure electromagnetic component.
- The electromagnetic component due to muon interactions and muon decay.
- The electromagnetic component due to low-energy hadrons (jet component).

Another important quantity used by this parameterization will be DX: the integral along the shower axis of the density between the height at the projected detector position and the height of the shower maximum, Fig.1. For each of the signal components the arrival time of the particles will be different and can also be parameterized.

So, the total expected signal in a surface station at certain distance r and with some relative depth DX, is:

$$S_{tot} = S_{em}(r, DX, E) + N_{\mu}^{rel}[S_{\mu}^{ref}(r, DX, E) + S_{em}^{\mu}(r, DX, E)] + (N_{\mu}^{rel})^{\alpha} S_{em}^{low-energy}(r, DX, E)\,. \quad (1)$$

The alpha parameter is obtained from simulations with different hadronic models, if $\alpha \approx 1$ it will be a very good approximation. The integrated signal as well as the time trace of each surface station is fitted by adjusting the parameters E, DX and N_{μ}^{rel} [6].

The primary energy and the number of muons are strongly related, and can not be determined independently. The approach used to solve this consists in parameterizing the number of muons as a function of the energy and X_{max} using hybrid events. With the number of muons, it is possible to reconstruct the energy E and the depth of the shower maximum X_{max}.

4. Software

Our principal interest is to work with this new detector, so the work should be done with simulations. The program used to simulate the air showers is CORSIKA (COsmic Ray SImulation for KAscade). CORSIKA allows us to fix the principal characteristics of the showers as energy, primary particle, magnetic field, first interaction. At the moment we count with a library of simulated events with the following characteristics:

- Primary energy: from 10^{18} to 10^{20} eV.
- Primary particle: proton and iron.
- Zenith angle: 0°, 25°, 45° and 60°.
- Azimuthal angle: random (0 - 360 degrees).

These simulations are being done in the LNS (Laboratorio Nacional de Supercómputo del Sureste de México), thanks to this it is possible to generate the data sets in reasonable times.

The OfflineTrunk (development version of the official software of the Collaboration) program will be used to know the response of the detector. The program already implemented the Universality method and allows to reconstruct the events using it. There are also some basic modules to simulate the SSD detector. The work in progress is mainly focused in these modules, in order to do an analysis of the signal.

We are working in a proper discrimination of the signal. As was mentioned, the signal will be separated in four components, which allows us a better understanding of the muonic and electromagnetic component and therefore of the mass composition of the showers. The main objective of the work is to have an adequate separation of the signal of each detector and also of the four components of the signal proposed by Universality. Once we reach this objective, an analysis of the different PMT's proposed for the SSD will also be done.

5. Conclusions

The main objective of AugerPrime is improving the studies on mass composition for the ultra high energy cosmic rays. It is planned to work for another ten years, in this way the Observatory Pierre Auger will have double the original data and will be able to do an event by event analysis.

Thanks to the new scintillator detector (SSD), it will be possible to discriminate the muonic and electromagnetic components of the air showers. The chosen method to do this is Universality. The new model proposes a parameterization of the signal in four components. An adequate separation of the signal will allow a better understanding of the ultra high energy spectrum. As a consequence of this, it will be possible to elucidate the possible astrophysics scenarios for the origin of the ultra high energy cosmic rays.

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