Hybrid Cosmic Ray detector at Pico de Orizaba

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Abstract

In this work we present the design features and simulation of the hybrid detector under construction at 4300 m.a.s.l. equivalent to 620 g/cm^2.The goal of this observatory is to study the mass composition of the cosmic rays in the energy range of $10^{15} - 10^{18}$ eV. The observation technique include particle counting and fluorescence detection in order to improve the Energy and X_{max} determination. This approach allow us to contribute in the knowledge of the knee composition, corresponding to medium to heavy nuclei.

Introduction

One of the open problems of the high energy cosmic ray is the composition of the primary particles with energies from 1×10^{15} to 1×10^{18}. In order to contribute to solve this issue, we have design and hybrid detector to be located in the Pico de Orizaba and Sierra la Negra Volcanoes. One of the advantages of the site is the altitude, 4200 m.a.s.l, which may help us to observe the extended air showers nearby their maximum development, improving the determination of the parameters of the primary particle. The optical properties of the site have been studied by several years, showing stability and darkness to declare it as a good optical astronomical site. So, we thought that the installation of an fluorescence telescope, should complement the ground array and improve the overall performance of this observatory. In the other side, the implementation of the hybrid technique, based in montecarlo simulations, may allow us to separate the light and the heavy primary components. Based in simulations, we expect good quality measurement of the number of secondary particles due to the proximity of the array to the level of maximum development of the EAS X_{max}.

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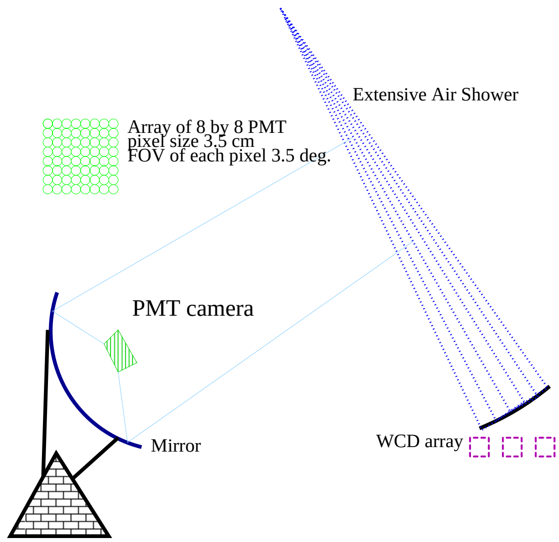


Fig. 1. Scheme of the ground array and the fluorescence telescope.

Ground array

The first component of this observatory, will be a particle counter detector [1], located in the Pico de Orizaba at 4200 m.a.s.l. ($620g/cm^2$). An scheme of the array is shown in the figure 1. Consist of 19 water cherenkov detectors (WCD), distributed in an hexagonal array in an area of $2.25km^2$, with a separation of 200 m between each one and 6 external WCD located at 750 m . Every single unit is a light tight polyethylene cylindrical water container of 3.6 m diameter and 1.5 m height, filled up to 1.2 m of purified water. The cherenkov radiation produced by the crossing particles, will be detected by 3 photomultipliers pointing downward to the reflective inner walls. Detector electronics consist of two main parts: 3 PMTś and the recording and transmission electronics with a high voltage power supply for PMTś and a low voltage power supply for the electronics. The signal detected by the PMT is amplified by a preamplifier, then is digitalized by an ADC unit and finally stored by a FIFO memory. This system have a 40 Mhz sampling rate, and the information acquired by each detector will be send to a central station of the array to the triggering system and stored in a PC for a further analysis, by optical fibers to avoid electromagnetic interference. The continuous duty cycle of the ground array will be useful to anisotropy studies of the arrival direction of the cosmic rays.

Fluorescence telescope

One of the characteristics of the fluorescence detection technique of high energy cosmic rays is to measure the number of charged particles produced during the developing of the extended shower as a function of the atmospherical depth. To archive this, a $1.0m^2$ segmented telescope will be mounted in the Sierra la Negra volcano, at 4600 m.a.s.l., looking above the location of the ground array, in order to measure common events, from 4200 to 6600 m.a.s.l. Detector electronics consist 64 PMTś placed in a 8 pmt cluster by 8 lines. Each cluster have a common dynode divider and a common high voltage source. The matching gain of each pmt in cluster is handle by a variable resistor connected between second and fourth dynode and the slide pin connected to third dynode. Every cluster of 8 pmt ' s are connected to a multiplexer circuit and then digitalized by an ADC and stored the data in the corresponding FIFO memory. The features of this fluorescence detector are listed in the table 1:

Mirror diam.	Focal dist.	PMT diam.	pixels	FOV
1.0 m	0.55 m	3.5 cm	8×8	$24^0 \times 24^0$

As a first step, we estimate the signal received by the camera is given by:

$$Q = \frac{\frac{E_o}{1.8} \times 5 \times S \times R \times \delta \times \eta}{4\pi R^2} exp[-\frac{R}{\Lambda}] \tag{1}$$

where $\frac{E_o}{1.8}$ is the number of particles produced at X_{max} to primary energies of 1×10^{17} eV, 5 is the number of fluorescent photons produced by meter, S is the effective area of the mirror of the telescope, R is the distance to the shower, δ it is the field of view of each pixel in radians, η the quantum efficiency of the PMT and Λ is the attenuation length at the altitude where the observatory is located. Sensitivity of the camera is limited by the background noise. The estimation of this noise level σ is given by:

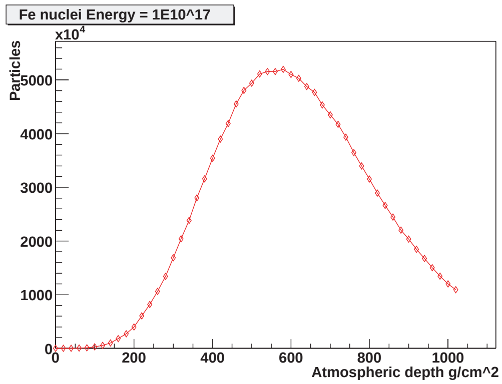
$$\sigma^2 = \Omega\nu\frac{R \times \delta}{c} \tag{2}$$

The expected noise level (ν) will be $200 - 500\frac{ph}{ns \times sr}$ in the UV range, and c is the light speed. Some expected examples of signal to noise ratio detection of a shower obtained by a line of 8 pixels of the camera, produced by a iron nuclei, inclined 20^o from the zenith and $E = 10^{17}$ eV are presented in the next table .

Pixel address	1	2	3	4	5	6	7	8
S, (ph)	39	45	50	55	59	62	65	66
S/N	0.9	2.7	5	5.2	5.4	3.5	1.8	0.8

Simulations and expectations

As we mentioned earlier, the fluorescence detector field of view will comprise from 4200 to 6600 m.a.s.l. So, to evaluate the expected signal at the telescope, we use the CORSIKA program in order to estimate the number of particles



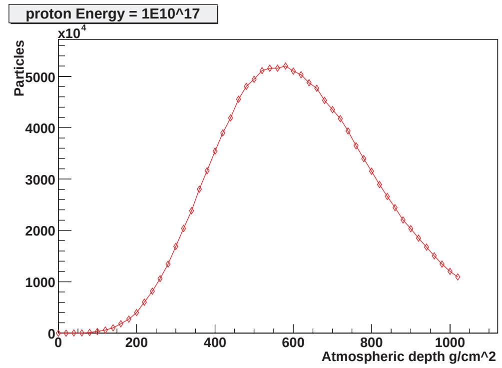


Fig. 2. Longitudinal profile produced by a Fe nuclei and protons with E = 10^{17} eV.

produced by the longitudinal profile of an EAS with energy and a mass composition within the ranges described before. Figure 2 shows the average longitudinal profile of 100 EAS initiated by a primary iron nucleus (left) and a proton (right) arriving with an angle in the range of $0^o to 28^o$ and energy 1×10^{17} eV, using QGSJET as interaction model, in order to obtain the predicted number of particles and the X_{max}. It is possible to see that the corresponding number of particles expected is larger than 5σ over the background noise and the variation along the atmospheric depth is $\sim$ 20%.

Finally, the expected rate of events should be estimated by the energy spectrum, corresponding to a energy threshold of 5×10^{16} eV, a shower with distance of 5 km, each pixel will detect 320 m of the fluorescence light path, for the 8 by 8 PMTś camera, an area of $12.8 km^2$ is covered, therefore a rate of $\sim$ 40 events per hour detected by the fluorescence telescope and 8 - 10 times more by the ground array are expected.

Conclusions

The hybrid array described may allow us to contribute to the study of the problems of the anisotropy and composition of the cosmic rays with energy above the knee, with the advantages of both detection techniques and the high altitude. This work was done with partial support of the CONACyT G32739-E grant.

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