# The Cosmic High Altitude Radiation Monitor (CHARM) at Pico de Orizaba.

**O. Martinez*, U. Cotti†, J. Cotzomi*, J.L. Diaz*, E. Moreno*, E. Ponce*, A. Rosado*, H. Salazar*, J. Sandre*, I. Torres†, E. Varela*, and L.Villasenor†**

* *University of Puebla, Mexico.*

† *Universidad Michoacana San Nicolas de Hidalgo*

***Abstract*. We present the status of a hybrid high altitude observatory including water cherenkov and air cherenkov detectors located at 4300 m.a.s.l. equivalent to 620 $gr/cm^2$, and (N $18^o59.1$, W $97^o18.76$) near Puebla City in Mexico. The detectors consist of 25 light-tight cylindrical containers of $10m^2$ cross section filled with 12000 l of purified water, covered in the inner walls with a high UV reflectivity material called Tyvek. Each one has a 8" hemispheric photomultiplier looking downwards. Those detectors are distributed in 3 hexagonal rings, with 330, 600 and 866 m apothem size respectively and rotated by $60^o$ to have a more dense array. The WCD containers were covered in the inner walls with a high UV reflectivity material called Tyvek. The Air Cherenkov detector array have also an hexagonal distribution but with 3 apothem sizes 80 and 150 m and 330m respectively. Each station consist in a hemispherical PMT looking upwards in a container including the DAQ and power supply electronics. The principal goal of this observatory will be to determine the mass composition of the primary particles of the cosmic rays with energy between $10^{16}$ to $10^{18}$ eV using together the capabilities and advantages of location and each detection technique. First tests and performance from simulation are presented.**

***Keywords*: new experiments,energy spectrum,mass composition**

## I. INTRODUCTION

Some of the more active issues of the ground based experiments is the study of the primary composition in the second knee of the energy spectrum. Taking advantage of the altitude and some facilities located in the Pico de Orizaba Volcano near Puebla City, we proposed the construction of a hybrid observatory called CHARM (Cosmic High Altitude Radiation Monitor). This observatory will use the advantages of the water cherenkov detection as reliable measure of the secondary particle number due to the primary cosmic ray and a good direction determination based in the flight time differences. This component of the observatory will give us a first energy and a arrival direction estimation, improved offline when the data will used in a fitting process with the lateral distribution function. And so, we get the core position, the total energy and the arrival direction of the EAS by WCD array. As complementary detection technique to obtain information related with the composition of the primary particle, we proposed an array of Air Cherenkov Detectors (ACD) distributed in a more compact array than the WCD to determine the temporal profile of the EAS in its travel towards the earth surface. The main goal is to determine the altitude at the EAS reach the maximum number of secondary particles or $X_{max}$ directly. This quantity is directly related with the mass of the primary. Using those techniques we expect to determine the trend of the mass of the primary particles in the second knee region of the energy spectrum of the cosmic ray radiation.

## II. WCD ARRAY

At 4300 m.a.s.l. in the southern face of the highest Mexican volcano called Pico de Orizaba, there is a almost flat square area of nearly 1 $km^2$. This surface will be the place used to install the CHARM arrays, the first one consist in 25 light tight cylinders of polyethylene each one with a effective area of 10 $m^2$, filled with purified water up to 1.2 m. They are covered in the inner walls with a high UV reflectivity material called Tyvek. Each one of those detectors have a 8 inches diameter hemispheric PMT looking downwards located in the center. The WCD array is distributed in a hexagonal grid with 3 concentric rings, the first one at 330 m, the second one is rotated 60 degrees refereed to the first, with an apothem size of 600 m and the outer WCD ring is located at 866 m from the center. In order to estimate the effective area of this array, we evaluate the reconstruction capabilities. It was build a events library generated with the standard CORSIKA program. The main characteristics of those events are: primary particles; proton and iron nuclei, energy from $10^{16}$ to $10^{18}$ and a zenithal distance of the arrival particles from 0 up to $30^o$. As it is shown in the Figure1. Those events were used as initial data in a reconstruction program and compared the rate of injected-reconstructed events and used as efficiency estimator. The trigger condition was that the WCD with highest signal recorded has at least 3 WCD neighbors with signal that allows to reconstruct the event. Also, it is possible to note that the ratio due

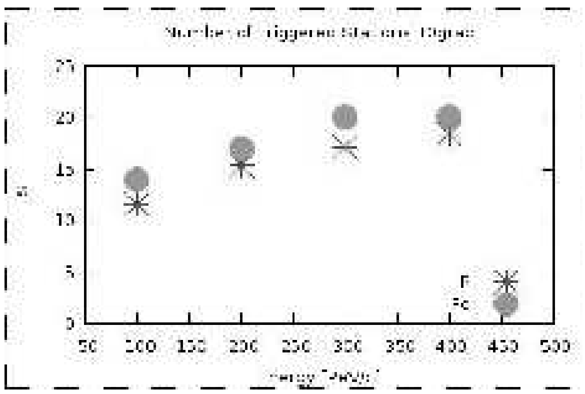

Fig. 1: Plot of the WCD triggered by injected events with primary energy and for different primary particles (proton and Iron).

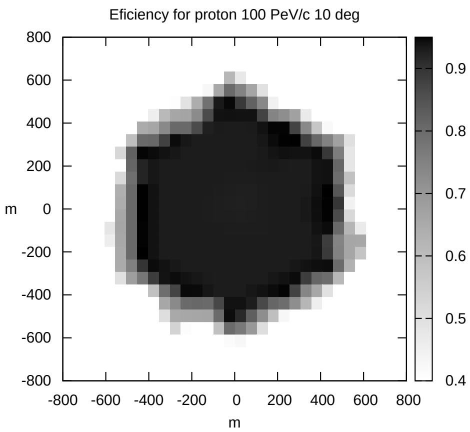


Fig. 2: Contour plot of the efficiency parameter for the WDC array for showers initiated by a 100 PeV proton injected randomly.

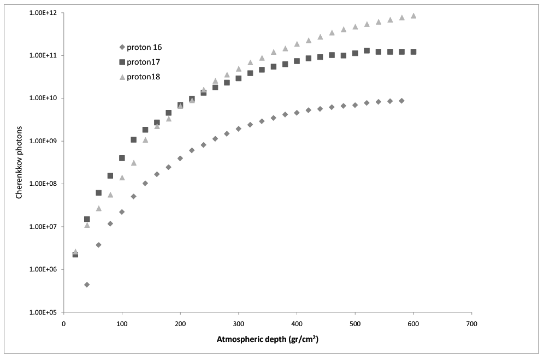


Fig. 3: Longitudinal develop of the cherenkov photons with the atmospheric depth for events initiated by vertical protons with energies from $10^{16}$to$10^{18}$ eV the observation level is at 620 $gr/cm^2$

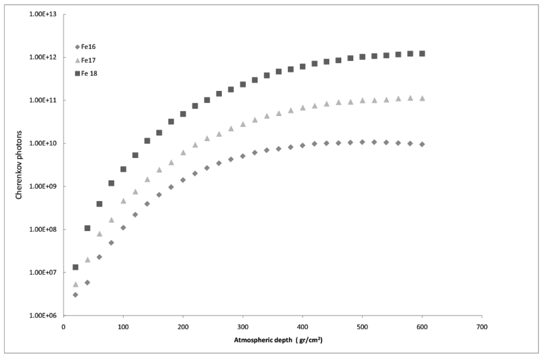


Fig. 4: Same as the Figure3 but for Fe nuclei, the maximum number of photons will reaches below the observation level for higher energies.

to light primary (proton) and the heavy one (Fe), have the same trend.

The energy dependence of the injection-reconstruction process was explored also. The number of WCD triggered within the energy range it is shown in the Figure 2. We have taken as efficiency threshold 60%. With the covered area and those parameters, our estimation of the effective total area of the WCD array was nearly $9 \times 10^5 m^2$.

## III. ACD Array

The second array that CHARM include is the Air Cherenkov Detector (ACD). This array was proposed in order to complement the WCD because this detection technique allow us to measure the temporal development of the shower in the upper atmosphere. Determining the altitude when the shower reach the maximum number of secondary particles ($X_{max}$) by the temporal behavior of the signal registered. This quantity $X_{max}$ is directly related with the mass of the primary particle ($< LogA >$) and therefore allow us to contribute to determine the basic trend of the composition of the primary particles in this energy range. Our approach to this study begins when the primary particle interact with the upper atmosphere, in the very forward direction of the shower, cherenkov photons are generated. We have simulated events with different energies and two different primary particles (proton and Fe nuclei) hitting the atmosphere vertically. The simulation includes the longitudinal generation of photons as the shower developed in the atmosphere.

The Figure 3 shows the dependence of cherenkov photons with the atmospheric depth measured in $gr/cm^2$ for energies from $10^{16}$ to $10^{18}$ eV. We could say that the amount of light generated by those events will permit us to determine the mass difference of the primary particles.

The Figure 4 correspond to Iron nuclei, and the expected signal from this kind of primaries will be smoother and stronger than the proton ones. The average

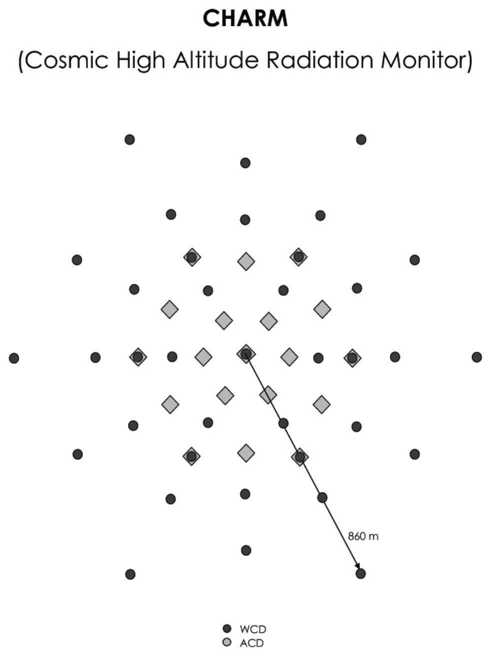


Fig. 5: Diagram of CHARM, the circles correspond to the WCD units and the squares to the ACD.

atmospheric depth for EAS initiated by Fe nuclei aren't reaches the $X_{max}$ even at the observation level if the primary have energy around $10^{18}$ eV and larger in the case of protons. The slope of the longitudinal function will help us to define the mass and using the WCD energy estimation in those cases. In the case of the lateral distribution of light, for the ACD, the operational energy range will starts at $10^{14}$ eV. It is remarkable the change in slope in the LDF shown at distances of nearly 150 m from the core of the EAS. By this feature in the light distribution, the first stage of the ACD array consist in 19 units. The separation in the two inner hexagons goes from 80 m, then 150 and the outer ring is located at 300 m. In a second stage, it is planned to extend the ACD array to the entire surface of CHARM. One of the features that we want to use is a custom made modular electronics. With this idea, the basic hardware will be capable to be set to the different time scales of both detection techniques. Once we have described both components of CHARM, a layout is presented in the Figure 5

## IV. Electronics and Tests

As one of the starting ideas for CHARM was the modularity, in this section we will describe the main features of the electronic system that could be used in both arrays. It is important to say that the altitude and adverse weather condition for all operative systems in particular electronics, made a difficult task to obtain a final operational and reliable design. At this moment, the growing capabilities and versatility of the modern analog to digital converters and FPGA electronics permit us design and built a custom made data acquisition (DAQ) based in this technologies. In the Figure 6 we show the schematic diagram of the DAQ used in the WCD. This DAQ system consist in a mother board with the FPGA, and Analog to Digital converter working at 200 MS/s install in a daughter board, a GPS receiver for the time stamp and a connector board RS-232. All this circuit is powered by a 5 V battery. This hardware will be connected with a PC by the RC-232 using a USB- serial cable adapter or a bluetooth wireless serial port adapter. We pursuit the autonomous operation of each detector as a primary goal of the design of CHARM.

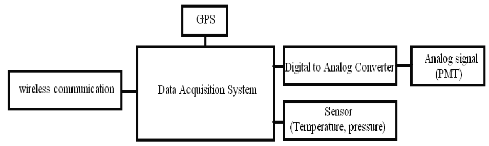


Fig. 6: Schematic diagram of the DAQ.

The sampling rate of the electronics for ACD array will be initially of 200 MSPS but the 400 MSPS option is under develop to assure the time resolution needed to measure rising and falling times. Finally we want to present as an initial test of the WCD system, a charge spectra obtained by a WCD as describes above and our custom made electronics. The Figure 8 shows the charge spectrum obtained with a 8 inches diameter PMT Hamamatsu (R5912)looking downwards of the center of the 3.6 m diameter tank. The operation voltage was 1300 V with a threshold of 3 ACD counts equivalent to 6 mV. It is possible to note the characteristics features of this plot, beginning with the first change in slope corresponding nearly with the vertical muon equivalent(indicated by an small arrow in the Figure) and the two straight parts, corresponding to single particle and small showers.

## V. Conclusion

We have briefly described the motivation, layout and some of the main features of the CHARM observatory. Using WCD in a high mountain as a primary detector, the energy and arrival direction of cosmic rays will be reliably measure and complemented by the longitudinal light development detected by ACD working in dark cloudless nights. The simulations of efficiency and longitudinal light distribution for this observatory and the

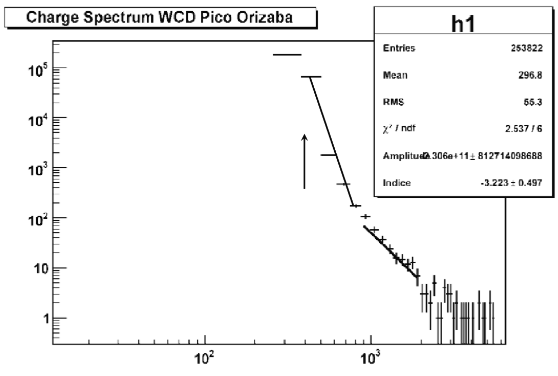


Fig. 7: Charge spectrum obtained with our DAQ system in a WCD located in the Pico de Orizaba. The small arrow indicates the equivalent muon deposited charge. Note the two well defined straight regions corresponding to single particles and small showers.

Fig. 8: A picture of the control shelter of CHARM array, some WCD are visible and the aeolic generator provide us of energy for electronic operations.

DAQ designed and tested will encourage us to continue building and operate the CHARM observatory. This hybrid technique of detection will allow us to determine the mass of the primary particles in the second knee energy range.

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