NOY: a neutrino observatory network project based on stand alone air shower detector arrays

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***Abstract*. We have developed a self powered stand alone particle detector array dedicated to the observation of horizontal tau air showers induced by high energy neutrinos interacting in mountain rock. Air shower particle detection reaches a 100% duty cycle and is practically free of background when compared to Cerenkov light or radio techniques. It is thus better suited for rare neutrino event search. An appropriate mountain to valley topological configuration has been identified and the first array will be deployed on an inclined slope at an elevation of 1500 m facing to Southern Alps near the city of Grenoble (France). A full simulation has been performed. A detailed cartography and elevation map was used to draw a neutrino energy dependent mountain tomography chart. The array acceptance was evaluated between 100 TeV and 100 EeV from a decaying tau air shower simulation. The effective surface is determined from the shower lateral extension at array location, and is found to be much larger than the geometrical array area. The single array yearly exposure will be 10^{14} $cm^2.sr.y$ at 100 PeV. The embedded data acquisition system consists of an 8 channels, 12 bits, 250 MHz digitizer associated to a FPGA containing a trigger definition design, a time tagging referenced by a GPS board and a Linux core processor. PMT high voltage supplies are remote controlled via serial or USB port. Data and slow control data are stored on a flash memory. Remote control and data transfer are operated under a commercial wireless communication system. This low consumption data acquisition system is self powered via solar energy. Several independent arrays can be deployed on the same site. Other sites around the world with a similar topography can contribute to a neutrino observatory network. Some other sites are already under study. At last, special care is dedicated to the educational and outreach aspects of such a cosmic ray detector.**

***Keywords*: neutrino, air shower, detection**

I. INTRODUCTION

The observation of earth skimming neutrinos have been proposed [1] as a rather sensitive method to detect very high energy cosmic neutrinos. Energetic cosmic neutrinos, while passing through atmosphere easily, can interact inside rock and produce leptons. Electrons will shower rapidly and have little chance to escape *(except at very high energies where LPM effect can inhibit shower development)*. Muon decay and interaction length are too large to induce an atmospheric air shower. The τ's have suitable range and decay length to escape the mountain and initiate a shower in the valley. A telescope able to detect the induced horizontal shower will serve as a $\nu_\tau \rightarrow \tau$ appearance experiment.

The observation of a large target volume is needed together with a high detection efficiency to overcome the low neutrino flux from cosmic origin. Several methods have been proposed for the observation of the emerging τ shower, most are based on the detection of the Čerenkov light emitted by the shower. We propose here to use a ground particle detection system within a specific mountain to valley topological configuration. When compared to light detection which can be achieved only on moonless nights in a non-polluted area, the advantage of ground particle detection lies mainly in its high duty cycle of nearly 100%. A required coincidence between several detectors reduces the background level to almost zero. Ground detectors provide also a good angular resolution allowing to reject spatially muons from downward or inclined old showers which could mimic neutrino events.

The specific configuration of mountain to valley which is required to detect neutrinos, implies to deploy a detection system in isolated regions where no supply is available. A self autonomous system becomes necessary and the present communication will shortly present the characteristics and performances of simple neutrino detector unit to be deployed in any convenient place.

II. SIMULATION PARAMETERS : NEUTRINO INTERACTION AND HORIZONTAL τ SHOWER

Simulations have been performed for neutrino energies between 10^{15} and 10^{20} eV to evaluate the acceptance of the proposed experiment. Neutrinos interact with nucleons in the medium mainly via charged current and the τ production is a dominant channel whose cross section varies roughly like $E_\nu^{0.4}$ where E_ν is the ν_τ energy [2]. A large fraction of the incident energy is transferred to the τ such as $E_\tau = (1-y)E_\nu$ where y varies from 0 to 0.5 with a mean value $\langle y \rangle = 0.25$. The produced τ will propagate in the medium before decaying. Taking into account energy loss via bremsstrahlung

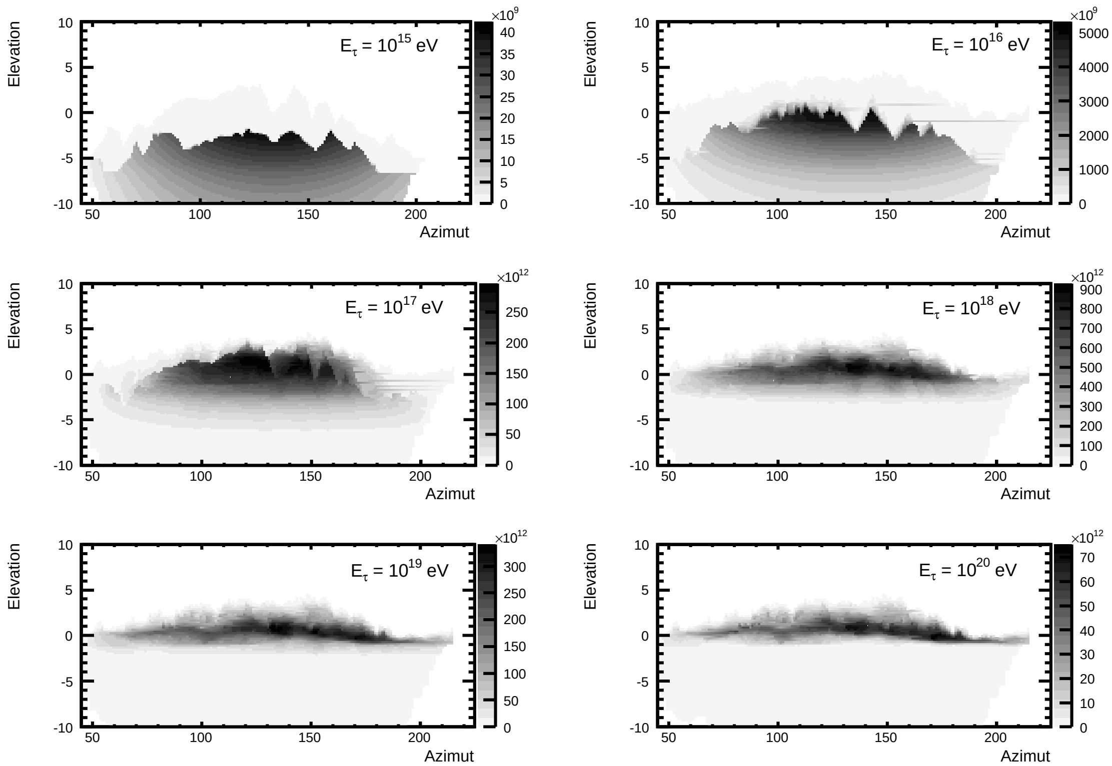

Fig. 1: Neutrino landscape : the sensitivity to ν_τ is computed for each pixel of incoming shower directions taking into account the real mountain topography. The neutrino sensitivity is given in cm ^{2} s for one year exposure of one cluster and for different neutrino energies. The detector array configuration is the one describe in the text. In these plots, each pixel is 6.1×10^{-5} sr.

and pair production a τ with $E_\tau \approx 10^{18}$ eV propagates nearly 8 kilometers in standard rock. Integrated over the whole thickness, the probability for the τ created at a depth X to emerge leads to the neutrino conversion efficiency given by (neglecting second order and ν_τ regeneration effects):

$$P_{out} \approx e^{-\sigma_\nu N_A X} \times \left(1 - e^{-\frac{\rho R_\tau}{\sigma_\nu N_A}}\right)$$

where σ_ν is the ν_τ rock total cross section, R_τ is the average τ range in rock.

For each incident neutrino energy there is an optimum rock thickness which contributes to the interaction. For the lowest neutrino energies a thin rock layer contributes and the effective interaction volume is dominated by the τ decay length.

The emerging τ will decay into a ν_τ and electrons and/or hadrons, which in turn rapidly initiate an air shower at the decay point. Due to the large Lorentz factors at these energies, the shower will point back to the direction of the decaying τ which itself points back to the incoming ν. Contrary to usual downward air showers, the present quasi horizontal shower will develop in a constant density medium depending on the elevation of the detection system. The shower first interaction point will vary with the τ decay length. A an example a 10^{18} eV τ has only 19% chance to initiate a shower within a 10 km baseline. With these fluctuations of the initial point, the showers will reach the detection plane at various ages of development. In the present stage of the simulation a longitutinal shower developement a la 'Hillas' is used. At the detection level, the lateral extension of the shower size is taken as the usual NKG lateral distribution function which depends slightly on the age. Since only nearly horizontal showers are concerned the detection plane is taken as vertical or slightly inclined. The effective area is determined by the distance from core impact where there is still a surface particle density of $1/m^2$ defining the detection threshold and taking into account the detector response. More refined simulations using the air shower code AIRES and the τ decay package TAUOLA are underway.

One should note here that the large fluctuations of the shower first interaction point forbid any precise reconstruction of the shower size from the ground particle density. Thus, such an experiment can only deduce the shower energy within a very broad range of energies and infer an even cruder lower limit on the incoming ν_τ energy. Measuring the shower size would have also required the containment of the shower core within the array geometrical boundaries, implying a very large detection array for the incident energies considered here. On the contrary, if the energy measurement is in principle not possible, the constraint on array size is relaxed and even a small array can be used to sample the shower

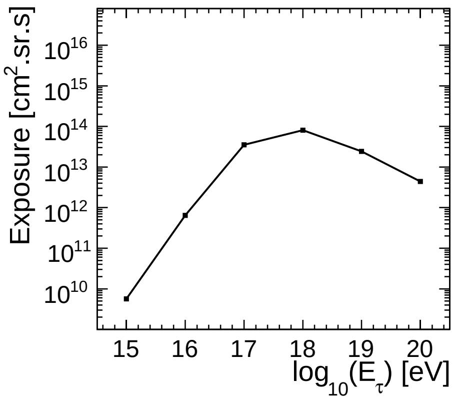

Fig. 2: Exposure in cm^2 sr s for one year and one cluster as describe in the text.

extension. A large effective surface can then be reached with a very small detector. Most of the detected showers will then be external to the array, without affecting the efficiency of shower front direction reconstruction not the angular resolution, provided that the front curvature is taken into account.

III. Simulation and performance

The detector performance has been studied using a realistic mountain/valley topography. The neutrino and τ tracking through the earth from the source to the detector was performed using a detailed cartography of the site including an elevation map around the geodesic location of the proposed site. The selected detection site is located near the city of Grenoble (France). The detection array will be installed at 1500 meters a.s.l. on an inclined slope, facing a deep 10 km wide U-shape valley and pointing at S-SE toward the 3000 m high Belledonne and Ecrins alpine mountain chains. A detailed mapping of the target (mountain) in terms of sensitivity to neutrinos was extracted from the simulation at different incident energies and is shown in figure 1. One can observe that the sensitivity to the lowest neutrino energies corresponds more to negative angle (upward going showers from the bottom of the valley) while highest energies are more sensitive to the top of the mountain. One can note that the mountain acts more or less as a prism or a spectrometer for neutrinos : highest energies on top, lowest at bottom.

The resulting overall exposure as a function of the incoming ν_τ energy is shown in Fig.2. The exposure peaks at a neutrino energy around $10^{17} - 10^{18}$ eV where it is close to 10^{14} cm^2 sr s. Assuming a E^{-2} flux, this corresponds to an integrated flux limit of $\approx 2.1 \times 10^{-6}$ GeV cm^{-2} sr^{-1} s^{-1} at 90% CL. The exposure increase with energy is due to the increase of the effective detection area and to the combination of the tau decay flight with the shower elongation that matches progressively the valley width of ≈ 10 km. At $\approx 10^{18}$ eV, the exposure saturates and then decrease because of the absorption of ν_τ's in the earth and excessive τ decay length. Note that the energy at which the exposure peaks depends on the target thickness and valley width as well as on the array pitch.

IV. Detector design

To achieve the goal of highest duty cycle as possible, one is led to choose a rather robust and simple system which can be deployed easily on any surface. The particle array unit consists of a cluster of five detection stations deployed on centered square positions with a pitch of 100 meters from the central one. Each detection station includes a plastic scintillator $80 \times 80 \times 4$ cm^3 faced by two 3-inches photomultiplier tubes at a distance of 40 centimeters. Plastic and PMTs are enclosed in a pyramidal sealed metallic box coated with diffusing paint. The overall size of each station is less than 1m^3. These elements were already used in several previous experiments [3] and have proved their robustness even in presence of hostile climatic conditions. At least a set of 3 stations would have been a minimum to triangulate, 4 stations to eliminate random coincidences induced by the rate of 150 Hz/m^2 from cosmic muons, and a set of 5 stations to improve the shower front precision measurement.

Each station is then be positioned on an inclined surface as required for the present purpose. The inclined surface is needed to improve the angular resolution for horizontal showers. The selected site has a slope of 30 degrees thus giving a array vertical extension of 100 meters. The angular resolution for horizontal showers is mainly governed by this vertical dimension. The stations are wired with low-loss cables to the central acquisition system. This connection allows the system to limit the data rate transmission, and the n-fold coincidence trigger can be build easily on the DAQ system. The trigger rate will be of the order of 3×10^{-3} Hz
Obviously the scintillation detectors are turned vertically to maximize the collecting area for horizontal shower. However an initial high statistics calibration of the "vertical equivalent muon" is realized using cosmic muons while the scintillator plates are positioned horizontally and in a second step switched to vertical position. A on-line continuous calibration with cosmic muons can then be used to control the detector response without any intervention on site.

V. Embedded Data Acquisition System

The data acquisition system consist of a single dedicated board including all the needed functions and with a low power consumption of less than 15 Watts allowing it to run in a stand alone mode with solar power supply. The board consist of 8 channels 12 bits ADCs running at 250 MSamples/s. These are driven by a XilinX Fx020 250 MHz FPGA with a PowerPC core under Linux. The remote programmable trigger is actually defined as a multiplicity level of n channels among m validated channels through a pre-defined threshold level on each

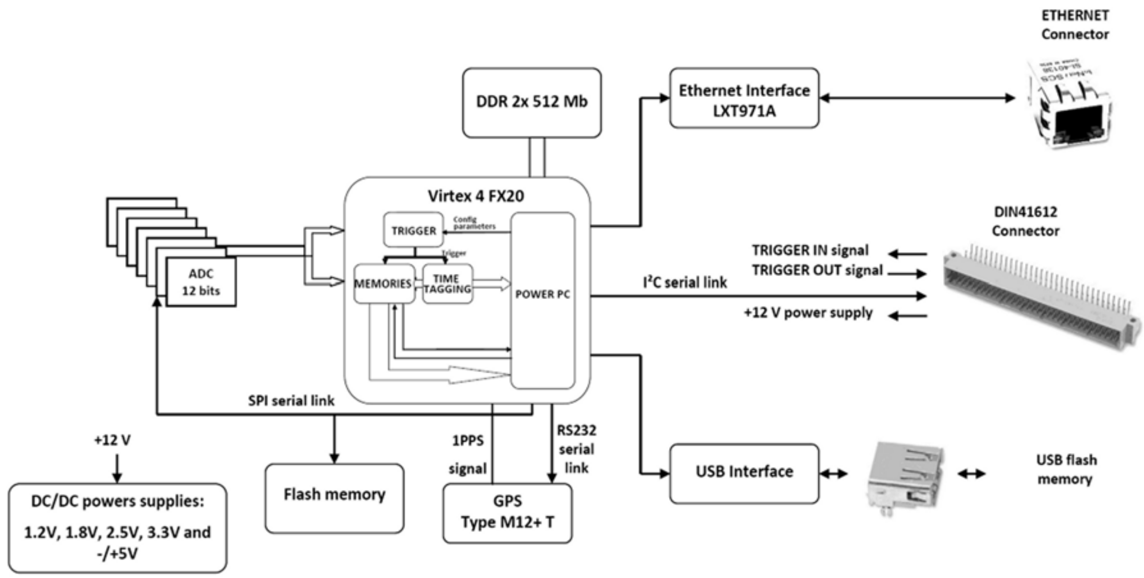

Fig. 3: Schematics of the data acquisition system.

validated channel. The multiplicity is defined within a programmable time gate on all required channels synchronized by the FPGA clock. A time tagging circuit is added including a GPS-timing card. The absolute time of the trigger is measured with a precision better than few nanoseconds. Internal Input-Output functionalities are performed via the on-board PC which also manages the data storage. An ethernet port, connected to a commercial communication system (either WiFi or GPRS modems) allows the wireless remote control of the system and the data transfer.

To power the PMTs, a 2 channel high voltage supply has been build for each detection station. They are controlled remotely via the PC through a multiplexor and a RS235 connection.

The requirement for the detector is to be installed in any isolated and unpowered place. It must be self powered, and attention have been paid to minimize the DAQ consumption. The total consumption of the DAQ and HV-supply does not exceed 20W. This allows to power the system via a set of photo-voltaic system delivering 150 Watt-peak and feeding a set of two 100Ah batteries. The size of the solar panels $(1.2m^2)$ is sufficient enough to provide energy to the system with a very low Loss of Load probability allowing to reach the goal of a very high duty cycle with a fully autonomous system.

VI. Present status and perspectives

Several scintillation detectors have been built for a previous outreach and education program introducing cosmic ray detection in schools [5]. These detectors are being reshaped for the present objective, while keeping the educative aspect in mind. Five detectors are actually running on ground near our lab. Long term tests have started to evaluate the robustness of the system, to measure the timing resolution and get an estimate on the rate of fake events. The DAQ system is tested and compared to a more classical one based on well known ADCs. The installation on site is expected to occur before winter. The expected performance of a single cluster unit is rather encouraging. To increase the sensitivity to neutrinos, the duplication of this system in several units is foreseen. Either these units are located close together or in different places, and provided that the topology of the sites reaches similar potentialities, they can be connected via a network. Several such systems could constitute a potential neutrino observatory and achieve a significant contribution to neutrino astronomy. Each system can be managed locally and the cost of development, running, data-taking and maintenance of each contributing unit is very low. At this stage of the project, three independent cluster systems projects are foreseen: two in the Alps and a third in the Atlas mountain (Morocco).

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