NICHE detector and operations

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Abstract. The Non-Imaging CHErenkov Array (NICHE) is a low energy extension to Telescope Array and TALE using an array of closely spaced (~ 200m) light collectors covering an area of ~ 2 square km. It is being deployed in the field of view of TALE and will overlap it in the energy range above 4 PeV. Cosmic ray air showers with energies 1-100 PeV are reconstructed using both the Cherenkov light Lateral Distribution and the Cherenkov time Width Lateral Distribution. These two methods will allow shower energy and \( X_{\text{max}} \) to be determined. A prototype of the array, called j-NICHE, has been deployed. The performance of detector’s components, current status of the detectors and the observations are presented.

1. Introduction

The mass composition of cosmic rays is very important to clarify their origin, because it must be strongly related to their sites of origin, mechanisms of particle accelerations, and propagation from the sources to the Earth. There is a general agreement in cosmic ray composition measurements that the fraction of the heavier component increases with energy around the knee region \( (E = 10^{15} - 10^{16}\text{eV}) \), see [1] for review). In air shower experiments, the types of primary nuclei that induce air showers can be inferred from the longitudinal developments of the showers thanks to the differences in the energy-per-nucleon and the interaction cross section with the atmosphere at a given total energy. The results from the previous experiments show that the cosmic-ray mass \( \langle \ln A \rangle \) increases with energy indicating a heavy-dominant composition at the knee. This is consistent with the rigidity-dependent stochastic particle acceleration models for cosmic ray sources that predict the maximum reachable energies \( E_{\text{max}} \propto Z \). On the other hand, it has been predicted that galactic cosmic ray sources such as supernovae cannot accelerate particles to energies greater than \( \sim 10^{18} \) eV, and together with the absence of strong anisotropies in cosmic ray arrival directions towards the Galactic plane, we conclude that cosmic rays with such high energies are of extra-galactic origin. In this case, protons and other lighter components would be dominant in this higher energy region, since heavier nuclei suffer from photo-disintegration processes by interaction with the cosmic microwave background photons during long distance propagation from extra-galactic sources. In fact, from recent measurements of the cosmic ray composition in the ultra-high energy region \( (E > 10^{18} \text{eV}) \) using the air fluorescence detection technique, a proton-dominant composition has been reported at \( 10^{18} \text{eV} \) [2, 3, 4]. Therefore, it is expected that there is a drastic change in the cosmic-ray mass composition in the energy range of \( 10^{16} \) to \( 10^{18} \text{eV}, \) i.e. from the heavier galactic components...
to the lighter extra-galactic components. The aim of the NICHE (Non-Imaging CHErenekov) experiment is to measure the mass composition of cosmic rays in this transition region.

2. NICHE at the TA site

A prototype array of 14 CDs were deployed in 2017. This array are called as j-NICHE to distinguish it from other NICHE endeavors. The positions of the deployed j-NICHE counters are shown in the left panel of Fig. 1. The detectors are deployed ~ 800m away from the MD site with 100m spacing to detect air Cherenkov lights generated by showers with $E \geq 3\text{PeV}$ together with the MD and the TALE FDs.

A j-NICHE counter detects Cherenkov light with a 3-inch photomultiplier tube (PMT, Hamamatsu R6233-100), and the output signals are digitized with an FADC (200MHz, 12 bits) and stored in a micro-SD card. A Winston cone of opening half-angle $45^\circ$ is attached above PMT to collect more inclined lights. We found the most of rays with $\theta = 43^\circ$ can not be seen by PMT from the result of ray-tracing simulation for a NICHE detector using ROBAST package\[5\]. The Winston cones are made by machining a solid aluminum 4-inch dowel at the University of Utah.

Data acquisition and triggering are handled by a FADC/FPGA unit made by a company (Brains, Inc., in Japan), and connected using SSH via a LAN port as well as it receives Bash commands on an incorporated Linux to control a set of components: turning on HV, open/closing a shutter and taking data. A trigger occurs when the moving average of the FADC output with a window of 16 samplings exceeds $7\sigma$ of its fluctuation. In each trigger FADC 1024 samplings (~5\mu s) are stored together with a timestamp of the 200MHz clock synchronized with the GPS-PPS signal in the micro-SD card in the detector enclosure. All the data taken at a night is retrieved via a wire-less communication system just after observation.

The gain curve of every PMT has been measured with YAP\[6\] attached on a PMT window. Absolute calibration of the j-NICHE PMTs in terms of a conversion factor from FADC counts to the number of photons were carried out using the CRAYS system, consists of a pulsed nitrogen laser and a chamber filled with a pure gas (> 99.999%, N$_2$ or Ar), which was also used for PMT absolute calibration of TA FDs\[7\].

The housing for the j-NICHE counters includes a rotating platter with a hole that serves as a shutter, keeping the PMT and Winston cone safe during the daylight hours. It also houses the

**Figure 1.** Left: The map around the TA Middle Drum (MD) site. The j-NICHE counters denoted by greens are deployed with 100m spacing ~ 800m away from the MD site. Right: A j-NICHE counter in the field with MD-FD behind.
batteries, data acquisition and control electronics. The j-NICHE counters have only one PMT installed per counter, but a two-PMT design for future NICHE hybrid array will allow for a local coincidence trigger and thus a lower threshold and/or a lower trigger rate.

3. NICHE operation

NICHE operation is held for a whole dark night from the end of the astronomical twilight to the beginning of the next astronomical twilight, thus carried out at the same time as MD-FD operation. Main PC at MD-FD building connects each detector via wire-less communication using SSH, and sends a command and gets a corresponding result using Expect program written by Don Libes, that makes it possible to automate interactions with other programs. Preparations of observation begins 30 minutes before the astronomical twilight, connecting and initializing every detectors and turning on HV with a shutter closed. Data taking starts till 15 minutes before the end, after opening a shutter at the beginning, and then data collecting and backup are executed. NICHE observation has regularly started in May 2018 when 10 counters were deployed then, but all the counter is done in Sep 2018. Total observation time is 103 days/625 hours and the number of coincidence events with over 4 detectors is 110,768 until June 2019. A typical trigger rates and a rate of coincidence events in 31 Mar 2019 are shown in Fig. 2.

4. Summary

NICHE experiment aims to measure the cosmic-ray composition in $10^{16}$ to $10^{18}$ eV by detecting Cherenkov lights generated by air-shower with 14 detectors placed in a grid and spaced 100 m apart. Each detector has mainly a single PMT and a FADC and a Winston cone attached above PMT makes it possible to detect lights with zenith angle $<\sim 43^\circ$. All NICHE detector has been deployed and taken data since May 2018.

References

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