VHE neutrino pilot observation with the Ashra detector

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Abstract**. The Ashra Experiment aims to catch the signals from air showers made by VHE cosmic rays with a newly developed detector. Its main features are an optics with high angular resolution and wide FOV, and an intelligent triggering system to obtain fine air-shower images. These characteristics are suitable for monitoring observation for emissions from transient objects in the Universe. Here we report the results from a pilot observation for neutrino emissions from objects, with the Earth-skimming neutrino detection technique. Even though it is a preliminary one, this is the first astrophysical result from the triggered images obtained in the Ashra Mauna Loa Site.**

Keywords**: neutrinos, PeV, air shower**

I. INTRODUCTION

Neutrino is one of the most promising candidate to probe the particle acceleration in the Universe. Recent observations with TeV gamma rays revealed that there are various kinds of sources with high-energy emission in the Universe. However, the mechanism of the particle acceleration is still unknown. Whether it is leptonic or hadronic (or both) is expected to be determined by neutrino detection most clearly. Also, observation of UHECR by the Pierre Auger Experiment suggested that UHECRs are correlated with the super-galactic plane [1]. For more detailed investigations, we must have a detection technique with higher resolution. Neutrino is one of the most promising tools, because it is never reflected by the magnetic fields in the Universe. Now the GZK neutrino is the most probable source, because Auger already showed that the UHECR spectrum does not conflict with the GZK mechanism [2]. The localization of sources of the GZK neutrino will possibly solve the mysteries about the UHECR generation.

However, neutrino detection has been challenging since decades ago. Following the detection of the signals from SN1987A by KAMIOKANDE [3] and IMB [4], various experiments tried to detect neutrino signals. The efforts resulted in understanding of MeV neutrino signals from nearest sources, like the Earth, the atmosphere, and the Sun. On the other hand, in energy range over GeV we have not yet succeeded in detection of significant neutrino signals. In Cherenkov experiments with ice, AMANDA experiment at the South Pole and its successor IceCube [5] are the leader. They published a result with 9 strings, but only set an upper limit to the neutrino spectrum [6]. Also, three experiments in the Mediterranean Sea are going on, and their combination, KM3Net project [7], is proposed. It aims to obtain target mass about 1 kilometer cubic.

Neutrino searches in higher energies, UHE region, also have not succeeded yet. The flux of the GZK neutrinos is expected to be its maximum at about EeV (10^{18}eV). In this energy region, detection with air showers is one of the most promising way. Recently, neutrino observations with air showers were reported [8][9][10][11]. The strength of this detection technique starts to be revealed. Experiments like ANITA [12] already set upper limits to neutrino flux in the energy range of $\sim 10^{21}$eV. They rejected models in that energy region which predict E^2 flux beyond 10^{-7} [GeV cm^{-2} s^{-1} sr^{-1}]. but did not discover any positive signal.

II. THE ASHRA EXPERIMENT

The Ashra (All-sky Survey High Resolution Air-shower detector) Experiment [15][16] aims to catch signals from transient objects in the Universe, in order to open the door to 'multi-particle astronomy' [27]. It can detect light generated in the atmosphere by high energy particles, such as very-high-energy gamma rays, ultra-high-energy cosmic rays, and very-high-energy neutrinos. It has also a mode to image with UV light without a trigger. The Ashra detector has an fixed optics with wide field of view of 42 degrees and high angular resolution of a few arc-minutes. As such, it is well suited to monitor transient objects, like GRBs. In this paper, we report the monitoring observation of neutrino emission from transient objects, such as GRBs and AGN flares. The results in the monitoring observation of GRBs with UV light are in other references [19] and a presentation at this conference [13].

The Ashra site is on Mauna Loa on Hawaii Island, the United States. It is located near Mauna Kea, one of the most famous observatory in the world. Another reason for the choice of the site is the Earth-skimming neutrino

Fig. 1: The Ashra detector (for lower elevation FOV). The right was taken after mounting the components.

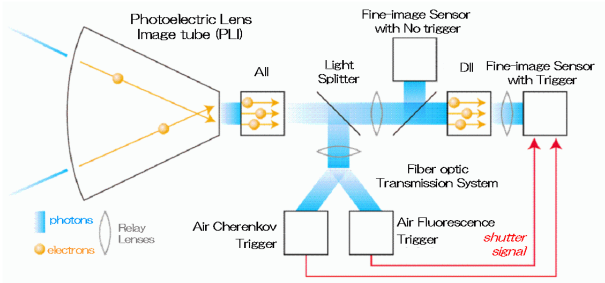


Fig. 2: Conceptual figure of 'Image Pipeline' and 'Trigger and Readout'. Light collected by Optical System is incident from the left [22].

detection, as mentioned in the next section. Details about this site, such as detector configuration, and operation of the observation, will be in another presentation at this conference [14].

The Ashra detector (Fig.1) can be divided into two components: one is Optical System, and the other is Image Pipeline and accompanying Trigger and Readout. The type of the optics is modified Baker-Nunn, one of the Schmidt type. It is composed of three correcting lenses, one spherical segmented mirror, and one spherical focal surface. The lenses are made of acrylic plates, while mirrors are made of glass plates. We designed the optics with ray-trace simulations. Deflection under gravity must be taken into consideration, hence we carried out structural calculations and confirmed that the deflection is not problematic.

After the design, optical components were developed. Efficient methods for mirror polishing were difficult to be established, but we overcome it. The components were shipped to the site in 2006 for a test observation. We assembled and adjusted them, and obtained good performances as a whole system. Angular resolution of a few arc minute was obtained over the whole FOV. The results of the adjustments in the test observation were shown in the proceedings [17][18]. Also, recent images obtained by the optical system at the site will be presented in this conference [13].

The other component in our detector is Image Pipeline and Trigger and Readout(Fig.2). Incident light collected by the above Optical System is focued on the input window of photoelectric lens imaging tube (PLI). Then, Image Pipeline divides, sends, and intensifies the output image of PLI, in order to acquire two types of fine images, with or without trigger. First, Image Pipeline amplifies incident image and splits it into two ways. In one way, Trigger and Readout determines whether the incident light is from cosmic rays. If it is, a shutter signal is sent to a sensor in the other way in Image Pipeline, to take fine image. In order to take as bright images as possible, it should make the image *wait* for the determination. This process is realized using an image intensifier with a phosphor screen of a long decay time. This concept, optical delay by combination of image intensifiers, was first found by CHORUS group [20][21], and we modified it [22].

III. Detection

In the observation we report, we used a detection technique called 'the Earth-skimming neutrino'. This detection technique was originally proposed in 1990's [23] and already used by other observations [8][10][11]. The essence of this technique is separation of target and detection. Small cross section of first interaction of neutrino favors dense material, while fine imaging of the interaction does not. If the first interaction is separated from the following interactions, we can evade from the above contradiction.

Let me describe the detection. Reaching the Earth, a neutrino enters into the Earth's crust and mountains, interacts with materials via charged current interaction, and produces a lepton. The lepton propagates in the crust with loss of its energy. If it is a tau lepton, it decays after exit to the atmosphere, and generates detectable air shower. The length of the propagation of tau lepton in the rock makes a cluster around a few 10 km above 10^{17}eV due to the energy loss. Hence we can detect tau neutrinos of decades of energies with a fixed geological formation.

This detection technique has a maximum sensitivity around 100PeV. Using this technique, we aim to connect PeV to EeV by lowering the energy threshold of neutrino observation with air light. PeV is the energy range where ice and water Cherenkov experiments have their maximum sensitivities, while EeV is the energy range where experiments with air shower have. For that aim, we think that detection of Cherenkov radiation from air shower is important. In order to detect Cherenkov radiation emitted forward, shower front must be directed to the detector. Therefore, we chose a geometry widely viewing rock of over 10km thickness, that is, mountain. We designed an observation facing the mountain (Fig.3).

In this observation we used a Light Collector toward Mauna Kea (right panel of Fig.1). It is composed of Optical System and Image Pipeline, designed as the final one. On the other hand, the Trigger and Readout was

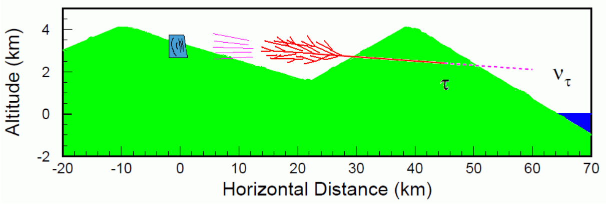


Fig. 3: Conceptual figure of this observation (the Earth-skimming neutrino detection technique). The right mountain is Mauna Kea and the left is Mauna Loa.

one used in a test observation. We modified it for this observation.

IV. Observation

We intended an observation in order to study neutrino emissions from transient objects. Also, performance check of our trigger system is another aim of this observation.

Before the observation, we simulated neutrino signals generated by tau leptons emerging from Mauna Kea (Fig.4). Then, we calibrated the detector with artificial sources, such as an LED and a radiant source. Furthermore, we verified the system's performance by an observations of cosmic rays (protons). This observation was carried out with an FOV closer to the zenith than in the neutrino observation. Fig.5a shows an example of obtained image of Cherenkov radiation from air-showers, and Fig.5b shows a simulated event by CORSIKA. We can see that the obtained data resembles the simulated event. It demonstrates well the strength of the high angular resolution of our detector. As shown by the comparison of Fig.4 with the data (Fig.5a), our detector has an ability of detecting air showers from neutrinos.

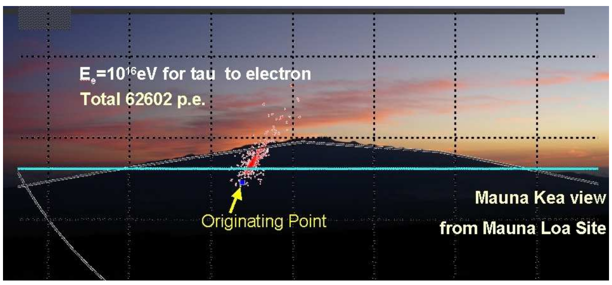


Fig. 4: Example of simulated neutrino event.

The observation for neutrino emisson was executed in a duration from September to December in 2008 (Tab.I). Fortunately we accomplished highly efficient observation. As a result we observed a GRB, GRB081203A, in a period before and after its occurrence, tens of GRBs after their occurrence, and tens of active galactic nuclei (AGN). Tab.II summarizes the observed objects and observed time.

[1]without full moon
[2]t_0 is the GRB occurrence time (2008-12-03 13:57:11UT).

TABLE I: Observation time

Period (UT)	Max. Observable Time [hr]	Observed Time [hr] (duty factor[1])
2008/10/28 – 11/11	95.5	75.3 (21%)
2008/11/15 – 12/10	164.6	140.5 (22.5%)

TABLE II: Observational objects

Objects	Emission type	Total duration [hr]
GRB081203A	precursor late prompt	0.7 (from t_0-2.83hr [2]) 0.7 (+1day)
13 GRBs (080205 $\sim$ 081025)	afterglow (month scale)	82.2
25 AGN (from Ref.[24])	continuous	244.2

The obtained data were analyzed. In order to estimate the sensitivity we must take into account spurious events generated by background cosmic rays. In principle, the Earth-skimming neutrino detection technique is free from background events, thanks to the screening effect of the Earth's rock. Also, the FOV of this observation is nearly horizontal, hence thick atmosphere screens the normal cosmic-ray events. We discussed the screening effects and confirmed the absence of background events from background sources. Then, the most frequent background was Cherenkov radiation from muons that interact with the detector itself. We simulated the radiation, and carefully removed them from the data.

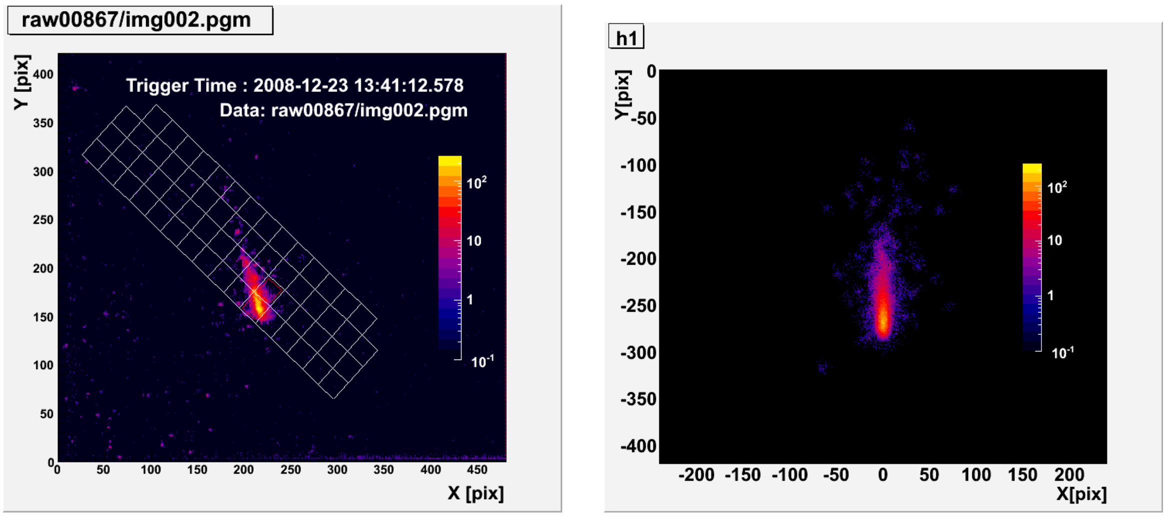
V. Results

We did not discover any candidate of neutrino emission in the range from tens of PeV to EeV. We set preliminary upper limits to the fluence and flux of source models, related to the mechanism for the particle acceleration in transient objects. All the following limits are derived with 95% confidence level.

For GRB precursor, we set a limit $E\phi(E) < 5.4{\cdot}10^{-8}$ [cm^{-2}], assuming a spectrum extended up to 5 EeV. For GRB late prompt emission, the obtained limit is $E^2\phi(E) < 4.3$[erg cm^{-2}]. Also, due to null detection including other observations, we cannot set any limit to the Lorentz factor of the shock shell. For GRB afterglow, the limit leads $E^2\phi(E) < 19$[erg cm^{-2}]. Furthermore, neutrino emission from AGN was studied. The limit for diffuse flux is about 2nd order of magnitude larger than that by other experiments, but better than Auger experiment at 100 PeV. In addition to that, we set a meaningful upper limit, $E^{1.4}\phi(E) < 1.3 \cdot 10^{-12}$[cm^{-2}s^{-1}PeV$^{0.4}$], based on a source model assuming proton synchrotron emission. This limit corresponds to a diffuse flux rejected by experiments. However, it is still meaningful as a limit for point source.

VI. Discussions

Neutrino emission in the prompt emission of GRB030329 was studied by AMANDA [25]. They set an upper limit of $E^2\phi(E) \leq 0.157$ [GeV cm^{-2}s^{-1}] with time window of 40sec, corresponding to a fluence of 6.28 [GeV cm^{-2}]. Also, the naked eye GRB,



(a) data

(b) simulated event

Fig. 5: Example of air-shower image from the cosmic-ray observation. The conditions for simulated event are as follows; proton, energy = 1EeV, core distance = 266m, angular resolution = 9 arcmin, and thinning = 10^{-6}. The color shows pixel value (max. is 255 counts). Total number of photoelectrons in triggered three pixels is 15468.

GRB080319B, were individually analyzed by IceCube [26], and they submitted similar upper limit for neutrino fluence. On the other hand, our fluence limit for GRB081203A, $E^2\phi(E) = 4.3$[erg cm^{-2}] is corresponding to $26.8{\cdot}10^2$ [GeV cm^{-2}], with the observational time of 2400sec. The difference can be understood by higher energy threshold of this observation. If our detector has a threshold two decades less than now, sensitivity is expected to be comparable with that by AMANDA. The threshold, about 100TeV, will be achievable with the final design, by changing electronics to the final one. It should be noted that, combination of the two observations for GRB081203A, the upper limit for neutrino emission and the optical observation with our detector [13], leads to the conclusion that it is not contradictory to the normal particle acceleration. This discussion is considered as a result from ‘multi-particle astronomy’.

Upper limits by the source integrated analyses (for GRBs and AGN) were also not contradictory with the normal particle acceleration. As mentioned above, the proton synchrotron model was already rejected by experiments as a source of the diffuse neutrino emission. However, our limits is still meaningful because it is a limit for point sources. They are not affected by the source distribution in the universe. This kind of observation will clarify much more the individual emission from the sources.

We stress again that our detector will be sensitive to neutrinos with energies of $1 \sim 100$ PeV. This energy range is just between the maximum sensitivities of ice experiments and air-shower experiments. For future neutrino experiments, pointing accuracy in this region will become important, in order to localize transient objects and investigate the mechanism of the particle acceleration in individual sources. The Ashra detector should be considered as a promising candidate to realize ‘multi-particle astronomy’, which is necessary to understand particle acceleration in the universe.

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